Purnendu Ghosh *Editor*

The Mind of an Engineer: Volume 2

INDIAN NATIONAL ACADEMY OF ENGINEERING
तमसो मा ज्योतिर्गमय
ESTD - 1987

Springer

The Mind of an Engineer: Volume 2

Purnendu Ghosh
Editor

The Mind of an Engineer: Volume 2

Springer

Editor
Purnendu Ghosh
The Executive Director
Birla Institute of Scientific Research
Jaipur, Rajasthan, India

ISBN 978-981-15-1329-9 ISBN 978-981-15-1330-5 (eBook)
https://doi.org/10.1007/978-981-15-1330-5

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

The Indian National Academy of Engineering (INAE) advocates, encourages and practises excellence in all its endeavours concerning engineering, technology and related sciences to meet the challenges of national importance and of global concern. Its activities include the formulation of technology policies, promotion of quality engineering education and prioritizing R&D activities. The INAE represents India at the International Council of Academies of Engineering and Technological Sciences (CAETS).

The book, *The Mind of an Engineer*, an initiative of the INAE, published in the year 2016 attempted to share the personal experiences of some of the Fellows of the INAE while they pursued their careers in science, technology and engineering. The book dealt with the reminiscences, eureka moments, inspirations, challenges and opportunities in the journey of the professionals towards their achievements and introspection.

The positive response we received on the book encouraged us to bring out a sequel to the book. *The Mind of an Engineer: Volume 2* covers diverse subjects that depict the beauty and the diversity of the mind of an engineer. This volume includes articles dealing with some important areas such as the academia's approach to professional challenges, the concept of Make in India, the experiences of working in public sector industries, innovative leadership and governance challenges in various engineering sectors without losing sight of personal involvements and approaches.

We believe that the mind of a creative engineer is a special entity. It is designed for fluid and methodical thinking. It has the ability to make meaningful associations and to discern the relatedness of various engineering components. It can see things in new perspectives. It has the ability to control the flight of ideas and has the ability to discriminate, differentiate and evolve a sense of cohesion. It may, however at times, suffer from swings of mood, but know how to navigate in the tides of these swings. The meaningful and constructive mind of an engineer works in the context of the human needs, orientations, experiences, emotions and consciousness. The world of engineering has changed and is changing fast. A new mind is evolving to deal with this world. Thus, a creative, responsive and ethical engineer becomes even more important in the twenty-first century.

This book would not have been possible without the substantial initiative and constant encouragement of (Late) Dr. Baldev Raj, the past President of INAE. The untimely and sudden passing away of Brig. Rajan Minocha, Executive Director of the INAE, is deeply condoled. It is most unfortunate that none of them could see the second volume in print.

We gratefully acknowledge the generous support of Dr. Sanak Mishra, President of the INAE, and Dr. B. N. Suresh, immediate past President of the INAE, for bringing out the volume. We are grateful to the Editorial Board of the INAE and the Fellow colleagues of the INAE, who have made unique and valuable contributions, and offered useful suggestions towards the publication of compendium. We thank them most sincerely. The expertise, views and perspectives of the contributors, we hope, will be meaningful to, and inspiring for the engineers, particularly the young professionals.

We gratefully acknowledge the editorial support of Dr. Subimal Sinha-Roy of Birla Institute of Scientific Research (BISR), Dr. Geetanjali Sawhney of INAE and Ms. Swati Meherishi of Springer Nature. We acknowledge the editorial assistance of Mr. Radhakishan Meghwanshi and Mr. P. K. Manoharan of BISR in bringing out this volume.

We look forward to receiving your considered views and perspectives regarding the usefulness and topicality of this book series. Your response and suggestions will be our guiding force to motivate and encourage us to bring out the future volumes of *The Mind of an Engineer*.

Jaipur, India Purnendu Ghosh

Contents

Editor and Contributors

About the Editor

Purnendu Ghosh is the Executive Director of Birla Institute of Scientific Research, Jaipur. Prior to this he was Professor at Indian Institute of Technology, Delhi. He has held visiting positions at the Swiss Federal Institute of Technology, Zurich, Switzerland; University of Melbourne, Australia; and National Research Centre for Biotechnology, Braunschweig, Germany. He has taken a lead role in augmenting bioprocess engineering and biotechnology activities in the country as a member of several Task Forces of the Department of Biotechnology, Government of India. He is the Founder President of Biological Engineering Society, and is currently the Vice President of Indian National Academy of Engineering. He is the Founder Editor-in-chief of INAE Letters, a Springer-Nature publication. Besides technical publications, he has written several books of different genre.

Contributors

Yogendra Pal Anand being selected for 'Indian Railway Service of Engineers', joined in May 1957 as Assistant Engineer and worked in numerous positions in 'open line', construction projects, R&D, as Divisional/Zonal Manager, and retired as Chairman, Railway Board. After retirement, he did short assignments with UNDP and AITD. He was first Chairman of International Institute of Waste Management set-up at Bhopal. He has been a member of INAE's Study Group on 'Indian Engineering Heritage (Railways)' (1996–2015), and of 'Forum on Technology Foresight and Management for Addressing National Challenges' (since 2012).

P. V. Ananda Mohan is Technology Advisor, CDAC, Bangalore and formerly General Manager and Executive Director, ECIL, Bangalore. He has published four books in the area of Residue Number Systems, Current-mode VLSI analogy Filters, VLSI analogue Filters, Switched-capacitor filters. He is a well-known expert in Cryptographic algorithm and System design for the Indian Armed Forces. At present, he advises CDAC on Cryptanalysis, Cloud Security, Cryptosystem Validation, etc. He was elected Fellow of IEEE. He is a recipient of the Ram Lal Wadhwa Gold Medal award by IETE and Indira Priyadarshini Award.

T. K. Bera joined as a Scientific Officer 'C' in chemical Technology division at Trombay, BARC working on a development project for heavy isotope separation in the year 1977. After obtaining encouraging results on bench and pilot plant scale trials, he was deputed to a Greenfield project for setting up of a technology demonstration-scale plant in 1986 and was designated as a project manager during 2001. Subsequently, he was promoted as Project Director of RMP and Associate Director of Chemical Technology Group, BARC. After successful execution of the project and its phase-wise expansion, he was further promoted as Director of Chemical Technology Group, BARC.

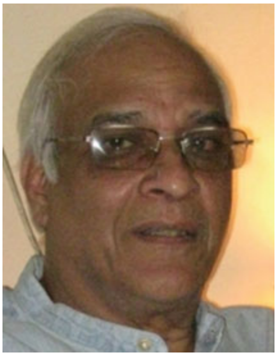
R. K. Bhandari is a distinguished alumnus of Indian Institute of Technology, Bombay, best known internationally for his outstanding professional contributions in the areas of landslide studies, disaster mitigation and disaster education. He was the first to unravel the fundamental mechanism of low angled landslides, jointly with Legendary Prof. J. N. Hutchinson, FRSE. He is also the only Indian so far to have received the coveted Varnes Medal, the highest International award for 2012 given at the UNESCO Headquarters in Paris for excellence in landslide studies. The other awards bestowed upon him include the Lifetime Achievement Award of the Quantum Campus, Omprakash Bhasin Award, Kuekalmann Award of IGS and Disaster Mitigation Award of the IIT, Roorkee. Currently, he is the Chairman of the Forum on Disaster Mitigation of the Indian National Academy of Engineering; a Member of the Advisory Committee of the National Disaster Management Authority and the Chairman of the Indian Roads Congress Committee on Disaster Mitigation.

S. S. Chakraborty Chairman, Second Vivekananda Bridge Tollway Company Private Limited, Chairman Emeritus, Consulting Engineering Services (India) Private Limited, is a preeminent engineering professional, recognized in India and abroad, not the least as Honorary Member, International Association for Bridge and Structural Engineering, Zurich. He has been awarded the Institute Gold Medal—considered the Engineering Nobel—in 2007 by the Institute of Civil Engineers (UK), Life Time Achievement Award by INAE. The Second Hooghly Bridge and the Nivedita Setu attest to his innovative mind.

Subhash Chander was formerly Professor, Department of Civil Engineering, IIT Delhi. He made significant contributions in the areas of Modelling and Simulation of Hydrological Cycle and Flood Forecasting. His research contributions led to the introduction of Models in Real-Time Water Resources Management. He developed time series of sub-basins of the Krishna Basin to help the Krishna Water Disputes Tribunal to allocate water between the states.

A. L. Chandraker joined Corporate Research and Development Division of BHEL at Hyderabad as Senior Engineer in 1978 and rose to various posts such as General Manager and Executive Director and Unit Head prior to retirement in 2009. During his career at BHEL, he developed a number of FEM and CFD based software for flow path analysis and blade design and filed five patents in USA. He led teams for a successful design of 8 MW high-speed impulse steam turbine and the creation of Centre of Excellence for CFD.

Pradeep Chaturvedi Vice President, World Environment Foundation, has been involved in sustainable energy planning and energy project implementation in India and Asia Pacific region for four decades. He also coordinated the project establishing the first renewable energy village in India. He was Member of Integrated Energy Planning Committee and has been on various Studies Committees of the World Energy Council. He is Fellow of Indian National Academy of Engineering and conferred a number of national and international awards. He has authored eight books and chaired a number of International Studies on Energy.



A. W. Date is Rahul Bajaj Chair Professor and Emeritus Fellow, Department of Mechanical Engineering, IIT Bombay. He has over 43 years of Teaching/Research at IIT Bombay with short visiting assignments at Cornell University and UIUC, USA, University of Karlsruhe, Germany, City University, Hong Kong, Swiss Federal Institute, Zurich, Switzerland, and Academy of Development Science, Kashele, Raigad District, Maharashtra. His research contributions are in the areas of Convective Heat/Mass Transfer Enhancement, Computational Fluid Dynamics and Analytic Combustion.

B. Dattaguru worked as a teaching faculty at the Department Aerospace Engineering at the Indian Institute of Science Bangalore between 1964–2004. He worked in the capacities of Chairman of Aerospace Engineering Department, Joint Advanced Technology Programme and Scientific and Industrial Consultancy. Currently, he is a professor in the Jain University located in the suburbs of Bangalore. On sabbatical, he worked at NASA Langley, PENN State University, USA, and University of Geelong, Australia. He graduated 25 Ph.D. scholars and has been the author of 200 scientific publications. He received several national and international awards including Padmashri (2005), Academic excellence award of DRDO (2002), Rustom Choksi Award (2001) for excellence in Engineering Research from IISc, Lifetime awards from ICCES 2014 (International Conference on Computational and Experimental Science) award in Changwon, South Korea, APCOM (Asian Pacific Congress on Computational Mechanics) award in Sydney (2010) and from the Society for Aerospace Technologies and Industries (2012), Bangalore.

Ashok Jhunjhunwala is presently Principal Advisor, Minister of Power and New and Renewable Energy, Government of India, and Professor, IIT Madras (on sabbatical). He has made significant contributions in the areas of Telecommunications, Computer Networks and Fibre Optics, Solar PV systems, Solar DC and UDC technologies, ICT based Education and Health Care, Entrepreneurship, Start-ups and Technology Incubation. His UDC project aims to enable a technique to provide 24X7 power supply to Indian homes. He has been significantly contributing to Education Reforms, Quality Enhancement, Technology Incubation, Industry-academia collaboration and Technology Development. He has been Member of Kakodkar Committee for IITs, NIT and AICTE Review Committee.

Anil Kakodkar served as Director BARC during 1996–2000 and as Chairman Atomic Energy Commission and Secretary, Department of Atomic Energy, Government of India, during the years 2000–2009. He played a key role in development and construction of 100 MW research reactor Dhruva, development of various systems for PHWRs, nuclear tests in Pokhran in 1974 and 1998, rehabilitation of the two units at Madras Atomic Power Plant and conceptualisation of 300 MWe Advanced Heavy Water Reactor (AHWR) besides significantly impacting every other aspect of atomic energy programmes. He was President on INAE during the years 1999 and 2000.

Prem Krishna after obtaining his Doctorate from the Imperial College of Science, Technology and Medicine, London in 1964, joined the faculty of Civil Engineering at the University of Roorkee in 1965 and retired therefrom in 1998. He also had teaching assignments at the University of Illinois, Urbana, USA, and the Imperial College London, UK, between 1968 and 1970. He worked assiduously to develop the field of Wind Engineering in India from 1978 onwards, providing leadership in building capacity in terms of human resources, facilities for testing, developing design support material, and, thus also placing the country squarely on the World Map of Wind Engineering. He served as the founder President of the Indian Society of Wind Engineering for seven years and also, President, International Association for Wind Engineering (1991–95). He is well recognized as an expert in the area of Structural analysis and design and specialized in large-span steel and cable-supported roof and bridge structures. He served as Vice-President, INAE, from 2008 to 2013. IIT Roorkee honoured him with the Distinguished Alumnus Award in 2012.

J. Krishnan worked in BARC on various research projects; focused on metal joining and developed several welding techniques, dissimilar metal joints, special welding processes, viz. electron beam welding, diffusion bonding. After retirement, he worked as Chair Professor at MS University Baroda and as a consultant in high-end welding.

K. P. Madhavan pioneered teaching and research in the areas of Process Control and Process Systems Engineering. At IIT Bombay, he had held positions of the Heads of the Chemical Engineering Department and CAD Centre and Dean, R&D. He had also played lead roles in setting up at IITB, the School of Management and School of Biosciences and Bio-Engineering. He had assisted a wide spectrum of industries in their R&D and technology development programmes.

Jayanta Mukhopadhyay is a professor at the Department of Computer Science and Engineering, Indian Institute of Technology, Kharagpur. His research interests are in image processing, digital geometry, computer graphics, robotics, bioinformatics and medical informatics. He received the Young Scientist Award from the Indian National Science Academy in 1992. He was a Humboldt Research Fellow at the Technical University Of Munich, Germany in 2002.

B. S. K. Naidu is the Founder Chairman and Chairman Emeritus of Great Lakes Institute of Management, Gurugram. He is the former Director General of NPTI and CPRI, Ministry of Power, Government of India. He was Senior Advisor to Advanced Engineering Associates International (AEAI) Cambridge, Massachusetts. He was the first scholar from BHEL to have been selected by the 'Confederation of British Industry' to work with several industries in Europe for specializing in Pumped Storage Power Plants. He has published 150 technical papers, 7 books and filed 10 copyrights. He was the key person for the National Training Policy for Power Sector, National Perspective Plan for R&D in Indian Power Sector and National Master-Plan for renovation and modernization of entire country's hydro-plants. He has received 20 professional awards and honours in Engineering and Management.

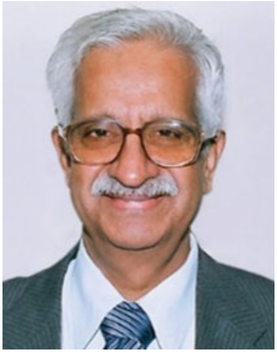
R. Natarajan has worked as a National Research Council Fellow in Canada and as a Humboldt Research Fellow in Germany. He served as the Director of the Indian Institute of Technology, Madras, from 1995 to 2001, and as the Chairman of the All India Council for Technical Education, from 2001 to 2004. He was the Vice President of the Indian National Academy of Engineering during 2002–2006 and the Chairman of the Research Council of the Central Fuel Research Institute, Dhanbad, during 1995–2005. He is Fellow of: Indian National Academy of Engineering, Indian Society for

Technical Education, National Academy of Social Sciences, Institution of Engineers (India), Indian Institution of Plant Engineers, National Foundation of Indian Engineers, Indian Institution of Materials Management and Madras Science Foundation.

K. R. Padiyar has been Professor/Honorary Professor at Indian Institute of Science, Bangalore, from 1987 to 2013. Previously, he was with Indian Institute of Technology, Kanpur, from 1976 to 1987. He was a visiting professor in Indian Institute of Technology, Gandhinagar, in 2014. He has published over 200 papers and 8 books in the areas of Power System Dynamics and Control, HVDC Power Transmission and FACTS Controllers. He has guided 30 Ph.D. students. He was a member of the Project Review Committee of the National HVDC Project in India. He is Fellow of Indian National Academy of Engineering (INAE), Institution of Electronics and Telecommunication Engineers (IETE) and Life Fellow of IEEE. He was awarded the Department of Power Prize twice by Institution of Engineers (India). He is the recipient of 1999 Prof. Rustom Choksi Award for Excellence in Research. He received 'Distinguished Alumnus Award' from Indian Institute of Science in 2014.

M. A. Pai is Emeritus Professor in Electrical and Computer Engineering at the University of Illinois Urbana-Champaign. He was with the Indian Institute of Technology, Kanpur, from 1963 to 1981 and at the University of Illinois Urbana-Champaign from 1981 to 2003. His research interests are in Dynamics and Stability of Power Systems, Smart Grid, Renewable Resources and Power System Computation. He is the author of several textbooks and research monographs in these areas. He is Fellow of IEEE, I.E (India), Indian Academy of Sciences, and the Indian National Science Academy.

Anant V. Patki was part of ISRO from 1967 to 2003. He had worked on India's first satellite Aryabhata and the Launch Vehicle SLV. Later, he developed a strong team of engineers, dealing with mechanical systems of space crafts, leading to INSAT and IRS series of satellites. He also worked as Visiting Professor at Department of Aerospace Engineering of IIT Bombay and Department of Aerospace Engineering of IISc, Bangalore. Post-retirement, he worked with an IT corporate and built a group doing IT enabled engineering services for many overseas giants.



V. S. Ramamurthy is a well-known Indian nuclear scientist with a broad range of contributions from basic research to science administration. He started his career in Bhabha Atomic Research Centre, Mumbai, in the year 1963 and made important research contributions in the areas of nuclear fission, medium-energy heavy-ion reactions, statistical and thermodynamic properties of nuclei and low-energy accelerator applications. During the period 1995–2006, he was Secretary to the Government of India, Department of Science and Technology (DST), New Delhi. He was also the Chairman of the International Atomic Energy Agency (IAEA) Standing Advisory Group on Nuclear Applications for nearly a decade. After retirement from service, he has also been actively involved in human resource development in all its aspects. He is currently Emeritus Professor, National Institute of Advanced Studies in Bangalore. In recognition of his services to the growth of Science and Technology in the country, he was awarded the Padma Bhushan by the Government of India in 2005.

Srinivasan Ramani has served as the founding director of the National Centre for Software Technology. He played a key role in creating India's academic network, ERNET, which brought the Internet to India. He was inducted by the Internet Society into their Hall of Fame in 2014. He has also served as the first director of Hewlett Packard Research Labs, India, Member of the Expert Panel of Advisors of the United Nation's Task Force on ICT for Development, President, Computer Society of India and President, International Council for Computer Communication.

Ranjit Kumar Ray taught at Bengal Engineering College, Shibpur (now IIEST Shibpur) for little over 11 years, followed by teaching at IIT Kanpur for 28 years. This was followed by a stint of more than 10 years in the R&D Division of Tata Steel Jamshedpur as a visiting scientist. For the last three years, he has been a visiting professor in IIEST Shibpur. He is a recipient of the Best Metallurgist award, the National Metallurgist award, the GD Birla gold medal and Honorary Membership of the Indian Institute of Metals, among others. He has been a visiting professor/scientist in a number of prestigious universities, research laboratories and industrial organizations.

A. Sanatkumar joined DAE in 1963 and retired as Senior Executive Director from NPCIL after 38 years of meritorious service. His career has been dedicated to establishment of all round, self-reliant indigenous capabilities to engineer vital on-power refuelling systems for PHWRs. His crowning achievement is the successful design and implementation of the Fuelling Machine Heads and Fuel Handling Systems, incorporating several of his original, unique, world-class concepts for the PHWRs at Tarapur 3 and 4. He is a recipient of Homi Bhabha Lifetime Achievement Award (2007), besides Indian Institution of Engineers' National Design Award (2000).

V. V. S. Sarma was formerly Professor, Honorary Professor and INAE Distinguished Professor, Department of Computer science and Automation, Indian Institute of Science, Bangalore. He has made significant research contributions in the areas of Artificial Intelligence and Reliable Computing. His studies in fault-tolerant computers have provided optimal multiprocessor architectures for hard real-time systems such as aircraft computers and methods for reliability assessment of such systems. His research on Speech Pattern Recognition systems using fuzzy approximation scheme is well known. He developed knowledge-based design environments for rapid design of automatic speech and pattern recognition products such as voice-operated telephone diallers.

S. Sreenivasa Murthy is Adjunct Professor, NIAS, Bangalore, and IIT Ropar and formerly: Professor, Department of Electrical Engineering, IIT Delhi, Vice Chancellor, Central University of Karnataka, Director, NIT Surathkal and Director, Electrical Research and Development Association, Baroda. He has to his credit over 300 papers, 7 books/manuals/conference proceedings and 18 patents. His research has led to technology transfer to Industry on Renewable Energy, Energy Efficiency and Drives.

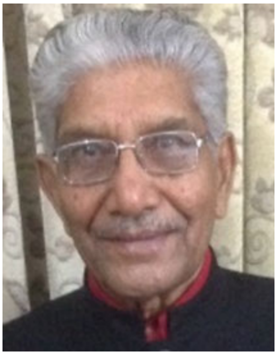
Mangu Singh joined Indian Railway Service of Engineers in March, 1983 and held various positions in operating, managing of Railway system and also planning, procurement and implementation of projects of Indian Railways. He joined DMRC at the inception stage and has been playing a key role in developing the Metro system in Delhi. He is also instrumental in assisting other state governments in developing Metro systems in various cities. Currently, he is working as Managing Director of Delhi Metro Rail Corporation. He is recipient of National Award (Railway Week Award 1996). He has also been awarded Eminent Engineer-2015 Award by Institution of Engineering and Technology, UK. He has recently been awarded prestigious 'Distinguished Alumnus Award' by IIT Roorkee. He is Fellow of Indian National Academy of Engineering, Fellow Institution of Engineers, India, and President, Tunnelling Association of India.

Manjit Singh joined Reactor Control Division of BARC as Scientific Officer in 1973. Retired as Distinguished Scientist in 2014. Worked as Head, Division of Remote Handling and Robotics and Director, Design Manufacturing and Automation Group, and Director, Engineering Services Group at BARC. He is the President, Robotics Society of India since its inception.

Maj. Gen. Surjit Singh AVSM, VSM, FNAE is a soldier by profession, an engineer by training and a story-teller by instinct. After retiring from the army in 1997, he served with Ashok Leyland as Director MDC for five years. For design and development of military equipment, he has received several awards and was admitted into the INAE in 1996. He has published six books.

E. C. Subbarao worked at Parry & Co, Ranipet, T.N., 1949–51, Westinghouse Research Laboratories, Pittsburgh, PA 1956–63, Indian Institute of Technology, Kanpur, 1963–81, and as Founder-Director of Tata Research Development and Design Centre, Pune (Tata Consultancy Services), 1981–1999 and later as Chief Consulting Advisor at TRDDC.

A. K. Suresh is a professor with the Department of Chemical Engineering at IIT Bombay. His broad research interests are in the area of transport and reaction engineering, with current research on membrane forming processes, solid-state reactions, liquid-phase organic oxidations and some fundamental issues on heterogeneous transport-reaction processes. His work has also been recognized through many awards and honours, among which may be mentioned the Visiting Fellowship of the Indian National Science Academy and the Herdillia award for excellence in basic research by the Indian Institute of Chemical Engineers. He was awarded a 3-year membership of the American Chemical Society in July 2015 in recognition of engagement with the Society's mission. He has held visiting positions at National Chemical Laboratory, India, Monash University, Australia, Australian Defence Force Academy, Australia, and Washington University in St. Louis, USA.



Paritosh C. Tyagi is presently Consultant in Environmental Management and formerly Chairman, Central Pollution Control Board, New Delhi. He has made significant contributions in the areas of environmental management and water supply and sanitation. He designed and constructed water supply, drainage and sewerage works in Uttar Pradesh as Chief Engineer. He assisted in the planning and evaluation of National Water Supply and Sanitation Programme as Joint Director in the Planning Commission, Government of India. He planned and implemented projects and programmes for control of air and water pollution as Chairman of Uttar Pradesh Pollution Control Board and Chairman of Central Board for Prevention and Control of Water Pollution.

K. K. Vaze joined IGCAR, Kalpakkam in 1974 and worked on Structural Analysis and Design of Fast Reactor Components. He joined the Reactor Safety Division of BARC in 1989 and contributed to Design, Structural and Safety Analysis of Heavy Water Reactors. He retired in September 2014 as Director, Reactor Design and Development Group. His fields of interest are: Nuclear Safety, Earthquake Engineering, Structural Analysis and Design, Structural Integrity Assessment and Failure Analysis. As a recipient of Raja Ramanna Fellowship, he is currently involved in the review of Safety of Nuclear Reactors and in development of Safety Codes and Guides.

K. Venkataramanan is an independent Non-Executive Director with Vedanta Limited and formerly Managing Director, Larsen & Toubro, Mumbai. During his tenure at L&T, he had spearheaded L&T's foray in the world of E&C and strengthened every aspect of EPC value chain and transformed L&T to one of the respected names in the global EPC fraternity. L&T Hydrocarbon has also established its identity in select overseas geographies like West Asia, South East Asia and Africa. He has played a key leadership role in L&T's power business initiative through EPC jobs in gas and coal-based power plants in India and abroad.

Y. V. Venkatesh was an Alexander von Humboldt Fellow at the Universities of Karlsruhe, Freiburg and Erlangen, Germany; a National Research Council Fellow (USA) at the Goddard Space Flight Center, Greenbelt, MD; and a Visiting Professor at the Institut fuel Mathematik, Technische Universitat Graz, Austria, Institut fur Signalverarbeitung, Kaiserslautern, Germany, National University of Singapore, Singapore, and others. Apart from stability theory, his research interests include 3D computer and robotic vision; signal processing; pattern recognition; biometrics; hyperspectral image analysis; and neural networks. As a professor at IISc, he was also the Dean of Engineering Faculty and, earlier, the Chairman of the Electrical Sciences Division. He is a Fellow of the Indian Academy of Sciences, the Indian National Science Academy, and the Indian Academy of Engineering. He was on the editorial board of the *International Journal of Information Fusion*.

Bayya Yegnanarayana is currently INSA Senior Scientist at IIIT-Hyderabad. He worked as a professor at BITS-Pilani Hyderabad (2016), IIIT-H (2006–2016), IITM (1980–2006), CMU Pittsburgh (1977–1980) and IISc (1966–1978). He published the book *Artificial Neural Networks*, and over 400 papers in speech, image processing and neural networks. He is a Fellow of INAE, INSA, IASc, IEEE, USA, and ISCA, Europe. He received the INAE's Prof. S. N. Mitra Memorial Award (2006), the 2013 IISc Distinguished Alumnus Award and the INSA's The Sayed Husain Zaheer Medal (2014).

Harnessing Science and Technology for Development: A Governance Challenge in Indian Context

Anil Kakodkar

Introduction

There are several components of India's growth story. Some are dependent on our demography, size of youth work force, market potential, growing aspirations and factors like that. The others are driven by the increasing role of knowledge and technologies in economic activities. With the highly competitive world that we live in, becoming increasingly knowledge dependent, the balance of trade is strongly dependent on our ability to leverage knowledge to add value or even better, to create new technological products that have competitive market appeal both in India and abroad. Thus, our ability to leverage S&T to create innovative products and processes, and to nurture a right innovation ecosystem to take them to the market place assume greater importance now than any time before. Creating and nurturing people capable of doing so in large numbers, and empowering the institutions that host them to deliver on this count, are the two most important governance challenges in contemporary India.

Today, total expenditure in R&D in India is comparable to or larger than such expenditure in countries like Israel, Canada, Sweden, UK, Switzerland, Finland etc. [1]. Further a simple back of the envelope calculation would indicate that our spending per full time equivalent in R&D is also comparable with most of the high performing countries. Considering the large population and the size of our economy, there is clearly a strong case to significantly enlarge our investment in S&T. However, with the level of current investment, clearly, India should have been a power house for new technologies that leverage the latest in research at least on par with the countries mentioned above. Our economy, however, is still very dependent on other countries, including some of those listed here, for our technology needs. Further, there is a serious disconnect, by and large, in terms industry investment and engagement in

A. Kakodkar (✉)
5/1104, Accolade cooperative housing society, Hajuri Dargah Marg, Behind LIC, Thane(West) 400604, India
e-mail: kakodkaranil@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_1

S&T system in the country. Under such conditions, we end up doing what others have already done, in our laboratories as well as in our industries. While instead of to importing products, making them here, is decidedly a superior option, developing competitive technologies here and leveraging them for manufacture of products in the country, considerably adds to our competitive advantage both in terms of sustaining competitiveness in our manufacture as well as bringing out new products ahead of others.

Innovation Ecosystem

For this purpose, as mentioned earlier, we need to enhance excellence in our R&D as well as ensure its deeper engagement with industry and entrepreneurship. This requires a conducive innovation ecosystem that picks up and encourages a potentially promising idea and facilitates leading to its translation to a successful commercial product. Such an ecosystem must support high quality teaching that takes a student all the way up to the current frontiers of knowledge, supports research that pushes these knowledge frontiers forward, supports translation of that research into new and robust technology products and nurtures entrepreneurship that commercialises the newly developed products. An important characteristic of such an ecosystem is the freedom for participants to interact with potential collaborators across different domain boundaries to translate research to business in a win—win mode.

In a world bank report [2] on 'The Challenge of Establishing World Class Universities', concentration of a very high level talent pool that is a magnet to attract more talent from outside, abundant financial resources and favourable governance with a high level of flexibility to preferentially carry a good idea forward, were identified as three key characteristics for a world class university. Clearly, such institutions that nurture a high level of creativity must have the patronage that assures them of the required financial resources, and at the same time provides complete immunity from external factors except for the expectation that they must excel in their respective domains, as judged by their peer community. Since quality education, skills, research and technology development, creating a culture of innovation and entrepreneurship etc. are the areas that must be of the key concerns to the Government with widest possible access to all those who are deserving. we need state funded institutions of excellence in such creative areas and a system of governance that meets the requirements as stated above.

Autonomy encompassing all its dimensions, e.g. functional, administrative and financial is crucial to achieving an effective system of governance in institutions of high excellence that nurture creativity. The institutions must be free to decide the programmes they wish to pursue within the stated objectives of the institution with a holistic interpretation as guided by the peers within and outside. While the institutions must be free to conduct themselves within the available capital assets, promised recurring expenditure and other resources generated by the institution, there must be assurance on availability of these resources and a supportive attitude to further augment them on the basis of justified needs. As a minimum, inflation correction would be one such need. The institution must have the freedom to administer itself including making all appointments on the basis of its needs duly driven by the institution management and broadly guided by the peer system in and around the institution. As a matter of fact, Dr. Bhabha had enunciated the principle, "find a right scientist and build the lab around him rather than the other way around". On the functional front, the institution should be guided by its peers on the basis of its charter. The peer community should represent all stakeholders consistent with the charter of the institution at the right level of eminence. Performance appraisal in the institution at various functional levels including at the level of individuals, should be done with a judicious combination of external and internal peers at sufficiently high level of excellence with a value system that covers all dimensions of expected performance.

Such autonomous institutions of high excellence and their members should be free to collaborate with others with complimentary capabilities. When one realises an eco-system encompassing the full range of capabilities necessary to translate a new idea or research finding into a new product and commercialise it in the market place, one develops the capability to make a high level contribution to the economic growth and the strength of the country.

As an example of the impact of such an excellence, it is worth recalling a study [3] compiled by PitchBook, a US—based private equity and VC research firm that ranked the top 50 universities that have produced venture capital—backed founders. The study that took into account funding data between 2009 to July 2014, and sifted through educational backgrounds of over 13,000 founders globally has revealed that the top universities have produced founders that have succeeded raising up to $3.5 billion capital in a period of five years (Please see the table below). It is heartening to see IITs figuring in the list as 4th top institution in terms of number of founders produced and the 3rd top institution in terms of capital raised by them. If such a thing can be done by IIT graduates in USA, clearly, there is a huge potential if we can leverage institutions like IITs on the Indian domestic scene. More importantly, if most of our higher technical institutions become like IITs, India becoming a global technology power house should be well within our reach. Today, however, we are far away from such a goal. Realising this potential in full is the real governance challenge before us.

Some Policy Initiatives

Over and above what can come out of knowledge institutions through their engagement with finance and business world, there are several other initiatives that the State needs to take. Let us now deal with them one by one:

1. Barring a few exceptions. we still have an issue of low industry investment in research This is a result of low industry confidence in such investments producing results. This perhaps is true not only for investments in public funded R&D, but many times also in the context of internal investments for R&D when the gestation periods are large and loss through technology diffusion is likely to be high. A supportive framework for public funding of pre–competitive research assumes importance in this context. This not only could become a good basis for industry involvement in academics and R&D, but also could significantly shorten the period for new product development at the industry level. CII sponsored Prime Minister's fellowships for Ph.D. Research is a good initiative in this regard. Such initiatives need to be scaled up overcoming the issue of finding eligible project takers in large numbers. There could be more such initiatives. Industry association funded and guided centers in specific areas, working with individual industry in a research park are some examples.
2. Another mode to seek larger private investment in R&D would be to call for competitive proposals for development of new technology products needed in large numbers from consortia of industry and academic/R&D institutions. The

requirement could be spelt out in terms expected functional performance. Partial support through public funding could be made available to a few best proposals along with a promise of minimum initial business (through public procurement) to successful product developers. Such mode is practiced in countries like US (DARPA, eARPA) and Japan. Such a modality is almost non-existent in India. Government Departments where technology plays an important role in their programme implementation should be tasked to proactively pilot such efforts.

3. Beyond the supply driven and demand driven product development, as discussed above, a large country like India also needs capability to develop and build large technology platforms such as aircraft, ships etc. Today there is some capability in key strategic areas. We need to build such capability in different sectors of economy. In the Indian context, this is best piloted in mission mode by identified agencies/SPVs, at least to begin with. For each such platform type, one would need at least one major laboratory to be the knowledge leader which can assimilate, hold custody and eventually develop the requisite technology. With progressive emphasis on 'Make in India', it is important that such laboratories wherever they exist are main streamed or created in case they do not exist. Establishing such laboratories in academic institutions has the added advantage of concurrent human resource development. A major gain with such an arrangement is the national capability to keep the technology continually rejuvenated without allowing obsolescence to set in. With encouragement to private sector in such development, it would be logical to expect private sector to also invest in such laboratories in academic and research institutions. Over a period of time, one should expect a national capability build up to build such large technology platforms on its own. A precondition for sustaining such a capability would be continuity of programme and business for the laboratories, architect/engineers and manufacturing workshops along with related HR activities so that the investments remain productive.
4. All new technology products face barriers to market entry from those whose business is likely to be threatened by the entry of the new product or technology. Depending on the larger strategic objective served by the new technology such as elimination of vulnerabilities, sustainability, environment protection, favourable balance of payment, job creation etc., there should be policy support for preferential market entry of such new technologies. In particular, wherever a product development has been supported through public funds, there should be assured market entry as long as the developed product meets the pre–specified functional requirements and the costs have the potential to become competitive at the commercial scale of production. It should be realised that translation of a newly developed product into a commercially robust product is an evolutionary process that does need to be supported till the product becomes self-sustaining in the market place.
5. Major expenditure routinely takes place in procurement of high technology items. The recent thrust on 'Make in India' is an important policy initiative to create jobs and value addition in the country. Linking knowledge activities (academics as well as research) with such asset/infrastructure build up would benefit both

the manufacturing domain by way of better assimilation of technologies and capability to build upon as well as the knowledge domain by way of better human resource development.

6. One very important aspect of governance in the context of development planning is knowledge—informed autonomous decision making in contrast to vendor driven decision making that has become very prevalent. This is of particular importance in the context of technology choices which necessarily require a more holistic decision making with a long term view in the overall national context. Mass transportation on water front as well as on ground, waste management, water—energy—agriculture and environment nexus etc. are some examples of issues that need a holistic knowledge—informed decision making. Availability of a high quality research environment well engaged with the on-ground situation is a pre-requisite for such decision making capability.

Focus on Rural Areas

Rural areas need greater attention because a large fraction (around two third) of our population still lives there, and bringing the level of livelihood in rural areas (today average per capita earning in rural areas is about half of their urban counterparts) at least on par with urban areas is important to bridge the serious divide between the two. According to socio-economic and cast census 2011 (SECC 2011), manual casual labour (51%) and cultivation (30%) constitute the main source of income in rural households. About 9.7% of rural households run on salary income. 56% households are landless. There is thus a need to infuse relevant technology that enhances income in rural areas. This would also reduce the migratory pressure on urban infrastructure, enhance food security by making agriculture remunerative enough as a result of greater value addition, access to wider markets, and stabilisation of prices, and would further add to supplementary livelihood opportunities through adoption of technologies. A sustainable model for technology enabled development in rural areas is thus necessary in my view to realise such an objective. In such a model Integrated Education, Research and Development Complexes, a knowledge domain that can attract best of researchers and teachers on one side, and remain engaged with meeting human resource and technology development needs in the rural neighbourhood on the other, would need to be developed. Such complexes (which could be called CILLAGE—a knowledge bridge between City and a village) should provide best of city amenities along with opportunities for spouses and education of children, and would become a place for world class research on technologies for value addition opportunities in rural surroundings and help promote knowledge enabled development in rural areas. A critical mass of high quality researchers in a CILLAGE complex with a number of livelihood demonstration centres in the neighbourhood duly backed up by micro—finance could nucleate sustainable development process that perhaps could replicate itself and spread.

Integrated Area Development

Planning for national development has to comprise a combination of top–down and bottom–up processes. Large projects that can benefit large areas such as communication and transportation infrastructure, large hydro and power projects, large industries etc. that require large outlays are better done as a part of centralised effort implemented in a top–down mode. On the other hand, there is a strong merit to a decentralised approach to planning and development since the resources can be put to best possible use taking into account the local needs. With knowledge becoming an integral part of the local development process as described above, the bottom—up planning and development can in fact become more effective and efficient. One would need to decide on an appropriate unit for integrated local area planning and development. Doing this at the block level may be most optimum.

References

1. Global R&D funding forecast. www.rdmag.com December 2011
2. Salmi J (2009) The challenge of establishing world-class Universities. The World Bank
3. Pitchbook, Venture Capital Monthly, August/September 2014 Report

My Tryst with Destiny

R. K. Bhandari

In this article, I write about some of the episodes of *my tryst with destiny*, in my long professional career as a Civil Engineer.

Tryst means a private romantic *rendezvous* between two ardent lovers. And this is indeed the *touch-and-go* story of unconditional love between me and my destiny. We have interludes of private conversations-long and short, scheduled and unscheduled, pleasant and unpleasant. Such meetings between us, leave me with all the time to pursue my work without worrying about what will happen of my actions or inactions because that role and responsibility, I have willingly and lovingly surrendered to my destiny. After going through the lights and shadows of the long years of experience, I regard this way of living as the best prescription I can write for those longing for lasting happiness in life!

Brihadranayaka Upanishads tell us: "You are what your deep driving desire is; As your desire is, so is your will; As your will is, so is your deed; As your deed is, so is your destiny". I'm now more than convinced that—*If you long for anything with unstinted purity of head and heart, you are someday going to hold it in your hand. The universe will start to rearrange itself to make things happen for you.*[1]

When I was experimenting with the above thought in the early years of my life, I came across the book*: The Life to Come;* written by E. M. Forster in 1922 but published posthumously half a century later. It convinced me without a shadow of doubt that—"*We must be willing to let go the life we have planned, so as to have the life waiting for us*".

I keep reminding myself all the time that *in life, four things cannot, and will not comeback—the spoken word, the sped arrow, the past life and the neglected opportunity.*[2] Further, our greatest glory in life is not linked with our rise, but in

[1]Dr Joe Vitale.

[2]Annon.

R. K. Bhandari (✉)
302, Kamdgiri Tower Kausambi, Ghaziabad, UP 201010, India
e-mail: rajmee@yahoo.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_2

rising every time we fall. In life, "*those who are overcautious about themselves fall into dangers at every step; those who are afraid of losing honour and respect, get only disgrace; and those who are afraid of loss, always lose.*"[3]

The above message reverberates in the most autobiographies of great men and women. In her book: *Freedom from Fear*, Aung San Suu Kyi opines that "*It is not power that corrupts but fear. Fear of losing power corrupts those who wield it and fear of the scourge of power corrupts those who are subject to it*". Personally to me it works wonders when we replace Fear with Faith in our lives. This simple leapfrogging from Fear to Faith instantly changes the entire landscape of life. I believe that, with fired imagination and sustained effort, we mortals can bridge the distance between faith and destiny. Towards that end, I was deeply inspired in the process by the following two short stories:

My first story is the most precious of the divine gifts to me, wrapped in the following parable from the *Tales and Parables of Sri Ramakrishna*[4]:

> Once a man went to a certain place to see a theatrical performance, carrying a mat under his arm. Hearing that it would be some time before the performance began; he spread the mat on the floor and fell asleep. When he woke-up all was over. Then he returned home with the mat under his arm!

Although the message conveyed by the above parable is loud and clear at its very first reading, there is a need to read it over and over again to understand and feel the depth of its true meaning. During our sojourn in this world, when we are young, we remain persistently under the illusion that we are here to stay forever and that there is plenty of time at our disposal to contribute our respective bits. As the years roll-by in the maze, one day we suddenly find that *the game is over* and the time has come to depart while we are still embroiled in the routine, chasing the shadows of wealth, prosperity and glory!

My second story is the priceless gift of Raman Maharishi personally hand-picked from his Ashram at the foot of the Annamalai Mountain in Tiruvannamalai.[5] Destiny placed me at the VIT University, Vellore, so that I could be blessed with the most transformational opportunity of my life in the pin-drop silence of just a few hours that I spent at the Raman Maharishi Ashram. It is in this Ashram that the following golden words of the Maharishi got engraved in my mind.

> The ordainar controls the fate of souls in accordance with their parabdhakarma. Whatever is destined not to happen will not happen, try as you may. Whatever is destined to happen will happen, do what you may to prevent it. The best course, therefore, is to remain silent.

The above two stories, coming together as they do from the great souls like Ramakrishna and Raman Maharishi, continue to illuminate my path through the thick and thin of life. To me, "*Ideals are like stars: you will not succeed in touching them with your hands, but like seafaring man on the ocean desert of waters, you choose them as your guides, and following them, you reach your destiny.*"

---

[3] Swami Vivekananda.

[4] Published by Sri Ramakrishna Math, Madras 600004.

[5] Raman Maharishi himself had set his foot here on 1st September 1896.

I have personally felt the transformational power of the great teachers of my time, and my mother was the first among them. Thanks to my revered parents and teachers that I have found a road on which destiny leads without giving me an iota of the feeling that I am following it. Indeed, we march together in tandem.

The scope of this paper is restricted to my professional journey into the world of Engineering, in keeping with the limitation of space. It began after I obtained my degree of Bachelor of Engineering from the University of Rajasthan in 1962 and the M. Tech degree in Geotechnical Engineering from the Indian Institute of Technology, Bombay, in 1964. Soon thereafter, I took my first job at the CSIR-Central Road Research Institute, New Delhi. As per the advertised position, I instantly became a scientist upon receiving my letter of appointment. It was the time when India was still recovering in the aftermath of the 1962 war with China. On day one of my joining, I was given the responsibility to lead projects on Landslides affecting India's strategic border roads in the environmentally fragile Himalayan belt. Little did I realise at that time that I was being wedded for life to the subject of Landslides many months before my wedding with Meena in 1965!

In the monsoon of 1965, spate of landslides struck various parts of the Himalayas opening a floodgate of self-learning opportunities for me. Professor S.R. Mehra, the then Director CRRI, asked me to lead a team of scientists to study the landslides in Sikkim and Himachal Pradesh. With the limited knowledge of the subject and almost no previous experience, I did as best as I could and worked hard to produce a fairly detailed report. Without even looking at my report, Professor Mehra asked me to apprise him of my findings and the scientific logic behind my decisions. He also enquired about the professionals I had questioned and consulted during my visit. He was not very happy when he heard in reply that I had written the report on my own, paid courtesy calls on the concerned Engineers and told them that the decisions will have to wait until approved by the Director. An unhappy Professor Mehra asked me to take a seat on the chair opposite to him and said—"Look, next time you lead a team, go as an Ambassador of this Institute and try to meet the highest professional in that organization. And learn to take decisions. Your right decisions will make you a better engineer and in case your decisions turn out to be wrong, there will be always time to correct them, and I will protect you." By hind sight, today, I have no words to express my gratitude to Professor Mehra who was ready to own my mistakes even in the formative stage of my career!

While at CRRI, in early 1966, I was selected for a scholarship to pursue my higher studies abroad. I was, however, not able to avail of the scholarship because as per the rules prevalent then, I had not completed the obligatory period of service. A great majority of my relations, well wishers and friends, with the sole exception of Professor Mehra, advised me to quit the job and go. Professor Mehra told me to stay on, learn to have patience, continue the good work and wait for the next opportunity, while assuring me of his support. Without a bit of hesitation, I declined the offer and continued with my work only to be surprised subsequently that indeed destiny had denied me the opportunity at that time, only because something better was in store for me!

Six months from then, Professor Mehra, true to his word, asked me to apply for the Science Research Scholarship of the Royal Commission(UK) for the Exhibition of 1851—the most prestigious and high value scholarship of that time. I submitted my application form with my research proposal. Imperial College, London being the world leader on landslide research at that time, I naturally connected my proposal with one of the flagship areas of research in the Department of Civil Engineering at the Imperial College. I was asked to name three institutions from any one of the commonwealth countries where I would like to pursue my higher studies. In reply, I repeated Imperial College London three times as my first, the second and the third choice—much against the advice of my friends. Their argument was that incase a slot for placement at Imperial College is not available, I will run the risk of losing the scholarship. However, exactly the opposite happened. One of the reasons I got the scholarship was also because the selection committee was impressed by my decisiveness in picking the topic of research as also the place of work. I came to know of this fact from none other than Sir W. D. Sturch, the then Secretary of the Royal Commission, a few months after joining the Imperial college. It may not be out of place to mention that Professor A. W. Skempton, FRS, in the department of Civil Engineering at the Imperial College under whom I had the privilege to get my first lessons on landslides, was himself the Chair of the Selection Committee.

Destiny played the dice yet again, and at the Imperial College, I found my dream placement with legendary Professor J. N. Hutchinson, FRSE who happily accepted me as his research student. Apart from being a professional giant in landslide research, he was known for his disciplined way of life, exemplary humility, exceptional power of imagination, focussed thinking and a deep sense of commitment to research and teaching.

I had scores of rare opportunities to spend quality time with him, especially during the field work and at his home. Whenever we moved up and down the slopes of the Isle of Wight and the Isle of Sheppey (in the United Kingdom), his eyes invariably saw at least one-hundred times more than what I could see or comprehend. My earlier education at IIT Bombay had equipped me to explain, why landslides had occurred where they did and why landslides did not occur, where there were none. But he was the first one to introduce me to the mind boggling spectre of landslides in the theatre of Nature and taught me to learn from every shred of field evidence and signatures left behind by landslides. His mastery to dig deep into the interplay of a variety of causative factors acting on the slopes over the geological time scale had no parallel. It was for the first time I began to realize that in Nature there is always much more to it than that meets the eye and the deeper we dig, the bigger is the haul!

My research at the Imperial College was supported both by the Royal Commission and the National Environment Research Council of the U.K. In the early period of my research on the Cliffs of the Isle-of-Wight, Professor Hutchinson and I came across a well developed mudslide, moving discreetly on nearly a flat slope. I never realized that a mere look at the mudslide will show-up on his face as a *Eureka moment*. Swiftly he turned his face towards me and told me that here is a hitherto unexplained problem I should consider to work on. I nodded without thinking as I heard him say that if the mudslide on a nearly flat basal boundary could be scientifically explained, the research can probably fetch me the degree of Ph.D.

Despite his sustained guidance and a comprehensive programme of meticulously conducted geomorphological mapping, geotechnical field and laboratory investigations, instrumentation, field monitoring and slope analysis spread over two years, I could not explain the fundamental mechanism of the mudslide. Frankly, I was a bit disappointed by the outcome of my research but Professor Hutchinson got even more excited as he saw the opportunity to dig deeper until the truth is found. I was asked to intensify the investigations and take recourse to field monitoring of transient pore water pressures along the discrete basal boundary shears. He had the sixth sense to *foresee* the artesian pressures arising from the undrained loading in the head region of the mudslide, long before I could demonstrate the same by field measurements.

Once again, the providence had something bigger in store for me. The challenge naturally shifted to the measurement of excess hydrostatic pressures on discrete basal boundary shears of the mudslide under study. To monitor rapid variations of pore water pressures within a slope, I needed quick-reading piezometers. Since no such piezometers were available in the market in the late 1960's, Professor Hutchinson insisted that I develop such piezometers in order to bring my study to fruition.

Jointly with the Bell and Howell Company of the UK, a strain-gauge type, transducerised stiff diaphragm piezometer was developed for the first time and rigorously tested and calibrated in the field on a number of mudslide sites in England and Northern Ireland. Subsequently, the mudslide in the Hampstead beds of the Isle-of-Wight was fully instrumented and its piezometric profiles were established. The results delivered *the last key that opened the door*. The field measurements provided for the first time–the much awaited hard evidence of artesian pore pressures arising from the undrained head loading of mudslides.

The above research finding not only earned me the Ph.D degree from the Imperial College in 1970 but it also yielded a game changing research case-record in Geotechnique which continues to appear in the Google search as one of the ten greatest papers on landslide research. After 42 years of sustained work in this field, it was in my luck to become the first and the only Indian so far to receive the 2012 Varnes Medal, the highest International Award for excellence in landslide research and practice, given at the UNESCO Headquarter in Paris. I felt really honoured especially because my supervisor, Professor Hutchinson was the recipient of the same award in 2004.

Soon after earning my Ph.D degree, I had several job offers in the U.K., and yet what is it if not the destiny operating through my parents love which brought me back home in early 1971. I came fully charged and inspired by the living legends like Professor A. W. Skempton, FRS; Professor A. W. Bishop; Dr Norbert Morgenstern, Professor Nick Ambraseys and Professor J. N. Hutchinson, FRSE, among others. Back at CRRI, I picked threads from where I had left in 1967 and dedicated myself fully to strengthening of the foundations of landslide research and practice in India.

In 1975, I moved over to the Central Building Research Institute at the instance of Professor Dinesh Mohan, the then Director, CBRI. It came for me as an opportunity to establish India's first Laboratory of Excellence in landslide studies. Within a period of five years, the CBRI became the first and the only institution in the country to be equipped with the first state-of-the-art Ground Penetrating Radar for subsurface exploration, the first Geotechnical Digital System for shear strength characterisation of discrete landslide boundary shears through simulated stress path Geotechnical testing, the first laser particle analyser for research on particle break down due to large displacements along slickensided slip-surfaces, the first pile drive analyser for diagnostics of pile foundations, the first set of vibrating wire piezometers for in situ pore pressure profiling of landslides and a fleet of sensors and field instruments for time-based monitoring and early warning against landslides. CBRI thus became the first institution in India with state-of-the-art capacity for scientific investigation of landslides.

In the year 1989, destiny suddenly opened a totally unforeseen, new window of opportunity for me to put my ideas into practice and create pace-setter examples. At that time-HABITAT in Nairobi was looking for a professional to lead a UN team in Sri Lanka, in the aftermath of several devastating landslide disasters. My name somehow reached the ears of Dr Ignacio Armillas, the UN-Habitat's Programme Director. He started looking for me in India at a time when I was touring Tanzania on a CSIR Mission. On my journey back to India, the destiny whispered into my ears that I should visit UN-HABITAT Headquarters in Nairobi and meet my friend Dr M. Ramaiah, the Director of SERC, Chennai, on deputation to UN-HABITAT. While I was sipping a cup of tea in the UN-HABITAT cafeteria, it was Dr Ramaiah who informed me of Dr Armillas' effort to contact me in Roorkee. Within minutes, I met Dr Armillas in his office and was interviewed for the position of Chief UN Adviser to the Government of Sri-Lanka. As he had already made enquiries about me during the process of short listing candidates, within about an hour or two of the interview, I was selected for the post. Within the next four months, I was already in Sri Lanka to lead the UN project on Landslide Risk Reduction.

I had the privilege of establishing Sri lanka's first laboratory on Landslide Studies and Services at the National Building Research Institute, Colombo in the early 1990 s, which has attained new heights over the period of the last 25 years. My team made a history of sorts when a 100-year-old-landslide at Watawala (which was a recurring annual nightmare) was permanently fixed by 1994 using, for the first time in the world, the innovative technology of directional drilling to effectively drain out the water saturated unstable mountain slopes by constructing an array of very deep and long sub-slope drains. So successful was the remedial scheme that for the Srilankans, Watawala landslide now exists only in the books of history. I regard Watawala as a place of pilgrimage and miss no opportunity to visit the site to *feel* the power of Science and Technology.

Back in India from Sri Lanka in 1995, my engagement with natural disaster mitigation initiatives grew faster than I could imagine. CSIR gave me the full opportunity to sustain my active participation in the disaster mitigation related national projects, alongside my other responsibilities. I studied the Malpa landslide tragedy of 1998; Gujarat Earthquake of 2001; Orissa Super cyclone of 1999 and the frequently occurring landslides in Uttarakhand. It was at that time that I was inducted as a member into the High Powered Committee on Disasters constituted by the Government of India. Of the many areas of my interventions and engagement with the HPC, my proposal on National Disaster Knowledge Network captured national attention and eventually became an important recommendation in the report of the High Powered Committee submitted to the Government of India in October 2001.

My destiny again played the dice to spring another surprise for me. During the coffee break after my presentation to the HPC on the National Disaster Knowledge Network, a gentleman (whom I did not know at that time) approached me and asked me to join Anna University and establish a Centre for Disaster Mitigation and Management in the University Campus in Chennai. The gentleman introduced himself as Dr. A. Kalanidhi-the Vice Chancellor of the University. The offer was totally unexpected, but genuine. Within days I got the formal offer and joined the Anna University by invitation in 2001. The Centre for Disaster Mitigation and Management at the Anna University thus owes its origin to that accidental opportunity and rare initiative by the Vice Chancellor.

Yet again, in 2005, I received an invitation from the Chancellor of the VIT University through Dr Kalanidhi, to establish a state-of-the-art Centre on Disaster Mitigation. We both drove from Chennai to Vellore to meet the Chancellor. The Chancellor was very quick in decision making and within minutes of the conversation, I was formally invited to establish a Centre for Disaster Mitigation and Management at the VIT University with all support guaranteed. Within less than six months of my joining, because of the exceptional commitment shown by the Chancellor, a state-of-the-art and fully staffed Centre for Disaster Mitigation and Management could be created with most modern of the equipment available in the international market. It was inaugurated by the Union Home Minister Shri Shivraj Patil in the presence of Gen N C Vij, Vice Chairman and Shri K M Singh, Member, National Disaster Management Authority; Shri V Shankar, Secretary, Border Management and dozens of disaster management experts from across the country. Today the Centre for Disaster Mitigation and Management at the VIT University is contributing to disaster education in a significant way.

While still at the Anna University, it is again out of nowhere that I got an invitation in 2003 to attend an interview in Nairobi for the position of Chief Technical Adviser (CTA) for the UN-Habitat's Iraq Programme. Upon reaching Nairobi, I came to know from a friend that my name was not on the original short list of candidates to be interviewed. Dr J. H. Moor in the Office of the Executive Director, UN-Habitat, reportedly added my name in the short list because he not only knew me well professionally but, in 1994, he had rated me as UN-Habitat's best CTA in the Asian region. With his providential intervention, I went through the process of formal interview and topped the panel, qualifying for the final interview with the Executive Director of UN HABITAT, Ms Anna Tabaiyuka. After an hour-long interview the same day, she put her signatures in the file. Although I was initially selected only as a CTA, after observing me perform under the most trying conditions in the war-torn Iraq, I was elevated to the position of the Programme Director of the Habitat's Iraq Programme during the period 2003–5. All this happened so swiftly as though the destiny had taken full control of my fortune.

In Iraq, the most deflating moment of my life was the ghastly view of the death and devastation unleashed by the terrorist bombing of the UN Head Quarter building at the Canal Hotel in Baghdad on 19 August 2003. The building where the UN staff had spent time discussing how to rebuild war-torn Iraq, was itself razed to ground with many causalities which included the Special Representative of the U N Secretary General. It was hard for me to believe that this was the place where, upon reaching Baghdad, I had lived in a six-bedded tent until a few days before the bombing incident. I could easily have been one of those killed but the providence again had a different design for me. What this single incident taught me in terms of disaster management, no class room education could ever teach. By hindsight, my disaster education would have been incomplete without the huge exposure to the highly professional and measured post disaster response by the Americans. I could see for myself the very thin line between life and death and the huge difference disaster managers can make in saving lives through the power of technology.

Disasters are the best school masters, a fact we often ignore in India. After the devastating Gujarat earthquake of 26 January 2001, I drew the attention of the then Director General of CSIR, Dr R.A Mashelkar about contribution CSIR could make to the world of learning. The various possibilities were also discussed with the then Secretary DST, Professor V.S. Ramamurthy and the then INAE President Dr A. Ramakrishna. All of them responded positively. DST funded my proposal on Seismic microzonation for safer construction. After the study was complete and the report was ready, the President, INAE, himself chaired a roundtable meeting at SERC, Chennai on 24 February 2003. The study report, adopted by the Department of Science and Technology, laid the foundation of disaster risk related initiatives by the INAE.

Convinced that INAE Fellowship can contribute hugely to the Government's initiatives on Disaster risk reduction, the ghastly Kedarnath tragedy of 2013 prompted me to approach Dr Baldev Raj, the then President INAE, requesting him to establish a Forum on Disaster Mitigation. So excited was he with the idea that to discuss my proposal, he himself chaired the first informal meeting of the Adhoc Committee on 29 January 2013. The follow-up meetings were held on 12 February and 19 July 2013 which eventually climaxed in the establishment of the INAE Forum on Engineering Interventions for Disaster Mitigation on 26 July 2013. Inter alia, the Forum has already delivered a most comprehensive set of Actionable Recommendations based on the outcomes of the two highly successful national level roundtable meetings on Landslides held in May 2015 and November 2015. The ensuing recommendations were well received by NDMA and other related institutions. The Government's recent invitation to me to join the National Advisory Committee to the NDMA now gives me a good opportunity to follow-up of the INAE recommendations.

In the aftermath of the devastating Chennai floods of 2015, it was at the initiative of Dr B N Suresh, the current President, INAE, that the Forum took up a Study on Urban Flood Disaster Mitigation under the leadership of Dr. C.D. Thatte. By now the INAE Forum on Disaster Mitigation is well established.

Although the focus throughout my career remained on Disaster Mitigation, my narrative for this paper will be incomplete if I do not mention about some of the totally unexpected opportunities that knocked my door at CBRI, Roorkee. In the year 1986, soon after assuming charge as the Director of the Institute, I had an accidental opportunity to meet the then Union Minister of Human Resource Development, Shri P. V.

Narsimha Rao, who had come to Roorkee to deliver convocation address. The Minister, in his speech, was highly critical of the Civil Engineers for designing buildings *which turn ovens in summer and refrigerators in winter*. At the luncheon hosted by the University Vice-Chancellor, I thanked him for alerting the civil engineers of the country, and conveyed my view that, without a strong political will, the situation is unlikely to improve. I most humbly expressed my disappointment that although the Government of India has created national laboratories like CBRI with all the sub-disciplines of Building science under one roof, yet the Government itself keeps ignoring CBRI even while dreaming of building resurgent India!

I was asked by the Hon'ble Minister to report at his residence in New Delhi, the next day which I did. Hon'ble Minister told me briefly about the Government's plan to build a network of functionally efficient Navodaya Vidyalayas across the length and breadth of India, and asked me if I was ready to *mount a tiger*? My nod was spontaneous and without any prior thought. Against the fierce competition from the CPWD and despite the stiff resistance from its then Director General, Shri Harish Chandra, the Minister was so impressed that the Navodaya Vidyalaya project was assigned to CBRI. My team lost no time to spring into action, and within a few months, the models of the designs of school buildings for different regions of the country were personally inspected, discussed and approved by none other than the then Prime Minister Shri Rajiv Gandhi. The Navodaya Vidyalaya Project, which had started in 1987 continued until 1999, well beyond the date I left CBRI in 1989. It involved the planning, design and construction of 305 schools, spread over all the States and Union Territories for which HRD Ministry paid more than Rs. 10 crore to CBRI at that time, giving it the most visible project since its inception. In 1988, from the Hon'ble Minister, I received the Science and Technology Award instituted by the Bhasin Foundation and CBRI benefitted immensely from the rapport with the Minister who, a few years later, became the Prime Minister of India.

In 1995, when Dr. R.A. Mashelkar became the Director General of CSIR, he invited me to return to the CSIR Headquarters in New Delhi from my UN assignment in Sri Lanka and asked me to raise the level of CSIR's International networking, and bilateral and multi-lateral overseas programmes. While in the flight from Colombo to Chennai on way to New Delhi, I conceived establishment of International Science and Technology Affairs Directorate (ISTAD) at the CSIR Headquarter. Dr Mashelkar instantly agreed with the idea of establishing ISTAD and gave the consent to the proposal on the very first day of my joining. What ISTAD could achieve during my five year tenure during 1995–2000 is a part of CSIR's history!

In the wrap-up to this article, I will like to say four things. First, I'm firmly of the belief that the real beauty of our most satisfying professional contributions lie in our nameless acts of accomplishments aimed at growing the culture of science around us and not so much in the indicators such as number of patents filed or papers published in the high impact factor journals. Second, we meet our destiny at points which often fall outside the printed maps in the Atlas of our making. Third, all our dreams can come true, if we have courage to pursue them endlessly. And finally, as Forster had said, "Failure and success seem to have been allotted to men by their stars. But they retain their power of wriggling, of fighting with their stars, and in the whole universe the only interesting movement is this wriggling."

Fifty two years ago, I have had the privilege to be a student in the Department of Civil Engineering at the IIT Bombay and in August 2016, as its distinguished Alumnus, I had the honour to deliver its Convocation Address. While congratulating the graduating students-I asked them to join *the wriggle dance* with me in the global arena!

An Academic's Approach to Professional Problems

Subhash Chander

Introduction

The approach to work depends on the environment in which one is brought up. In my youth I have seen many of my countrymen from earlier generation sacrificing their careers and devoting their life for the cause of freedom from the British rule. Their sacrifices created an urge in my generation to work to improve life in India after independence. We were given opportunities to gain technical knowledge on highly subsidized tuitions fees, hostel accommodation and other facilities. The times highly motivated us to make a mark and gain knowledge to solve the problems facing the country. Engineering education focuses on problem solving, and it aptly matched my own determination to gain in depth knowledge useful in the solution of problems in the area of water resources. The Water Resources Group at IIT Delhi, which, I joined in 1961, encouraged professionals from Government organizations to discuss their problems and use our knowledge base to find solutions. Here, I will discuss some cases to show how our mind worked to find solution to the problems using latest tools/analysis and synthesis in Hydrology/Hydraulics.

Design of Cavitation Free Transition for Sutluj-Beas Link

The Bhakhra-Beas Board was seized with the problem of designing a transition from a circular section to a rectangular section supported on piers for Beas-Sutlej link. The Board had approached the best Laboratory in India to suggest shape of the nose of piers, so that negative pressures do not develop in the area and damage the piers. The laboratory is famous for testing designs using hydraulic models. The report was

S. Chander (✉)
302, Ganapati Apartments, GH-27, Sector 56, Near HUDA Market, Gurgaon, Haryana 122003, India
e-mail: chanders68@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_3

examined by us in IIT. The Reynolds number which governs flow in closed conduits was calculated for the model. Its value was 1/25th of that of prototype. Therefore, it became evident that shape of piers in the model derived at low Reynolds Number was not likely to work without cavitation. A suggestion was made to test the model in wind tunnel at 15 times the Reynold number of the hydraulic model and see whether changes are required to ensure cavitation free design. The Board accepted the proposal and experimentally determined the shape of piers supporting the roof was provided to the Board. The model was 1/25th of the size of Prototype. After determining the shape of the piers ellipses were fitted on either side of the piers and instead of supplying the engineers the coordinates of the nose curve from the model as multiplying them would have magnified the errors in measurement. The major and minor axes of the ellipses fitted to experimental data were given in the report. Before supplying the results model was remade using the calculated coordinates and was found to work without generating negative pressures. The Board discussed our report and accepted the shape suggested by us. The structure is operating for the last 40 years without any cavitation even with an imperfect assumption and determination of shape of piers at a much lower Reynolds number. The engineers told us that fitting of ellipses helped them to precisely obtain the curved shapes for the nose of piers producing a streamlined shape.

Real-Time Flood Forecasting of Levels of Yamuna River at Delhi

In 1971, Central Water Commission was using Gage to Gage correlation to forecast the flood levels at Delhi. The problem was to forecast the levels as flood levels start rising at Delhi till the time flood recedes to a level below the danger mark. The past data was analyzed to understand the formation of floods in the river and it emerged that a simple reservoir and time delay could describe the formation of flood wave in the catchment using the input hydrograph data at an upstream point.

The time delay was found using the travel time between the upstream point and at Delhi Bridge, and reservoir characteristics were obtained from the past data. The model was tested by the engineers in Central Water Commission by forecasting a flood in 1971 the monsoon. There was a good match between the observed and forecast values, and the time for which the flood was above the danger mark at Delhi. The model was a behavior model and was imperfect to the extent that time of travel for various floods would vary between the upstream point and the downstream. But it paved the way for useful interaction with the premier agency to upgrade their river forecasts on all India basis.

Location of Hot Water Outlet in a Man-Made Reservoir at Korba in Relation to Inlet Point of Water for Cooling Purposes in a Thermal Power Plant

The problem was to locate the outlet so that hot water from the thermal power plant gets cooled by evaporation by the time it reaches the inlet point. The engineers wanted that we make a 1/25 scale model of the system in IIT and show that hot water cooled before it reached the inlet. The cooling had to take place by evaporation from the water spread of hot water as it travelled from hot water outlet to the intake point. In actual reservoir in the field it was found that at different sections nearer to intake the water on the surface was hotter as compared to water at the bottom of the reservoir. When we took temperature measurement on the hydraulic model the water next to the bed was found to be hotter than at the surface. The 1/25th scale model reduced the depth of the reservoir to 1/25th of the depth in the prototype and the sun rays penetrated the water depth in the model to heat the bottom surface which in turn heated the water. The model was abandoned and problem was split into two sub-problems. First problem was the determination of area of reservoir surface which takes part in the evaporation to cool the hot water between the outlet and inlet. The second problem was to develop a mathematical model using energy balance approach to forecast the temperature reduction for various ambient temperatures, relative humidity, wind speed, and water temperature. The area was determined for an outlet inlet configuration, which gave the area required to cool the hot water in the hottest month of May each year. The experiment to determine the area for various inlet-outlet configurations was carried out in a flow visualization tank. A co-axial diagram for computing the inlet temperature using climate variables was provided to the thermal plant for adaptive management of cooling in the plant for the suggested configuration of inlet and outlet for various ambient temperatures using the mathematical model. Three dimensional problem in this case was split into two problems and an approximate approach was used to find solution to meet the deadline.

Spacing of Embankments on Both Sides of the River Yamuna so that Delhi Is not Flooded if 1978 Flood Recurs in the Yamuna Basin

It took three days of active consultation with the engineers of Central Water Commission to define the deliverable by IIT. It was decided that IIT will prepare a report showing the impact of various spacing of the embankments on water levels at Delhi Bridge, for the passage of 1978 flood wave in the basin. The gauge data available with the commission along the river as 1978 flood breached the existing embankments was supplied to IIT. IIT formulated a conceptual model of the river reach and developed a new methodology in three months to answer the question. Recommendations were also made to get one foot contour survey of the Yamuna flood plain so that we could use St. Venant equations to recalculate the results for comparison with the new methodology. We repeated the work when survey data were made available to us after two years and found that the earlier work gave as good results as the established methods we used after the data were made available. These results were used to determine the water way and foundation depths of all bridges constructed on river Yamuna in Delhi State, and to rebuild the embankments from Kalanaur to Delhi. This again illustrates the point that engineers need quick answers, and are willing to accept reasonable assumptions as long as the results are validated.

Impact of Forests on Floods in Ramganga

The impact of catchment treatment and tree planting by forest department of U.P on floods in Ramganga river basin on the basis of hydrological/hydro-meteorological data on treated portions of the basin was another interesting problem. One of our PhD students decided to work in this area and collected hydrological, hydro-meteorological and catchment treatment data. After analysis of the data it emerged that catchment treatment has no effect on floods of 50 years and higher return period. Given the monsoon climate and topography in this area, low flows in the river decreased during low rainfall periods. These were controversial statements. Most people believed that floods in rivers decrease because of forestation, and flows increase in dry periods. Our conclusions were explained by drawing the attention of the forest officials, that the soil absorbs low intensity rainfall as infiltration capacity of the soil is greater than the intensity of rainfall thus decreasing surface runoff. During the rainless periods the new plantation transpires the water in the soil emptying it for next rain. However, during high intensity rains which are usually preceded by low intensity rainfall, the soil is saturated and it has practically no effect on floods higher than 50 year flood. Our conclusion is supported by the historical fact that this region has faced catastrophic floods in last weeks of August and first week of September when the catchment is saturated by rain in the earlier periods. It also emerged from the study that plantation in central portion of the catchment can increase the intensity of floods. The reason being that delay time of runoff increases due to plantation in middle reaches. The runoff from this area in some cases matches with the arrival time of flood from upper catchment thus increasing the flood intensity just downstream of middle catchment. In this case data were analyzed to bring out the impact of treatment of the catchment. It required a number of meetings with the agencies to convince them that each catchment/basin is different and its behavior is a function of topography, geology and hydrology, and that results cannot be generalized.

Creating an Interactive Simulation Model for Lago-Di-Trassimino Perugia, Italy for Developing Solutions to Improve Tourism in the Lake Area

This problem was identified to help the environmental and tourism department as well as the local administration to improve the foot fall of tourists in the area to boost the local economy. This required that the lake has sufficient water during the tourist season so that all recreational facilities on the lake are operational. It was decided to augment the water in the lake from adjacent basins. The problems posed was to develop a simulation model of the lake so that the quantum of augmentation is decided. Thirty years of data of lake levels was available to check the validity of the software which was designed at IIT and delivered to hydraulics department of Perugia University, our clients, to develop a project report for funding to the government in Rome.

The experience I gained in solving problems for the diverse groups helped me to coordinate the implementation of computerization of administrative functioning at IIT Delhi. The stakeholders were, the IIT administration which funded it, the average worker who had to use the application, technical group whose advice I sought to develop the infrastructure, technical committee ably supported by administrative computerization support service, consisting of software professionals and chaired by Head computer centre who coordinated the design of software with the consultancy firm, the humanities department which planned the training of the staff and the one page support pamphlet for each desk in the sections. It is heartening to note that the application is fully operational in IIT since last 20 years and has been updated over time by including new rules and procedures.

Disposal of Silt from Balancing Reservoir in Bhakra Beas Sutluj Link

The following cases pertain to the period after my superannuation from IIT Delhi.

The problem arose in Himachal Pradesh because of pumping of silt slurry from balancing reservoir to a natural stream between the balancing reservoir and the river Beas. The silt settled in the stream. During high intensity rain the stream overflowed its banks and flooded the agricultural area, depositing coarse silt and ruining crops. I was invited to join as non-official member of the committee constituted by the court for suggesting a suitable solution to off the problem. The solutions on the table ranged from a pipeline to carry the silt from balancing reservoir to either the river Beas or Sutluj. After lot of discussion, the colleagues on the committee agreed to use the hydrological characteristics of the stream to solve the problem. The innovative solution was to pump the silt whenever the flows could carry the silt in the stream to the river to a level when it starts flooding the adjoining agricultural lands. A communication system was set up on the stream, nearest to flooded area to communicate levels in the stream to the dredging party to enable them to start dredging and pumping silt within the specified levels. The court accepted the solution and requested the committee to monitor the functioning of the solution for next two years. The system is functioning to the satisfaction of all parties saving money and installing a system which constantly monitors the applicability of solution.

Quantitative Analysis for Equitable Distribution of Water Between Riparian States of the Krishna Basin

I joined interstate water resources Andhra Pradesh as a senior consultant in 1997 to assist the State, before the tribunal which was set up to allocate water of the river Krishna between riparian States. My terms of reference were to assist the legal, technical and administrative teams to create the basis on which the State of Andhra Pradesh could logically present their case before the Krishna Water disputes Tribunal II for equitable distribution of water between the riparian States. The riparian States are Maharashtra, Karnataka and Andhra Pradesh. After assessing the availability of data, it emerged that the utilization data which are needed to develop a virgin time series were not available on monthly basis to A.P from upper states. Annual utilizations for the State and cropping patterns in the basins were used to determine utilizations required at appropriate time scale. Rainfall data was obtained for all the IMD stations within the Krishna basin. The density of rain gauges was augmented in various sub-basins with time. For example, there were 10 rain gauges for first 10 years, they were increased to 20 for the rest of record. In such cases rainfall to rainfall regression models for the common data time interval was used to homogenize the data. It was decided to determine the water availability in the 12 sub-basins of river Krishna on monthly basis for the sub-basins using measurements on the river at central water commission data stations and rainfall data from IMD. The strategy employed was to use measured data after validation using standard methods. The utilization data on annual basis was used to develop annual time series for all the basins, and water generated by each state was determined. Since all these basins contribute to flow at the terminal point of Vijayawada, the contribution of each sub-basin was suitably modified so that annual contributions from sub-basins match the virgin flows at the terminal point. These annual flows were divided using gauged flows at Central Water Commission stations into monthly flows. A multiple reservoir simulation Mike Basin model was used to determine how the projects were impacted in the State of Andhra Pradesh because of allocation by the previous Tribunal and additional allocation to Upper States. I filed an affidavit as an expert witness on behalf of state of Andhra Pradesh on water availability and impact of allocations upstream on A.P in 2008. I was cross-examined for over three months by the other states on the Issues identified by the tribunal to determine the new allocations to various states as well as to address their concerns on my statements in the affidavit and conclusions. The affidavit was based on whatever data was available with the state of Andhra

Pradesh and paved the way for the tribunal to introduce quantitative methods to address the issues. The states were asked to supply latest data. CWC provided the expertise to the tribunal with two assessors and other engineers to work out the water availability with the new data available with the tribunal. It is heartening to note that my affidavit set a precedent to use quantitative methods in the allocation of water between the states keeping principles of equity, hydrological factors, demography, and riparian rights in mind. A major recommendation accepted by the tribunal was to set up a Board with adequate powers to implement the decisions of the tribunal with online data exchange from projects to make the process of utilization by various projects totally transparent.

During my dealings with the engineers since 1968, I find that they are devoted to find creative solutions to the problems in hand and are result driven. Usually the problems are under or over specified, and need to be diagnosed. Deliverables can only be defined after assessing the data available with the organization. The methodologies to be followed are identified. Professional's time frame is more or less immediate; therefore, standard software to analyze the problems is preferred. The solution is found using the identified methodologies and checked with other formulations using simplified assumptions. The result is evaluated to see whether it matches the observation in the field and can be explained to a logical group. Otherwise, new methodology such as the one described in the inlet outlet case is evolved. The results are presented as per the deliverables and should be in a format which helps them in implementation. Fitting of ellipses to the nose of piers instead of coordinates of experimental data helped considerably in implementing recommendations. Mathematical/conceptual models or simulation models help immensely in solving hydrological problems quickly and ensure that law of conservation of mass is not violated in the computation processes at all junction points.

The data availability decide the methodology, deliverables and the choice of model. Models help to develop consensus between diverse group of stakeholders involved in real life situations. The impact of conclusions reached in the Krishna case was determined by the riparian States using data in my affidavit, and I was interrogated with their interpretation for weeks to demolish or accept the line of reasoning. Such an approach brings transparency to the decision processes, a boon in multi stakeholder groups for consensus building. They also help to build confidence in the accepted solutions. The underlying concept followed by us as engineering academics in all the above cases as well as others I had the good fortune to be associated with is that different or alternative methodologies are better even though our understanding of the physical processes that were modeled were not perfectly understood. Integrating new tools/technologies to find solution to professional problems in reasonable time was the guru mantra.

Why Can't We Do It Here? How Early Can Innovation and Entrepreneurship Be Taught?

V. S. Ramamurthy

"Have the institutions (in particular IISc and the Indian Institute of Technologies) over the past 60-plus years contributed to making our society and the world a better place? Is there one invention from India that has become a household name in the globe? The reality is that there is no such contribution from India in the last 60 years," thus spoke Mr. Narayana Murthy during the IISc convocation ceremony held in Bengaluru on Wednesday, July 15, 2015." (The Hindu July 16, 2015)

It is not surprising that the scientific community and the teaching community in the country were taken aback and consider this as an unfair criticism. After all, free India has always been a country in transition. When the country came out of the colonial rule in 1947, we inherited a large underfed population, poor resources and poor infrastructure including the educational infrastructure. It is our early investment in higher education and industrial infrastructure that led us to where we are today. If India is no longer a country of chronic food shortages, if India is recognized as a global player in selected areas of high technology like atomic energy and space in spite of several decades of demeaning technology denials, it is the human resource nurtured by our educational institutions. Almost the entire Indian diaspora in Silicon Valley or in Route-28 are products of the very Institutions those Mr. Murthy is critical of. US gave them a different kind of opportunities that India did not provide and they delivered differently. Can it be held against the Indian educational institutions? At the same time, the message from the full text of Mr. Narayana Murthy's address appears to me somewhat different and relevant. Mr. Narayana Murthy was simply lamenting "Where is the Indian Silicon Valley? Where is the Indian Route-28? If a small Indian diaspora can do it there, why not in India?"

It is well known that Innovation and Entrepreneurship characterize the genetic map of the US science and technology systems. How is the Innovation and Entrepreneurship ecosystem in India? Indian civilization is thousands of years old. A civilization that has survived natural disasters, external invasions and internal conflicts for so

V. S. Ramamurthy (✉)
National Institute of Advanced Studies (NIAS), IISc Campus, Bangalore 560012, India
e-mail: vsramamurthy@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_4

long can't but be innovative and entrepreneurial. Three centuries of colonial rule had their impact on this ecosystem. Innovation and entrepreneurship got more and more limited to trade and commerce with deliberate efforts by the colonial rulers to scuttle local resources and talents. Not only India missed the industrial revolution but it also lost the ecosystem for technology and skills related innovation and entrepreneurship. Dominated by government led initiatives in the early decades of free India, the Indian society itself evolved as a risk-averse society with emphasis on jobs and family businesses.

India did realize rather early that it is important to nurture innovation and entrepreneurship amongst the technically qualified youngsters if the country has to draw the full benefit of the technological developments of the twentieth century in the country and across the world. The establishment of the National Science & Technology Entrepreneurship Development Board (NSTEDB) under the aegis of Department of Science & Technology and a chain of Science and Technology Entrepreneurship Parks in some leading technical education institutions were perhaps the earliest efforts in the country to promote technological innovations and entrepreneurship among young students. Unfortunately, the government controlled license- quota environment of the pre-90's did very little to encourage entrepreneurship. It is interesting to note that India and China embarked on entrepreneurship training almost at the same time.

When India opened its economy to the global markets in 1991, there was of course a wide spread apprehension that India may not be able to face the global competition. There was also a perceived window of opportunity. Thanks to many new initiatives taken by the government such as the creation of the Technology Development Board and the Technology Business Incubators, the country witnessed many new technological successes some of which were indeed globally competitive. The TBI's offer not only technical and infrastructural support to aspiring youngsters but also an integrated package of support services with moderate costs. The Biotechnology Industry Research Assistance Council (BIRAC) under the aegis of the Department of Biotechnology is yet another initiative of the government to bring academia and the Industry closer leading to new products and enterprises. Who can forget the outstanding successes of Indian start-ups in the global vaccine market? It is indeed intriguing why we are not seeing such successes in other sectors. It is even more intriguing to see that some of the initiatives have become non-functional today. There is indeed an urgent need to review and understand why there were many successes in the early years after the liberalization but not now. It is my perception that today innovations in the IT industry are primarily driven by the industry itself while there is substantial participation of the industry in nurturing innovations in the biotech industry. Fortunately, these developments have also attracted venture capitalists from across the globe. The recent reverse migration of technopreneurs is yet another encouraging sign. These developments are bound to strengthen the ecosystem for innovation and entrepreneurship in the country. Unfortunately, in the manufacturing sector requiring large investments, the industry participation is minimal and entrepreneurship is yet to take roots. Government initiatives within the framework of global trade agreements are unavoidable.

Last but not the least, it is important to remember that innovation and entrepreneurship are not limited to the technology domain alone. They have to percolate across all segments of the society. This can happen only when innovation and entrepreneurship training become part of our educational system. This calls for a close cooperation between the educational institutions, the government, the industry and the public at large. Professional academies like INAE have a major role in making this possible.

A large number of people in my age group have children abroad. I am no exception. My daughter lives in California. Parental responsibilities demand that you visit them periodically. When you visit them, you do not know how to spend your time and one of the pleasant duties is to escort the grand children to the school. During one of my visits, I happened to escort my grandson to the school on a Saturday for some extracurricular activity. The teachers were kind enough to permit me to sit in a comer of the room and watch the children without disturbing the class.

After the usual pleasantries, the teacher asked every student what they had for their breakfast. The students were asked to write it down on a wall poster. Every student was also asked to say a few words about their breakfast. Typical of most US schools, the ethnic diversity was obvious and that reflected on the breakfast menu. The enthusiasm of the students to describe what they had for breakfast to an audience, not all of whom were familiar with those items, was obvious. At the end of the day, the students were asked to bring one or more photographs of the breakfast items prepared in their house with brief descriptions of how they are prepared, their nutritional value etc. and a sample portion. The student-teacher and the student-student interactions were so lively that I decided to accompany my grand son to class the following week. The next session started off with all the photographs neatly arranged on a display board. The students took their turns to come in front and give a brief description of the items that they brought, their ingredients and how they are made. Every student was then asked to name one or more breakfast items that he liked most. It was amusing to note that every student wanted something different from what he has for breakfast in his own house. I was also surprised to see that the humble idli was one of the popular breakfast items among the students though very few of them had the luxury of having idlis in their house. Apparently, a popular Indian restaurant in the vicinity was tickling their taste buds with steaming idlis and tangy sambar and chutney.

During the week, my daughter had a call from the teacher and was asked whether she would volunteer to demonstrate idli making to the students during the next session. My daughter ended up in the class room the next week end with all the paraphernalia and made idlis in front of all the students. At the end of the day, my grandson was asked to work out how much it costed to make one idli. He had to also explain why it costs more in a regular restaurant.

It was then time for me to return. I heard from my daughter that after sometime, when there was a student fest in the school, my son wanted to put up an idli stall and ended up with a tidy sum as profit in his pocket. I now realize that the teachers had created an entrepreneur in my grandson without saying so. I now realize that it is never too early to introduce innovation and entrepreneurship.

Engineering Education and Sustainable Development

R. Natarajan

Engineering education has in the recent past undergone a major transformation across the world in highlighting *Outcomes-based Education* and is driven by corresponding accreditation imperatives. The National Board of Accreditation Graduate Attribute #7 on *Environment and Sustainability* prescribes the need to "*understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development*".

While the importance of *Sustainability* is gaining in importance, there is no generally accepted definition of the term. Those who support the concept disagree in its precise meaning; while those who do not support it, agree that it has no meaning at all! There is also no widely recognized way to *measure* it.

The Imperatives of Sustainable Development: There is no alternative to Sustainable Development; it is already too late; we need to stop current trends; we need to do things differently, and to do different things. Over millennia, we have moved from survival economy and lifestyles to consumption economy and lifestyles. We need to move from consumption economy and lifestyles to conservation and preservation economy and lifestyles.

There are many dimensions of Sustainable Development: Each alphabet opens up opportunities and possibilities. For example, with the letter *E* we have Energy, Education, Environment, Efficiency, Ecology, Emissions, Economy, Employment, Equity, Engineering, Earth, Ethics, etc. With the letter *R,* we have Reduce, Re-use, Recycle, Renewable Energy, Resources - Exploitation, Conservation, etc.

Concepts of Sustainability and Sustainable Development: The pioneering definition of Sustainable Development is from *The Brundtland Report,* 1987: Sustainable Development meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

R. Natarajan (✉)
52/1, 13th Cross Road, Between 4th and 6th Main Roads, Opp. Jayanti Apartments, Malleswaram, Bangalore 560003, India
e-mail: natarajan60@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_5

Other definitions include: Living within 'the carrying capacity' of the Environment; Realization that the biosphere is both for us and for our descendants. A very popular expression is: "We have not inherited the Earth from our parents; we have only borrowed it from our children". Sustainable Development is an intergenerational concept, seeking equity over time, and minimization of disparities between generations.

Since the present standard of living is low in most emerging economies, people aspire for a higher standard. Sustainable Development cautions that there are limits to such growth: Due to: finite stock of resources (both energy & materials); pollution of the environment; exploding populations; escalating aspirations; and conflicting interests.

Human Survival and Development depend on two crucial factors:

- Population control; and
- Successful Management of the world's natural resources.

"No development plans will be expected to bear fruit unless efforts are made simultaneously to contain population", concluded M. S. Swaminathan Committee recently.

Some Laws Governing Sustainable Development

Summary of the *Three Laws of Thermodynamics*:

All energy conversion processes are governed by the Laws of Thermodynamics. The following popular presentation of the three Laws brings out the hopelessness of the energy situation for mankind:

- **First Law**: You can't win; you can only break even.
- **Second Law**: You can break even only at the absolute zero (Carnot efficiency is 100% at $T_2 = 0$).
- **Third Law**: You cannot reach the absolute zero.
- **Conclusion**: You can neither win nor break even!

The Fundamental Law of Energy Use:

"Unless the ratio of benefit to cost, measured in units of energy, is greater than 1:1, the potential resource will fail to become an actual resource." This Law defines energy resources, and provides the standard that all potential energy resources and energy technologies must meet. For example, food, fossil fuels, fissile fuels, etc. are economic sources of energy only if they can be obtained at an energy/work cost that does not exceed the energy or work benefit obtained from them.

Thus, the following have little meaning in terms of energy resources:

- Estimates of crude oil in the ground.
- Calculation of earth's total energy content.
- Solar insolation intercepted by the earth.

The moment that more energy is required to find, extract, process, transport and use a barrel of oil, than can be obtained from it, or in exchange for it, there will be no more potential reserves of petroleum. *Technological* feasibility neither equals nor forecasts *economic* feasibility.

Some Environmental Principles

In addition to the general principles of Sustainable Development, the Engineering Council identifies four key *Principles of Environmental Protection, impinging* upon Engineers' concerns:

- ***The Prevention Principle***: is based on the universal concept of Prevention being better than Cure. This Principle accords priority to anticipating and preventing pollution and environmental harm.
- ***The Precautionary Principle***: This requires that "where there are significant risks to the Environment, precautionary action should be taken to limit the use of potentially dangerous materials, or the spread of potentially dangerous pollutants, even where scientific knowledge is not conclusive, if the balance of likely costs and benefits justifies it".
- ***The Polluter-Pays Principle***: This Principle requires the producer of any environmental damage to meet the financial costs of that damage. In law, an "avoidance cost" approach is employed, which requires the State to set standards, and the Polluter to meet compliance costs.
- ***The Principle of Integration***: This concerns the need for integration of environmental consideration into all areas of decision-making, so that measures taken to improve environmental quality in one area are not undermined by unforeseen side-effects, or contradicted by action taken in another area.

Two Conclusions of World Energyconference (1989)

These two conclusions are as valid today as they were then.

1. "***Fossil fuels will continue to meet most of the world's growing energy demand***".
   The implications of this conclusion are: *World energy demand is bound to increase monotonically due both to increase in population and more energy-intensive lifestyles. Most of this energy demand will be met by fossil fuels. This conclusion underscores the inevitability of our dependence on fossil fuels, and the need for us to use them rationally.*
2. "**The economical rational use of our energy resources is essential for protecting the environment**".
   This establishes the nexus between Energy and Environment. Modern living depends on the use of energy resources, and all energy use is accompanied by environmental degradation. Higher efficiency of energy use has the twin benefits of slower resource depletion and reduced pollution.

The Four Laws of Ecology

In order to survive on the earth, human beings require the stable, continuing existence of an appropriate environment, which encompasses a thin skin of air, water and soil. Barry Commoner has enunciated four Laws of Ecology that highlight the scope of this science of planetary housekeeping:

I. ***Law Everything is connected to everything else***: The ecosystem consists of multiple interconnected parts, which interact with each other. The feedback characteristics of ecosystems result in amplification and intensification of several processes.

II. ***Law Everything must go somewhere***: In nature, there is no such thing as "waste"; nothing can be expected to "go away".

III. ***Law Nature knows best***: Modern technology aims to "improve on nature". This law holds, however, that any major man-made change in a natural system is likely to be detrimental to that system.

IV. ***Law***: ***There is no such thing as a free lunch***: In ecology, as in economics, this law is intended to warn that every gain is won at some cost. In a way, this law embodies the previous three laws. Because the global system is a connected whole, anything extracted from it by human effort must be paid for; payment of the price cannot be avoided, it can only be delayed.

Un Decade of Education for Sustainable Development (2005–2014)

The overall goal of the UN Decade of Education for Sustainable Development (DESD) is to integrate the principles, values and practices of sustainable development into all aspects of education and learning. This educational effort is expected to encourage changes in behaviour that will create a more sustainable future in terms of environmental integrity, economic viability and a just society for present and future generations.

Implementing the mission involves: promoting and improving quality education; reorienting educational programmes; building public understanding and awareness; and providing practical training.

Kofi Annan, the former Secretary General of the United Nations has said: "*Our biggest challenge in this new century is to take an idea that seems abstract—sustainable development—and turn it into a reality for all the world's people.*"

Several distinctive Generic Sustainability Competences have been identified:

- Competence to think in a forward-looking manner, to deal with uncertainty, and with predictions, expectations and plans for the future.
- Competence to work in an interdisciplinary manner.
- Competence to see interconnections, interdependencies and relationships.

- Competence to achieve open-minded perception, trans-cultural understanding and cooperation.
- Participatory competence.
- Planning and implementation competence.
- Ability to feel empathy, sympathy and solidarity.
- Competence to motivate oneself and others.
- Competence to reflect in a distanced manner or individual and cultural concepts.

Innovative Engineering and Leadership for Achieving National Goals

Pradeep Chaturvedi

Introduction

This paper can be appropriately started with an epilogue which is a quotation from Dr. Kalam's Book "Thoughts for Change – We Can Do It". He writes "Advances in Technology need to give a quantum jump in the Economical Status of the country. Industry developed countries have understood this fact. If we, too, understand it, then we will be one of the leaders in the world…If we change our mindset then India certainly has a big chance of becoming a global leader in the knowledge age". His book then focuses on Creative Leadership to Support Innovation. Dr. Kalam has related innovation with economic development; technology and engineering.

Role of Innovation in Competitive Global Economy

Innovation is now the key to growth in the competitive global economy. Government and business have critical role to play in strengthening the Innovation Ecosystem. The government has to provide the enabling policy interventions; strengthen knowledge infrastructure: improve inter-institutional collaborations; provide mechanism of business innovation at all levels, especially medium, small and micro enterprises; and provide vision to a national level road map for innovations. The business organizations have to identify and project the necessary framework of support from the government for enhancing innovative efforts and undertake innovation. Innovation ecosystem when supported by the government as well as the business will have a better chance of survival and growth in developing countries.

P. Chaturvedi (✉)
World Environment Foundation, M-52, Part II, Greater Kailash, New Delhi 110040, India
e-mail: pradeepc08@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_6

Strategic and organizational factors separate successful big-company innovators from the rest of the field. Innovation is difficult for well-established companies. By and large, they are better executors than innovators, and most succeed less through game changing creativity than by optimizing their existing businesses.

According to McKinsey & Company since innovation is a complex, company-wide endeavour, a set of cross cutting practices and processes are required to structure, organize, and encourage it. Often overlapping and non-sequential practices resist systematic categorization but can nonetheless be thought of in two groups. The first group which is 'strategic and creative in nature' helps set up priorities, and the terms and conditions under which innovation is more likely to thrive. The second group deals with how to deliver and organize for innovation repeatedly over time and with enough value to contribute meaningfully to overall performance.

Opinions differ because those involved in the process of innovation firmly believe that there is no proven formula for success when it comes to innovation. McKinsey & Company in 2015 conducted a multi-year study comprising in-depth interviews, workshops, and surveys of more than 2500 executives in over 300 companies, including both performance leaders and laggards, in a broad set of industries and countries. They observed that a set of eight essential attributes are present, either in part or in full, at every big company that is a high performer in product, process or business model innovation.

Leadership for Innovation

Corporate transformation through fostering innovation and ideas management is an important issue for discussion. Leadership is looked in the overall canvas of political leadership, corporate leadership and social leadership. At the same time, innovation is also viewed in terms of strategic relevance and developing innovative management practices and converting innovations into commercial reality. Though social innovation is much talked about but it does not dictate or transform the economic markets or set rules for them. Social innovation is globally playing an important role, but it will take time for social markets to make effective inroads into economic development model. Engineering interventions are important for success.

A corporate strategy for innovation needs to be evolved. Experts realize that corporate policies, processes, procedures and support tools should encourage and enable responsible innovation. Board should put a framework in place to encourage intra-preneurship as a viable alternative. The Board should also identify and tackle obstacles to innovation, barriers to entry and factors that increase the cost, complexity and difficulty of doing business. They should be prepared to work with other companies and with governments to reduce or overcome the obstacles.

Board should agree on their appetite for various forms of risks, recognize that innovation involves risks, and take practical steps to reconcile the requirement of both new developments and maintaining prudent control. Boards need to establish an appropriate balance between entrepreneurship and risk taking; and between the formulation of strategy and its implementation. Building appropriate checks into support arrangements and tools can ensure that new developments do not infringe laws, rules, policies and license conditions.

Essential Attributes for Innovation

In the digital age, the pace of change has gone into hyper speed, so companies must get strategic, creative, execution, and organizational factors right to innovate successfully. It has been concluded that if companies assimilate and apply certain attributes in their own way, in accordance with their particular context, capabilities, organizational culture, and appetite for risk, they will improve the likelihood that they can light the spark for innovation.

Following eight attributes have been identified by various management companies and experts.

(i) *Aspire*: US President, John F. Kennedy's bold aspiration, in 1962, to "Go to the Moon in this Decade" motivated a nation to unprecedented levels of innovation. Indian Prime Minister, Narendra Modi's call for "Make in India" has similarly set in motion a large number of innovative actions both in terms of policies as well as programmes though technological and engineering innovations have still to catch on. A far-reaching vision can be a compelling catalyst, provided it's realistic enough to stimulate action today.

(ii) *Choose*: Innovation is inherently risky, to be sure, and getting the most from a portfolio of innovation initiatives is more about managing risks than eliminating it. Executives must create some boundary conditions for the opportunity spaces they want to explore.

(iii) *Discover*: Innovation also requires actionable and differentiated insights—the kind that excite customers and brings new categories in markets into being. One can look for insights by methodically and systematically scrutinizing three areas: a valuable problem to solve, a technology that enable a solution, and a business model that generates money from it.

(iv) *Evolve*: Business-model innovations—with change of the economics of the value chain, diversity of profit streams, and/or modify delivery models—have always been a vital part of a strong innovation portfolio. Established companies need to reinvent their businesses before technology-driven upstarts do.

(v) *Accelerate*: Virulent anti-bodies undermine innovation at many large companies. Cautious governance process make it easy for stifling bureaucracies in marketing, legal, IT, and other functions to find reasons to halt or slow approvals. Therefore, it is necessary to find pathways to accelerate actions.

(vi) *Scale*: Some ideas, such as luxury goods and many smart phone apps, are dusting for niche markets. Others, like social networks, work at global scale. Explicitly considering the appropriate magnitude and reach of a given idea is important to ensuring that the right resources and risks are involved in pursuing it.

(vii) *Extend*: In the space of only a few years, companies in nearly every sector have conceded that innovation requires external collaborators. Flows of talent and knowledge increasingly transcend company and geographic boundaries. Smart collaboration with external partners, goes beyond merely sourcing new ideas and insights; it can involve sharing costs and finding faster rules to market.

(viii) *Mobilise*: How do leading companies stimulate, encourage, support and reward innovative behavior and thinking among the right groups of people? The best companies find ways to embed innovation into the fibers of their culture, from the core to the periphery.

Research has also observed that big companies do not easily reinvent themselves as leading innovators. Too many fixed routines and cultural factors can get in the way. For those that do make the attempt, innovation excellence is often built in a multiyear effort that touches most, if not all, parts of the organization and getting time to mobilize all stakeholders to appreciate the effort.

Indian Model of Innovation

The focus obviously has to be on entrepreneurs or SMEs. This is not accepted conceptually but it is true. We need to trust smaller organizations for innovation.

At the onset of 21st century a need was felt for the ‘Indian Model of Innovation’ that focuses on ‘affordability’ and ‘inclusive growth’, and which can be a model for emulation by countries across the globe facing similar challenges for sustainable development. Indian entrepreneurs and policy makers have accepted this inclusive model of innovation.

Creative Leadership to Support Innovation

Whether innovation will be supported or not has a lot to do with the leadership.

Dr. A. P. J. Abdul Kalam, Former President of India, in his Book “Thoughts for Change – We Can Do it” (2013) has elaborated on the linkage between national economic development and creative leadership as below:

- Nation’s economic development is powered by competitiveness.
- Competitiveness is powered by knowledge power.
- Knowledge power is powered by technology and innovation.
- Technology and innovation is powered by resource investment.
- Resource investment is powered by return on investment.
- Return on investment is powered by revenue.

- Revenue is powered by volume and repeat sales.
- Volume and repeat sales are powered by customer loyalty.
- Customer loyalty is powered by quality and value of products.
- Quality and value of products are powered by employee productivity and innovation.
- Employee productivity is powered by employee loyalty.
- Employee loyalty is powered by employee satisfaction.
- Employee satisfaction is powered by working environment.
- Working environment is powered by management innovation.
- Management innovation is powered by creative leadership.

Thus, a relationship has been identified amongst economic growth, management innovation and creative leadership.

Each element mentioned above needs to be understood in the contextual framework. The interpretation will depend on economic and social structures in which they are applied. These elements also need to be carefully interpreted in the corporate context. However, the above gives an indicative and broad framework of the role of leadership in a knowledge society where tangibles have been replaced by intangibles.

Achieving National Goals: Make in India, Digital India and Ease of Doing Business Initiatives

The Prime Minister is focused on these three initiatives and is looking forward for suggestions and solutions for implementation of these three initiatives through innovative processes and routes where engineering inputs are crucial.

Dealing with 'Make in India Initiative' first, it is a massive challenge and calls for creating strong capital markets, upgrading technological and engineering base and ensuring skills development appropriate for emerging production needs. 'Make in India' programme can only be a success when people have confidence and faith in 'Made in India' products. The key issue is how can that be ensured? This calls for defect-free and uniform quality production that performs to expected standards, create high level of confidence, first in the Indian consumer and later in foreign consumer. The Indian manufacturers have to understand that they have to follow only one quality standard for consumer in India and abroad. There is no doubt that once the quality is established Make in India programme will become a success and larger number of foreign investors and producers will flock to India. They will not just come for supposed to be 'cheap labour', 'unskilled manpower' and 'poor quality standard enforcement regime'. This requires new platform and approaches for engineering applications.

'Digital India Initiative' is expected to have an overarching impact and on paper a number of plans have been developed which need to be detailed carefully. All stakeholders including the suppliers and vendors have to be brought in tune with the quality performance so that timely project completion is possible. Sustainable project management practices will have to be incorporated. Emerging fields of engineering will have to be carefully integrated, both for software as well as hardware. Needless to say this again calls for engineering interventions of the highest order.

'Ease of Doing Business Initiative' is generally being interpreted as getting licenses, getting clearances, ensuring taxation compliance and land, water and electricity acquisition. No doubt these are amongst the ten indicators on which the World Bank rates different countries for Ease of Doing Business. Currently India is rated 146 and the Prime Minister has called for an all out effort to improve India's position to at least 50. The Department of Industrial Policy and Promotion has launched an initiative with 14 indicators to support growth on Industry and business in India. The Parliamentary Committee on Ministry of Commerce has called suggestions on, 'Ease of Doing Business'. The issue is highly complex and many of the inputs can only be effectively planned by engineering interventions. It is time that highest platform of engineering professional deliberates on it and provides inputs. Unless the rating under Ease of Doing Business in India improves making India a global manufacturing hub will become a pipe-dream.

The last important issue is that in spite of two decades of 'market reforms' people still distrust the market. The debate is going on between 'pro-market' and 'pro-business'. Experts defined that pro-market is to believe in competition, which helps keep prices low, raise the quality of products and leads to a "rules based capitalism" that serves everyone. To be "pro-business", on the other hand, means to allow politicians and officials to retain power over economic decisions and this leads to crony capitalism.

Whereas the pro-market environment can be created through high level of innovation promotion through technological and engineering innovations, the pro-business model can be promoted irrespective of technological interventions but only through policies favouring a few interest groups irrespective of competitive market benefits accruing to the user.

All the initiatives are expected to create inclusive growth thereby the rural poor also come into mainstream of economic growth through appropriate skills development, digital connectivity and productive labour route.

Leadership of highest level is called for to ensure such results through innovation in creating short duration effective skills development programmes for persons with low level of education; improving and disseminating digital literacy; and introducing higher productivity based manufacturing platforms.

Conclusion

Dr. Kalam's mission for life was to uplift the common man out of poverty. In his book 'Target 3 Billion', Dr. Kalam wrote, "More than 3 billion people live in rural regions, and the empowerment of these 3 billion is an issue that needs urgent attention today as the world talks about inclusive development. The empowerment of rural regions of the world is critically important from the perspective of inclusive development, sustained peace and shared prosperity in the world". Dr. Kalam has shown how the leadership can bring about a transformational change in growth pattern through innovative measures and its time his preachings are followed.

Innovation is the mantra for future growth and can only be supported by forward looking visionary leadership. The attributes of innovation and the leadership traits have to be matched to ensure that the knowledge society is fully utilizing the emerging technological and engineering prowess and do not hesitate to bring around factor changes through innovation, and thereby prosperity to the mankind.

A Journey from a Remote Village to Capital of India

S. Sreenivasa Murthy

I was born in a Karnataka village in 1946, a few months before India's Independence. My father was a primary school teacher and mother a highly religious house-wife. My father's first appointment was at a tiny village Hosahalli on the banks of Tunga river at a distance of 6 km from the District center of Shivamogga. It had less than 30 houses and the situation has not changed even now. The village Mattur situated on the other bank of the river was subsequently known as the "*Sanskrit*" village as most of the villagers knew how to speak Sanskrit. The twin village complex of 'Hosahalli-Mattur' was mostly inhabited by '*Sanketi-Brahmins'* well versed in *Vedas, Sanskrit and Music*. My father and our family received considerable affection and respect from these villagers till date and I found this association very rewarding. The place is unique with nearly 100% literacy and most of the families have relatives abroad mostly in USA being active members of NASA (North American *Sanketi* Association). Hosahalli school was run in a temple and my father was responsible for constructing a separate school building by impressing the district educational officer. I spent my pre-school life in this village and remember little about it except narration by the elders. It seems I was a chubby social kid attracted to neighborhood feeling at 'home' in all the nearby houses making my mother to search for me during lunchtime.

Then my father underwent a 'Basic Teacher Training' based on the concept of Mahatma Gandhi at Devanahalli near the present Bengaluru Airport. The idea is to teach in schools skills such as spinning, operating *Charaka*, horticulture etc. apart from 3R's. After this training my father had to be posted to select 'Basic Training' schools. Thus he was shifted to village Belagutti in the same district where I joined for my primary school and learnt spinning, gardening etc. It was like any other village with little facilities (no electricity) and infested with snakes.

There was a breakthrough in 1954 when my father succeeded in getting a transfer to his native place Shikaripur, a major Taluka town in the district. Thus, I had

S. Sreenivasa Murthy (✉)
GF-G, IMG-Elite, Raghavanapalya, JP Nagar, 9th Phase, Bengaluru 560108, India
e-mail: ssmurthy4@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_7

opportunity to study in a bigger town, with population of about 10,000, which had electricity although my house was not electrified making me to study under kerosene lamps. Since I was doing well in studies I got ‘double’ promotion and jumped from 3rd to 5th standard at the Govt. Middle School there. After completing the middle school I joined the local Municipal High School towards matriculation. I stood first in each class throughout this schooling period and earned admiration and affection from my teachers. Although I studied in government schools, I had many good and inspiring teachers, which is in contrast to impressions of govt. schools today. I had excellent teachers in Mathematics and Sanskrit. I studied in Kannada medium till matriculation with no subject deficiency although our English communication was weak. Based on my experience, I see merit in teaching in mother tongue in initial stages and shifting to English medium in higher education, which is manageable. I stood first for the school in the Matriculation examination in 1961 with 83% marks and 22nd rank for the then state of Mysore which was considered a proud achievement for a small town boy. Icing on the cake was my scoring 100% in both general and optional Mathematics. This was a proud and happy event in my life that was to decide my future.

Due to my above merit, my teachers and well wishers advised my father to admit me to a good college in Bangalore (present Bengaluru) for pre-university and not to the nearby college in Shimoga which was not rated high. My father took me to Bangalore and I was easily selected for the National College, which was then rated as the best college in the city. This was my first visit to Bangalore (to any city for that matter) that was away from my Shikaripur town by 350 km, and I was simply bewildered by the vast difference in this city ambience compared to where I came from. While I could easily get admission to the best college in the city I had no place to stay. Monthly charges of about Rs. 60/- in most local Hostels were expensive for my father to afford with his monthly salary of about Rs. 100/- as a teacher. However I was extremely lucky to get admission in Sri Ramakrishna Students’ Home (normally addressed as ‘Home’) that provided free boarding and lodging to its inmates. This is a unique institution of Bangalore inspired by Ramakrishna Mission, not directly administered by them, that has been helping merited and needy students since 1919, mostly supported and managed by old boarders. I shifted to English medium in the college and faced initial hick ups. I envied my city-bred classmates who spoke fluent English while I was fumbling to speak even two sentences. Slowly I picked up and tried to catch up with them. But my Kannada was better than theirs and I won prizes in Kannada debates. National college had good teachers and I learnt all I needed in the classroom as ‘coaching centers’ were unheard of those days with private tuition resorted by weak students. Well known Gandhian Dr. H. Narasimhaiah (a Padmashree awardee and later VC of Bangalore University) took over as Principal of the college that year and he taught us Physics. I was deeply impressed by his personality as he was a simple, dedicated and inspiring academic always wearing white *Khadi* shirt, lungi and cap. He lived in a room in the students’ hostel and slept on the floor using a mat and a bed.

At this juncture a benevolent decision of Govt. of India turned out to be a great boon to me that steered my future growth. Dr. K. L. Shrimali, then education minister introduced a new National Merit Scholarship for teachers' children from that year (1961) based on the Matriculation performance. Fortunately I stood second in merit among teachers' children in Karnataka who took matric examination that year and thus bagged this merit scholarship. For the first time I saw my name appearing in Newspapers as the list of selected candidates for this scholarship for the state was published in the press. My happiness knew no bounds, as it was a great relief to get over financial problems and pursue my studies unhindered. In retrospect, I consider two factors that crucially decided what I am today-selection in Ramakrishna Students' Home and getting this National Merit scholarship. I am ever grateful to my country and society for helping me at this critical juncture to pursue my studies. The monthly scholarship amount of Rs. 50 and Rs. 100 during pre university and degree classes respectively worked like oxygen for my education.

I passed pre-university in 1962 in first class with high merit to get admission in BMS College of Engineering (BMSCE) for the five-year integrated engineering degree program. There were only two engineering colleges in Bangalore then against over 100 today. Admissions then were purely on performance in pre-university with no entrance tests and associated coaching. I realized that self-study was more effective than classroom teaching although we had quite a few good teachers. With examination oriented education emphasized in colleges affiliated to universities there was little scope for innovation. Unfortunately the situation is no better even today. But we studied textbooks cover to cover and solved almost all numerical problems with great excitement. The first three years were common after which we branched out. I chose electrical engineering (EE) in which I specialized in last two years. BMSCE had good EE faculty and lab. I was also active in co-curricular and extra-curricular activities. I won prizes in inter college Kannada and English debates, contributed to literary activities such as poems and articles, took part in plays. I was secretary of electrical engineering society. Since we had only one annual examination to face we had enough time to indulge in such activities. I found the all-India tour in the final year a great experience in knowing India. This truly expanded my horizon to appreciate the variety of our country.

'Home' and Ramakrishna Mission (RKM) molded my personality in those teenage years. Hard work, dedication, discipline, integrity, self reliance were the traits instilled in me by these great institutions. I learnt that there was no short cut to success and there was no substitute to hard work and dedication. The six years I spent in 'Home' (1961–67) was memorable and pages can be written on this unique experience. It was totally managed by the student inmates under the direction of the hon. Secretary with only a cook and a utensil cleaner being paid staff. Housekeeping including toilet cleaning was done by students, which made us to recognize dignity of labor the value I still relish. This made us to survive in any part of the world as we were trained to take care of our needs. My association with RKM has stood the test of time, as Swami Vivekananda is my prime role model. The three-week summer retreat on value education I attended in Mysore Ashram in 1966 steered by Swami Harshanandaji, present Head of Bangalore Ashram, greatly influenced my life as regards spirituality, human values and ethics. The inspiring lectures by the well-known Swami Ranganathanandaji, who subsequently rose to become the president of the Mission, greatly influenced my thoughts. The spiritual universal preaching of Vivekananda devoid of dogmas and superstitions can truly guide ones life to fulfillment. I am convinced that 'value education' must be integral to any education scheme. This conviction made me to be associated in later years with the value education center of IIT Delhi as Faculty and organize relevant activities.

Another critical and happy turning point in my life was the announcement of the result of my final year examination, which declared that I obtained 9th Rank to the university for the B.E. degree in Electrical Engineering (EE) in 1967. This distinction made me proud; my name appeared in Newspapers as first ten ranks were announced which I have kept as a souvenir.

National economy was not as flourishing as it is today with tight job market and non-existent campus recruitments even to the brightest needing one to strive hard for future career. With my interest in higher studies I applied for Masters program in IITs and received interview calls from IIT Bombay and Kanpur. I took a train from Bangalore to Mumbai on the way to Kanpur. Dr. KVV Murthy and Dr. K Shankar of EE department of IITB, being my past contacts, provided wonderful hospitality and mentored me on what course to choose. I was selected to the M Tech program in Energetics and advised by my above friends to go for this choice due to excellent faculty that included Dr. K. C. Mukherjee and Dr. R. E. Bedford. I did not proceed to Kanpur and elected to stick to IITB for M Tech. Thus I was attracted to the strong and great magnet of IIT Family whose association I cherish till date. By this experience I could clearly identify the distinct improved quality of IITs over university affiliated engineering colleges where I came from. Innovation and open-ended teaching learning are the hallmarks of IITs. Dr. Bedford was an outstanding teacher and an excellent human being who inspired me immensely. I had the privilege of doing my M Tech thesis under his guidance to complete my post graduation in 1969. I continued to be in close contact with him till his end. The monthly scholarship of Rs. 250/- at IITB was a luxury and life in Hotel-I was cozy compared to deprivation of under-graduate life resulting in my putting on weight.

Then I joined for my first job as a Lecturer on 5th Sept. 1969 in a grade of Rs. 400–950 in BITS, Pilani, a serene campus. Thus, I moved further north to a harsh climate of extreme Rajasthan weather. Prof. I. J. Nagarath was a dedicated teacher I met there, who has penned several good quality books. I too wanted to be a good teacher and to make my classroom delivery interesting and effective. I referred to the MIT book on effective teaching and tried to follow its tips. This was a good pedagogic effort I would advise to all those joining teaching profession.

I had immense desire to pursue for Ph.D., and BITS then was not found very suitable, with IITs being preferred destinations. I applied for Lecturer's job in IIT Delhi and was called for interview. Based on my good interview performance I learnt that the committee was inclined to consider me for Associate Lecturer (AL) position on contract so that I could also work for my doctorate. I took courage to write a letter to Prof. C. S. Jha the senior-most professor and first Indian head of EE deptt. of IITD (and later to become Director of IIT Kharagpur, VC of BHU, educational advisor to GoI and founder fellow of INAE)) as his area of specialization was of my research interest to take me as AL. I received a quick but negative reply from him that disappointed me. But I had a great and pleasant surprise after a few weeks when I received another letter from Prof. Jha that IITD was prepared to take me as AL in EE deptt. That was one of my happiest days and a major turning point in my professional career.

I joined IITD as a faculty member on 2nd Nov. 1970 that facilitated me to engage in both teaching and research. I was back to IIT fold and registered for my Ph.D. next day under the guidance of Prof. Jha to work on "Generalized Rotating Field Theory of Electric Machine", the topic pioneered by him with highly cited classical papers. While being a Lecturer I secured my Ph.D. in 1974 and promoted as Asst. Professor in 1975. As an outcome of this Ph.D. work I published my first classical and highly cited paper on "general rotating field theory of asymmetrical machines' in the reputed Proc. IEE published from UK. This paper is even referred in textbooks today.

EE Department of IITD had inspirational teachers and researchers such as C. S. Jha, P. V. Indiresan, S. C. Dutta Roy, A. K. Mahalanobis, P. S. Satsangi, V. S. Rajamani and J. Nanda who built the department from scratch and guided young faculty like me as role models. They grew to become National/international figures with great contributions. They instilled special values and procedures in the department. According to one 'ranking' recently, this department was ranked first in India and 50th in the World among EE departments that must be attributed to above values. There was no hierarchy and a senior most professor was treated equal to a junior most lecturer so that all faculty felt they owned the department. Faculty selection was open, transparent, informal and strictly on merit. Any one can suggest a bright candidate for possible induction. A faculty would be inducted in any area provided one is excellent irrespective of the need in the department, the philosophy being that an excellent faculty would academically contribute to glorify the institute. On the contrary a sub-standard faculty would not be inducted although there is need in that area, as he/she may ultimately be a drag.

'Seniority' has no place in IITs (even in IISc) and one is chosen for a position based on suitability and interest. This is the unique feature that has made these institutions great and others in the country rated lower. 'Flexibility of cadre' practiced in IITs is a great boon so that number in any faculty cadre can be altered to reward/promote a good candidate. Same scheme is recently introduced in NITs, which would definitely impact them positively. If any institution or university aspires to move to higher level, above concepts/values must be introduced.

I had the first opportunity to visit abroad when I was deputed in 1975 by IITD to UK under the IITD-UK collaboration arrangement and spend with Dr. J. E. Brown of University of Newcastle upon Tyne. Coordination of the visit by British Council was excellent. Incidentally Dr. Brown was the Ph.D. supervisor of Prof Jha at U of Bristol. My working with Dr. Brown on "Capacitor self excited braking of Induction Motors' was truly exciting as he was a perfectionist and our brainstorming meetings led to new fundamental concepts of non-linear behavior of such machines leading to classical publications later. I visited the universities of Loughborough, Bristol, Imperial college, Aberdeen, Liverpool, Glasgow, UMIST apart from a few leading electrical industries. Thus I had the first hand experience of working of British universities which were rated superior to Indian counterparts including IITs. Integrity, time management, good governance and discipline make their education superior to ours. We have lot to emulate to make our higher education comparable to global levels.

I returned to IITD in 1976 and pursued my interest in teaching, research. curriculum and lab development. I am a strong believer in close Industry-Academia interaction and wanted our activities to be of interest to Industry. Mr S. G. Ramachandra Vice President Kirloskar Electric Co (KEC) showed special interest in me and encouraged my interest in industry interaction. I took a major consultancy project for KEC on “Magnetic Noise in Induction Motors” and successfully developed a design based noise prediction method. During this period I received the President of India Prize for the best research Paper published in the Journal of Institution of Engineers (India).

Based on my research in UK, I initiated a new research area on “Self Excited Induction Generators” (SEIG) and I am proud to say that based on my work supported by my colleagues guided by me, IITD today is globally the strongest center on R&D in SEIG with large number of papers, student theses, sponsored projects and patents. My first Ph.D. students (Bhim Singh and A. K. Tandon) registered with me and did commendable work in the above areas; I am happy that both of them have great accomplishments in their career.

Based on my academic contributions I was promoted as Associate Professor (in Professor’s scale) in 1980. I visited University of Calgary in Canada during 1980–82 under sabbatical leave at the invitation of O. P. Mallik and G. J. Berg that gave me a unique opportunity to undertake new research in a western university ambience with distinctly superior facilities compared to IITs. My research there led to many classical highly cited papers in international journals. Significant ones are on “instantaneous symmetrical components and operational equivalent circuits of induction motors” and “Analysis of Self Excited Induction Generators (SEIG)”. My paper on SEIG published in Proc. IEE in 1982 has very high citation index and referred till date. I got the initial experience of presenting my papers in reputed IEEE international conferences in New York and Orlando and meet my peers.

On return to IIT I pursued my research in SEIG. I proposed a new Master’s program in “Power Electronics, Electric Machines and Drives” (PEEMD) which was started in 1987 after a rigorous review by expert committees and internal boards. This has become a very popular program conducted through industry interface with several post-graduates in high positions in academia and Industry. IITs have great academic autonomy to start any academic program which is an outcome of rigorous internal and external discussions. We need to respect this autonomy without interference by external regulatory bodies, to maintain their standards and be forward looking.

I was confirmed as Professor in 1983, perhaps one of the youngest to be rewarded with this post during that period. Since I superannuated from IITD in 2012, I served as professor for nearly 30 years.

During 1985–86, I was invited by Kirloskar Electric Co (KEC), Bengaluru to work in their R&D unit as a consultant and to guide them on new industrially relevant research. I focused on ‘Wind Electric Generators’ (WEG) and 1-phase SEIG for portable gen-sets. I developed the first indigenous 55 kW Induction generator, which was built and installed successfully in the field for Wind Power. The novel 1-phase SEIG is a unique invention of mine, which has led to several patents and papers with applications in renewable energy based off-grid generation. The area is still researched today at IITD. My visit to KEC gave me a unique industrial experience to know in close quarters the industrial problems and processes. It is my strong view that academia must be encouraged to make such industrial visits that should form a prime activity to promote industry-academia interaction so that teachers may sensitize students on industry in classrooms. Faculty reward system must encourage such visits.

During the above period I taught a course in each semester at IISc as adjunct professor apart from undertaking joint project of relevance to KEC with a colleague in EE department that led to quality publication.

In 1990, I was invited to take over as Director (CEO) of Electrical Research and Development Association (ERDA) at Vadodara (Baroda), an Institution maintained by Electrical Industries and supported by CSIR. Since I wanted to assume this position on deputation from IITD, the period as per norms had to be restricted to two years. Mr K. K. Nohria (Crompton Greaves) and Mr P. R. Bapat (GKW) were Governing council chair during that period. Both were great visionaries committed to industrial growth. It was a pleasure for me to work with them as I came into close contact with doyens of Indian Industry. I organized a major international conference ELROMA jointly with IEEMA at Mumbai in 1991. Apart from facilitating continuing education program for Industry I gave research orientation to ERDA and promoted academia interaction through MOU.

As ‘General Chair’ I organized the first IEEE international conference on “Power Electronics, Drives and Energy Systems” (PEDES) during Jan. 1996. Event was organized by IITD jointly with U of Wisconsin (USA) and IIT Kanpur. Prof Deepak Diwan of UW was another General Chair from USA. It was a grand event with good international participation. I am glad that my efforts to start this event resulted in a well established new series of PEDES conferences held every alternate year in different locations and branded as a quality conference under IEEE.

I was Head (Chairman) of the Electrical Engineering Department of IITD during 1998–2001. This was a major administrative responsibility to steer one of the biggest departments comprising around 50 Faculty and 100 support staff running 2 UG and 6 PG programs apart from around 100 doctoral students. I took it both as a challenge and opportunity to enhance academic and research output of a premiere IIT. Though managing highly competent and individualistic faculty was a challenge, well-structured democratic processes involving Faculty board and professorial committees were helpful. At the end of my term I had the fulfillment of effectively contributing to the growth of the department. I started a new Bachelors program in EE (Power) and a dual degree program in ICT. Prof VS Raju, the then Director was very supportive. Since department had acute shortage of space I succeeded in adding a floor on the top and reorganized the laboratories for better teaching and research. I could inject a few bright faculty. Deregulation and decentralization were strengths of IITs that came in handy.

In 2003, I was invited by Govt. of India to take over as the founding Director of NIT, Surathkal after earlier RECs were converted to NITs. Then HRD minister was keen to have IIT professors to steer these new NITs. Thus a few IIT professors opted to take up this unique responsibility to bring in IIT culture in NITs. I took major academic and administrative reforms in tune with IIT norms at Surathkal with positive results. Course/curriculum structure was modified. Laboratories were modernized through World Bank Funds under TEQIP. NITK Beach was formed. Research programs reoriented. I promoted international collaboration through linkages with Institutions in Korea and Japan. Feedback from Faculty and students indicated that I could inject new spirit in this NIT. Due to change in Central Government in 2004, the new minister decided to send back the above IIT professors and I was back in IITD in 2005. I am satisfied that strong views I conveyed to policy makers to make NITs on par with IITs are gradually receiving attention.

I took my second sabbatical during 2008 to be a visiting Professor at Ryerson University, Toronto, Canada. I developed and taught a new graduate course on "Alternate Energy systems" which was well received by the nearly 40 registered students. I used high tech classroom facility of the university that included 'blackboard' software. I wish Institutions in India developed similar classrooms for effective teaching and evaluations. I spent part of this sabbatical at GE, IISc and CPRI at Bengaluru, resulting in value addition to research.

I made several visits to leading Institutes and Industry as below during summer vacations: MIT (USA)—July 2002; GE (John F Welch) Technology Centre, Bengaluru—INAE Distinguished Professor cum visiting consultant—July 2007, May/July 2009, Oct–Dec. 2008, May–July 2010, Trident Powercrafts Pvt. Ltd, Bengaluru—INAE Dist. Industry Professor—June 2007. U Of Waterloo & Ryerson Univ—May–July 2011.

Finally I superannuated from the service of IITD in June 2012, thus ending my long innings of 42 years in this great institution, and decided to relocate to Bengaluru, although I could continue as emeritus professor at IITD.

Then Director of IITD nominated me for the position of Vice Chancellor of Central University of Karnataka (CUK) in Northern Karnataka, based on which a search committee suggested my name among a panel to the President (Visitor of the university) who picked my name. After some introspection I decided to take up this responsibility and took charge in Jan. 2013. CUK was in a formative stage being operated from Gulbarga University Campus. I worked hard to move the university to its new designated 650 acre campus at Kadaganji, 30 km from Gulbarga (Kalaburagi). My proud moment was when the new campus was inaugurated by the then HRD minister on 30th Nov. 2013, which made faculty and students to rejoice. I also initiated new integrated science and engineering programs at CUK which is unique. My mission was to make the campus 'green' through planting of over 10,000 saplings. Then MHRD informed me that my appointment was for the residual period of the earlier VC and hence had to relinquish my post on 28th Feb. 2014. Since I never went after 'power' in my career, I gladly gave up. But I am convinced that these new central universities need lot of handholding by MHRD by ensuring visionary leadership and support similar to other central institutions.

Then new PES University at Bengaluru invited me to be an emeritus professor and academic advisor till July 2015. From March 2015 to Sept. 2016 I was functioning as distinguished Professor at Central Power Research Institute at Bengaluru guiding researchers on ‘Micro-grid’. I am also functioning as adjunct professor of IIT Ropar and adjunct faculty at NIAS, Bengaluru. I was a member of the academic delegation of IIT Ropar in 2016 visiting UK, Canada and USA towards Faculty search, collaborations and interaction with Indian diaspora. I have a passion to help new IITs for academic development based on my experience. Recently I am approached by IIT Palakkad for such an association.

I may list the highlights of my professional and research contributions as: (a) State of art and highly cited research on Self Excited Induction Generators for off grid renewable energy based power generation, (b) field installation of pico-hydro plants in Karnataka based on my invention, (c) design, development and field installation of Wave Energy based induction generator in Kerala, (d) indigenous switched reluctance motor development jointly with Industry, (e) CAD lab. for electric machine design, (f) a novel 1-phase brushless ac generator—an improved version developed through support from MSME (GOI) and prototype 5 kW, 1-ph. SEIG built for field trials for renewable energy applications, (g) design software for ARNO-convertors developed for ABB, (h) design software on induction motors with variable frequency supply for traction and cement mill drive for BHEL, (i) design software for performance evaluation of 3-phase induction motor for traction application with inverter fed supply” for BHEL, (j) World Bank supported Energy Audit facility at IITD.

I made short visits to several countries for professional engagements and conferences such as: United Kingdom (1987, 1989, 1993, 1995, 2007), Denmark (1987), United States of America (1982, 1989, 1995, 2003, 2010, 2011), Oman (2001), Switzerland (1984), Singapore (1997, 2013, 2014), Nepal (2004), Japan (2005, 2010), Korea (2005), China (2005), Australia (2006), Thailand (2007), Taiwan (2009, 2014), Kazakhstan (2011), Turkey (2013) and Bhutan (2015). These resulted in international linkages and formulation and execution of joint programs with some of these countries such as research projects, short term courses and lab. development. I was coordinator of Indo-UK program on microprocessor applications in drives and DST nominated India Coordinator for the joint Indo-Canadian and Indo-Australian program on “Sustainable Energy”. I led the Indian delegation for the Indo-Australia workshop on sustainable energy held in Sydney in 2006 and organised the Indo-Canada Workshop on ‘Electricity generation using renewable energy’ in 2009. I facilitated MOU and linkages with universities in Japan (Kumamoto, Kagoshima), Korea (KAIST, KIER), Canada (Waterloo, Ryerson), USA (Wisconsin), UK (Sussex).

I had the privilege of teaching over 5000 students with fairly good feedback at UG and PG levels on Electric Machines, Drives, Energy conversion and renewable energy. Some of these courses are recorded in the studio of Educational Technology Centre of IITD, packaged in over 15 video modules available to other Institutes and beamed through TV channels. I am proud that I have taught among the brightest in the country that included well known IITD Alumni such as Raghuram Rajan (ex RBI), Vinod Khosla (VC promoter), Rajendran (NIIT). I have delivered over 180 popular and special lectures at the invitation of several organizations in India and Abroad (Canada, USA, Japan, UK, Singapore, Taiwan). My other contributions to knowledge dissemination activities included organizing series of curriculum workshops to prepare lab. manuals and new curriculum and Continuing Education programs targeting professionals.

My professional work is reflected through 300+ published papers, 100+ theses supervision, 90+ sponsored research and industrial consultancy projects, 40+ Technical reports, 7 manuals/conference proceedings, 18 patents and 100+ reviewed papers of several international journals including IEEE, IEE/IET, Elsevier.

My awards and recognitions include: Life Fellow of IEEE (Institution of Electrical and Electronics Engineers-USA), Fellow of Indian National Academy of Engineering (INAE), Fellow of IEE/IET (UK), Life Fellow of the Institution of Engineers (India), Life Fellow of IETE (Institution of Electronics and Telecommunication Engineers-India), ISTE/Maharashtra Govt. Award for outstanding research, IETE/Bimal Bose Award for contribution in Power Electronics, 2007 IEEE/PES Chapter Outstanding Engineer Award. A recent international recognition was to choose me by IEEE/IAS as Distinguished Lecturer (DL) for 2014–15 to facilitate being invited Globally to deliver specialist lectures.

My significant contribution to outreach activities are: General Chair of the 1st IEEE International Conference on Power Electronics, Drives and Energy Systems for Industrial Growth (PEDES' 96) during 1996 in New Delhi; Patron for PEDES-2012 during Dec. 2012 at Bangalore; Technical Chair of the IEEMA organised Conference ELROMA in 1992, 2004 and annual conference of Elec. Engg Div. of IE(I) in 2005; Symposium chair of IEEE symposium on "Sustainable Energy and Global synergy" held in Ryerson Univ. Toronto in 2008; general chair of the INAE conference on "Research Policy for Sustainable Energy" in New Delhi (2009); convener of Electrical Engineering Section and member of Energy Forum of INAE. As consultant to UN-ESCAP, I steered the UN supported Workshop on "Advances in Fossil Fuel Technologies and Investments for Power Generation" in New Delhi (*June 2012*) *Organized by* APCTT UNECE and UNCTAD that was followed with the UN workshop in Almaty (Kazakhstan) in Nov. 2012 I had the privilege to serve several professional societies such as IEEE, IEE/IET, IE(I), ISTE, IETE in several capacities I have served in National committees of Industry associations like CII, IEEMA & FICCI and also in committees of UPSC, AICTE, NBA, NPIU, DST, TIFAC, DSIR, MoI, MNES, CBIP, BEE, CSIR, NRDC, MHRD, TERI etc. I am member of appellate committee of NBA and mentor/auditor of Engineering Institutions supported by World Bank Project, TEQIP.

My interest areas are Electric Machines, Drives, Power Electronics, Renewable Energy & Energy efficiency and engineering education. Apart from these mainstream subjects, I have passion on value education and sustainable technologies that brought me to work with value education and rural technology centres of IITD. I tried to promote Indian values among IIT community through lectures from external experts including Ramakrishna Mission with teachings of Swami Vivekananda who combines science and spirituality. I am very proud of my country that provided me opportunity to evolve from a humble rural ambience to a position of recognition in Nation's Capital.

Exciting Moments of Research

Jayanta Mukhopadhyay

Introduction

When I joined the Ph.D. program at my alma mater, the very first question bugged me was, what I was supposed to do to qualify as a researcher? The other obvious question was why the Government was paying me a scholarship or fellowship? Was it meant for demonstrating creativity on my intellectual exercises? Was it a kind of support from the society, as it extends to other forms of recreational arts and faculty? Did my country really expect me to solve a burning problem, which would bring the progress and prosperity of this nation? Frankly, I was confused and I should admit that till date, there is no qualitative change in the state of my confusion in this regard. However, I started on my own way looking at various issues on a research area of electrical sciences, called image processing, without bothering much about their impact and applicability.

Search for Something

In my early research days I had the least idea about what I was going to do, and what excitement awaited me in future. Of course, I was very much excited to dream that excitement. Nevertheless, there were other motivations also to pursue the doctoral degree. I wanted to be in academics and realized that freedom can be bought by having a Ph.D. degree. So I wanted the degree as quickly as possible. I was fortunate in various ways. I had wonderful friends, who also joined Ph.D. programs of my Institute around the same time. The ambience surrounding us was intellectually vibrant with a mood of great expectation and excitement for the coming days. Above

J. Mukhopadhyay (✉)
Department of Computer Science and Engineering, IIT Kharagpur, Kharagpur 721302, India
e-mail: jay@cse.iitgp.ernet.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_8

all, my supervisor (Prof. B. N. Chatterji), one of the nicest persons I know, gave me all the liberty of choosing my research problem and carrying out my study in my own way. Frankly, it was an adventure for all of us. We didn't really know what the things to prove were, but we wanted to prove something. It was that search for 'something' initiated my research career.

In those days, it was not easy to get reading material, in particular the published work in journals and conferences related to field of one's interest. Our main resource was our library. It was quite a thrilling experience to walk down the semi dark allays of the bound-journal section of the library and then started looking for a paper you intended to read. The joy of getting the desired one is no less than the discovery of an island after an uncertain voyage across the ocean. Sometimes, we used to mail our reprint request, specially printed on a post-card size hard paper, to a researcher in foreign lands. Before it got lost into oblivion, one would be surprised to get a delivery suddenly with compliments from the peer researchers. Those were my prize collection, and I am having still them in a few bound volumes. Now-a-days, we have the comfort of getting almost any work by the mouse-click from the digital library of our Institute and also some of them are available free in the internet. Even requesting an article from its author by sending an email is a rare phenomenon. Though digital connectivity has opened up the much coveted store house of knowledge and information, it has robbed the excitement of uncertain walk through among the journals and magazines lying in the corridors of a library.

First Research Problem

My first research problem started with designing an algorithm for thinning a 3-D object, which is represented by discretization of its spatial occupancy in a 3-D binary array. The problem was introduced to me by my friend Dr. P. P. Das (PPD). In his Master's thesis he implemented a known 2-D thinning algorithm. When I approached him for a possible research problem, he suggested, "Why don't you extend the algorithm to 3-D?" The next day, I came up with a solution with full implementation and results. The thinning of a pattern may be carried out by iterative deletion of boundary points, till the pattern gets fragmented or eroded completely. It provides a skeletal representation of the object. In the 2-D algorithm, there are a few neighboring conditions to be checked for a point before its safe deletion. I simply extended these conditions to 3-D. Fortunately, the work got accepted without any trouble in an international journal, which happened to be my first published research paper in a journal. Interestingly, a few months later, we got a rebuttal from two researchers, who showed and proved with counter examples that our method had flaws. In some cases, 3-D patterns loose connectivity. The editor-in-chief of the journal was kind enough to forward their criticism to us for a review. Not only we accepted it, but also we came up with an improvised version of the algorithm which got published along with the criticism in the same issue of the journal. It made me happy twice because—it increased my understanding of the problem and it also increased my paper count! The incident was a good lesson to me. It revealed that we should not be afraid of criticism, which actually helps in improving ourselves. Sometimes we felt terrible when we found our work got rejected by our peer reviewers, and our instant reaction appears to be a lamentation on the injustice ushered from irrational reviews! It should be otherwise. We should be positive enough to look for exciting revelations out of those comments and criticisms, and engage ourselves to resolve issues, that rise subsequently. Research is exciting as long as you are in the process of improving and developing your work.

Cooked Up Problems

In those days I read a little, but worked more on my own ideas. I must admit it is not an ideal research methodology. Probably the pasture was green enough to get my work published in some of the reputed international journals. I do not think in today's research work it is advisable. We should have sufficient background information and knowledge about the topic of our research. In the past, our window to the outside world was also small, and we needed to dream on our "cooked up" problems more than studying the real world applications. I was working on recognition of 3-D objects without even having any access to a digital camera. In fact, I was looking for 3-D real life images for testing my algorithms and techniques, which were mainly developed on synthetic data set of small 3-D binary arrays. I soon found that the kind of data I was looking for was partially available in the form of depth maps of visible surfaces, called range images of an object or scene. I did go through a few papers on range imaging and analysis of range images, and started sending my request to peer researchers for providing me sample range data. In one fine morning, I received a big packet from Prof. Kosuke Sato of the Osaka University, Japan, containing the much needed data set in a floppy. However, he also threw me a challenge for deciphering the data file, as there was not sufficient information (or I was not good enough to deal with them readily) in understanding the format of the data. So it took a few days to dig those numbers, to arrange them in a meaningful 2-D array, and finally to get the display of objects on your screen for ultimate confirmation of your prized possession. Looking back, I must say those were my moments of excitement. However little it may appear in today's context, it gave me the opportunity of testing and adapting my algorithms on real life images! It did save my Ph.D. work from being castigated as mere hypothetical exercises!

A few early concepts I was quite enthused about, were the concepts of digital neighborhood plane (DNP) and neighborhood plane set (NPS), which I had introduced for capturing local structural information of a 3-D point. Initially I conceived about nine DNPs each containing at most eight neighboring points. Later, my friends Prabir (Dr. P. K. Biswas) and Vosky (Dr. S. S. Biswas) incorporated four more additional planes which may contain at most six neighbors. The NPS of a point is the set of DNPs on which the point has sufficient numbers of neighbors. Using this feature we designed algorithms for segmenting 3-D surfaces and for extracting wire-frame structures of 3-D objects.

Distance Functions

Around same time we were also fascinated about discovering new metrics or distance functions in arbitrary dimension. My friend PPD did excellent work in this area and I was encouraged to join the search for new classes of distance functions. So one morning I went to PPD and suggested a new class of distance function based on t-maximum operations. I was not sure enough whether the function is sufficiently novel. But PPD was quick to fire it up and spent a few days to come up with a set of theorems and proofs elucidating properties of this class of distance function, which we named t-cost distance function.

What fascinated me most were shapes of digital circles and spheres of those distance functions in 2-D and 3-D, respectively. In particular, we observed interesting variations in those shapes for octagonal distances, which are defined from paths generated by a sequence of different types of neighborhood definitions. PPD showed how vertices of these hyperspheres could be computed given the neighborhood sequence of an octagonal distance function. We further simplified this computation and used it for computing vertices of a digital circle and a sphere, in the form of a convex polygon in 2-D and convex polyhedron in 3-D, respectively. When Ashwath (Dr. Ashwath Kumar) joined as a Ph.D. scholar under the joint supervision of me and Prof. Chatterji, I suggested him to develop different geometric computational techniques exploiting their shapes. Subsequently, he came up with efficient techniques for computing geometric transformation, normals at boundary points of 2-D object, and cross-sections of 3-D objects using medial axis transform (MAT) based on octagonal distance functions. He also showed how these transforms are useful in fast rendering of 3-D objects. We studied also the proximity of these distance functions to the corresponding Euclidean norms exploiting the geometry of their circles and spheres. Previous to our technique researchers adopted only the analytical methods for computing the bounds of the deviations from Euclidean norms and obtained the optimum distance functions minimizing these bounds. However, the mathematics involved in this process, may be quite rigorous and in many cases (e.g. for octagonal distance functions), we still do not have such analysis. As our approach was from a different perspective, it gave a new insight to some of these distance functions, which were empirically found to provide good approximations, but remained unexplained from their mathematical properties. Yet, the limitation of our technique lies with its extension to dimensions higher than 3-D. Things get really murky there and I invite budding researchers to take the challenge for finding good approximations of Euclidean norms in higher dimensions using the geometric approach.

A Lull Period with Fractals

There are also lull periods in your research career. Particularly, one may feel tired and exhausted with similar nature of research problems and ideas. So on one fine morning one may find that all the excitement of having fresh ideas suddenly vanishes your routine work and assignments. This is the time for one to ponder for a new direction. For me it was the fractal modeling of objects and patterns, which drew my attention. I was engrossed with the beauty of those fractal patterns generated from simple mathematical expressions, and interested on modeling 2-D patterns using iterated function systems (IFS), a set of contractive affine transformations. During this period, one of my B.Tech project students did develop a tool for modeling such pattern by covering the target shapes with tiles of different geometrically transformed replica of the same and created artistic scenes of trees, rocks, huts, etc. However, what impressed me the most is the tall claim of getting a very high compression ratio of images using this model, though its algorithm was not published apparently for commercial reasons. Still today I am not sure about its existence. In any case, I was motivated to look into compression algorithms based on the IFS and took Jacquin's algorithm using partitioned iterated function system (PIFS) as a case study. We studied its convergence properties during decoding and came up with an efficient linear time decoding algorithm, much faster than the iterative process. In this modeling we showed that the image space is partitioned into chains of pixels forming a typical structure named circular plant, which originates from a cycle (called limit cycle). The convergence of the fractal code depends on the convergence of these limit cycles. Hence by tracing a chain backward, we could compute these limit cycles and subsequently could compute the converged values of the pixels in one shot. We also used this concept to design a novel video compression algorithm. In this algorithm with the help of the circular plants of a reference frame other collocated temporal frames are encoded. Unfortunately, the performances of these compression algorithms were so poor compared to the standards such as JPEG, MPEG, etc., that these findings had little impact in this area of research.

Living with Ideas

In the mean time, I was also attracted to color processing and started playing with colors by changing their saturation and hue following CIE chromaticity chart. In fact, the idea came to me in early nineties while supervising an M.Tech thesis. But it finally got shape when I was visiting the University of California, Santa Barabara (UCSB) in the summer of 2000. Living with an idea and finally exposing it are quite exciting. It happened to me in other cases also. You live with these ideas for years and finally become bold enough to bring it out with much more details and impact. This was also true for our analysis of fractal decoding algorithms, which took around three years to be considered seriously. Very recently, I reported a new class of distance function, named weighted t-cost distances, which was actually conceived around six to seven years back. When you are pondering on research ideas, you have all the excitement of a child, who is impatiently waiting for a grand event being unfolded before him. However, the most difficult stage is the sustenance of that idea and repeatedly revisiting it under various contexts. Finally, you have to take a decision for its full exposition. At that stage you are like a director of a movie, who has the sketches of his scenes and shots. You need to choose your actors, their roles and final execution plan with thorough experimentation and theorem proving. In this process, do not expect that the outcome will be always in confirmation of your hypothesis and expectation. However, in most cases, you are sure to reach a state of new realization and confidence in your research goals.

Necessity of Survival

I started my discussion with a few questions on motivating factors of research. Those questions are bound to occur at various stages of ones career in different forms. It ranges from questions related to progress and evolution of human civilization, to mere mundane needs of an individual for getting a degree or promotion. Frankly, motivation of research is multi-faceted. Sometimes it is the product of creativity of passion; sometimes it is the necessity for the survival of an individual in his/her professional world. I am fortunate to supervise a few students toward their doctoral degrees. Some of them are very bright and capable of carrying their research work almost on their own. They mostly sought my opinion and suggestions on certain matters and queries. Some of them needed my involvement only in the stages of problem formulation, but could carry out on their own thereafter. For an exceptional few, I had to plan for almost everything including writing the codes of implementation. But I am doubly thankful to them for driving and pushing my research agenda. My passion on color processing rose also out of this necessity. I entered into the wonderful world of problems on color constancy, retinex processing and color demosaicing. In the retinex processing, we proposed a network model of retinex computation, which is aimed at annulling illumination variation in a scene toward restoration of colors of pixels. The model was inspired by biological processing that goes in our visual pathway. Color demosaicing is an operation required for converting a color filter array (CFA), which has only one predetermined color component at every pixel in an interleaved fashion, into a color image with full resolution for every color component. There are various algorithms for this purpose. We proposed a Markov random field (MRF) based post-processing technique for improving the quality of demosaiced images obtained by using any one of those algorithms.

A Chance Meeting

While I was working on this problem, I had the luck of meeting Sanjit-da (Prof. Sanjit K. Mitra of UCSB), who was visiting my Institute in the year 1999. I consider that was one of the important turn around in my research life. That time he was also working with similar problems. He invited me to visit his laboratory in the summer of 2000. I readily accepted. Not only in 2000, I visited his laboratory in subsequent years of 2001, 2003 and 2004. I would have done it every year, unless I got myself busy with the headship of the Computer and Informatics Center of our Institute. Working and Spending time with a person like Prof. Mitra, you have the fortune of getting exposure to different types of problems in the areas of signal and image processing. In particular he drew my attention to the problems of processing in the compressed domain. That is how I started looking at issues related to development of algorithms for compressed images and videos.

Conclusion

I thought that I would try to capture my exciting moments of research, but it ended up with sketches of some of my research problems and a brief history about their genesis. My moments of excitation are hidden under those research impulses. They are under those sudden twists and turns, when out of nothing suddenly I come to realize you come to realize that there are a few things yet to be done. However little is their impact, I was are the only person you are the only person in this world who thought about it. I had the fortune of sharing these excitements with my teacher, with my students, and with my friends. That is what I enjoyed the most, and am still enjoying.

The 'Making' of the Mind of an Engineer—Some Thoughts on Engineering Education in India

A. K. Suresh

Introduction

The academic training an engineer receives in his/her education sets the initial conditions for his/her contributions as an engineer. The successes and failures of our engineering sector are therefore traceable, in some measure, to the education system that prepares our engineers. This is not to deny the importance of life and experience in what an engineer delivers in her profession; it is rather that, if education is completely irrelevant, there is a problem right there that needs to be addressed. After seven decades of independence, it is therefore pertinent to look at how our engineering education system has evolved and how it has delivered.

In 1947 when India looked with hope towards her future as a free country, an immediate problem she had to grapple with was that of a severe shortage of skilled engineering manpower needed to address the gargantuan developmental challenges that lay ahead. Faced thus with the urgent task of developing the manpower needed, the leadership of the day opted to adopt the western model of engineering education for our country. In this article, I take a look at the way the system has evolved over the years, how it has performed and attempt to analyse what, if anything, is missing in the discourses that shape engineering education in the country. For present purposes, I use the terms 'engineering' and 'technology' interchangeably, as referring to the same general body of activity.

A. K. Suresh (✉)
Department of Chemical Engineering, IIT, Bombay, Powai, Mumbai 400076, India
e-mail: aksuresh@iitb.ac.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_9

A Little History

Let me pause to take a look at the sort of technological world that India stepped into, when she became independent. The twentieth century was characterized by an unprecedented development in science and technology, with its epistemic centre in the west. Engineering achievements in communications, transport, healthcare and other areas completely transformed the lives of people and communities. This, and the resultant growth of the big corporates, led to an ascendancy in the prestige of engineering and management education. The land grant universities had already come into being in the US in the previous century, but the focus of education changed from imparting practical skills to imparting the fundamental principles of science and mathematics. The Society for Promotion of Engineering Education (SPEE) had been formed in 1893 to oversee this change in the US [1].

The second world war saw an increasing emphasis being brought on research in the University scene. This saw, in the US, the SPEE being transformed to the American Society for Engineering Education (ASEE), a society which played an important role in shaping curricular changes. The war also brought into sharp focus the destructive potential of technology, and led to a certain amount of disillusionment with technology. Above all, it led to the recognition of a need for a 'character-building' component as an essential part of engineering education. Subsequent events through the 1960s, connected with the Vietnam war and consequent general social unrest on campuses, forced the emphasis back from research to teaching in the US to an extent [1]. Thus, in addition to the discourses on science and commerce, a democratic discourse was starting to play a role in engineering education. Another consequence of this was the initiation of several affirmative action programs in the Universities, aimed at recruiting women and minorities into engineering.

If a phenomenal growth of technology (and its use for good and bad) was one distinguishing characteristic of the previous century, another was a sharp discontinuity in the political order in the world. Post-war decolonization and the drain of the two wars saw a decline in the power of Europe and the rise of America. Many countries obtained political independence after the Second World War, resulting in a complete redistribution of political, economic and social power in these countries. While developments in science and technology and development of engineering manpower went hand in hand in the western countries, this was not so in the newly independent countries, in which a continuity in local technological traditions had often not been maintained. Not surprisingly, countries like India opted for the western model of education.

This then, was the world scene at the time of India's independence. Having set herself a target of becoming an Industrial economy and with 36 Institutions in the country offering a first degree in engineering with an annual intake of about 2500, the task to build up the educational infrastructure was urgent. Thus forced by need and propelled by aspirations, India undertook a massive expansion of engineering education in the following years. The Indian Institutes of Technology (IITs) were created by an Act of parliament. In the second plan period (1956–61) four of the original 5 IITs (IIT Kharagpur was already functioning by then) and 11 of the 17 Regional Engineering Colleges (RECs) were established [2]. Simultaneously, several new engineering colleges were also started, and the existing ones significantly expanded. In contrast to the Institutions existing at the time of independence which had a fairly static curriculum which emphasized practical aspects of engineering over principles, the IITs were envisaged to have a dynamic, science-based curriculum. The five IITs gradually took on a character inspired by the American model of Land Grant Universities where research is considered to be as important as teaching. The growth of the research culture was further fueled by the creation of Government Departments such as DRDO, DST and DOE in the 1970s. On the Industrial front, the vision was to spur the development of home-grown, science-based technologies—the CSIR had come into existence for this purpose even before independence. On the whole however, the development in this direction was slow, and opportunities for the graduates of the IITs seem to have been less than challenging.

The general emphasis of the early curricula was on basic and engineering sciences, with a significant content of Humanities and Social Sciences. The ‘professional’ content of the individual engineering disciplines was limited to 30–35%. However, subsequent developments saw a progressive dilution of this philosophy, with the professional content increasing at the expense of basic sciences, engineering and humanities (see [2] for an interesting account of the evolution of the curriculum at IIT Kanpur). A partial compensation was sought to be provided by increasing the flexibility in the curriculum, but the net result has still been a dilution, especially of the humanities component. There has also been a gradual erosion of those components of the curriculum which sought to bring the student close to engineering practice, such as industrial internship. Other changes have been forced by developments in computerization and the rise of new specialized disciplines.

Performance of the System Over the Past Decades

The performance of the system can be measured against the yardstick of what the society generally expects out of its educational system. These expectations can be grouped under the following heads:

Manpower training: Creation of trained manpower

- for the government and private domains to boost the productivity of the Industrial and agricultural sectors,
- to provide directions to harness science and technology in a responsible manner for the public good,
- to provide policy directions so that India may set and work towards its developmental goals, and also offer original thoughts on global issues.

Research: Provide thought leadership and enrich the global ‘knowledge pool’; also create adequately skilled research manpower for the Industrial and Governmental R&D sector.

Development: Provide

- technological solutions to the country's problems so that the fruits of development reach all sections of the society,
- goods and services that enhance the quality of life of all sections of society.

Considered against these expectations, it must be admitted that significant achievements have been made. IITs have become known worldwide for the quality of their graduates, there have been important contributions to the published and patent literature in engineering disciplines, there have been important additions to national infrastructure. All these have contributed to an increase in the quality of life for a large section of the population. The INAE has recently brought out a compendium on Indian engineering achievements [3]. That said, it must also be admitted, if one takes a dispassionate view, that there seems to be a disconnect between the achievements and the goal of building a technological society that is just, fair and equitable, and at the same time forward looking and a role model to the global community of nations. While the education system has been churning out its graduates, the country's development has been uneven, with the fruits of technology largely going to the urban sector. This has led to a migration from rural to urban areas, resulting in a whole new set of challenges for the urban sector, and a progressive worsening of the rural situation in several states. Large unanswered questions remain on the manner of utilization of national resources, and the way in which developmental goals are set. In research too, it has been said that the problems being addressed in our institutions of higher learning are those made fashionable in the west; the Indian elite institutions have not, in general, been seen as a fountainhead of new ideas or new technologies. On the manpower training side, IITs were expected to act as role models for the rest of the engineering institutions in the country, but the gap between the first tier colleges and the rest has, arguably, only widened over time. The result is that, while there has been considerable expansion in the number of graduates coming out of various engineering colleges in the country, much of this number is generally seen to be of too poor a quality to attract the attention of employers. There also seems to be a disconnect in general, between the training a student goes through in the engineering college and the kind of vocation they pursue after graduation. Clearly, there are problems of considerable magnitude crying out to be addressed.

Reasons for the Expectation-Achievement Gap: An Analysis

The disconnect mentioned above between the broad goals of nation building and the achievements of the engineering sector points to a problem of awareness: does our training of engineering professionals make them sufficiently aware of the nature of their activity, its place in society, and the socio-cultural milieu in which that activity would be taking place? These questions are more relevant to engineering training than to scientific training—while the answers science seeks are of a universal character, engineering solutions, though technical and maybe based on universal scientific principles, have a social, political and cultural context to them. Staudenmaier [4] argues that different cultures develop different ‘technological styles’. Viewed from this perspective, the problem may be traced back to the discourses that have defined and shaped engineering education in our country. Sadly, a deep analysis of this issue has been missing so far, the easier route of uncritically following the best practices evolved in the west being usually taken.

An examination of the situation reveals that the discourses which have held sway through the evolution of the engineering education in the country have traditionally been those of science and commerce. The situation is not unique to India [5], but probably has stronger implications for a young country like ours with aspirations of leapfrogging across the developmental divide. Good engineering, in the end, is more than about application of science (since the same principles can be built into a multitude of technological solutions, some relevant and others less so to the context of application), and more than about creation of wealth (since questions of equitable development, environmental concerns, societal concerns have to be factored in). This implies that the engineers should be made aware, as a part of their academic training, of the other discourses at the intersection of which their activity stands. These other discourses that may be mentioned are those of engineering itself, philosophy, history and democracy.

The Engineering-Philosophy Discourse

These are considered together because a number of issues are common to the two threads; further, the nature of engineering is, after all, a question in philosophy. It is a thesis of this essay that philosophers in India have not become engaged adequately with this question. Indeed, philosophy of technology is a relatively new discipline even on the world scene [6].

The question I want to address from a philosophical standpoint is whether engineering deserves its own place in the sun apart from that of science. Let us first note, with this purpose in mind, that it is really not necessary to distinguish between ‘science’ and ‘engineering science’; the whole thing is really a continuum.

What is the nature of engineering? Is it technical art, is it applied science? Views have tended to swing between these two extremes. The former view emphasizes the creative aspects of technology, and hence, attempts to trace a continuity with art. This view gained prominence at the time of the Renaissance in Europe, but the proponents of the view tended to be from backgrounds other than science and engineering, and therefore had little first-hand experience with the methods of either. Technology may have come about initially as an expression of man’s creativity being employed towards a better lifestyle, but over the millennia, science has caught up to a stage where it is itself spawning technologies. Further, technology has become indispensable to the progress of science as demonstrated by the need for sophisticated instrumentation and computing devices, not to mention gigantic artefacts such as the Large Hadron Collider. This symbiotic existence of science and technology in the modern day, makes it difficult to draw a clear separation between the two, but more importantly for our purposes, it diverts attention from other aspects of the personality of technological activity, than the purely scientific. While the heavy scientific underpinning of technological action (see Mario bunge [6]) cannot be denied, the type of superstructure technology builds has to be sensitive to multifarious other factors, as already pointed out. The view has been put forth by Skolimowski and others [6] that science is about what is, while technology is about what should be; in other words, science concerns itself with the world as it is, while engineering tries to change it to better suit our purposes. This then brings up the question of who decides what is to be. If it is accepted that this decision is itself external to technology, it leads to the view that technology is value-neutral, a view that may not be entirely correct (besides having undesirable connotations on the responsible use of technology) considering that many technologists are self-motivated in their work.

One has to thus accept a working definition of technology in order to make progress, while the philosophical questions continue to be debated. Following Vincenti [7], we may think of engineering as being concerned with the design, production and operation of artefacts which change the world around us in some premeditated way, in order to achieve some recognized need. The centrality of design in the activity of an engineer has often been emphasized [6, 7]. Vincenti [7] describes the hierarchical structure of the design activity, and shows how the upper strata of the activity (which are concerned with the conception of the problem and its formulation in engineering language) are subject to contextual influences from other fields such as sociology and environment, while the lower strata (concerned with the production of plans, prototypes, etc.) depend on 'engineering knowledge' that derives from a complex interplay of experiment and theory. This latter thus employs methods similar to science, but is a body of knowledge that stands on its own.

From the viewpoint of epistemology, recognizing that the body of engineering knowledge is something that stands apart from, and converses with, the body of scientific knowledge, has important implications not brought out by the simplistic view that engineering knowledge is a part of scientific knowledge. Recognizing this and according to engineering knowledge its rightful place is essential to the growth of that knowledge, and for preparing the ground for original contributions in engineering. The relevance of the above to the present analysis of engineering education are obvious. A view of engineering that emphasizes its individuality emerges as an essential component of engineering education. The lack of this is probably a main reason why there is a neglect of (one might even say a lack of respect for) purely engineering work in the academic sphere. Vincenti's account of airfoil research in the early decades of the last century is instructive on how important such research can be for progress. Similarly, in the initial years of the biology revolution, enormous effort was spent on generating random mutations and screening the mutants for desirable traits, and much progress in industrial biotechnology resulted from such efforts. Of course, such purely empirical research does involve considerable investments, but history shows that such investment is worthwhile in creating a leadership position in technologies. It may even be argued that a similar order of importance and multiplication of effort is necessary for developing meaningful solutions to the problems that beset India’s countryside.

The History-Democracy Discourse

As in the case of the previous discussion on engineering and philosophy, it pays to consider history and democracy together in this broad analysis. History is replete with instances of public pressure influencing the adoption or abandonment of technologies: developments in the tobacco industry, automotive fuel (lead and its replacements), Chlorofluorocarbons, are prominent examples. But there are also debates engendered by social (rather than human health) issues that have impacted technological developments—we in India are witnesses to several. Staudenmaier [4] recognizes three phases in the life of any successful technology—a design phase, a maintenance phase and a senile (or obsolescence) phase. The design phase, which we may call as the phase of ‘tooling up’, is characterized by flexibility—the technology is responsive to external inputs in this phase. In the maintenance phase, the technology has gained such momentum that the society tries to adopt itself to its ways—the technology itself is rigid in this phase. In the final phase, other competing technologies, themselves in the design phase, are trying to replace the old technology, but the rigidity developed in the maintenance phase tries to counter this. The point is illustrated by the history of the automotive industry in the US. Staudenmaier also categorizes the different stakeholders who play a role in the adoption (or continuance) of a technology in its various phases, among various constituencies. His illustrations are instructive of the kind of democratic pulls and pressures which are active at various stages in the life of a technology. It is particularly important to recognize the vested interests that come into being in the maintenance phase of the technology, supported advertently or inadvertently by governmental regulations and societal adaptations to the technology, which often militate against rational decision-making.

Since historical times, technology has inspired excitement and awe on the one hand, and fear on the other. Philosophical discussions on technology have tended to be of two kinds: the analytical tradition referred to in the earlier section is a late entrant in the field; the earlier tradition by far, is concerned with the effect of technology on society and is continuous with traditions in sociology and the humanities [6]. The kind of fear inspired by technology, that it has a Frankenstein-type potential to run on its own logic and take over its maker, is prevalent even today and is articulated in discussions of artificial intelligence, genetic engineering, and so on. The wealth of fiction and movies on such themes is also a testimony to the public imagination that the theme captures. Given such a scenario, views held by influential people or cliques, well informed or otherwise, have played an important role in history in advancing certain types of development over others. For example, the view, going back to Aristotle, that there is a fundamental difference between ‘natural’ substances and human-engineered artefacts, and that technology can never reproduce ‘natural’ substances, formed an important basis for the criticism of alchemy. Proceeding further, similar views also delayed the emergence of synthetic organic chemistry as a discipline. It is a consequence of the political developments of the twentieth century that public opinion is increasingly taking a position of influence in deciding on technological options.

In recognizing the role of democracy in technological decisions, one should emphasize the need for informed debates; engineers and technologists themselves have the role of spreading awareness about the pros and cons of different technological alternatives. While there is often an impatience about the time taken for decisions to emerge in a democratic set-up, if the delay is caused by informed debates, it is time well spent, since adoption of large scale technologies can completely alter the landscape of society for decades to come. A knowledge of democratic traditions and institutions, would therefore seem to be an essential component of the repertoire of an engineer.

Conclusion

In this essay, I have tried to take a step back and seek reasons for the gap between the performance of our educational sector and its engagement with national developmental goals, and identify the missing pieces in the thinking that informs engineering education in the country. A preoccupation with the ‘disciplinary’ content of engineering curricula, which has led to a total lack of an in-depth analysis of the different discourses that should inform engineering activity, is identified as the main reason for the gap, and for an uncritical adoption of western models to answer our educational needs. Clearly, such an analysis has to be an ongoing one which continuously interacts with the ‘practice’ of engineering education. It also calls for a continuous research effort and development of resource material in areas such as the philosophy of technology, history of technology and the nature and role of democratic institutions in the context of engineering activity. It is essential that such developments are rooted in the Indian context for them to make a significant difference to the preparedness of our graduates to address our engineering and developmental challenges. Perhaps there is an urgent need for an Institutional framework which, from a vantage point, takes a meta-level look at the contextuality of engineering activity and develops this ‘confluence of discourses’ to guide the development of engineering education in the country. Such an Institutional framework seems essential so that the output of the engineering education system is relevant to, and sensitive to, national needs, while at the same time being in step with international developments.

Acknowledgements Discussions with many friends and colleagues have helped in the evolution of this article. In particular, conversations with Prof Sharan, Retd. Professor of Electrical Engineering, IIT Kanpur (and presently at IIT Gandhinagar) on the general theme of this essay are gratefully acknowledged.

References

1. Wikipedia article on American Society for Engineering Education. http://en.wikipedia.org/wiki/American-Society-for-Engineering-Education. Accessed 19 Mar 2014
2. Prabhu SS (2000) Engineering education in a flux: the IIT Kanpur story. Cover story in Directions 3(5). Available at: http://www.iitk.ac.in/infocell/Archive/dirnov3/cover-story.html
3. Glimpses on Indian engineering achievements (2013) Indian National Academy of Engineering, New Delhi
4. Staudenmaier JM (1988) The politics of successful technologies. In: Cutcliffe SH, Post RC (eds) In context: history and the history of technology. Research in technology studies, vol 1. Lehigh University Press
5. Johnson S, Lee A, McGregor H (1996) Engineering as captive discourse. Soc Philos Technol 1(3–4)
6. Philosophy of Technology (2013) Stanford Encyclopedia of Philosophy. Available at: http://plato.stanford.edu/entries/technology/
7. Vincenti WW (1990) What engineers know and how they know it: analytical studies from aeronautical history. Johns Hopkins University Press, Baltimore

No Job Is Small or Big; It Is the Way in Which You Do Makes It Small or Big

B. S. K. Naidu

I was born in a middle-class family. I was schooled in small towns of old Madhya Pradesh. Thanks to my mother who taught me basics very early with her meager qualification of just primary education, where of course she was a topper. My father was in the State Government service. I have fond memories of my childhood. Once I was given an opportunity to deliver a lecture on "*Goswami Tulsidas*" representing the primary school which fetched me a medal. I clearly remember the process of overcoming the stage fear in that big Town Hall packed with elders where I was feeling too small. I little realized then that it would be at the bottom of a long series of invited lectures and standing ovations at international forums in 5-continents including my lead speeches at the United Nations, Global Environment Facility (GEF) and the World Bank etc. and 20 professional awards.

I did my engineering from the State's oldest Government Engineering College at Jabalpur. I remember my Russian professor Dr. A. G. Tyrichev very kindly. His popular catchphrase was "Full work, full marks, No work, no marks". He was in charge of Project Work in the final year of our 5-Year degree course in Mechanical Engineering. He allotted me a relatively insignificant project on "*Calibration of Carburetor's Jet*". Against several IC Engine projects, my project appeared relatively small. However, I did it with full attention and industry. My diligence and attention to minute details impressed him and he not only gave me 100% marks but also got my Project included in the list of Final Year Laboratory Examination of IC Engines. This made me think for the first time in life that "*No job is small*".

I recall an interesting event of my fourth year studies in the Hostel. A chapter on *Redundant Frames in "Theory of Structures"* use to bother us. One day we accidentally evolved a very simple (though time consuming) method of solving the problems by step-by-step resolution of forces in mutually perpendicular directions. I became very enthusiastic and spread the technique in my entire batch. I happened to visit my college after several years of my passing out and heard one of my junior

B. S. K. Naidu (✉)
201-Shelton Vista Plot-71, Sector-28, Nerul West Navi Mumbai, Maharashtra 400706, India
e-mail: Dr.bsknaidu@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_10

colleagues say "Naidu's method is still popular and we are sure of getting min. 20 marks in that paper", making me think once again "no innovation is small".

Life continued through a Masters in Hydroelectric Engineering and a Ph.D. in Water Resources Management which I thought was a less significant discipline compared to Aeronautics, Nuclear Engineering or Information Technology. But again sustained efforts in my own field made Americans invite me twice to their country to bestow upon me the highest honors of their respective entities; in 1990 by the CULA, Los Angeles, California for award of D.Eng.(Hon) in Hydro Power Engineering & Technology which I had the privilege to receive along with Hon'ble Nelson Mandela who received D.Lit.(Hon) in the same convocation, and in 2012 by the American Academy of Water Resources Engineers (AAWRE), Reston, Virginia for award of their highest honour "*Honorary Diplomate, Water Resources Engineer*".

This journey from an insignificant Municipal school in Mandla to United States signifies a couple of things when I look back. One, no job (or discipline) is small or big by itself, it is the way in which one pursue, makes it small or big and secondly, it is not the institution where one is schooled that matters, but the way one positions in the space really matters.

In the year 1968, I was earmarked not formally selected yet, by HE(I)L as a Post-Graduate Engineer and in the meanwhile I received a firm offer to join Machine Tools Corporation and deputation to Czechoslovakia for training. I ventured to meet Shri S. Swayambhu, Chairman of HE(I)L Bhopal (later merged with BHEL) to seek his advice. He advised me not to waste my PG qualification and take a chance to wait for HE(I)L's formal selection. Shri S. Swayambhu was a great Power Engineer and used to be our hero. He was the first head of CPRI in Bangalore. Later in the year 2000 when I took over additional charge of CPRI as Director General, my photograph found a place in line with him in the big Conference Hall of the prestigious institution; I felt his blessings coming from heavens and complimenting me for continuing as a Power Engineer. My 'Research and Testing' strategic initiatives at CPRI took the organization to new heights of distinction in internationally recognized research, testing superiority and peaking revenues. CPRI gave me a great sense of fulfillment where I instituted a Gold Medal in my father's name for the best paper published during the year based on testing clues/data. *National Perspective Plan for R&D in Indian Power Sector* prepared by us in June'2002 gave a tremendous impetus to research activities in the following years.

During my early days in BHEL, I happened to publish a suggestive paper on "Scope of research in air-injection techniques with reference to hydraulic turbine operating requirements" in the Indian Journal of Power and River Valley Development, June 1975 issue. Later availing Confederation of British Industry (CBI) scholarship 1975–76, I went to UK as a Visiting Engineer and was posted to Boving & Co., London. One day my Chief Manager Mr. G. T. Keast came to my desk and congratulated me for having published an article in International Water Power and Dam Construction, London, February 1976 issue. I could not believe it and got a copy from him. I found that my Indian article was abstracted there. My surprise heightened when I was deputed to their collaborator's Laboratory in Kristinehamn, Sweden in the month of May'1976. I was received by Mr. Gusthavson who took me to his section to show the entire set-up commissioned by him on the lines suggested by me in the above paper which he could source out on his own. I realized that the world was round and very small.

While in BHEL one of the prime assignments given to me was to design a Francis Turbine Runner from the first principles of Hydrodynamics for the first time in the country. It was more of a tedious research project with no internal guidance (runners being totally imported) and poor computing facilities of 1970s. When my design was model tested, its peak efficiency came out to be 87.5% against 90%+ in the international arena. Though this work was later recognized at Hydroturbo'81 in Czechoslovakia and IAHR'90 in Yugoslavia, I was somewhat disappointed with the efficiency level achieved. At that juncture, I got a message from Dr. H. N. Sharan, Director (Engineering) BHEL Corporate Office Delhi that "Even if it was 60%, it would still be our own design". He left an unforgettable impression on my mind.

Similarly Dr. V. Krishnamurthy, Chairman, BHEL left an indomitable impression on my mind by sponsoring me for the Confederation of British Industry (CBI) scholarship of one year advanced training in Europe (which I had won in an All India competition) and then historically sponsoring my visit back to India in the middle, to present a paper at the World Congress of IWRA at New Delhi It was quite an experience for me to address a World Congress at the age of 30!

Later in BHEL, I remember once in 1981, Shri B. S. Kochar, Chairman, BBMB walked in requesting us to study the overload margins in Bhakra turbine-generators. It was entrusted to me as a small assignment. I took it rather seriously and expanded the dimensions of the study from signature analysis of the machines to material testing to vibration analysis to design margins to furthering power generating capacity of the machines by opting thinner and effective insulation in the stator slots and even changing the runner profiles to higher specific speed versions; little realizing that it was heading towards a New science of "Uprating & Refurbishment of Hydro Units". It became a *pioneering and trend-setting study in India* fetching me the Willie (a German Scientist) Memorial Award at IIT, Delhi.

I shifted to NHPC in the year 1982. For the next decade I worked sincerely pouring my heart and soul. As Chief of Corporate Planning Department for the longest tenure, I was instrumental in sanctions of projects worth 2265 MW involving an investment of Rs. 5400 Cr., authorized share capital growing from Rs. 800 to 2500 Cr., Corporation upgraded from "B" to "A" schedule, Five-Year-Plan exercises of NHPC. When I started handling Hydro-Environment Interface (having created an environment cell in my department), no one was talking about positive impacts of Hydro, closing one eye of the decision makers. Our sustained efforts brought it on the assessment formats of evaluation matrix.

With the awareness of uprating potential of Hydro spreading across the power sector, during the Power Ministers' Conference held in Jan'1987 a resolution was passed that an All India study of Renovation and Modernization of Hydro Electric Power Plants would be conducted by NHPC and with the background of Bhakra study naturally it was entrusted to me. Assisted by Shri A. K. Tripathi, I did it with full vigor and dedication. Having become one of its kind first national study for a country of continental dimensions, we were invited to the First International

Conference on Uprating & Refurbishing Hydro Power Plants at Strasbourg, France during Oct'1987. I presented the study. This study taking the shape of the first ever made national master plan on Hydro R&M across the globe became a star of the show at the Conference. Mr. J. Warnock, Managing Director of Acres International, UK chairing the Conference said in the midst of a standing ovation "Here is the first ever attempted comprehensive study of all the operating plants in a country of India's size dealing with all aspects from Civil Engineering to Electronics, which is going to become a forerunner of such studies by other nations." Indeed Norway followed us the very next year.

We were confronted with another problem of silting in Hydro turbines, damaging their under-water components. I again took the problem seriously and not only worked on solutions in terms of repairs and preventions but also started looking at the design aspects little realizing that it was giving rise to new engineering practices in Renovation and up-gradation of silt prone Hydro Power Stations and a New science was emerging later labeled as "Design of Hydro Turbines for silt laden flows", accepted for post-graduate studies and recognized internationally. I was invited to Europe (United Kingdom, Norway and Austria) and South America (Argentina) to share this specialized knowledge.

In view of my contributions *CBIP's highest honor, their Diamond Jubilee award*, was bestowed upon me in the year 1989 for my outstanding contribution to Hydropower development in the country.

Prof. Pradip N. Khandwalla of IIM, Ahmedabad approached me to contribute to a "*Study on Human Excellence*". The basic idea of this study was to understand why some persons are able to achieve so much, and others with comparable background and intelligence end up doing nothing of any consequence. I did contribute to his interesting study which was later published by him in a book titled "Fourth Eye-Excellence through Creativity". It reinforced my belief that the creativity can flourish in every job, even in seemingly smaller jobs.

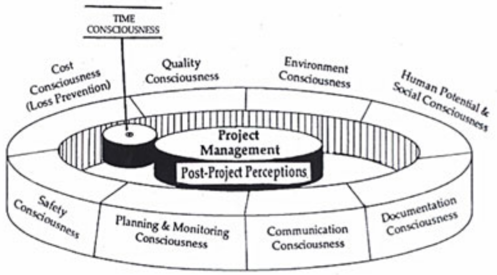
Renewable Energy, when I entered the field in early 1990s, was in a nascent stage (kW scale) in India, far from any economies of scale. I took the responsibility for strategic interventions in the India's renewable energy sector by identifying barriers faced at macro and micro levels, exploring remedial options and strategic 'niche' interventions with potential ramifications in terms of replicable models with multiplier effects. Today it has much higher share of >50,000 MW (more than 7 times of Nuclear Power) and is being seen as the energy of the future. In 1997, I was declared "*Renewable Energy Man of the Year*" by the National Foundation of Indian Engineers.

As Director, REC (A Navratna Company), I was involved in 1999 with UNDP/GEF project on "*Optimizing Development of Small Hydel Resources in the Hilly (Himalayan and Sub-Himalayan) Regions of India*". When we went to submit our report to the UNDP office in Delhi, they very much liked our format and the findings. Later they informed us that UNDP Headquarters have directed them to keep our report as a Model sample for future projects.

At REC, I also advanced a new concept on "*Project Management*" which was evolving in my mind since NHPC days and I presented it as a Key-Note Address at an International Conference in Singapore in November 1999. Various failures and successes met with in real life projects with the same operating tools like OR/PERT/CPM/OAS/MIS/DSS etc. have time and again pointed towards one basic thing viz. Human mind is crucial to make conscious judgments on optimization of all tangible and even intangible variables influencing a project. The Concept of making human being as the hub of management activities should logically lead us to '*Consciousness Concept Model*', as it is the man behind the machine who matters. Ten (10) Consciousness Elements were comprehended as crucial ingredients of the 'mind-set' of a successful "Project Manager", pictorially depicted in the diagram alongside.

If the Project Management has to succeed on Indian soil, we have to develop the *Project Management discipline as a Science of Consciousness.* Suitable training packages would have to be evolved for the prospective project managers with exclusive modules aimed at generating 'consciousness elements' itemized above and more importantly the terminal modules aimed at bringing equilibrium amongst them, appreciating the tradeoffs and inter-linkages involved. An appropriately conditioned mind so trained would possess 'just consciousness' capable of taking judicious decisions during project implementation. This would certainly add a new dimension to the Project Management and if pursued in right earnest, can bring results which would surprise many and Indian consciousness and ethos in Project Management would become a guiding light for the future generations.

A new Concept in Project Management



Elements of Consciousness required in Project Management (Just Consciousness with proper trade-off)

On the above concept, I received appreciation from the then-Cabinet Secretary to Govt. of India, Shri S. Rajgopal. Another dose of appreciation I got from Dr. APJ Abdul Kalam, the then-Principal Scientific Adviser to GoI on my Institution of Engineers (India) awarded paper on "*R&D Vision for 21st Century with special reference to Power Sector in India*" in 1999.

I took over NPTI as its Director General in the year 2000, at the rank of Addl. Secretary to Govt. of India. I found that the performance graphs of this Apex Institution in Training and HRD of Power sector were continuously declining during the previous decade making it a sick organization in the bankrupt power sector. The real challenge was to make it self-sustaining. It needed out-of-the-box thinking for setting the gears right. We resorted to the following strategies:

(1) With the permission of the Ministry of Power, we formulated a *National Training Policy for the Power Sector* (first time in the country) mandating 1-week training/year compulsory for every one working in the sector and earmarking 1.5–5% of salary budget for training. This policy when implemented all over the country in March'2002 generated 10,00,000 trainee-weeks of training load annually besides earmarking of funds for the purpose.
(2) The above initiated flow of trainees but not the revenue earnings for NPTI on the plea that any cut on the budget is always on the head of training. Then we organized an All India conference of Regulators under the chairmanship of CERC and got a resolution passed that training expenditure would be a part of O&M expenses which are built into the tariff. The moment tariff is realized, cash is available for reimbursement to training.
(3) All the processes involved in the steps-1&2 above took two years at the fastest pace but we were committed to self-sustenance from Day-1. We therefore pioneered unique programs viz. B.Tech./B.E. (*Power Engineering*) and PGDC in specialized segments like "*Power Plant Engineering*".

"*Power Systems Engineering*" etc. at NPTI. We offered the *Art and Science of Power Management to the Reforming Indian Power Sector* by way of **First Ever** AICTE/UGC approved MBA Program on the subject, under the auspices of the *Centre for Advanced Management & Power Studies (CAMPS)* started by me. These programs have unmatched reputation in Power Sector. The product of all these courses not only got absorbed in the industry but also took a premier Training Institute 'NPTI' to new heights of excellence across the globe.

During my tenure, we expanded 4-Units of NPTI to 10-Units across 5-Power zones of the country with total self-sustenance within 5-years **making it the largest Power Training Institute in the world.** The quantum jumps NPTI experienced in its operational parameters during my tenure (2000–2005) have made an unrepeatable history. The mechanics and dynamics of growth with stability and self-sustenance were acclaimed by one and all. In one of the Governing Council meetings, the Chairman asked me "Don't tell us what you have done; tell us how you have done?" That was the highest compliment, I thought as I got a chance to explain *how we set the sails to go in a particular direction even when the wind was blowing in a different direction.*

My professional life provided me a rare combination, 32-years of rich Industry experience in country's premier organizations with subsequent 16-years in Research, Training and Education creating the brains behind the country's power and energy sectors. I also have satisfaction of having documented my experience in 150-technical papers (90 in international fora) ending with 7-books on Renewable Energy including conventional Hydro (whose renewability comes out of nature's hydrological cycle) for PG studies-my choicest gifts to the younger generation.

On the eve of my retirement from the Govt. service, I was picked up by Reliance Energy as their Director General (Trg & Dev). I was stationed at Reliance Energy Management Institute (REMI) Mumbai where I spent highly productive 3-years. As in-charge of training more than 25,000 people from gross root level to the level of CEO's of various Units across the country, and several thousand engineers from 35 SEBs and DISCOMs, I realized that training them in their functional spheres was not enough. I developed a *'Helicopter skill centric 360 Degree Training Model'* © circumscribing attitudinal, behavioural, functional and commercial competencies with a capacity to have a bird's eye view of the entire business as well; a unique concept and *a* **'First' for any Corporate Business** to transform the entity into a Learning Organization of distinction to be competitive at all times. I also evolved a "*3-Orbits Learning Model*" © for an effective, value oriented, holistic and sustained Capacity Building.

Capacity Building continued in my work profile and I joined Advanced Engineering Associates International, (AEAI) USA for their USAID project on Capacity Building in Energy Sector, in Afghanistan as their 'Senior Advisor' for two years. It was a pleasure to train Afghan engineers who were polite and keen learners.

Since 2010, my academic work continued further through the Institute of Energy Management & Research (IEMR) later rechristened as the Great Lakes Institute of Management (GLIM) Gurugram (*as their Founder Chairman and now continuing as Chairman Emeritus*) in the field of energy/management education, providing me great satisfaction and recognition by the Higher Education Forum (HEF) through their First "**Outstanding Academic Leadership Award-2014**".

When I was elected as Fellow of the Indian National Academy of Engineering (INAE) in 1993, I felt happy that I am among the luminaries of the country. My picking up so called small jobs in a conventional field on the way of my career and doing them as perfectly and as innovatively as I could, did not cause any setback against the Missile and Nuclear scientists, Information Technologists, or Industrialists of highest repute.

Lessons learnt from my professional life are simply:

1. No job is small or big by itself; it is the way in which you do makes it small or big.
2. When you take up a new challenge as an opportunity and proceed, you find so many hidden opportunities unfolding in a cascading manner that astonish and overwhelm you.
3. Self-esteem emerging out of original work motivates you more than any other external stimuli.
4. Anything you succeed in doing for the first time in any domain be it your organization, your sector, your country, your continent or the entire globe, gives you an awesome sense of fulfillment.
5. If you contribute in any sphere it pays back, if not immediately, in some years for sure.

6. Any original ideas and thoughts you generate at your end can be transmitted to the other end of the world, sometimes even without your knowledge, more so in the present digital world.
7. The wind may blow from any direction, but the direction in which you go depends on how you set the sails.
8. Engineering is not just application of science but genuine innovation while applying science and it can be philosophized for its influence on a larger domain.

When I Look Back My Career at BARC…

Manjit Singh

I joined BARC in the year 1972 after my graduation from the Punjabi University, Patiala, Punjab. After one year orientation course at BARC Training School, I joined Reactor Control Division of BARC in the year 1973. I have been lucky to have worked under the guidance of a great man (late) Shri S. N. Seshadri during the period from 1973 till 1986, when he suddenly expired at the age of about 56 years. Shri Seshadri could motivate a large number of persons like me to take up challenges and deliver at any cost. I have also been lucky to have a team of very competent engineers reporting to me.

During early days, PHWRs were built with the provision of dumping the Heavy Water moderator for reactor shutdown. Subsequently, it was decided to introduce solid absorber elements into the reactor core using remotely operated reactivity control mechanisms. Indian research reactor 'DHRUVA' and power reactor at Narora were designed with mechanical shutdown system. Being safety critical system, design of shutdown mechanism is challenging in itself. At the time of reactor start-up, the absorber elements are withdrawn one-by-one and for shutdown, rod falls freely into the reactor core in a given time period, also ensuring minimum terminal velocity at the end of its travel. Moreover, depending upon reactor layout and number of such mechanisms to be provided on the top of the reactor, space available for the mechanism is limited, which makes it a custom-built design. Design of the mechanism is also dictated by the weight of the absorber element, its travel, withdrawal time and its rod drop characteristics. Shutdown mechanism is built with modular construction giving ease of maintenance, fail-safe and free fall for the required length of travel giving consistent rod drop performance. This assignment was first-of-its-kind for Indian research and power reactors. Being safety critical system of the reactor, design is qualified through prototyping and subjecting it to life-cycle testing to demonstrate its reliability and repeatability in its performance. Design of shutdown

M. Singh (✉)
B-703, Jai Balaji CHS Ltd, Sector 6, Nerul, Plot-26, Navi Mumbai 400706, India
e-mail: Manjitsinghbarc64@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_11

mechanism adopted in the research reactor DHRUVA and power reactor at Narora is considered to be 'Benchmark design' for subsequent reactors.

The next challenge on which my team worked was design and development of BARC Coolant Channel Inspection System (BARCIS) for in-service inspection (ISI) of coolant channel of 220 and 540 MWe PHWRs. The assignment was given by Dr. Anil Kakodkar, our Ex-Chairman, AEC in 1991. The system was successfully developed in a record time of less than a year. A number of BARCIS units are in regular use at various Nuclear Power Plant Sites. I feel proud that our team could contribute significantly towards Nuclear Power Programme of the Department. BARCIS has been in regular use at all our PHWRs for ISI activity and thus forming an important tool in the coolant channel health assessment programme of PHWRs.

Based on the successful deliveries mentioned above, Dr. Kakodkar entrusted the development of robust remote handling and robotic products for use in radioactive environment to my team in the year 2000. We could deliver rugged duty mechanical master-slave manipulator and servo-manipulator to various users. We also developed mobile robots for remote survey and inspection of radioactive areas. We took the challenge of building a mobile robot with on-board manipulator and remove Anti-Tank Mine Fuzes remotely at Ordnance Factory Khamaria, Jabalpur, in the year 2007. On another front, we developed an automated Guided Vehicle (AGV) based Materials Transfer System for use in the manufacturing environment in the year 2010.

The most satisfactory experience has been the design and development of indigenous low-cost Teletherapy Machine for the treatment of cancer. Cancer is a major public health concern in our country, and due to various reasons the incidence of cancer is expected to increase substantially in coming years. Considering the growing need of such machines in the country, we have developed a state-of-the-art machine Bhabhatron incorporating the latest concepts in safety, control and user interface in the year 2005. This low cost machine has a number of features superior to any other machine in the category. More than 30 machines are operating at various cancer hospitals and treating large number of patients on regular basis. These include rural and semi-urban areas where our machine has unique advantage of running even on battery/small generator during power-cuts. We could also deliver a robust Radiotherapy Simulator to localize the treatment volume to be subjected to radiation during radiotherapy treatment, in the year 2011. Currently we are working for the development of an indigenous low-cost robotic system for minimally invasive surgery which is a special type of servo-manipulator. The imported systems are prohibitively expensive. Based on our experience in servo-manipulator technology, we are confident of meeting this challenge in reasonable time.

The experience of working at BARC has been satisfying and I will cherish this forever. I consider the motivation from our leaders and team-work have resulted in success in all our endeavors.

Engineers—Pre-eminent in Society

S. S. Chakraborty

There was a time when engineers were recognized in the society at a personal level. For example, in a private university near Thanjavur in Tamil Nadu, a campus road has been named after Sir Visvesvaraya, the redoubtable Indian engineer of the 20th century who also proved his mettle in governance! But, the name is more readily associated with his engineering accomplishments, Krishnaraja Sagar Dam being the crowning jewel, rather than for his administrative excellence. Equally telling is the fact most of the other roads are named after scientists and mathematicians, discounting a scattering of experts in aerospace.

Take another example, the Inter-University Centre for Astronomy and Astrophysics in Pune. I know the campus roads are named after doyens of the field the institution promotes, astronomy and astrophysics.

It almost feels like that in a predominantly engineering institution, the private university mentioned above, there is a level of "tokenism"! So sad. Well, engineers of today can only sigh: "Where have we gone wrong?"

We need to start at the beginning. Engineers. Who are they? Are they so special that they need to be recognized as a separate breed? How did they become engineers? Who do they serve? Who, if anyone, do they guide? What is their purpose? What is their status in society?

The last question is perhaps the most critical.

These questions have been asked many times and have been answered too. Yet, there indeed is a need to revisit them, particularly as the context keeps changing befitting a growing society.

Let us define engineering as opposed to science. A wise man once said, "The scientist seeks to understand what is; the engineer seeks to create what never was." Let

S. S. Chakraborty (✉)
TransAsia Infrastructure (India) Private Limited, Eros Corporate, 5th Floor, Nehru Place, New Delhi 110019, India
e-mail: Sudhangsu.chakraborty@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_12

this be our starting premise—engineers are creators. That is, engineering is undergirded by creativity. Sure, engineers are not in the same mold as Picasso, Salvador Dali or Raja Ravi Varma. But, the same may be said in reverse too.

At the same time engineers are practical scientists. They would complete a job at the earliest opportunity under the given constraints and not wait indefinitely to meet an asymptotic line.

Engineering creativity does not allow unlimited freedom to explore—after all, in its analytical avatar, engineering is a reincarnation of science—but the canvas is large, indeed very large for an engineer's creativity to shine through and it is ever expanding.

The Kieler Horn Folding Bridge, in the German city of Kiel, conceived by an architect and realized by an engineer is a prime example of engineers' creativity and creation. The bridge has become a tourist attraction, pride of the locality and a tribute to the ingenuity of engineering. About every hour or so "the middle of the jetty… swivels, pulls, flips, and folds…" to let ships pass through and to let pedestrians cross as required. Engineering comes alive during the operation of the movable parts to let economy move! Engineering and economics working in tandem.

Engineers fulfil the dreams, ideas and imaginations of people, including engineers, to effect in reality. Consider Eiffel Tower, designed and built in 1989 by engineers of a company owned by engineer Alexandre Gustave Eiffel; in the face of constant adverse criticism by groups of architects and also the literati of that time in France. Creation it is; and also the most visited monument in the world today.

Consider also the 1450 ft Willis Tower, earlier known as Sears Tower, structurally designed by Fazlur Rahman Khan, pioneering the concept of "Bundled Tube" structure which revolutionized the building of skyscrapers. The concept has been used in many tall structures since then including the *Burj Khalifa* in *Dubai*).

Before I conclude this section wherein I have tried to list and elucidate on the creativity of engineers, I would mention one more structure, in much more detail. The Second Vivekananda Bridge Tollway project. Near the Dakshineshwar Temple in the northern reaches of Kolkata, there is a bridge crossing, the venerable steel truss bridge, popularly called the Bally Bridge. While still being useful, it was realized that northern Kolkata needed another cross-river facility. Thus was born the Second Vivekananda Bridge.

But the birth was far from natural; problems were galore and were coming from unknown corners of society. These were handled by experts from various fields but it was anchored by an engineer. An innovative structural system, the extradosed bridge, was almost thrust upon.

It, given the difficulty of a bridge within 50 m of an existing bridge that is still in use; the congested heavily trafficked and densely built-up environs on either banks of River Hooghly; the spiritually uplifting spires of the Dakshineshwar Temple that ought not to be over shadowed; the necessity of integrating the bridge with the city road network, particularly on the Kolkata side, and on the Howrah side, connecting the bridge with both NH-6 and NH-2 required a high level of multi-disciplinary expertise. Of course, as in any such project within an urban conglomeration, there was difficulty in land acquisition and it was achieved smoothly; engineering contributing intensely yet going unrecognized.

If you do want to get a handle on the size of the bridge, look no further.

No one knows the name of the engineers, even while marveling at their creation. This why the engineering profession is languishing in obscurity. No wonder, the profession recognized the bridge for what it is: garnering the Award of Excellence from the American Segmental Bridge Institute, USA.

There are countless examples of such innovations, ideas and concepts translated into reality for society to benefit for centuries. If one understands the background of various engineering creations one sees, it would not be possible to go unimpressed with the creativity disguised in them, be it the Jawaharlal Nehru Stadium in Delhi, Bandra-Worli Sea Link in Mumbai, the successful space missions of Chandrayaan and Mangalyaan, the cranes that dot the skyscape in skyscraping building sites, the huge machines that operate in open-cast mines, the tunneling machines that create the "tubes" for the metro systems, the nuclear containment vessels and the control systems that govern the operation of the facility. One must acknowledge that engineering, as a whole, is an integrated profession. Yet, one may say, not with abandon, but with humility, that civil engineers anchor the disparate streams of engineering.

So, to answer the opening questions, engineers are rational and analytical artists, creating masterpieces that excite people while serving them and also expanding the scope of their profession. They indeed are a special breed for the simple reason they have defined what appears to be an oxymoron—rational artist.

How did engineers become engineers? Through education, of course. Engineering education, besides developing the mindset of rational, step-by-step thinking, must also invoke and nurture the creative spirit of the students. Is this happening in India? Perhaps not. We are into a particular mode of engineering education that appears not to be too keen in promoting the creative art of engineering. Why is this a point of argument in this discussion? The answer comes straight out of how we have defined an engineer, a rational artist, imbued with creativity.

We must focus on implementing projects, but as engineers we must also involve ourselves at the stages of conceptualization and planning so that a project can carry a holistic character. If you read about how the Mars Lander mission of NASA came about it becomes evident that comprehensive involvement of engineers in this mission from the first step contributed immensely in its astounding success. Or think of the SpaceX initiative of ElonMusk, a rocket retrofired to land on a ship!

Unfortunately, the engineers are seldom inducted in the planning process with the result that, more often than not, the concept gets modified during implementation culminating in something at variance with the original perception.

Coming down to the real world in this regard, to a large extent how the Second Vivekananda Bridge, we have talked about it much technical detail earlier, metamorphosed from a government department driven project into one that became the curtain raiser for PPP mode of execution is a lesson in how an engineering project comes alive; rather must come alive. With engineers' participation from the phase of identification stage. An entrepreneur and engineer got involved and led the efforts in this transformation. A dream, of the people, came true.

If engineers learn how to conceptualize the product from the bare specifics offered at the induction of a project, they cannot but be ensured of its success. Engineers must be taught to lead the society by being involved in the process, from beginning to end. Here is where our engineering education maybe lacking. As we would see later, this might even be the causal factor in the perceived relegation of engineers in the eyes of society.

Engineers serve the society. This is an insipid statement, as it is expected that every citizen would serve society in whatever capacity, even as he serves himself. This is almost a direct take from Adam Smith who said that the baker does not bake bread for feeding the hungry but for earning his livelihood. But, in the context of engineering, it goes much deeper than that.

Engineers, because of the specialized training they get, are expected to guide the society even as they serve the community of which they are a part. It was 1964 and nature created havoc—washed away sections of the rail link between Rameswaram and the mainland across Palk Strait. Engineers were called in. The link was restored in 46 days even as the project was scheduled for 6 months. This is leadership and commitment by engineers to society and the country at large.

Let us also look at what happened in the aftermath of the Bhuj earthquake. The codes that engineers use in engineering became very stringent, demanding details that were not in the cards up until then. These measures ought to be looked at in two different ways.

One, the profession implicitly admitted that the then extant codes were not up to scratch. Continuous improvement was perceived as basic duty of the engineer; the demand arising from within the profession itself. The code was further rationalized and strengthened.

Two, there were murmurs from the construction industry that such tightening of the codes may make scrupulous engineers vulnerable at the hands of a few unscrupulous ones; a valid concern and this must be taken as a clarion call for the profession to wake up the sleeping community.

But this wakeup call must be clarity personified. It is this lack of clarity, in the language the general public can understand, that led to six seismologists being incarcerated (though all but one was subsequently exonerated) in the famous L'Aquila earthquake case in Italy.

Coming to the language in which engineers should speak to the society, there really can be no better example than how the engineer convinced the public body of the feasibility and safety of the iconic Firth of Forth Bridge. Just two images will make the case and rest it too.

We must see the above in terms of serving as well as guiding the society.

But, engineers are also humans, after all. As human qualities, good and bad, permeate through all strata of society there are instances of engineers falling prey to the songs of sirens, like greed, jealousy, unethical gaming of the system and others. A professional body, in one of the developed countries, once received a letter for interpreting a particular clause of a code. Later it became clear that the interpretation offered was in the interest of a company with high-level ties to the professional body and against that of a smaller company—a classic case of conflict of interest and the Supreme Court of the country ordered the professional body to pay reparations.

Obviously the above incidence is not to the credit of the profession. Yet, it does illuminate that practicing professionalism demands that one wades carefully through the waters. If nothing else, this incident proved that engineers are part and parcel of society. It is perhaps impossible to claim that the above is a one-off incidence. But what we must remember is the importance of ethics in engineering; this must be one of the founding pillars of what defines an engineer.

Engineers serve multiple purposes in the cause of society. First, they promote rational analysis imbued with practicality. Second, they cater to the demands of society. Third, engineers look forward, always thinking, "How to do this better?" This could have an effect on the society, if only the society had been prepared to receive the message. This process of preparation is also a mode of serving society. Fourth, engineers protect society, many times after the fact but sometimes proactively. Addressing climate change and developmental concerns, say, conceptualizing, designing, constructing and operating a solar chimney.

To err is human and engineers are not an exception. But, the profession has internal checks and balances that take it forward. The benefits of admitting one's mistakes is a big lesson engineers impart to society. Of course, overarching all of the above, engineers create. This role goes unacknowledged for the most part.

It is time to wonder about the status of engineers in society. Sometimes in the past, engineers were admired across all levels of society. It is not the case now. What caused this transformation?

Perhaps engineers contributed to it. Take the case of Krishna Raja Sagara (KRS) across the River Kaveri. We celebrate it as the creation of Sir Mokshagundam Visvesvaraya.

That word creation! The dam was "created". Now, who "created" the Bandra-Worli Sea Link? We do not think of it but take it for granted.

It was merely designed and built. No one associates "creation" with a bridge these days. Note the change in the perspective. In "creation", he who creates, engineers, is put on a pedestal. In "designing and constructing", the engineer becomes a mere worker. In our hierarchical society, does anyone care about workers? Engineers do the job and take home the salary. There is no "vision" associated in this endeavor.

To get society to glorify engineering, engineers have to become visionaries. They should avoid being risk-averse, within the constraint of time, space and economy, yet follow the professional standards. This ties in well with the idea that engineers are creators but unlike artists, they are constrained by their profession and perceived duty to society. The unwanted, undeserved relegation of engineers in society hierarchy must be righted immediately.

Now, much as I do not like comparisons, I would like to ask how many of us know on which date Engineers Day falls in India. While you are googling "Engineers Day in India", let me ask you, do you remember Mother's Day? Oh, yes, the second Sunday of May, every year. What about Valentine's Day—14th February, pat comes the answer. Same for Children's Day—November 14th. Yes, we will remember all annual day celebrations/felicitations, but not that of the engineer. Engineers celebrate Engineers Day, but it is confined to the professionals. Correct me if I am wrong, have we had the President of India felicitating engineers on our day? He/she may have, but it really does not stay in our minds, much less in the minds of those who are not engineers.

The only way to right this imbalance is to actively go after the decision makers and demand a seat at the table along with the other decision makers. We have to demand our rightful recognition from the society.

One last matter upon which I would like to make a strong statement. It is not for prestige alone that I seek a seat at the high table for engineers. But, most projects that are delayed, or are in arbitration—if you look behind far enough—had their problems seeded at the initiation stage; without the involvement of engineers. A wrong alignment, not sufficient time for doing proper technical due diligence, the process of government procurement, so on and so forth. It is only by sitting at the high table and raising our voice, engineers would get back to their glory days of deep and wide appreciation from society. That should serve as one of the motivating factors for budding engineers, who, unfortunately drift away from their competencies gained over four years in search of greener fields.

Talking of green, engineers must keep "Going Green" as one of their fundamental drivers.

To conclude, engineers are creators. They become so by the dint of their efforts-education, professional practice, and research—institutionally supported. They serve the society in myriad of ways. Impart pride to the society through their eye-popping accomplishments. And, they lead the society too, showing what can be achieved. The dual mandate, to be a worker and be a leader too, is a knife-edge balancing act. Engineers have to perfect their skills in this.

Engineers must work towards projecting themselves to society in two distinct ways—a productive member of society while leading it.

They are, thus, part of, yet distinct and pre-eminent. But, to get this message across, they must make themselves visible, not be delegated to the lower tiers of mere project implementation.

Make yourselves visible, engineers!

Evolving Ideas of Teaching and Research in Engineering Institutions During My Journey in Academics Over Five Decades

Bayya Yegnanarayana

Background

Being in the academic field for over 5 decades, I felt that I should write my views on teaching and research, especially in engineering institutions, based on my experience. Frankly, I have been collecting my thoughts on this subject over the past several years, and I do express them in limited forums, like in my general talks I give while addressing the students and faculty in academic institutions. I am very hesitant to put my thoughts in writing, as it may invite criticism because many of the ideas go against the currently held views by most educational planners and administrators. Finally, I ventured to write this, mainly expressing my personal views, based on the changes I have been observing in the education field during my 5 decades of teaching and research in engineering institutions. Please note that these are my personal views, many of which may not be backed up by solid facts and figures.

I would like to emphasize that this article is only about teaching and research, and not about coaching and training. I feel that coaching and coaching institutions are meant to prepare for competition, like in games, and have limited or short term goal. On the other hand, training is for preparing some one to acquire a skill, mostly for living with that skill. But teaching is meant to prepare students for learning how to learn. Research is meant mostly for developing creative abilities, especially to generate new ideas. Hence all these four are meant for different groups of people with different aims, and there is no conflict or overlap among their roles. This writing is only about teaching and research.

I am expressing these views in the backdrop of the following developments in recent times. We often hear these days that we should have over 1000 universities, producing 10,000 Ph.Ds per year, and having online classes with over 100,000 students per class. We seem to focus excessively on the number of Ph.Ds to be produced,

B. Yegnanarayana (✉)
International Institute of Information Technology, Gachibowli, Hyderabad 500032, India
e-mail: yegna@iiit.ac.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_13

and on making the Ph.D. degree mandatory for promotion even in ordinary teaching colleges. Since research is measured in terms of number of publications, citations and awards. People seem to be working towards them, instead of doing any serious research. The proliferation of journals and conferences is testimony to this. Also, there is a growing belief expressed by many planners and educators that teachers can/should be replaced by technology. In such an environment, it is difficult to convince the administrators of teaching and research institutes that the real meaning of teaching and research is different from what is happening in their places.

In this article, I try to give one view of teaching and of research, which many may not agree in public, but accept it as correct in private. This write-up also reflects my bias acquired over the past 50 years of my teaching engineering students and also doing research in engineering institutions. In the process of this writing I try to clarify the five terms relevant to this topic, namely, education, learning, knowledge, teaching and research.

Let me assert that I am a teacher by choice, and not by chance or accident, and hence I kept away from administrative roles as far as possible throughout my career. Based on my teaching experience (this is my 51st year of teaching), I feel that teaching involves production, perception and learning of patterns. Here teaching refers to teaching human beings by human beings, and hence the link to the biological neural network (BNN), i.e., the human brain. The main feature of the BNN is pattern processing, which includes the multimodal nature of pattern perception and learning. The production part of teaching is the ability of the teacher to produce multimodal data of a concept, to convey the pattern to the listener. Note that the pattern exists in a high dimension space of the data, and it cannot be compressed. The listeners can then perceive the pattern in the multimodal data and attempt to learn by developing associations or links to the patterns already developed in the listeners' minds. The ability of capturing the pattern in the data and associating it with other patterns in the brain is the process of learning. The teacher enables this to happen by generating appropriate multimodal data. Thus significant effort on the part of the teacher is in generating the multimodal data for a given concept. The multimodal data here means the gestures through vocal, hand, facial and the general body movements, besides the other data, if any, such as slides, audio and video demonstrations.

The multimodal data need not be unique or precise. Actually being precise (in the form of definition or unique description) is not a virtue in teaching. Some variation helps the listeners to learn better. The pattern information in the generated multimodal data is captured by the multimodal nature of pattern perception and learning ability of the biological system, i.e., BNN. Interestingly, teaching is also a continuous learning process for the teacher, as while expressing the concept through multimodal data, the teacher comes up with better ways of producing the data for the same concept, based on his own feedback and the feedback from the listeners' reactions, in the form of gestures, questions and comments. A good teacher is one who can produce such multimodal data to convey the concept through the pattern information in the data. Thus there could be good teachers or bad teachers (initially in their career), depending on the effort they put in. But generally, there are no good or bad students. We will also see below that teaching almost becomes a prerequisite for research.

Coming to research, it is common to mention that there is a methodology for research, and that it can be described or discussed in a structured manner, as though it has some beginning and ending. But in my opinion, research has no methodology or structure to describe. Research is a process and not a product. It is for the process that a person is credited with a degree such as Doctor of Philosophy. The thesis examiners, while recommending the award of the degree, usually mention that 'the candidate has demonstrated his/her ability to carry out independent research'. In research, the candidate should demonstrate their ability to see the problems clearly, and in the process of finding solutions, they may generate more problems than solutions.

Research involves understanding and building links among the components of the problem, rather than breaking up the problem into subproblems, leading to destroying the problem itself. One can appreciate what constitutes great research, by recalling great research ideas, such as Maxwell's equations, Sabine's formula, Shanon's information theory, Kalman filtering, to name a few in my domain of research. Ultimately, both research and teaching are passionate endeavours, and cannot be done by mere training or coaching. In this context, let us recall how ideas of teaching and research have evolved over the past several decades. First, we will consider teaching.

Evolution of Teaching

In 1950s, some of the teachers in schools and colleges used to teach with passion. For example, it was language and arts classes that were more interesting than science and maths classes. The teacher teaching Shakespeare drama used to enact the event in the play in the beginning of the class, and then explain the English part of it. Likewise, teacher of Telugu poetry used to start the class with pleasant rhythmical recitation of the lesson, and then explain the meaning of the poem, along with several linked stories. I was fortunate to have such teachers in my college. Where are those teachers now? In 1960s teachers try to prepare the lesson with a desire to communicate the concept to the students. Textbooks were very carefully and concisely written. Not many questions or worked out examples were available in the books. Also, the teachers did not focus much on working out examples in the classes. Since copies of the books were limited, students used to write notes carefully in the classes, and supplement with additional reading material in the libraries. For some subjects, lab experiments supplemented the classes. There were fewer exams. Students were credited for asking good questions. There were not many questions in the books, nor there were many question-banks. Mostly, the annual exams were used to assess the candidates. The dynamic range of the performance of the students is indicated by the range of marks the class gets, mostly in the range of 0–70% marks. In fact getting more than 70% was rare and exceptional. Thus the students know where they actually stand in the class.

In 1970s, the teachers started using overhead projection of transparency sheets for class room lectures. Then the teachers were busy preparing the transparency sheets, and in the class they were not thinking of developing the concepts with illustrations. The students tend to look at the projected material rather than watching the multimodal display of information by the teacher through his gestures, voice modulation, with on the fly illustrations and stories. Question-banks for various subjects were coming up, with even answers to some of the questions. This helped the teacher to set question papers easily. It also helped the students to follow the pattern of questions that the teachers would ask. Thus the students slowly lost their ability to make and ask their own questions. The teachers also are slowly trying to adopt to the pattern of the questions in the question-banks, instead of trying to create questions based on the interaction with the students in the class.

Introduction of the credit system with electives in 1980s gradually produced distance between teacher and students. Teachers definitely lost touch with the students, as the students from different disciplines and departments assembled for the class hour and then dispersed. With the wide variety of the background of the students, the teacher was forced to dilute the contents of the course, and also lost time for providing the background of the prerequisite courses for significant part of the course. Giving assignments and solutions to problems, and also continuous evaluation through frequent tests and exams, resulted in transferring the load of evaluation to teaching assistants, thus further reducing the contact between teacher and students. Also, the problems, questions, answers, etc., all of them were tailored to enable the teaching assistants to evaluate the students. In 1990s the curriculum, the course contents, teaching and evaluation became more structured towards grading the students. The concept of learning is either ignored or diluted. The craze for better grades/marks due to competition among students has increased, which in turn has increased even the distance among the students, and the distance of the student with the teacher still further.

In the decade of 2000, drastic changes took place in education system, with computers becoming easily available, and communication through internet making the distant people apparently closer, and the closer people distant. Many more worked-out examples, with easily implementable software packages, have changed the way books were written. While it helped a few motivated students with better access of these resources, the general attitude of the students was to get some how good grades/marks and a good job after that. There was less exposure to concepts in the classes any more. The teachers and the system also were tuning their activities to cater for the needs of the students rather than educating them. For example, the question papers were of objective type to tick an answer among the alternatives.

The average grades of students were thus jacked up, with almost making 70% or equivalent as a poor mark/grade, 90% as average and 99% or more as desired/required. Even the institutions were evaluated based on how many students get such high grades. Thus while it used to be difficult to get 70% or more up to 1970s, it turned out that now it is difficult to get less than 70% or equivalent grade. With far lesser effort on the part of the student, they are rated high, almost making it appear that all the students are in a small dynamic range at the top. Because of this, grades/marks can not be used for discriminating the abilities of students any more. In addition, there are too many activities focussed around internet and mobile, with no time for concentration on learning. Learning is reduced to mere acquisition of skills/data, which is provided outside the classroom without teachers, like video lectures, online courses, etc.

The decade starting with 2010, with the availability of smart phones and internet connectivity, has changed the meaning of student and studies. There is very little attention in the classes. Most lectures are reduced to mere projection of slides, with the intention of pumping the students with data. With online courses and mass learning classes, the purpose of education became giving certificates, diplomas and degrees. The focus is only on tools and their usage, which is more like a technician job. The emphasis on explaining and understanding concepts is gone, and the basic subjects are replaced with skill-oriented subjects. Throughout this evolution, instead of exploiting the technology for improving the quality of education, we seem to let the technology drive the education system. Education is viewed more from business point of view, and several business models have evolved for imparting education. There is very little learning in its true sense any more, at all levels starting from the primary level to the university level. We have almost reduced the role of a teacher to that of a facilitator/mentor, rather than that of teaching and learning.

Evolution of Research

Let us review how the concept of research is evolving over time. In 1950s, there was hardly any serious talk about research. Very few people opted to work for research degrees. The few that were doing research were doing on their own interest, without expecting any return out of it. There was also very little support for doing research. Most people were happy with a basic degree to make some living after that. In 1960s, people, especially in the teaching profession at elite institutions, were doing research mainly for professional growth. At that time, many lecturers were working for Ph.D. under the guidance of senior faculty, mainly at IISc and IITs. With very little access to computing and experimental facilities, they were able to do excellent research, as reflected in the publications in peer reviewed international journals. It is interesting to know that most of them did not know much about those journals, except by their access through libraries, usually 3 months or more after their release.

Availability of computing and experimental resources improved significantly in 1970s, leading to computer-oriented research, but still most of the research was experimental or theoretical. This was the period when money for research was being made available at some of the leading institutions through sponsored research projects, mainly from government agencies. The computer-oriented research took a big leap in 1980s, with the availability of powerful (at that time) mainframe computers at several leading institutions and laboratories in the country. In that euphoria, less of practical/experimental work was being carried out, as every one was busy doing scientific programming for research.

In 1990s, the meaning of research was getting dwarfed. As many computer-oriented gadgets being made available, and doing work with computers became easier. All problems were oriented towards computer modelling and simulation.

Also, it helped in thinking of bigger problems with large number of parameters for modelling and optimization. Setting up experimental facilities for verification of results and thinking of such problems reduced drastically. During that period, even writing abilities were also affected due to extensive use of word processing tools. Most research was aimed at collecting more data for analysis with computers.

In the decade of 2000, the experimental work in most engineering disciplines has practically vanished. Almost all laboratories were filled with computers, with prominent display of monitors and keyboards everywhere. It was almost difficult to find out to which engineering discipline a lab belonged to. Many of the research scholars did not have a feel of the values of the parameters in the real experimental facilities. On the other hand, for senior researchers, the computational facilities augmented their engineering skills acquired through experimentation. The 2000 decade also has seen the vanishing of writing skills among students completely, as most research scholars spend their time in typing and editing, as dictated by the tools such as Microsoft word and Latex.

As senior faculty, we were helplessly looking at how the students were busy spending most of their time in formatting, and tuning the figures and tables for better display of the document, but at the cost of understanding the contents of their display. Research scholars spent all the time in front of a monitor, pretending as though they were doing serious research, whereas they were only searching all the time aimlessly. Due to fast switching, they also lost the ability to focus on any topic or equation or figure. Writing papers was reduced to writing reports with casual English and poor organization of the thought process in their minds. It was also obvious that the aim was on getting more papers published. There was also proliferation of journals and conferences to meet this demand. It became a fashion/necessity that the conference deadlines decided on what to submit, and then quickly managed to write a few lines based on some simulation work. It was no more that you had ‘something to convey’ and hence wrote a paper. It has become a routine exercise to write something and submit. Some organizations also insisted on journal papers for faculty promotions. To meet this demand, many online journals came up, making a mockery of research and its reporting. With emphasis on numbers and quantity, plagiarism has crept in. Organizations proudly announce that they have acquired plagiarism detection software to check such happenings. What a tragedy we have ended up with in the domain of research.

We almost lost control on research in the decade beginning 2010. Proliferation of the so called institutions of higher learning, research universities, etc., with emphasis on number of Ph.Ds and research papers, rather than quality, working towards awards and recognition, data-oriented computer-based research. All these contributed to the confusion on the meaning of research. It appears that, instead of understanding research, and then doing it out of passion for it, it is routinely claimed that whatever any one is doing is research. Even the high school students or 1st year undergraduate students talk of doing research, without understanding the meaning of research. I hate to think of what is in store for us in the coming years.

It is unfortunate that the tremendous potential of the developments of communication and information technologies is grossly misused in teaching and research.

Otherwise, these developments should have significantly enriched our learning and creative abilities through good teaching and research, and also should have produced excellent teachers and researchers. Unfortunately, we have misused the technology, by making teaching and research as business opportunities. Many start-ups and coaching centres (most of them have no idea of education) approach us with proposals that they can help us with tools/gadgets to improve our teaching and research abilities.

Current Practices Affecting Teaching and Research

Teaching

– Absence of good teachers: Students are not getting the high dimension pattern for absorbing the concepts.
– Projecting .ppt slides: Missing or destroying the pattern information.
– Text books: Poorly written with too many distractions like unnecessary colours, worked out examples, programs and exercises.
– Worked out examples: No motivation for the student to think about a solution.
– Ready-made programs: Students do not develop the logic for solving a problem.
– Learning from examples: Not thinking about concepts and logical reasoning.
– Learning by doing: Without understanding principles.
– Too many distractions: Fast changing data, with no time to absorb the pattern, if any.
– Too much emphasis on applications without learning concepts. Too much of technology and gadgets.
– Continuous evaluation with too much focus on assignments and exams in a semester: This results in short-time remembrance, and forgetting them soon after the semester.
– Objective type questions: Working from the answer, and not solving the problem.
– Grading system with high grade points or marks: Misplaced emphasis and poor judgement of the standard of a student, thus conveying false impression of accomplishment, talent and abilities.
– Competition, rather than cooperation: Education is not a zero-sum game.
– Too many competitive exams with focus on problems and their solutions.
– Acquiring skills during school/college: This is a wrong notion, as education is meant for learning how to learn, and not how to acquire a skill. Skill development institutions are different, like polytechnics.
– Too high exceptions of salaries and positions, without really deserving.
– Too much of societal and parental pressure on the students: Education is viewed as a business opportunity, and not as a process for learning.

– Summer and winter internships: Doctors do these after their studies, whereas engineers attempt to do it during their studies, without consolidating the subjects they studied.

Research

– Searching the web: Directionless most of the time
– Misplaced emphasis on research without passion
– Misplaced emphasis on degrees
– Poor writing abilities due to typing, cut and paste process, editing tools, etc.
– Poor reading abilities due to lack of concentration, and also due to poor quality of books
– Starting (catching them) young, especially for research is wrong, as it takes time to understand what research means
– Talking about research without knowing what it is
– Whatever one does is being projected as research, instead of doing real research
– Proliferation of research universities, without any significant research in them.

Management Perspective

– Looking at education as a business opportunity, and applying management principles, like for any zero-sum game.
– Aiming at products (students) for IT (information Technology) ready, skill equipped, technology ready, etc., is not appropriate for education.
– Should technology drive education, or education drive technology?
– Generalizing from a few successful/failure cases, as often used as case studies in a business model, is not appropriate for education.
– Goal of education: Need to improve the average for the prosperity of a nation, and not aiming at excellence in some specific items and individuals.

Some Points for Good Teaching and Research

Points for Good Teaching

– Teaching refers to teaching human beings endowed with biological neural networks (BNN) for pattern processing.

- Being precise is not a virtue in teaching: Learning takes place only when there is some vagueness, as precision involves only listing of facts.
- Multimodal nature of pattern perception and learning by BNN requires that teaching should cater for it.
- Teaching is a continuous learning process.
- Learning is the ability to absorb the pattern in high dimensional space, and hence the teacher needs to create the pattern in high dimensional space.
- Learning by doing works only when the process of learning is understood.
- Reducing the problem to subproblems or the divide and conquer paradigm is not relevant most of the time in teaching, as it destroys the pattern information in the problem (as in .ppt slides).
- Difference between teaching (making the students learn the constraints and hence acquire knowledge) and coaching (involving taking students along a specified path): Compare construction of sentences naturally and those following strict rules of grammar, or compare printed characters and written characters.
- Disadvantage of continuous evaluation/grading: Likely to disrupt long term retention.
- Teaching is a prerequisite for research, as it enables creating/generating multi-modal patterns of a concept (Recall the missing art of storey telling in teaching these days).

Points for Good Research

- Research is a process and not a product: Ph.D. is a recognition for the process.
- Research has no methodology, as the underlying process is unstructured.
- Research is not only finding solutions to a problem, but ability to see the issues in the problems, and this in turn may generate more problems than solutions.
- Research is a passionate endeavour.
- Research involves, reading, writing and sharing ideas with colleagues for comments and criticism.
- Research is a cooperative effort, and not competitive. IPR (Intellectual Property Rights) issues need to be addressed in this context, and not in a commercial context.
- Research involves developing and building links among patterns, and not breaking them up.
- Research needs concentrated effort without too many distractions.
- Mere search inhibits research.
- Discipline in writing is essential, and hence the need to focus on writing for journals instead of for conferences.
- Research guide is like a coach for a game, as his/her goal is to act as a critique, and not as a promoter of the effort.

Summary, Conclusions and Recommendations

Summary

In this article I tried to explain the evolution of teaching and research over decades. In the process we may understand the meaning of the terms like coaching, training, teaching and research. Coaching refers to taking the student along the path of the solution, like taking some one to a destination by hand-holding. Obviously the student will not know how to go by himself later when the need arises. Training refers to making the student to acquire a skill, so that he can use that skill repeatedly in a job. It does not involve any creativity or learning. Teaching refers to the process of generating a multimodal and multidimensional data to convey a pattern to the listener, which he/she can easily absorb due to pattern processing ability of the human mind.

Research involves ability to create new patterns based on the patterns already acquired through learning. It is important that people understand the meaning of learning, knowledge and education. Learning involves perceiving patters in high dimensional data, and developing associations with the existing patterns in human mind. Knowledge refers to understanding the constraints from examples, so that the legal variations are captured within those constraints. Finally, education means learning how to learn, which is made possible mostly by teachers.

Conclusions

Despite the fact that over the past few decades we are continuously making changes in the education system at various levels, there is hardly any positive comment on the standards of the education system, especially in the teaching and research domains. It is fashionable to compare us and our system with systems in other countries, especially with China and USA, in terms of papers published, number of Ph.Ds, awards, percentage gross domestic product (GDP) spent on research, etc. But it is unlikely that even with increased investment to higher levels, we can make any significant progress, as it appears that we are moving in the wrong direction. In my opinion, teaching and research are local and culture-specific. Borrowing or copying other models will not work. A country's progress should be measured in terms of (a) increase in the average level of education (b) increase in number of good teachers who will make it possible, and (c) research will follow automatically. The effects of current fall in standards of teaching and research may take us to such low levels very soon, that we may reach a point of no return in about 5 to 10 years, if corrective mechanisms are not put in place now.

Recommendations

- Make classroom teaching more purposeful and interesting, rather than dispensing with classroom and student-teacher interaction. For this we definitely need more teachers.
- Emphasize writing and reading, not typing, editing and searching.
- Make an effort to teach in a way that students learn.
- Learning is an effort to understand legal variations of an idea or concept, like construction of sentences with deviations from grammar/syntax.
- Think about problems, not solutions. Write your thoughts, express them and discuss.
- Solutions to problems are always worked out in mind first, and the gadgets are useful mostly to verify those solutions in mind. Otherwise, gadgets can reduce the degrees of freedom in our thought process.
- Search only with a purpose in mind. Otherwise, searching can distract and disturb our pattern formation and hence research abilities.
- Restore the missing art of storey telling in engineering presentations and teaching over time.
- Recall great research ideas, processes and results.

Final Remarks

Currently the tremendous progress in technology and communications is being grossly misused, thus reducing our abilities to do good teaching and research. This needs to be corrected, and hence this article. Note that good teaching and research evolve with good environment and practices. They cannot be created by a procedure or a rule. I strongly believe that a country's progress should be measured in terms of number of teachers, especially good teachers, it produces, and not in terms of number of Ph.D.s, or number of papers published, or number of award winners, or number of universities, etc. This is because, each teacher can brighten the lives of 30 or more students in a class, some of them may become teachers a few years later. Note that teaching is not a zero-sum game, as in the case of business. Here there is only gain, and no loss whatsoever. This is the beauty of teaching and research.

I would like to end this writeup by recalling (in a lighter vein) my observation on how books in engineering have evolved over the past six decades since my student days. In 50s, books were written, carefully explaining the concepts clearly, with hardly any questions at the end of the chapters, at least in some good books. The idea probably was to make the readers and students think on how to make a question or how to ask a question to the teacher in a class. Thus the books in any subject also were about 300 pages or so. In 60s, many books have questions at the end of the chapters, and there were also books with mainly problems on a particular subject, like Parker Smith's "Problems in Electrical Engineering". Thus the students and teachers started looking at those problems for both exercises as well as for preparing question papers for examinations.

In 70s, books started giving not only problems at the end of chapters, but also answers to the problems. This helped the students to work towards getting the answer to the question, rather than understanding the question and attempting to solve the problem. In 80s, the books started giving worked out examples within each chapter, enabling students and teachers to focus more on those things, rather than the text part describing the concepts. The sizes of the text books also became bulky, as most books are over 600 pages or more. In 90s, books started giving programs for some problems within the text itself, making it even easier for the student to simply run the programs and look at the results. This made the students skip reading even the solutions of the problems carefully, leave alone reading the text, which habit has almost vanished among many students.

In the decade of 2000 something very significant has happened in engineering studies. Books like “All in ONE” with only problems and solutions for many subjects in each engineering branch have appeared in the market. Both students and teachers focussed mostly on these books mainly from examination point of view. This has resulted in the erosion of class room teaching of concepts completely, as the engineering education system geared up only for conducting exams and giving grades to students. It appears as though whatever the students learn is from the example problems and solutions given in such books.

At this stage in the middle of the 2010 decade, it is difficult for me to guess what is in store for engineering education by the end of this decade. From this development, I could bring an analogy of human learning vs machine learning. One of the elusive goals of scientists and engineers is to make machines learn like human beings, so that machines can be made to perform tasks similar to those by human beings. But we seem to have achieved the goal of making machines and human beings similar in their learning abilities, by making human beings also learn from examples, just as we make machines learn from examples in machine learning. Thus we made both of them nearly same by making humans do the way the machines do, rather than the other way. Can we call this as a great achievement in education over the decades?

An Engineer's Prayer to the Blue Fairy

Srinivasan Ramani

Introduction

As I write this article, I feel like a little boy in front of the blue fairy [1], asking her to grant me a few wishes. The fairy I address is human ingenuity, the collective abilities of millions of humans to innovate their way out to a better life. I would be very satisfied even if a few hundred engineers and students read these pages, and are stimulated to try to solve some of the problems discussed here. My own background ensures that I talk a bit more about Information Technology (IT) than about other matters; but, IT is not a branch of technology that works miracles in isolation. It has inter-disciplinary roles to play with almost every field of engineering and technology. IT becomes particularly valuable when it is used to solve practical problems, to make us live and work better. We need to think about IT driven changes in the socio-economic context, to derive their full benefits.

Use IT to Create More Jobs

IT and IT enabled services (ITES) have had a remarkable impact on the economy. They have really enabled Indian pioneers to put knowledge workers at the service of the global economy, creating jobs and contributing to our export earnings. It is amazing that already, IT and ITES contribute to India's Gross National Product more than the value of all the rice and wheat the country grows annually! However, the number of jobs created by IT and ITES are not big enough to answer the challenge of job creation satisfactorily. It is easy to use IT to improve productivity and/or efficiency, but it is more difficult to use it to create large numbers of new jobs. This is

S. Ramani (✉)
C-501, Mantri Pride, Near Madhavan Park, Jayanagar Block I, Bangalore 560011, India
e-mail: Ramani.srini@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_14

the major boon I ask from the blue fairy! Tell us how to create more jobs using IT or otherwise. This topic is, however, complex, and requires a separate article altogether. So, I will reluctantly move to the other boons I need to ask.

Get Rid of Car

The revolution that will lead us to the goal has already made a lot of progress, but we need to take it to completion, to derive the full benefits. A written description of the goal will help. I would like to have a virtual car as my next car. It should be available anywhere, anytime. Tap an app on my cell phone and optionally enter a destination and time of departure; I should have the driver calling me up, and turning up in a few minutes to take me where I wish to go. This solution is already there, is it not? Let us look at what is not there.

For one thing, I have not got rid of my car! It wastes parking space in my building, and in the places I visit. We have not recognized the virtual car will be a major solution to traffic problems and atmospheric pollution in the next few decades. We have not recognized that it will create employment in significant numbers. We have only grudgingly accepted it as yet another enterprise and have done nothing to promote it. We allow vested interests to try and shackle innovation so that moribund ways of providing transportation can flourish without competition. The issue is not one of administrative decisions; it is about the right visions for transportation systems of the future. Society needs to recognize that IT has made it unnecessary to have personal vehicles in most cases and should create the right policies. What are required are tax incentives to promote the use of shared vehicles, encouraging investments in companies providing shared vehicles, and support employment generation for a large number of drivers. If A invests a certain sum of money in buying a car, he gets a tax benefit on the car loan that finances the purchase. There should be a comparable tax benefit for B who invests a similar amount of money in an app-based cab company that provides him a virtual car. In fact, B should get a higher tax benefit because a virtual car does not impose the social costs a personal car imposes on the country.

The use of shared vehicles will reduce wasteful investment in vehicles, because shared vehicles are far more productive. It will also increase the productivity of drivers as it avoids drivers having to waste their time waiting for private car owners. The money required to buy a personal car is enough to build a small house for a rural family, or to create a job for someone. The efficiency of rented vehicles will make our road infrastructure vastly more productive.

Make Buses More User-Friendly

Buses have to provide for the bulk of intra-city and intra-district transport capacity. One reason car or bike ownership is preferred by those who can afford them is that buses are an unfriendly lot as they work today. The IT revolution offers solutions to make them more efficient and easy to use. The App based Taxi business shows how easy it is to display the location and movement of a vehicle on anyone's smartphone. Why can't every bus be a 'thing on the Internet'? Why can't my cell phone show me when the next bus going to Gandhi Market will reach my bus stop and whether it will have a few empty seats or not, using information picked up from a smart phone on the bus? After all, the GPS system enables cell phones to find out where they are from minute to minute. Why can't we centralize and use such information in each city, to control real-time allocation of buses to different routes to make them more responsive to demands?

A related issue is that of supporting innovation. When government monopolies run buses in cities and towns, they usually persuade regulatory agencies to prevent competing new systems being used, for instance, they get the agencies to ban shuttle services to and from airports or railway stations. The extension of app-enabled technology to vehicles carrying multiple independent customers is a necessity to improve efficiency.

Containerizing Retail Delivery

E-commerce has made it so much easier to order anything from vegetables to clothes and cameras much simpler and more efficient. The volume of goods delivered is increasing steadily. E-commerce reduces the need for going out to buy things as and when needed, as well as the need to stock up things for future use. As a result, it improves efficiency of the economy and promotes better use of resources. E-commerce ending in retail delivery of physical goods is not yet a major part of the retail sector in India, but is a rapidly growing part. A concern about this business is the fact that it consumes a lot of packing material and creates a whole lot of waste, including plastic waste. Garbage disposal is already a big problem in Indian metros and the growth of online purchases of retail goods will surely make this problem worse. There is a need for India to be pro-active and find solutions to the problems that E-commerce is creating.

One solution is to containerize retail delivery by inventing cost-effective, re-usable containers. Plastics manufacturers are already making containers for use by E-tailers to deliver perishables. However, there is no standardization of such containers in India and no significant efforts have gone into designing ideal containers for our environment. The is no regulatory requirement as yet to ensure that the E-tailing industry makes efforts to reduce the waste it creates. The problem is not merely a problem for India, but one for the world. Good solutions should preferably be globally acceptable ones. This will mean cooperation and learning from others as we finalize our designs, but it does not mean that we cannot hope to make major advances. With luck, we might even develop an export market in containers!

Making Electricity Supply More Reliable

We are at a major inflection point in terms of the production and distribution of electricity. For a variety of reasons, including political ones, we have an electric supply system that does not promote efficiency and productivity. Most Indian cities and towns do not adhere to good standards in electricity distribution. Frequent interruptions of power supply damage equipment and reduce productivity of the economy as a whole. All this ends up increasing the cost of goods produced and services created. A major advance would promote the use of distributed generation of energy to the extent possible, increasing the robustness of the overall system. A good part of distributed production could come from solar panels. Throughout the world, miscellaneous technical and economic arguments are advanced to resist such distributed energy creation. It is important that India figures out its own solutions to the problems envisaged. It is often argued that an energy production unit in customer premises could put at risk the lives of wiremen working for the centralized electricity distributor, by sending out power to a line they are repairing. Surely, Indians can install suitable technical safeguards against such risks. The cost of protection systems would easily be justified by the benefits of permitting small units to produce electricity at customer premises. India should not wait for others to develop relevant technology to make this practical. In another direction, effective use of solar energy does require good battery technology. India should make its own contributions to this field.

Incidentally, I am writing this article in Bangalore in October 2016. The power has tripped about twenty times during the writing of this article. The building's diesel generator kept coming up to meet every trip. The UPS under my table did its bit, but with all this, it was difficult to avoid repeated interruptions of my work.

A silver-lining in the cloud is the commodification of what is called the solar UPS. Such a device uses a micro-processor to control charging of a UPS battery by a solar panel when it provides power. When solar power is not available, it uses power from house wiring to charge the battery. Intelligent policy making would provide incentives for the use of such systems. They will reduce our dependence on conventional power stations and make supply of electricity to households more reliable.

Standardized Financial Reporting

If you use a credit card, or if one of your cheques is encashed, you get an email, an SMS, or both depending upon the preferences you have indicated. Every month, you also get a bank statement for every account you have. Mutual funds and other investment managers send their own periodic reports as well. At the end of the year, you hand over relevant statements to someone who first types in everything, to create an integrated picture of your income and expenditure. This is a good example of a very inefficient system in which an intelligent human being has to retype into a common format what has been received electronically in different formats. Yes, it does create a job for a human, but a tragic dead-end job, which adds no real value to the economy! You might as well pay him his salary and have him do something he enjoys doing, like learning music or bodybuilding! The tax consultant does not send you the integrated account created by him; he says that such and such software is required to open it, and that software is not meant for customer use! Therefore, you, the customer, never get to access an integrated financial record of your own.

It is not very difficult to design a computer readable format, for sending reports of financial transactions. A suitable app on a computer or on a cell phone at the customer end can display the contents in a form suitable for the end-user to examine. Software can integrate multiple reports into a complete personal record of incomes and expenditures for the year. Reports should help us understand our situation, not merely meet some legal reporting requirement! Promoting a common reporting format is the responsibility of the concerned regulatory authority. Government departments concerned with efficiency and transparency in the financial sector also carry their share of responsibility in this regard.

Satellite Based Text Messaging

There are many places in the country where cell phone connectivity is non-existent or poor, such as rural areas that do not generate attractive enough profits for cell phone companies, and hilly areas where the topology makes it difficult for cell phone company towers to cover the territory. Boats at sea are also out of contact with the cellular network once they move away from the coastline.

Some of these problems can be solved easily but are made difficult by administrative and political considerations. For instance, you might have a cell phone that works well where you live, but the company that provides the service may not support roaming in rural areas that are mostly covered by a public-sector company. So, there are places that have cell phone coverage, but where your phone does not work. This is apart from areas where no cell phone works anyway!

Because of the problems described above, one cannot depend upon the cellular network alone for providing communication in times of personal accident and in times of disaster that affect large numbers of people. Cellular communication failed whole villages and districts during floods in Himachal Pradesh a few years ago; media reported that electrical power supply was interrupted and that diesel fuel ran out in a few days in many places, and so cell towers stopped working.

I would like to ask the blue fairy—grant us a wish: we would like to have a system using communication satellites to enable affordable cellphones to send and receive at least text messages. We would like this system to work without depending upon a cellular communication tower being within a few miles of the customer location. We do not mind if the messages are routed between the satellite segment and the cellular network through ground terminals operated by cell phone companies. We do not mind if the messages are subject to legally approved monitoring by government agencies to prevent anti-social elements misusing the system. We do not mind paying reasonable extra charges for such satellite-based communication. We would like the system to support the use of scripts of all major Indian languages. Give us a system that is reliable, works everywhere and is affordable for the vast majority of users.

I will rest with these requests, my dear fairy! You, in the form of human ingenuity, have given us so much and will no doubt give a lot more in future!

Reference

1. Collodi C (1986) The adventures of Pinocchio. http://fathom.lib.uchicago.edu/2/72810000/72810000_pinocchio.pdf (The Walt Disney adaptation of this story turned the fairy in this story into the "Blue Fairy")

Grassroot Innovation, Laboratory Experiments and Modeling: Case Study of Appropriate Technology Development

A. W. Date

Introduction

Research Scientists and Engineers working in Government labs and Educational Institutions often doubt if interacting with people in the unorganised sectors such as tribal villages can provide opportunities for innovation, and, hence, refrain from such an interaction. There is ample evidence in the country that shows that such opportunities readily present themselves and successful innovations are possible. Such innovations also offer research opportunities whose successful persuites can also be presented for career advancement. Interactions with organised industry or engagements in frontier research are not necessarily the *only ways* to engage in satisfying research activity.

The author was fortunate to be presented such an opportunity by the *Bhumiputra Pratishthaan* an NGO in Thane District. The next section describes the innovation process which alerted the author to the need for carrying out systematic laboratory experiments as well as theoretical modeling for design optimisation.

The academic investigations aptly corroborated the contributions of the Tribal people to the innovation process. These contributions highlighted the need to respond to the beneficiary-concerns in a practical design because these concerns address the limit situations of the people in the unorganised sectors. Such new constraints lead to new innovations.

A. W. Date (✉)
Department of Mechanical Engineering, IIT Bombay, Powai, Mumbai 400076, India
e-mail: awdate@me.iitb.ac.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_15

The Innovation

The Setting

On a rainy day in August 1973, the author paid a visit to village Kondhaan, Taluka Manor, Dist: Thane, Maharashtra where an NGO called Bhumiputra Pratishthaan (BPP) had initiated tribal development work in 1972 in consultation with National Institute of Bank Management (NIBM). The NIBM had conceptualised *Farmer's Service Society* (FSS) to enable otherwise non-credit worthy small and marginal farmers to obtain bank loans through group loans lent to the FSS to carry out cooperative activities. The NGO, the local branch of Bank of Maharashtra (BoM) and workers of a local people's movement Bhumi Sena (BS) were the partners in the project. In order to ensure recovery of loans, procedures were jointly laid out and several economic activities were to be supported through appropriate technological interventions. The organisational strength of BS, the spirit of service of the NGO and the financial strength of BoM were considered important attributes of the partners.

One major problem faced by the tribal farmers was that of *Khavti* loans taken at exorbitant rates from money-lenders. The need for such loans arose because by end-of-July, the farmers ran out of food stocks from the previous year's harvest (about 600–800 kg/acre). As such, to carry out the hard tasks of paddy cultivation during transplanting and subsequent harvesting operations, farmers had to borrow money to buy rice from the market. In July, the prices are high and when the new crop arrives in September/October, the prices fall. As such, farmers ended up effectively making repayments at high interest rates.

In order to address this problem, NIBM proposed introduction of *Quick-Yielding Variety* (QYV) of rice invented at International Rice Research Institute (IRRI), Manila. QYVs mature in 90–100 days as against 120–135 days for middle- and late-varieties traditionally cultivated by the farmers. The introduction of QYVs would thus not only obviate the need for *Khavti* loans but will also vacate the land for leguminous or vegetable crops to be taken during the remaining 30 days of monsoon. The leguminous crops fix Nitrogen in the soil whereas cash incomes can be realised from vegetables.

The QYVs, however, have a short dormancy period (up to 72 h after harvest) and if not dried quickly after maturity, the paddy begins to germinate. Since sun-drying is not possible during the latter part of monsoon, farmers lost 30–40% of their crop through germination. It is for this reason that farmers did not opt for extensive cultivation of QYVs. The need to cultivate QYVs, however, is particularly great for small and marginal farmers. In the absence of suitable means of drying their crop, small and marginal farmers agreed to commit only a part of their (typically 2.5 acres and less) land to QYVs. If a mechanical dryer were available not only would crops be saved, but farmers would also be encouraged to take two crops from their total land.

There were 3 more reasons why farmers were reluctant to commit larger portions of their land to QYVs. These were

1. The harvested paddy was difficult to thresh using their traditional method because of its high (26%) moisture content as against about 13–16% in traditional sun-dried varieties. They did not have a mechanical thresher
2. QYVs required use of chemical fertilizers which they had never used
3. The straw of QYV plant was shorter (only about 1 ft long) than traditional variety. This, they felt, will require too much straw for thatching roofs and more closely spaced rafts and bamboo purlins will be required.

In spite of these reservations, many farmers had agreed to commit 10 Gunthas of land for QYVs. In Aug 1973, therefore, when the crops had arrived, the chief of the NGO requested the author, during his visit, for a design of a suitable Dryer after being told that the author possessed a Ph.D. in *Heat Transfer*.[1]

The Problem Statement

Work on finding an appropriate technology solution to the drying problem began at IIT Bombay in 1973. Currently, the farmers obtained about 100 kg/acre of QYVs and the total yields were 800 kg to 1000 kg/acre. The farmers live in small hamlets with populations varying between 100 and 500 and land holding varying between 25 and 100 acres. The yield of the early variety of paddy thus varied between 2 and 10 tons per hamlet. This much paddy must be dried in ten days. It was quite possible that, if farmers were satisfied with the drying technique proposed to them, they would prefer to plant greater quantities of QYV paddy. Therefore, the Dryer design must be amenable to an augmentation in its scale (to about 25–100 tons of paddy in ten days) without excessively increasing its cost and sophistication. The farmers would also be interested in using the Dryer for late varieties (which are dried in the sun and which have poor milling characteristics, in addition to incurring considerable handling loss and loss to rodent attacks in the fields) which mature in late October, to obtain greater yields after milling. All these constraints and requirements emerged through a dialogue and therefore the technical specifications for the Dryer were as follows:

1. Capacity per day: 0.5–10 tons.
2. To be simple to construct and operate by farmers themselves.
3. When the demand for the Dryer increases, the smallest-capacity unit must be amenable to an increase in the scale of operations without greater sophistication and without additional constructional and operational difficulties.
4. Since drying is a once-a-year operation the capital cost of the Dryer must by as low as possible.

[1]The author's Ph.D. work involved solution of Partial Differential Equations of mass, momentum and energy transfer in a particular situation. He had never dried anything!

Alternative Solutions

After specifying the problem in technical terms, the spectrum of drying techniques was scanned in terms of capacity/batch, drying time, area requirement, uniformity of drying, mechanical and constructional sophistication, ease of operation, possibilities of self-help in construction at operation, suitability to purpose (consumption, market or storage), known users of each technique, pressure-drop and heat-mass transfer characteristics for paddy grains, Fig. 1 shows the alternative solutions.

Figure 1a shows the solution developed by the farmer's themselves. Freshly threshed wet paddy was tied in a cloth and hung on top of the Chulas. Unfortunately, this did not result in even drying and, in fact, the paddy at the bottom got *cooked.* Therefore, the present author along with workers from the NGO assembled a direct-contact dryer (Fig. 1b) from corrugated GI sheets that were readily available with the NGO. This required continuous stirring to prevent cooking and was found to be very cumbersome although during one night of continuous work, nearly 6 bags (about 500 kg) of paddy was saved from germination.

While such impromptu solutions must be invoked in an emergency, a more reliable design must be sought. Further field work then brought to notice a solution practiced at the Agr Res Station (AGR) near Khopoli in Raigad Dist. The AGR used Infra-Red bulbs for radiation drying in a large shed on the floor of which Paddy was

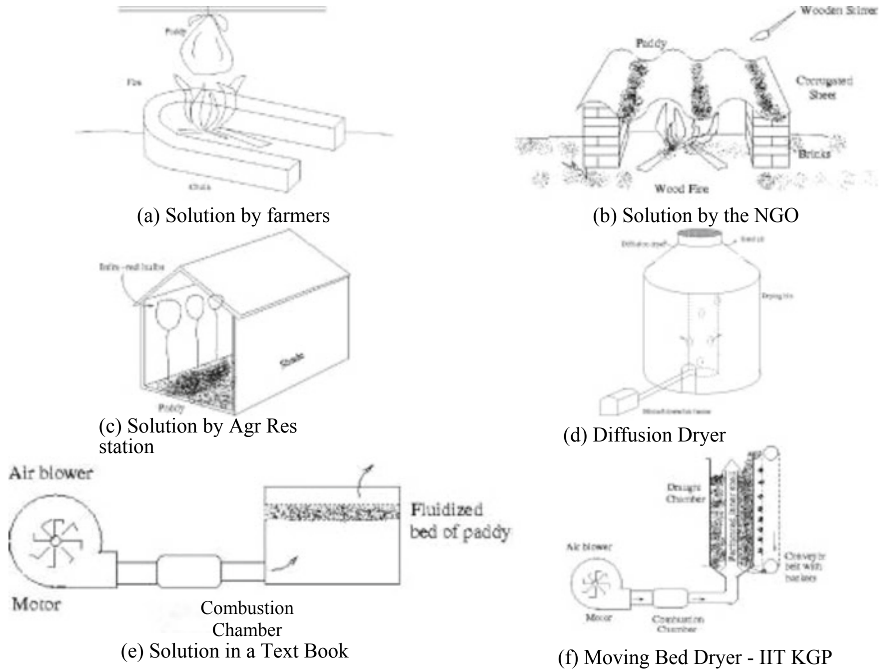


Fig. 1 Alternative drying solutions for paddy

continuously stirred (Fig. 1c). Obviously, such a solution will require a very large area.

Figure 1d shows the Diffusion Dryer routinely used on American farms. In this dryer, grains are stored in a bin and hot air infiltrates the stagnant grain mass through central perforated pipe. Diffusion drying is a slow process and therefore not suitable for rapid drying required to prevent germination of paddy. Diffusion dryers are used mainly to prevent fungal attacks during long-term storage. Library search showed that Fluidised Bed Dryer (Fig. 1e) [1] may be used. The drying rate of such dryers is of course high but the area required tends to be large for the same quantity of grains. Also, for maintaining fluidisation, large air flow rates are required. Finally, Fig. 1f shows a Moving Bed Dryer developed at IIT Kharagpur. Hot, upward flow of air is bled through a central perforated pipe closed at the top. The air penetrates a downward flow of grains which are collected at the bottom and raised to the top outside the Dryer by means of a conveyor belt. The Dryer thus requires two driving motors; one for the air blower and the other to drive the conveyor. Although, counter-current moving bed dryers achieve a fast rate of drying with minimum area, there is considerable constructional and operational complexity and cost is high for application in a tribal village.

Innovation Process

Since, none of the solutions listed above appeared to meet the requirement of rapid drying in a tribal village situation, it was decided to build on the field experience at Kondhaan. Experiments were initiated in the Mechanical Eng. Dep. of IIT Bombay.

Initially, a small quantity of grain were put in a conical hopper bin as shown in Fig. 2. A screen was inserted between the hopper-bottom and the connecting pipe to prevent grain from falling. The pipe was connected to an air blower. The intention was to stir the grain as in Fig. 1b while the air flow would bring about convection drying which will be faster than diffusion drying. To his surprise, as soon as the blower was started, the paddy grain flew into the face of the author! A colleague[2] then pointed out that it was nothing but a *spouted bed* that he had seen in USSR for combustion of coal.

This discovery of Spouting led the author to consult book on Fluidization by Leva [2]. This book, in a small half-page section on spouting, showed the principle of spouting as shown in Fig. 3 (left). Spouting is carried out in a cylindrical container with a hopper-bottom. When the air-blower is started, the upward moving air through the stagnant grain mass experiences increasing pressure drop while a spout is formed in the center of the vessel. The momentum of the air-jet penetrates further up the grain mass creating a *dilute phase* in the core while the surrounding annular *dense phase* descends due to gravity. The downward flow of grain is *entrained* in the dilute phase where it travels up the spout.

[2]Late Prof. A. Jaganmohan, Mech. Eng. Dept.

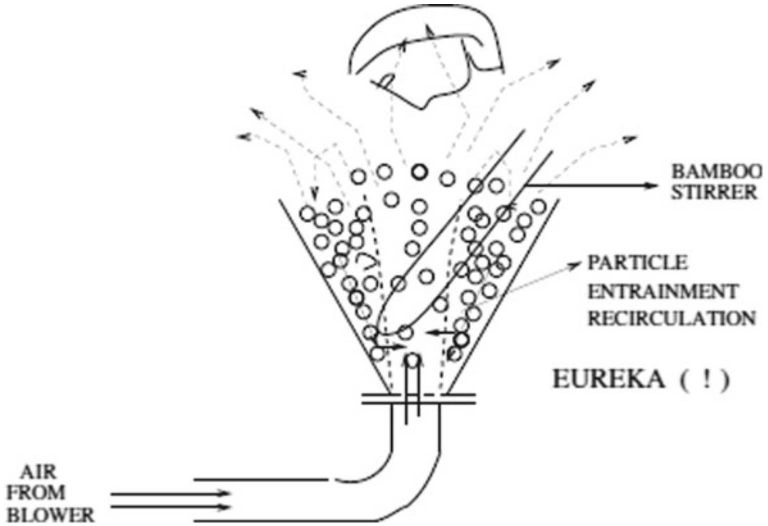


Fig. 2 Eureka!—spouting discovered

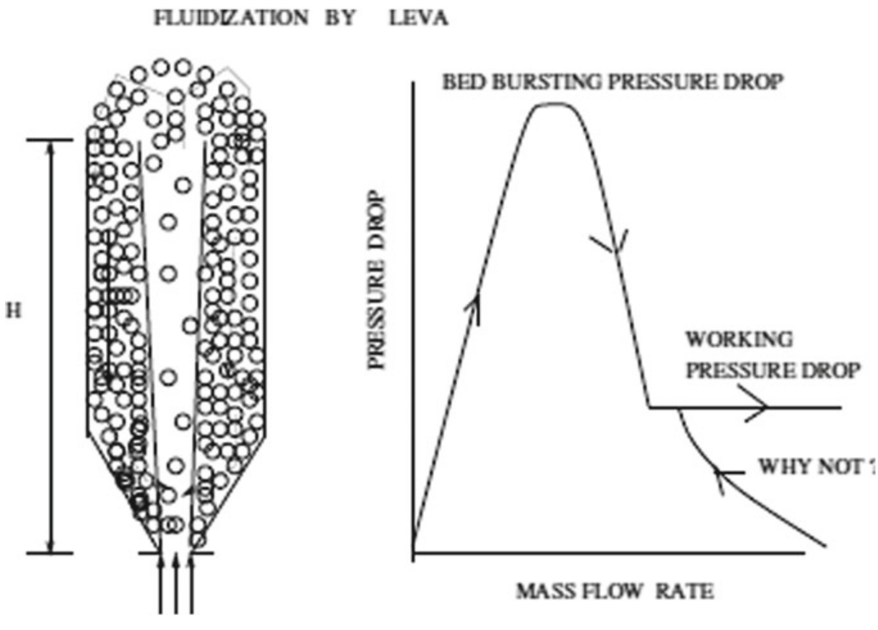


Fig. 3 Principle of spouting

Ultimately, if the air supply pressure is adequate to overcome the bed pressure-drop, the spout *ejects* out of the bed-top creating a fountain. The grains, after loosing their momentum, begin to *free-fall* back into the vessel. Thus, a grain circulation is established while the air is let off to the atmosphere.

The great advantage of this technique is that the hot-air used for drying itself brings about grain circulation and the need for a conveyor belt used in the moving bed dryer (see Fig. 1f) is obviated. Figure 3 (right) shows that till the spout penetrates the grain-bed, there is rise in pressure drop while the air mass flow rate increases. The pressure drop peaks and the value of this peak pressure drop is dictated by height H of the bed and the properties of the grain. However, after ejection through the bed, the pressure drop suddenly falls to a stable working pressure drop that hardly changes with increasing air flow rate. In practical dryers of this type, a separate compressor (a low mass flow—high pressure device) is needed to overcome the peak pressure drop whereas a blower (high mass flow—low pressure device) takes over during steady state operation [3]. Besides, the stability of spouting requires geometric precision to ensure perfect verticality of the vessel as well *as* perfect axisymmetry.

Failure to observe vertically and axi-symmetry results in collapse of spouting. This is of course not a desirable feature of Dryer used for village application.

These shortcomings of the conventional spouting bed alerted the author to look closely at Fig. 3 (right) again. It was obvious from this figure to probe the question.

Instead of raising the pressure drop to a peak value and then dropping down to a low working pressure drop, why not start with a zero pressure drop and high mass flow rate and approach the working pressure drop with a lower mass flow rate?

This question led to the a modification of the conventional spouted bed as shown in Fig. 4. In this dryer, an un-perforated draft tube (PVC) was held centrally by means of internal ring type locators. The bottom end of the tube rested on the screen between the air supply pipe and the conical hopper. The surrounding annular space is then filled with paddy to 1.2 m height (equal to 85 kg or 1 bag of rice). The air blower is started. Air experiences little pressure drop up its travel through the tube. The tube is then gradually lifted creating a space between the tube bottom and the hopper-bottom. The annular grain now entrain into the air-jet and travel up the tube. If not arrested by means of an inverted conical cap, the grains tended to fly-off. With the cap, the grains were directed downwards to fall onto the free surface of the annular grain bed. Thus, grain circulation was established. Further lift of the tube, increased the grin circulation rate further. However, after a certain lift, spouting ceased. This was because the supply pressure (about 18 cm of water) was not high enough to support spouting. An optimum lift height (h) was determined from working experience.

There were several advantages achieved in this new design. The Dryer was taken to village Damkhind (see Fig. 5 (left)) in late August- early September 1974 and QYVs cultivated by the farmers were successfully dried in monsoon conditions. The cylindrical vessel was 40 cm dia, cone angle 40°, supply pipe and draft tube had same diameter =50 mm. The air was heated in an internally baffled box which was placed above a wood-fire. 1 HP blower (eff. ~ 30%) was used. Figure 5 (middle) shows a bag of wet paddy being emptied in the dryer. Figure 5 (right) shows villagers performing the *biting test* to determine whether the paddy was dried or not. This was necessary in

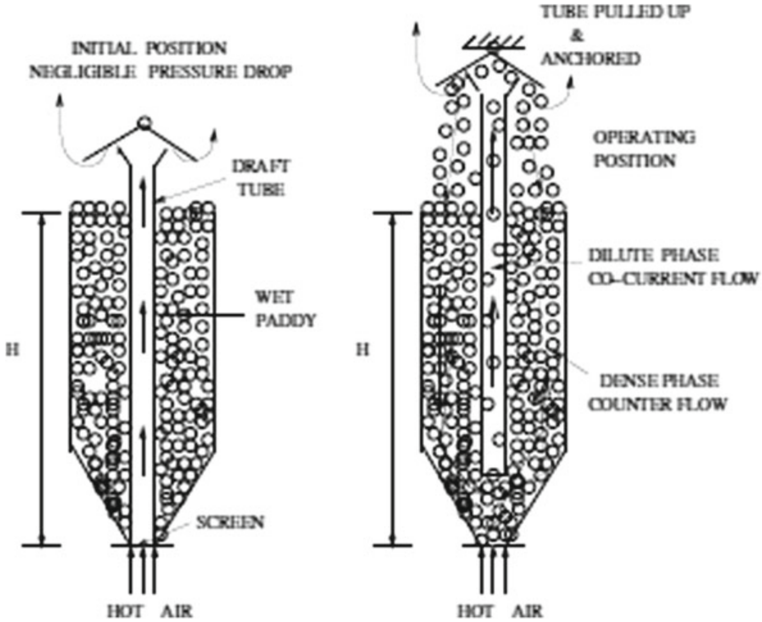


Fig. 4 Spouted bed dryer with a draft tube

Fig. 5 Dryer in use at Village Damkhind, Taluka Manor

the field conditions because there were no means to measure the moisture content of the dried paddy. Villagers experience came handy! Later, the approved dried paddy was collected in a Polythene bag and its moisture content determined in IIT Bombay. It was found to be 12.8%! (close to required 13%). 85 kg of paddy was typically dried in 2 h 30 min under monsoon conditions (or, approximately, 0.7 Tons in 24 h).

How to Scale-Up?

The villagers were satisfied with drying performance and soon queries began about scaling up issues because, in a single village, nearly 10–20 tons of paddy would have to be dried in subsequent years. Following a typical engineer's instinct, the author began to dream of a big, tall dryer.[3] However, the villager in Fig. 5 (middle) quickly intervened, drew a picture on the ground by using a stick and said:

> Do not build a big dryer. Instead make it like a *Flower*!

His suggestion is depicted in Fig. 6. The figure is self-explanatory and subsequent calculations showed that a 3.5 HP motor-blower with 6 drying bins operating in parallel will achieve drying rate of 5.4 tons/day using villager's design.

The author was hugely impressed by the villager's power of expression. It showed that not only *a* technical product was transferred to the village but, in fact, the Technology was also transferred. This distinction between technique or product and Technology[4] is of paramount importance in Appropriate Technology Development.

The villager's suggestion for a parallel-bins design stemmed from the fear that a big dryer will lead to quarrels! He, therefore, preferred a dryer in which each

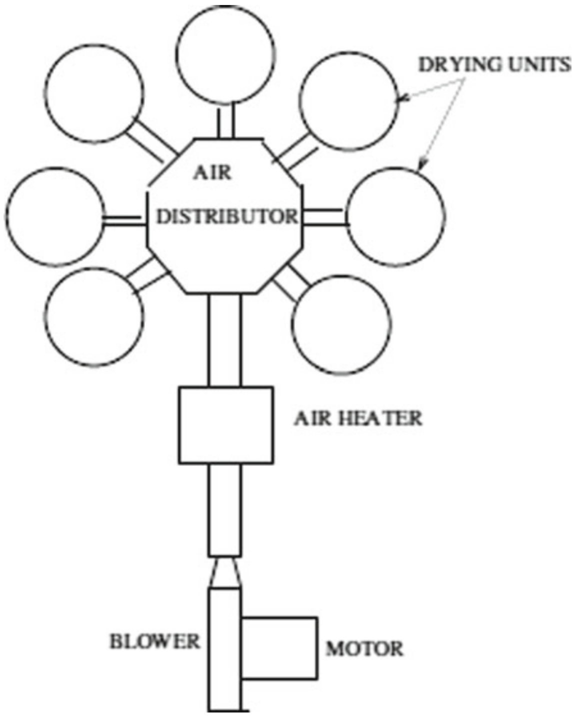


Fig. 6 *Make it like a Flower!*—People's scale-up design

[3]Such tall spouted bed dryers are used in Canada for drying wheat and peas (see, for example [4]).
[4]This author prefers to define Technology as *The Logic of Techniques*.

individual brings his bag(s) of paddy, loads it himself and takes away the dried paddy. No mixing, which will require weighing before and after drying with inevitable cheating and hence, quarrels. Besides, in a large-bin dryer, there is no guarantee that the villager will get back paddy grown on his farm. Such apprehensions are very real and it is incumbent on the engineer to respect them.

Acknowledgements The author wishes to thank the organisers of the National Symposium on BARC Technologies for Development of Rural India for inviting him to deliver a Keynote lecture on this largely unpublished work although some parts of the work have been reported in [5, 6]. The laboratory and modeling work was carried out by author's M.Tech and B.Tech students [7–10] at IIT Bombay.

References

1. Davidson JF, Harrison D (eds) (1971) Fluidization. Academic Press, London
2. Leva M (1959) Fluidization. McGraw-Hill, New York
3. Mathur KB, Epstiein N (1974) Spouted beds. Academic Press, New York
4. Mathur KB, Gischler FE (1955) A study of the application of spouted-bed technique to wheat drying. J Appl Chem 5:624
5. Date AW, Jagadish BS, Shah JN, Subbarao V (1976) Mechanisms for transfer of appropriate technology from institutes of technology to rural areas. Report submitted to the CSIR, Government of India
6. Date A (1981) Understanding appropriate technology. In: Cole S, Acero L, Rush H (eds) Methods of development planning: scenarios, models and micro-studies. UNESCO Press, Paris
7. Limaye VV (1979) Field testing of a paddy dryer. B.Tech thesis, Department of Mechanical Engineering, IIT Bombay
8. Joshi A (1985) Hydrodynamics of a modified spouted bed. B.Tech thesis, Department of Mechanical Engineering, IIT Bombay
9. Sanghvi PJ (1984) Hydrodynamics of a modified spouted bed. M.Tech thesis, Department of Mechanical Engineering, IIT Bombay
10. Talele VL (1985) Hydrodynamics and heat transfer of a modified spouted bed. M.Tech thesis, Department of Mechanical Engineering, IIT Bombay

Journey of an Engineer

A. L. Chandraker

Introduction

I had a dilemma about what to write, about self or about the engineer I am. I realized after reading "Krishnam Vande Jagatgurum"—a treatise by Late Shri Ganashyam Das Birla—that writing about self is very difficult and an awkward job. His well wishers insisted he write his autobiography and rightly so that succeeding generations get benefit from his life stories, struggles and experiences. However, he could not decide and sought an advice from late Pt Madan Mohan Malaviya who asked him to write about Lord Krishna's teachings on 'Karma' so that whole humanity can get benefit. Since the topic here is about the engineering community and to know about mind of an engineer, I decided to follow middle path by writing about my growth as an engineer in the hope that some of my experiences, knowledge and working strategies may provide guidance to the young readers.

Learning Through Childhood

I belong to a farming family with the only exception of my father who was a teacher in a government school in a village of Durg District in the new state of Chhattisgarh. My first Guru was obviously my father who had a distinction in his career in a sense that he studied up to class 4, then did 4 years of farming due to family condition and then continued remaining studies in school while maintaining top position in study. He used to solve all the questions in examination adding at the top of answer sheet, a note stating the required number of answers may be selected for evaluation. The first lesson I learnt from this is that one should be ready for any type of questions in

A. L. Chandraker (✉)
A-8/2, Bhel Colony, Opp. Loyola Degree College, Old Alwal, Hyderabad 500010, India
e-mail: Alc357@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_16

examinations and problems in life. Nothing is more or less important, all problems are to be treated with equal importance. This always helped me succeed in getting first in rank in schools and district level till higher secondary where I was placed as a rank holder in MP HSSC Board.

I studied as a resident student since Class 6 onwards till my Doctoral studies. This has helped me a lot in terms of making me independent in thinking, planning and executing various tasks and projects in life and at work. I used to read all types of books, even unconnected with the class books. While I was in Class 5, I read Sanskrit language at home and appeared for Sanskrit examination Prathama (which was taught in class 6 onward) and scored highest mark. My love and speed for reading were very good. In class 8, I was given around 50 children classic novels to be distributed to the class section students. I read first all the novels in a day then distributed to colleagues. In my school classes 8 and 9 usually were part of middle school and high school. In high school one need to choose one stream out of 3 streams: mathematics, biology and arts streams. I came to know that one can complete 2 classes in one year. After self reading physics, chemistry and mathematics of class 9 for few days, I approached to the school Principal to allow me to appear for class 8 and 9 together. However, the principal persuaded me not to do so.

Memoirs of Higher Studies

During engineering graduate study I had a typical habit of writing condensed notes for each subject, say 3–5 pages for each thick book of pages around 400 or more. The result was that I needed to spend just 15–30 min for one revision during examination whereas my colleagues used to study throughout the night. Another habit I had was not to copy or seek any help for solving home assignments. I was of belief that if any student of my class solves the assignments, then I can also do. I used to love all the subjects in engineering such as engineering economics, refrigeration, automobiles etc. So I applied for PG course on different subject to different institutes. I landed at IISc (Indian Institute of Science), Bangalore for Masters of Engineering since I was selected directly.

My postgraduate and doctoral studies were self driven with the help of library journals and reprints from abroad. My preferred subject during ME studies was turbomachinery as taught by Prof. S. Soundarnayagam. I chose Aero-acoustics topic for PhD research. My guide, Professor M. L. Munjal had wide experience on acoustics which helped me in bridging aerodynamics and acoustics. I learnt from my guide two things for the Fortran programming: first, the right hand side, say b in a statement $a = b$ must be defined before and second, one must check the program manually before punching the code; else the output from computer will be numbers but not the actual solution. The days at IISc shaped my future and made me independent, planner, task-oriented and to a certain extent a work-alcoholic.

Initial Moulding at the Job

My first job which lasted till retirement was at Corporate R&D Division of BHEL where I joined as Senior Engineer in July 1978 and retired as Executive Director & Head of the unit in April 2009. This 31 years of service was very fruitful, challenging and rewarding too.

The first thing after joining, I decided was to align myself with Turbo-machinery field in fluid mechanics area (known now as Computational Fluid Dynamics) rather extending my PhD work. BHEL is primarily a turbo-machinery company dealing with steam, hydro and gas turbines, compressors, fans and blowers besides other power plant components like boilers, ESP, generators and motors. There are no machines or components designed here where fluid does not flow through.

Fluid mechanics computing has been a tough job for a Mechanical engineers in those years and every mechanical engineer preferred working on Stress Analysis rather than Fluid Mechanics. So for this reason I preferred turbo-machinery flow analysis as my career in spite of advice from well wishers. Fluid mechanics is the study of non-linear field with difficulty in convergence and stability during iterations. My strength was Fortran programming and knowledge of various numerical techniques which prepared me well for this field.

Finite Element Method (FEM) in the 1980s was the most popular and a developed technique for stress analysis and loss-less fluid flow (Laplace and Elliptical Flows). However I preferred not to use the standard code of FEM since it made me feel enslaved to the code. I wasn't in favour of applying standard code for routine work hence decided to learn FEM from scratch and develop my own programming codes. Hence 6 months after joining, I took up a project based on FEM for analysis of pipe flow. I set a target for myself to complete FEM learning and code development and then apply and validate for flows through a pipe. Incidentally, BHEL R&D has been a great institution for giving engineers space and freedom to work independently on any topic related to BHEL products. During the course of my work I also picked up FEM through lectures of Prof. G. C. Nayak (Univ of Roorkee), who had worked under Prof O. C. Zienkowitcz, the main initiator of FEM. This interaction helped me to write FEM based codes. I have a good flair even now for writing Fortran based computer programs. I wrote various FEM based codes such as CASFLO (for blade-to-blade cascade flow analysis, assuming Laplacian field), 2D-FEM (FEM code for 2-dimensional Laplace Field), 3D-FEM (FEM code for 3-dimensional Laplace field such as 3d bend) for internal use.

I realized the need to extend finite element concept to finite difference method FDM so that surface curvature can be accounted. I wrote and applied 9-node Lagrangian element instead of usual differencing schemes. This way I developed a code GENFIND (Generalized Finite Difference Scheme) and applied to curved 2-dimensional field such as meridional space of hydro turbine impeller.

Blade Design as an Art

Blades are the most important components in power plants. It is like what a heart is in a human body. So my interest expanded from duct passage to steam turbine blades. Flow through them is no more Laplacian. One needs to solve Navier Stokes equations which is very challenging thing for CFD engineers. One needed to know new technique FVM (Finite Volume Method) based on time marching method. I put a lot of struggle (say 1000 h continuously) to develop 2d-TMM (two dimensional time marching method based code for flow through 2D blade-to-blade cascade assuming Eulerian field), ensuring stability of differencing scheme and convergence of solution. Many a time I lost hope. Around the same time I was invited as a visiting fellow to Whittle Laboratory, University of Cambridge. There I worked with John Denton, Director of Whittle Laboratory and original writer of FVM for cascade flows. The visit and interaction benefited me a lot. My code finally worked to a good extent provided initial guess of field is good one.

Next logical step after cascade analysis was blade design which is kept confidential by turbine manufacturers worldwide and a company need to pay millions of dollars for collaboration. The blade profiles need to be purchased for case to case basis as they are all patented ones. I decided to work on design of indigenous blades for various conditions (such as Mach Number, inlet/exit angles, solidity and so on) for turbines covering both impulse and reaction ones and blades of various shapes such as cylindrical, tapered, twisted etc. This work spanned over one and half decades since it was enormous and needed to be tested theoretically and experimentally in both subsonic and transonic cascade tunnels. It finally needed to be patented to protect it.

I took as a first task to design LP (low pressure) bladings which are long, twisted and made of many 2-dimensional cascade profiles stacked over the blade height. I started to work from scratch, debugging available blade profiles, scanning through blade related literature. It involved working on drawing board then on autocad (which was just getting introduced) and at the end getting various profile shapes. Now each profile shape was needed to be smoothened (else losses due to profile surface unevenness would outgrow other kind of losses). This pushed me to write a code on Bezier Curve (Code BEZIER) to ensure continuity of surface co-ordinates and slope, through Bezier knots. The profile shapes are to be corrected by curve fitting through BEZIER program. Once Bezier fitted profile is designed it needed to be evaluated aerodynamically for loss estimation through standard time marching code or CFD (Computational Fluid Dynamics) code for number of times to cover a range of operation (such as flows and cascade solidity). The work was repeated to design a number of suitable profiles which can be stacked over the height to make one 3D twisted blade. After long and hard work I was successful in designing a suitable twisted blade and visualize on a computer screen. The work was considered so important that it was chosen to be a front page cover on special issue commemorating a decade of Corporate R&D activities.

Aiming at Innovation

I realized that the recognition of self and Company occurs by international patents. So I decided to design various kind of blade profiles and file for patents. A couple of years went into consolidating my work of a decade. In all I as a single innovator and BHEL as a company was granted five US patents on cylindrical subsonic and transonic blade profiles, LP blade and Francis hydro turbine.

The patenting activities gave me confidence and we further decided to design, manufacture and test 8 MW high speed impulse turbine with drum type rotor. I took this work as project leader with a team of more than 20 engineers. It took almost 30 man-years since work involved a range of technical activities such as blade design and analysis by a number of codes including CFD codes, stress analysis, rotor dynamics, bearing design, gear box selection, manufacturing of blade, casting of casing and exhaust hood, forging of rotor, testing of cascade at R&D and NAL in Bangalore. Finally it became a success after getting the turbine manufactured by our sister unit at Ramchandrapuram, Hyderabad and successfully testing at compressor test rig. This work led OEM (Original Equipment Manufacture) feeling for our work. It did not involve any collaboration even with existing foreign collaborators. The work was filed for an Indian Patent.

Toward Excellence

After reaching to maturity and lot of experience through two decades at Corporate at R&D, I decided to put a proposal for creation of Centre of Excellence for Computational Fluid Dynamics (COE-CFD). Since all the power plant components at BHEL units need CFD modelling and study for performance upgradation I felt a necessity for a grand infrastructure involving a new building, procurement and establishing most of the reputed CFD software, computer hardware nodes to work and remote networking with units (Bhopal, Trichy, Hyderabad, Hardwar, Ranipet etc.) so that each unit can log their jobs from own place. The dream came true in about 18 months and COE became functional. Initially a group of dozen engineers got trained in simulation of CFD through Boiler, ESP, Generator, Pump, hydro-turbines and Steam turbines among others. Later on each unit was encouraged to get trained here and work for their units.

The importance of the centre was recognized by the publication of the building and CFD work on cover page of a special issue on Corporate R&D activities. To commemorate CFD activities, two national conferences were arranged where delegates from many industries, National Labs and Educational Institutions participated.

Time for Governance and Retirement

In Nov 2008, I was designated as unit head (Group General Manager, then Executive Director) to look after R&D unit. The unit had many disciplines such as Mechanical, Electrical, Electro-Magnetic & Chemical departments, Solar & Photo Voltaic groups, Cryogenic & Superconducting Generators department and Robotics cells among others. I advised the new engineering recruits to work and only work because it is not only good for the company but also for them to carry forward in life whether at R&D or outside. Publications and patents are real evaluators and should be the motto. I retired with satisfaction on 24 April 2009 after completing my tenure.

Ultimate Satisfaction

In the year 2009, a little known but smart and ambitious company MAXWATT Turbines Pvt Ltd at Bangalore was trying to expand its product range and acceptability as industrial turbine manufacturer in India and abroad. It had no collaboration for blade design which was it's weak point. The management approached me to strengthen steam flow paths and blading design activities in the company. This work involved identifying, implementing and making user friendly software for steam flow design besides creating database of appropriate blade profiles and train their engineers. I joined as a consultant (designated as Vice-President, R&D) in Nov 2009 which I am continuing till this writing.

I found this company as high risk taking and challenging one since the turbine product range they were handling were exhaustive. It was competing with reputed manufacturers in Condensing turbine with and without bleed and/or extraction, Back Pressure turbine with and without bleed and/or extraction for power generation and supply to industries. Each turbine is usually unique and designed as per order. The blades are critical to achieve efficiency and to fulfill customer order. Another aspect of this company is the delivery time mostly limited to 6 months. So the design needed to be fast and reliable.

I took this as an opportunity to prove my knowledge in the field which are usually not possible at companies where only collaboration based designed blades were to be used. Here this company was willing to take commercial risk by using my yet to be fully proven blade knowledge as the other option available to them was to go for collaboration which was cost prohibitive.

At the end, both myself and the company got benefitted. Company became OEM on blades and my blades got manufactured and field tested which gave me tremendous satisfaction.

We designed steam flow paths and their bladings for large number of turbines catering various specifications which were unimaginable to me. Many these turbines were supplied to countries like Korea, Kenya, Ukraine, Russia, Japan, Mexico and Bangladesh.

Conclusion

This phase of my life, perhaps was the test and recognition of my knowledge. It gave me ultimate satisfaction in the sense that turbines and blades designed and processed by me helped the mankind. My knowledge did not vanish without practical use which every engineer wishes at the end. I feel I lived my technical life with contentment and happiness because my work is physically visible in many sites in India and abroad, generating continuous power for industries for years to come.

The remarks referred in this memoir are purely my views only, they need not reflect the views of the companies mentioned herein where I served over 31 years.

Challenges in My Journey Towards Achievements

J. Krishnan

Early Life, Education

Born in a middle-class family among seven children, challenge was to finish studies, get a job and extend financial support to my father. My dad's vision was very clear: he wanted me to Graduate in Engineering, end up with a Ph.D. and proceed abroad. Schooling and pre-university education proceeded without any hassles. Engineering education was financially a very tough thing.

To get into IIT I had to face a very heavy competition; every aspirant almost got into some coaching class; professional coaching involved heavy finance, the class schedules often clashed with the school final exams, and it was not an easy job to focus on both, with equal attention. On the other hand, I had to focus on admission programme of University of Madras—covering 8 colleges in the State. I got a late admission to one of the colleges. Here, started my journey for becoming an engineer; long cherished dream of mine and of my father; for the first time, away from home and alone; started slowly getting accustomed to things, met different types of students, took some time to understand the system/type of living over there, spotted an opportunity for me to get a merit-cum-means scholarship, which I could get and that took me smoothly through the five-year B.E.-Honours programme. For the Honours programme two extra subjects need to be studied and minimum 70% aggregate marks to be scored. Immediately after the final semester exams started preparations for the BARC Training school selection programme; a threshold to a professional career.

> In the middle of difficulty lies opportunity. Albert Einstein

J. Krishnan (✉)
M. S. University, Vadodara, Gujarat 390001, India
e-mail: j.krishnan23@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_17

Beginning of Journey

With only a bachelor's degree I started my journey, entered BARC, only to be of financial support to my father. The desire for higher education is constantly there inside me. Entry into BARC was after a temporary defeat for me. Napoleon Hill quoted "opportunity often comes disguised in the form of misfortune or temporary defeat." I have always liked R&D, specifically in engineering. Little did I know that entering BARC would provide me a platform for my higher studies, viz; M.Tech. and Ph.D. Twelve full years rolled by—marked by marriage, fatherhood and promotions in office, but my yearning was for higher education. On one fine morning, my Head of Dept. asked me if I had interest in pursuing M.Tech. With delight, I said yes, and the procedure started; again, I had a temporary defeat with respect to admission but it was resolved due to intense efforts of Head and soon I was into the M.Tech. programme. After a gap of Twelve years I faced difficulties in the classroom, but my inner fire for a Ph.D. degree kept me moving. Changed over from my regular M.Tech. programme into one by research and gained lot of ground in that. Thus, converted a challenge into an opportunity. On successful completion of M.Tech., my Head of Dept. was again after me to go for my Ph.D. with a demand that it should be completed within three years—a challenge in disguise. Encouraged by my M.Tech. experience I readily accepted this. During this subsequent period of a decade and half I deeply rooted myself in the domain of welding, rather solid state welding, less explored area in the country.

> A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty. Winston S. Churchill

Before joining the Ph.D. programme another disguised opportunity came my way, viz; visit to Iraq on an official assignment of teaching welding, to the Iraqi Atomic Energy Department. What an opportunity to go deeper into welding! Little did I foresee this was a precursor to my future assignment about two decades away.

After the assignment was over, came back to India vigorously started the Ph.D. course work. Remembering this would be the final classroom interactions with conviction and hard work pushed through successfully and settled for the experimental work. The permissions for carrying out experiments in the Defence labs were there and full-fledged experiments were started. Perseverance did pay. Thanks to the research environment in BARC. The expected results were there and the thesis could be compiled and submitted. Lifetime ambition of a Ph.D. degree was realized.

> Spend eighty percent of your time focusing on the opportunities of tomorrow rather than the problems of yesterday. Brian Tracy

Sensing the final decade of my career, i.e., prior to retirement, persevered for fulfilling my ambitions: developed techniques in welding for control of distortion, assured quality and improvising manufacturing cycle time, developing technology and infrastructure, developing a range of dissimilar metal joints for various critical applications, innovations in in-house heat treatment and constantly on the lookout for newer techniques.

Acquired expertise in the following: Diffusion Bonding of dissimilar metals, Distortion control in Heavy Welded Structures, Vacuum diffusion brazing, Electron Beam Welding, Friction welding. Also, developed skills in the following: Taught Material Science to training school Mech. Engg. Trainees, Delivered lectures to ISNT-level 2 participants, Basic Course for ASNT level III. Organized welding course (Basic and Advanced) in CDM to BARC participants. Guiding Ph.D., M.Tech. and B.E. project work done in CDM, BARC Professor HBNI, BARC. Course co-coordinator—INS, Industrial Courses: Welding NDT and structural integrity—2005 and 2006. Examiner: M. Tech. and Ph.D. in IIT, Powai, Referee for welding project under BRNS, BARC. As a result of all these activities, I was shortlisted for Technical Excellency Award—an award of highest order in BARC—met with temporary defeat—I was not the final awardee.

> I will prepare and some day my chance will come. Abraham Lincoln

But these were disguised opportunities: the innovative idea in Heat Treatment brought for me the Prime Minister's Shram award. This was won for the first and only time in the history of the division (CDM) in BARC. Two of the dissimilar metal joints attracted lot of importance, national and international. One of them was awarded a Patent and the crown of all this was election to the INAE—my lifetime ambition.

More was to follow: within days of retirement got an invitation from a leading company in Mumbai to work on welding related problems in nuclear field. After a period of three years I was selected and offered a dream job, i.e. Chair-Professor in the MS University. There was a precursor to this almost two decades ago.

My Journey Continues

We are all faced with a series of great opportunities, brilliantly disguised as insoluble problems.

> Each problem has hidden in it an opportunity so powerful that it literally dwarfs the problem. The greatest success stories were created by people who recognized a problem a turned it into an opportunity. Joseph Sugarman

Nurturing Professionalism

Anant V. Patki

Introduction

My generation has witnessed enormous changes around it in almost every field: vehicles, travel time, communication, entertainment, healthcare, consumer goods, housing and so on. I feel proud that I had the privilege to contribute a tiny part of that. Engineering is a vast endeavour today, encompassing every walk of human activity. Looking back, I feel happy to share a few things from my fifty years of association with engineering. Many great personalities steered my course on this journey. Great indeed, not because they influence many, but because they visualize, plan, think, act, and lead, and always think of the society before everything else. Unfolding the journey not only helped one in introspection but also to share thought on what I consider are the traits that a good engineer should have at the back of his mind to guide him through his professional journey. In a way, some past events will come forth, some views, though personal, can be shared, some take-away and reflections that can make us think further.

Ignition

'Engineers are like Brahma, The Creator. They create things that did not exist before'- one of my favourite professors used to tell us when I was studying engineering. I vividly remember him telling this very often, with full conviction. Coming from a typical middle class family with semi-urban background, I thought I had studied enough and started looking for a suitable job after my graduation. We visited a few factories as part of our graduation program. Those jobs didn't impress me.

A. V. Patki (✉)
Flat No. NB 2/202, Dahanukar Regency, Plot No.1, Dahanukar Colony, Kothrud, Pune 411029, India
e-mail: Patki.anant@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_18

Became they involved supervising workers, fighting with union leaders, running after production schedules and repetitive assignments. Not much scope for creativity, I thought. Back in the college, I asked my professor, where do I find that kind of environment. ‘Go for higher studies, get into R&D’ was the prompt advice. I took that seriously, and decided to pursue post-graduation studies. There was news about boosting up the defence expenditure and the R&D budget. An Indigenous fighter aircraft (HF 24) project was undertaken at HAL on war footing. HAL itself was a creation of Walchand Seth. The Walchand College of Engineering, Sangli, where I was studying was a result of his foresight. And the Walchandnagar Industry, which I visited on our industrial tour, was established by him. Moving from sugar plant they started making sugar plant machinery and boilers, reaching all over India. Later in my life, I had an occasion to visit that plant again to witness our thick rocket case being rolled. Sethji’s foresight in acquiring such a huge land (the longest airstrip in India, until recently, was the one inside this factory) and setting up an aero factory when the world war was still on, still fascinates me. Taking right inspiration from that, I joined IISc for further studies in the Department of Aeronautics (now known as department of aerospace) in August 1965. That was the first major turning point in my life.

Focusing

The aero course was quite stimulating. Well learned faculty, good laboratories, many experimental project going around, weekly seminars and impressive inter departmental activities. What impressed me the most was art of analytical treatment of many engineering problems to the extent they appeared deceptively simple. This training of visualising the key phenomena helped me a lot later when dealing with complex problems. I owe this vision to Prof. C. V. Joga Rao and Prof. A. K. Rao. Soon, with our newly acquired wisdom, my fight sorties with Prof Damania, one month’s summer training at wind tunnel at NAL and two month’s industrial training at HAL, I was raring to get into aero-arena. The sixties were full of hopes for aeronautics in India. The 1962 war followed by 1965 debacle forced government to fund many new activities supersonic wind-tunnel at NAL, MIG project at HAL, Air force wanting a better strike power, IIT’s starting the aero course. Luckily, computers and IT industry was yet to appear on scene and the aero students those days were looking for opportunities in aero industry itself. However, the main beneficiary, from the point of view of getting the aero manpower, was the United State of America. Because President Kennedy had promised ‘Man on Moon’, before the end of the decade thereby pushing The Apollo programme to the top gear, resulting in flooding of grants at many US universities. So, the scholarships were easy to come for aero students, and many of my batch mates vanished. I decided to continue, and never regretted that, till today. Then came the second turning point in my life.

Fine-Tuning

Dr. Homi Bhabha died in Air India air crash of Boeing 707 in January 1966. He was the chairman of the Atomic Energy Commission, and the Secretary to the Department. Being a physicist, he had established a small rocket launching station, TERLS, at Thumba, near Thiruvananthapuram with international cooperation, for the purpose of space physics. Under UN agreements, sounding rockets for these missions were coming from USSR, France and USA. Dr. Vikram Sarabhai accepted to take over and became the new chairman of the Atomic Energy Commission. Both Dr. Bhabha and Dr. Sarabhai had worked at IISc with Sir C V Raman in the early forties. So, the student community at IISc was watching these developments with keen interest. I was deeply impressed by Dr. Sarabhai's declaration, soon after taking over, regarding establishing a research centre to develop indigenous rockets, and use the technology for Indian masses. The world had just then seen the marvel of satellite TV transmission, live relay of 1964 Olympics from Tokyo to US via a geostationary satellite Syncom 3. a miracle indeed, for many people at that time, in terms of technology, watching the 100-m sprint real time, taking place on the other side of the globe and to see result even before it was announced. I decided and in spite of stiff opposition from my parents, moved to Thiruvananthapuram to join ISRO.

Dr. Sarabhai had accepted the offer on his own term. He was a man with exceptional ability. Coming from a business community with lot of family heritage, it is rare to have interest in fundamental science. He simultaneously worked on chemicals, pharma, textiles, management, atomic energy and space physics. Noble at heart, his interest also extended to art and culture. Dr. Sarabhai picked a few key experts with some related experience to accelerate his plan. One of them, who left lasting impression on me, was Dr. Vasant Gowarikar. Expert in his own field of polymer chemistry, with decade of experience at UK, he soon built an all-round team and developed the powerful solid fuel that a good rocket programme needs. The successful PLSV, going all the away to Moon and Mars, uses this fuel and all chemicals needed for the stages developed using indigenous technology. He was an excellent team builder, and had admirable ability to judge and motivate people. He was a very assuring person, full of confidence and human touch. He taught people to take pride in what they do. Watching and following him was a kind of internship for me to migrate to technology management. Funding was no problem, neither then nor now, though one had to make a good case for that. Dr. Sarabhai shielded the new organization from bureaucratic processes and delay. Many call Sarabhai a visionary. I feel he was more than that. He knew how to convert the dreams into reality with clear goal setting, freedom of approach, intense interactions, transparency and data sharing, clear division of work, regular reviews and mid-course corrections, analysing failures, ownership of responsibility, personal touch with the team mates, external support in key areas, involvement of related R&D groups/academics, he, in effect, laid a solid foundation for the road ahead and success of ISRO's missions. To me, these were lessons in management, key to achieve something as a team. There were many broad and subtle aspects to learn and practice, and I tried them to the best of my capacity.

ISRO was full of opportunities. Not many engineers are fortunate to find a job which meets their aspirations. I wanted creative assignments and opportunities to master the engineering that was provided by indigenous rocket programme, launcher for India's first satellite launch vehicle SLV, Rohoni Satellite for SLV, Aryabhata-India's first Satellite putting India on world-space map, a dozen imaging satellites for resource mapping, planning and monitoring, another dozen for metrology- gathering 24 × 7 weather data over large sub continental region including oceans, communication satellites for domestic and international use, and satellites providing hundreds of TV channels. Working on so many projects for the nation was a very satisfying feeling indeed. In the process, I was a gainer too, promotions, international travel, awards, rewards, fellowships, recognitions, status and respect. And also, the Newtonian realization, that what I have studied and acquired was a pebble in this ocean of technology. Continuous learning is essential when you wants to reach the state of art technology. Broader understanding of allied fields also becomes a prerequisite. At a higher level of engineering and technology one can't be far from basic sciences. With this realization, I spent some time at IITB and IISc as a visiting professor. It was great help to update my engineering and narrow the technology gaps that get generated with time. Interaction with faculty from different domains who work in frontier areas was very gratifying experience indeed.

Sharing the Lessons

My career of fifty years brought me in contact with a variety of people attached to different groups, suppliers, sub-contractors, fabrication agencies, R&D institutions, academics, students, user departments, government agencies. Many of them were not as lucky as me, to get a dream assignment. As a matter of fact, most of them were not looking for one. For bulk of them it was just a job and not a career. Actually, engineers are quite high on the social ladder in our country. but a good job essentially means a good package for them, a tool to meet their ever-growing needs. For an overgrown country, the majority of learned people turning into self centric lot, showing no concern, for the rest of the society, is a serious cause of concern. Further, even when a job is not to one liking, one needs to take pride in doing that. Even in routine jobs, one notice lack of honesty, commitment, ownership and absence of professionalism. Society would suffer seriously if this situation continues. This lack of value system needs to be amended.

The Second Innings

Post retirement, I got into an IT major, to boost their ITES. That was the third turning point in my life. Moving from a protected environment to a corporate sector was a real challenge. Relatively young and inexperienced team, high attrition and movements, ever growing business targets, demanding customers, deadlines with penalty clauses, no R&D were tests of my adaptability and effectiveness, notwithstanding my technical standing and engineering skills. But, my earlier learning and not-tested skills surfaced to the brink. My second innings was also satisfying,- developing teams to do engineering on screen, working on hundreds of short term projects with minimum resources, dealing with 60 odd overseas customers, developing new areas of expertise in tune with the market, pushing the business and the resources to over five times in six years. This success was also reflected in my personal balance sheet as well. A glaring reflection on a society, where lucky ones, working with relatively low technology are much better off financially, while serious research workers have to struggle throughout their lives. Nevertheless, there is lot to learn for the older and traditional sectors from this new wave corporates. There are several practices that contribute to the productivity and efficiency such as trimmed manpower, less paper work, quick decision process, no frills or subsidies, less leaves, use of cell phone, e-mails, computers, and video-conferencing, networking and information base, less travel, less meetings, cost consciousness, eye on return on investment, quick filling the resource gaps, mechanism for fixing the responsibility and speedy court marshals.

Conclusion

And the Take Away

Now in the third innings there no races are to be run, no proving yourself, no working for money. It is time to think and share what one learned and practiced. People often used to ask us, after our Satellite launches and Vehicle flights, 'how far we are from US or Russia in the race'? Dr. Sarabhai would have disliked the question, I guess. He was not for race. He wanted us to do what the country needs. While doing so, we were often handicapped on many fronts due to by lack of technology and quality products was available in India. For hundreds of items, starting from simple rivets onwards, we had to run to get import licences and foreign exchange. The liberalisation has done away with these procedures now, but the status of engineering goods has not changed much. Indian industry is unable to take advantage of the enormously growing consumer market. In fact, the goods produced here have to compete with international products now. So, with the protection gone, customer—the importing. We import aircraft, warships, fighter jets, gliders, guns, medical equipment, instruments and simple looking spectacle glass. We also import food items, clothes and toys such as balloons and tops. The bulk of industry is happy getting into 'licence production' of international brands. The so called ‘big domestic market’ has fallen for foreign brands and goods. In the absence of strong liability laws, the majority of industry does not produce quality products. Lack of good R&D pushes even a good product out of market in competition. Products are no longer domain specific now. Importance of multidisciplinary research is not realised. Modernization and up gradation in terms of materials, instrumentation, automation are needed. The goods sold in the days of captive market now need to be tuned to the ‘voice of customer’ in terms of improved performance and standards. All this may sound tough, but it is a matter of survival if not a matter of national pride.

Journey of a Teacher-Engineer

Ashok Jhunjhunwala

Introduction

I came back to India in 1981 and joined IIT Madras as a faculty member. I wanted a telephone for my home. I had to wait for eight years in a waiting-list to get the telephone. I went to purchase a two-wheeler, a Bajaj Chetak Scooter, and paid for it; only to be told that I have been put in a queue and may have to wait for three to four years. I went to book an LPG gas cylinder for cooking; by then, I was prepared for a waiting list. When I asked the clerk at the booking counter to register for the wait-list, the old man told me, while entering my name and address, that I was unlikely to get it in my life-time, but I should still put the name as my children would benefit.

My engineer mind was perplexed—why had we got it so wrong in India. Why could we not change? I had spent six years in USA. I had not found the people there much wiser or more intelligent or more hard-working. What was wrong with us? What would be the role of an engineer in driving change?

The Beginnings

I soon found out that there was no academia-industry interaction, and entrepreneurs coming out of an educational institute were unheard of. Industry had very little R&D of its own and preferred to manufacture for a protected market by importing technology and know-how. Most goods were affordable only to a small section of the society.

It took me several years of struggle and experience to discover the possible answers. I came to a peculiar conclusion that at times businesses and policy-makers

A. Jhunjhunwala (✉)
Department of Electrical Engineering, IIT Madras, ESB 331A, II, TeNet Office, Chennai 600036, India
e-mail: ashok@tenet.res.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_19

face constraints when driving certain services to scale. This is especially so when a society imports technologies and products required to provide the service from an economy which has much higher purchasing capability. The products would have been designed to be affordable in that higher-income economy but not affordable for a low-affordability economy. Businesses and Policies, which would have otherwise driven the services based on these products to scale, fail to do so. If the affordability gap is large, a quantum reduction in the cost of the product is required. Such quantum reduction requires disruptive innovation and when it succeeds, it makes the technology and the product different from the original.

This learning did not come quickly, but happened step by step, while I was experimenting, doing wrong things, failing but persisting.

My First Learnings

My first learning in this direction came from the usage of lab-equipment for teaching at IITM. When I taught at Washington State University, a class of 50 students will have 25 (if not 50) lab kits, and the students will work in pairs (and sometime on their own) to carry out the experiments and learn. At IIT, these lab kits were imported or used imported technology, even when manufactured in India. They were quite expensive in the Indian context. So, while teaching a class of 50 even at a much-better funded IIT, only one or two experimental set-ups were available. Either the students worked in turn (each spending too little a time) or they would just watch a demonstration. I recognized that this would severely constrain learning. I wondered why these experimental set-ups and kits could not be redesigned to have much lower cost, so that 25 sets could be purchased by IITM. I took up this challenge and the first of the several kits that we designed (Fibre Optic Educator) and commercialised reached most of the 4000 engineering colleges across India and millions of students and faculty were educated using these. Since then, I have participated in designing several other lab-kits.

One of the most gratifying experiences was when I was called by the Secretary Higher education of Gujarat to a workshop for engineering teachers in January 2015. As some urgent work kept the Secretary away, I landed amongst these teachers all by myself and started interacting informally. I was surprised that most seem to know of me. When I asked how they knew me, the answer came—we learned our fibre-optics using your kit. I had even forgotten about this kit by then.

Economy of Shortages

I soon recognized that this problem was not confined to education alone. Most of the products were manufactured using licensed technologies from developed nations, and were affordable to only a small section of Indian society. Industry could therefore never scale. Services provided were limited to a few and the nation lived with shortages. I recognized that products and services have to be redeveloped at price-points affordable to a larger section of Indian public. This process required transformation in products and technology. I also recognized that this could not be done by Industry alone and a strong academia-industry collaboration was required.

I started making efforts to work with the industry. I used to ask them how much would that imported equipment cost? I would ask them to give me the money that would buy them one such equipment and I would not only develop the equipment, but also transfer the technology to them. Trusting me, the Chairman of an industry gave me ₹100,000 to build a Power Line Communication Equipment. We jumped into it with an army of B.Tech. students. I had never built anything before but we learned. One of the senior persons from industry helped us. It took us a year and we built the first equipment, but we learned that it was one thing to build a prototype, whereas it is quite different to build something which could be manufactured, that would work 24×7 without failing, and also be a commercial success. We learned more from industry personnel than they learned from us. The system was never designed by us such that it could be commercialised. But our prototype, invited international business partner and could bargain a 50% cost-reduction.

The word went around the industries, and I started getting calls to repair some imported equipment and build some small ones. My students, inspired by our success, plunged into each such opportunity. A surprising thing was that I was not just teaching them, but started learning from my students. Over time, I have found learning from younger colleagues and students is the best way to keep oneself abreast with technology. Technology changes rapidly. Continuous learning is the only way. I find many senior engineers learn primarily from vendors and from a bit of reading. This is not enough. Learning form youngsters who build things adds up and makes one innovative.

Taking Risks and Entrepreneurship

As we took up the development of lower-cost products, we recognised that Indian industry not only had very little internal R&D, but was somewhat risk-averse. To introduce new products to the market, a different approach was needed. We discovered Start-ups and Entrepreneurship in the Indian context to bridge this gap. We started incubating companies somewhat informally in the beginning, as the Indian Academia did not encourage start-ups in 80's and 90's. Questions used to be raised whether the educational institutes were to purse "Saraswati" or "Lakshmi." This, however, did not deter us, as we considered this the best way to translate technologies developed.

As mentioned earlier, India was struggling to install new telephones with the waiting list as long as eight years. At the same time, telephones were no longer considered a luxury, but something that brought in work-efficiency, and was a tool for development. Getting telephones to every village was considered equally important.

We first thought that it was lack of technology which was preventing this, but by the early nineties, we started looking into the economics of telephony and the costs involved in each element. We came to the conclusion that telephones in India could reach no more than 4% of Indian homes at the prevailing capital and operational costs. These costs had to be brought down by a factor of four for the telephone to get to 50% of Indian homes. As costs of other elements involved in the electronic telephone network were going down due to Moore's Law, the copper based local loop was dominating the total cost per line. The only solution was to replace the copper local loop with wireless. Wireless was, however relatively expensive at the time but we recognised that we were replacing copper with electronics. Recognizing that Moore's law was on our side and a programmable architecture will help us bring down the costs, our team consisting of a start-up and IIT R&D team, took the challenge to build a system and deliver a solution. By 1995 they designed a DSP-based Wireless in local loop called corDECT WiLL. It brought down the costs of installing a telephone line by a factor of four, and about a million lines were installed. This triggered the bringing down the price of mobile telephony and the cost-constraint was broken. From 7 million telephone lines when we started this development, India has grown today to 950 million telephones today.

Building a Delivery Team

The task of building Wireless in Local Loop was indeed a very challenging proposition. Fortunately, there were three of us amongst the faculty at IITM, who were committed and knew the basics of what was to be done. With expertise in different disciplines, we had learnt the difficult art of working together, but we needed experienced industry personnel too, who could convert our ideas into products. We made a list of some 8 alumni of ours, who were working in different industries in India. We decided to travel and meet them to sell our dream of 100 million wireless phones (to begin with we could not envisage anything more) in India. If we could get 5 of them, we would start the effort. Fortunately, all eight of them quit their jobs and joined us, not knowing where their salaries would come from. Now we needed the funding as well as support of Department of Telecom to help us define specifications and carry out pilots. We decided to not go to Government for financial support. Instead we sold the dream to industry to support the development. We went to the Government only for defining specifications and for pilot-deployment. Having tied up all this, we needed a somewhat larger team. Students at IITM for the most part were inclined to go abroad for higher studies at that time. We had learnt that many young engineering graduates from tier-2 colleges were bright, even though they may not have got adequate undergraduate education. Once inspired, they were capable of working very hard and make up for their weak background. They would then deliver the impossible. We had done it and had learnt that an army of inspired young men and women with proper guidance is the best resource that we in India have. We just needed to identify them and build them up. They have never failed us. It is with such a team that we took up the challenge and built corDECT WiLL in two years, at the price target that we had set. We had set the stage for wireless to take off in the nation.

Once the industry-academia collaboration coupled with youngsters succeeded, the formula could be replicated to translate technology in many spheres and make a difference to the lives of less-privileged people in India.

Proliferation of Start-Ups

India has 600,000 villages and most did not even have a telephone line in the 90's. CorDECT WiLL was used by a start-up to help setup a telephone and Internet kiosk in a village like an operator-assisted Public call office, except that it supported Internet service in addition to a telephone. A large number of services were provided to the villagers using this. Telemedicine was used to connect village folks to a city doctor. A telemedicine kit was developed by another start-up, which allowed a doctor to measure temperature, blood-pressure and ECG of the patients remotely. Internet was used to provide remote education by yet another start-up. A program was created to support the farmer in early identification of crop diseases using pictures transmitted over the Internet and providing timely advice for remedy. A whole host of Government services was provided on the Internet. This was carried out in 2001, when Internet was still in its early phase and data communication was yet to be supported on mobiles.

The successful translation of innovative technologies developed by IITM working with multiple start-ups, was the basis of changing the minds in academia. Saraswati and Lakshmi were recognised to work in tandem to strengthen technical institutions. We helped IITM formulate the first set of processes for setting up incubators in an institute. This started getting replicated throughout the country, with Department of Science and Technology taking an initiative to create incubators in various educational institutions. At IIT Madras, it took us time to set up formal incubators. But once they were set-up, start-ups happened fast. Till date, I have personally incubated almost 100 companies. A large number of technologies and products have been developed as a result. We founded IITM Incubation Cell and Rural Technology and Business Incubator (RTBI) and subsequently a Bio-incubator and Med-tech incubator at IITM.

These Incubators accelerated technology development and translational work. RTBI was focused on incubating companies providing products, services and employment in rural India. It was instrumental in setting up India's first rural BPO, so as to create livelihood in rural areas. Several companies looked at outsourcing production to Rural India. We developed an ATM machine, at a cost of 20% of what was available in the market, so that financial services could reach different parts of the country. Recognising that we were dealing with semi-literate people, when we worked in rural India, we decided to focus on using local language voice-based communication for all kinds of transactions. But voice recognition and text-to-speech were not available in local languages, and whatever recognition existed, gave a large number of errors. A a start-up is specialised in ensuring reliable services in the presence of these errors. The technology was used in the financial domain, with farmers in agriculture, and for "conversations" with mothers in a mother-and child health care program. The academia start-up combination often enabled what was otherwise considered impossible.

Industry—Academia Connect and Research Parks

In 2004, I joined the board of SBI, the largest bank in India and IDRBT, a technology subsidiary of Reserve Bank of India. I found that technology can make a major difference in banking and financial systems. We computed the costs incurred by a bank when one goes and makes a deposit or withdraws money. If no technology was involved, it would amount to about ₹250 per transaction today. Half of it had to do with cash-teller (front-end), whereas the other half involved handling of accounts (back-end). Computers and communications connecting all the branches could significantly reduce the latter and could enable anywhere banking. ATMs, Internet banking and mobile banking could largely eliminate the former and introduce any-time banking. It appeared to be an impossible task in India to get all this done, but hard work and perseverance have moved the country. Not only anytime anywhere banking has become possible today, but a transaction involving Internet banking or Mobile banking costs a bank only between ₹2 and ₹3 per transaction and that involving ATM costs about ₹15. It was especially important in a country with large population and where most transaction amounts are very small. Later we helped create Mobile Payment Forum of India and were instrumental in defining the person-to-person mobile payment process, irrespective of their mobile operators, their banks and the technology providers. Mobile wallets and mobile payments are changing the country and bringing forth revolutions in sectors such as transport (Ola and Uber) and retail purchases. When the problem of frauds in credit-card transaction was brought to our notice, we came up with the idea of sending an SMS as soon as a transaction is carried out. It significantly reduces frauds and India may be the only country where this is adopted by all bankers.

Our work in financial sector reinforced the value of industry—academia interaction. The problem is that Academia believes that Industry is not interested in working with them and only wants to import technology. On the other hand, Industry believes that Academia is too focused on publishing papers and cannot help them develop technologies which can be taken to the market. There are truths in both these sentiments, but they are partial truths. If prejudices are left aside and both learn from each other, wonders are possible. In fact, a combination of Academia, experienced industry persons and enthusiastic youngsters possibly defines the best Innovation eco-system today. After experimenting with this multiple times, we decided to formally enable it by setting up a Research Park, adjacent to IIT Madras. IITM already had excellent faculty and bright youngsters. We needed to bring industry into the eco-system. Industry would be invited to set-up their R&D centers at the Research Park.

However, the rental contract with industry would include an obligation for industry to work on R&D with IITM and earn certain amount of credits. The industry-auditors would then insist that joint R&D and earning credits become the responsibility of someone and impact their variable salary. These people will then do their utmost to work with IIT. Proximity and obligation would enable breaking of barriers; once they start working together and get some success, nothing will stop either of them. IITM Research Park (IITMRP) started operations in 2011 with 400,000 sq.ft of built-up space. It houses about 60 R&D centers of Industries, working closely with IITM. The incubators and incubated companies are also located at IITMRP. The Park has now been expanded to 1.2 million sq.ft and over the next two years, the number of R&D companies in the park is likely to touch 200.

The Next Frontier

About three years ago, we turned our attention to the chronic power-problems of India; huge power-cuts and large percentage of homes unconnected to the power-grid and significant section of people's inability to pay for even below-cost tariff. We needed a technological breakthrough, just as wireless was in telecom. We had little expertise in this area, but rather than simply complaining, we decided to learn and attempt to make a difference. Our formulae of leaning from youngsters and colleagues helped us once again. We started looking at how a simple Indian home could get some power from a roof-top solar panel to power at least some lights, fans and electronics items. We started with a small size (125 W) low cost (₹5000) solar panel. We were perplexed by what we learnt. While the solar panel gave us varying electrical power through the day, we found that 15% or more would be lost when we convert this DC power to AC power and synchronise to the grid. We tried to get better converters, but even at very high cost (disproportional to that of solar panel), the losses would not be below 10%. We were then told that another AC to DC converter will be needed to charge the battery from the combined solar and grid power and yet another DC to AC converter when power is drawn from battery to power load. Each of these converters would have similar losses. Then there will be battery losses (10% for Lead Acid batteries). In other words, 55% or more solar power would be lost before it reaches the load. There was no answer to my query why we are wasting expensive solar power. It was then pointed out to me that loads are becoming all DC needing DC power input. I knew all electronics needed AC-DC converters. But so do LED lights and the fan's Brushless DC motors (which saves over 50% power as compared to AC-motor based fans). All this made no sense. We therefore came up with the Solar-DC concept, departed from conventional wisdom, and introduced a DC power line for homes. Solar will power the line directly and so will be the battery. Loads will be DC powered. Only the grid-input will be converted from AC to DC. Of course, it involved complicated design to get this done minimising the losses, but far more difficult was to overcome the mind-set which had settled this issue over a century back and considered AC power-line as the only future. Technology development was only one task, but there were no manufacturers and no standards. We had to create a standard, develop the technologies required, and commercialize them and carry out pilot deployments in a significant number of homes in multiple cities and villages. Slowly, the tide is turning. DC power-line at home and offices and DC-powered appliances will bring in sustainability and make solar energy the norm. Maybe India can get 50% of its power from solar by 2030.

We now work on electric vehicles. That is another frontier to capture. India's growing pollution and its forever dependence on imported oil will not go without it. By 2030, India can have all its transport running on electricity. While conventional power can charge the vehicles in the night time, solar power will do so in day time. Technology and Policy can enable this. We have to have faith in ourselves. An Engineering mind must be humble, committed to sustainability, in tune with the human values, and should believe that "nothing is impossible."

My Professional Life Experience: A Continuously Rising Learning Curve

Yogendra Pal Anand

Introduction

Born in present Pakistan (on 12 December, 1934), I was in 8th class when Pakistan was formed. Due to the travails of the partition, our family suffered heavy loss of life (I lost my father and three small brothers), but somehow my education continued and in 1952 I joined Punjab Engineering College, then running as a guest institution at Roorkee (it shifted to Chandigarh in 1954) and my degree in Civil Engineering (then designated as B.Sc (Hons.) in 1955. I had topped in the Punjab University in both the Intermediate and the Engineering Degree examinations.

I appeared for the Central Engineering Services Examination of the UPSC in 1955 and being successful, joined Indian Railways (Indian Railway Service of Engineers) in May 1957. In the meantime, I had worked as Asst. Engineer (Design), PWD (Punjab), Chandigarh from April1956 to February 1957.

Professional Experience on the Indian Railways

I had the most enriching experience in various positions during my service with the Indian Railways, and I had the privilege of superannuating from its highest position as Chairman, Railway Board, on 31 December, 1992. During the course of my nearly 36 years of service, I had the opportunity to work on Southern Railway, on North-east Frontier Railway, then in Research Design and Standards Organization (RDSO, Lucknow), on North-East Railway, in Railway Board, on Northern Railway, on Central Railway, and again in Railway Board. During my service on the Railways, I passed through the various hierarchical levels as Asst. Engineer, Executive Engineer, Deputy

Y. P. Anand (✉)
Flat No. 513, Pocket C, Sector A, Vasant Kunj, New Delhi 110070, India
e-mail: ypanandindia@yahoo.co.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_20

Director (Research), Deputy Chief Engineer, Divisional Superintendent, Addl. Chief Engineer, Director in Railway Board, Chief Track Engineer, Divisional Railway Manager, Chief Engineer, General Manager (Northern Railway, &, Central Railway), Member (Engineering) in Railway Board and retired as Chairman, Railway Board, and ex-officio Principal Secretary to Govt. of India.

Thus, I had the opportunity to work at various levels in the 'Open Line' (for maintenance of railway track and bridges and all other civil structures for the running of train services), 'Construction' (new lines, bridges, guage conversions, and surveys, and major works on the Open Line), and the prestigious administrative posts on Open Line and in Railway Board, and in Railway's R&D centre. While my whole service on Indian Railways has been an inspiring curve of continuous learning, I can recall the following as my most notable experiences during my service:

1959–65: I could make major contributions as AEN and XEN for construction of 38 km long new BG railway line from Old Malda to the bank on the Ganges opposite Farakka, for conversion from MG to BG of strategic line from Katihar to Sinhabad, and for construction of BG line from Kishenganj towards New Jalpaiguri, all these in record time targets on NF Railway. The innovative steps also included developing wagon ferry crossing arrangements opposite Farakka on the Ganges, particularly during the 1962 Chinese War when, this being the only Broad Gauge route then available towards Assam, the ferry crossing capacity was raised from two to eleven ferries per day in the shortest possible time.

1965–72: I could make important contributions towards setting up and expanding track research, testing and monitoring systems in the RDSO, Lucknow, particularly for introduction of the first higher speed Rajdhani route from New Delhi to Howrah. Also, during 1969–70, I was sent as a member of the expert R&D team by Indian Railways for the upgradation of speeds on Bangkok – Sila-at north line of State Railway of Thailand. It had been a rare experience.

1972–77: As Deputy Chief Engineer (Construction) on NE Railway, I could bring about major changes in construction methods, including those for track construction and bridge rebuilding, during conversion of Samastipur-Sonepur section from MG to BG. For conversion of the first section from Samastipur to Muzaffarpur (52 km), the usual conversion method was totally changed. Earlier, many months were taken to convert a section under traffic and it was opened at low speeds which were raised gradually as the BG track structure got stabilized. For the first time, a 10 day complete traffic block was imposed and a welded track structure was provided and opened at near final speed after being tamped with on-track machines. This was a revolutionary change in the method of gauge conversion on IR. However, there was also a very tragic incident because Shri L.N. Mishra, the Railway Minister, was killed in a bomb attack at Samastipur station while inaugurating the first BG train to Muzaffarpur on 1 January, 1975.

1981–84: As Director (Track) in Railway Board, made special efforts towards setting up of concrete sleeper factories and introduction of concrete sleepers on a mass scale on IR. This not only introduced a massive upgradation in track structure (to a long-welded track laid on pre-stressed concrete sleepers with elastic fastenings and a deeper ballast cushion) but also the concomitant changes from manual to mechanized track maintenance and track laying systems.

1984–89: On NR, as CTE and CE, pushed through modernization of track structure and mechanization of track maintenance particularly on the Mughalsarai-Ghaziabad trunk route, which could yield higher line capacity in terms of train speeds and loads.

As General Manager (Central Rly) I could get the work of remodeling of the Victoria Terminus station revived, which had been stalled for a long period. This remodeling was necessary to reduce the minimum time interval between successive local trains so that the line capacity could be raised. However, due to the likely heavy dislocations during the work of remodeling it had been practically shelved. The proposal was revived and work was started while I was there, and thereafter it was successfully completed.

As Member (Engineering) and as Chairman, Railway Board, I sponsored and pushed through the revolutionary Uniguage programme for the conversion of nearly 9000 km from MG/NG to BG, including 6000 km being converted @ 1200 km per year within the Eighth Five-year Plan itself. The proposal was presented before the Prime Minister himself and was soon approved. This introduced the project of gauge conversion on a mass scale on Indian Railways. Basic changes were introduced in procedures for sanction of specific proposals without delay and in guidelines for conversion procedures and its execution. Also, I could get the work started on the construction of rail-um-road Chittauni-Bagaha bridge connecting U.P. and Bihar across the Gandak river, which project had been practically shelved after its foundation stone had been laid in 1973 by the Prime Minister herself. This had been done due to the fear of the risks involved in the success of the proposed river training system. The problem was reconsidered and successfully resolved. The project proved to be a great success in establishing a direct rail-cum-road communication between east UP and north Bihar, and also in reclamation of a large area of flood affected lands.

Foreign Experience

During service on the Indian Railways (1957–1992), I also had the opportunity of visiting many foreign countries on officially sponsored professional assignments. I was sent to Switzerland by IR for 1-month training on Swiss Railways (1969). Again, I was deputed to Thailand for seven months as a member of the Experts Team from Indian Railways (RDSO) to study and upgrade their Bangkok—Sila-at North route during 1969–70. I was deputed to visit China on a brief Seminar-cum-study tour of Chinese Railways in 1986. Again, I visited Germany, UK, USA and Canada on official assignments to review the advanced procedures of track management (1988). I was privileged to visit USSR to attend meetings as Co-chairman of the Indo-USSR Railway Working Group (1991) and to be deputed for visits to Paris, Lisbon, Brussels, Frankfurt to attend meetings of UIC/ORE and IRCA (1992). Just before my retirement I had the unique opportunity of going on an official visit to Pakistan as head of a team from IR in November, 1992. There, I led discussion with the Pakistan Railways including a meeting with their Minister for Railways. Soon after retirement too, I was officially invited to attend an International. Railway Seminar (April, 1993), held at Tehran, Iran, and there I presented a Paper on ‘Problems, Opportunities and Perspectives of the Indian Railways as a National Transport System’.

Academic Qualifications & Professional Memberships

While working in various positions on the Indian Railways I also kept pursuing further studies and was awarded Ph.D. by IIT, Delhi, in the subject of 'Waste Management' in 1991. I had also studied for and obtained Post-Graduate Diplomas in 'Gandhian Studies' in 1984 from Punjab University and just after retirement in 1993 in 'Econometrics' from Annamalai University.

During the course of my service, I also acquired many professional memberships and took active interest in their proceedings. These include: Fellow, Indian National Academy of Engineering; Fellow, Institution of Engineers (India); Life Member, Indian Building Congress; Life Member, Solar Energy Society of India; Fellow, Indian Institute of Bridge Engineers; Fellow, Institute of Urban Transport (India); Fellow, Indian Arbitration Council; Fellow, Institute of Rail Transport; and Fellow, Indian Inst. of Permanent Way Engineers (India).

After Retirement from Indian Railways—Professional Experience

After retirement from the Indian Railway service I have remained involved in professional (engineering) activities even while I gradually moved progressively towards the Gandhian field. Soon after retirement, I worked with the UNDP on a 10-week assignment for a study on India's Transport Sector (1993). I was also associated with the Asian Institute of Transport Development as a Senior Research Scholar from April 1993 to May 1996. During this period, I also participated actively in a project to upgrade the design of Cycle Rickshaws and wrote articles on transport-energy issues and non-motorized transport in journals as well as jointly authored books on 'Non-motorized Transport of India: Current Status and Policy Issues' (1996) and 'Transport energy Nexus—Towards Sustainability' (1999), both published by the AITD.

Soon after retirement, I was actively associated in setting up an INAE Study Group, named as 'Indian Engineering Heritage (Railways)', and constituted by highly experienced recently retired railway officers from all branches. It remained active till 2015, holding periodic meetings regularly and collecting historical information and data since the inception of Indian Railways in 1850s covering its all branches of engineering and train operation. The Group has published four reports, the fourth being titled, 'Role of Technology in Capacity Augmentation and Railway Development' in 2015.

Because of my deep interest in the subject of 'Waste Management' I had been trying for the setting up of an appropriate institution for taking up practical projects in this area. Finally, with the initiative of Vigyan Bharati, I succeeded in having the 'International Institute of Waste management' set up in Bhopal in 2009 and functioned as its first Chairman during 2009–2010.

I have also been a Member of the INAE's 'Technology Foresight and Management Forum' since it was set up in 2012. The Forum has nine members who hold discussions and take up and work on selected areas of technology. As a part of my contribution, I had finalized a short thesis, titled 'Issues in Waste Management' (published by INAE in 2015). In the same context, my detailed paper, titled 'Cleanliness-Sanitation: Gandhian Movement and Swachh Bharat Abhiyan', has been published in the RITES JOURNAL, vol.17/ 2, July 2015.

After retirement, I have been honoured as an 'Engineering Personality' by Institution of Engineers (India) in 2004, with 'Outstanding Contribution Award' by Indian Building Congress in 2010, and with the 'Alumni Achievement Award', 2013, by the National Academy of Indian Railways, Vadodara.

After Retirement from Indian Railways–Experience in the Gandhian Field

Since retirement, I have also been closely associated with a number of Gandhian institutions and studies in Gandhian thought. I joined the Governing Body of the National Gandhi Museum (and Library), Rajghat, New Delhi, in 1994 and then worked as its Director for ten years from June 1996 to July 2006. I had the opportunity to participate in an International Conference on Gandhian Concept of Non-violence, in Santa Cruz, USA (1995), in an International Seminar on Gandhian Concept of Freedom, in University of Calgary, Calgary, Canada (1997), and in a Seminar on Gandhian Political Thought in University of Trieste, Italy (2000). On invitation by Indian Council of World Affairs, I delivered Keynote Address on 'Gandhian Legacy: Its Relevance in the twenty-first Century' at IIIrd Spain—India Dialogue Forum 2007 at University of Valladoid in Spain on October 16, 2007.

At present, I am a Life Member of the Indian Society of Gandhian Studies; Vice-Chairman, Working Committee, Gandhian Seva & Satyagraha Brigade, New Delhi; Member, High Level Dandi Memorial Committee (under Ministry of Culture, Govt. of India); and Hon. Fellow, Centre of Gandhian Studies, GITAM University, Visakhapatnam.

During this period I have written a number of papers related to Gandhian thought. My published books and compilations in this field include: *The Essential Relationship between Netaji Subhas Bose & Mahatma Gandhi* (1997); *Birth of Free India's National Anthem: A Gift from Netaji Subhas Bose* (1997); *Non-violence in a Violent World: A Gandhian Response* (1995); *What Mahatma Gandhi Said about Atom Bomb* (1998); *Mahatma Gandhi & the Railways* (English and Hindi editions, 2002); *Mahatma Gandhi on Lord Buddha and Buddhism* (2003); *Mahatma Gandhi and Art* (2003); *Mahatma Gandhi and Satyagraha: a Compendium* (2006); *Albert Einstein and Mahatma Gandhi: The Centenary of Physics, War, Satyagraha and Peace* (2006/2010); M*ahatma Gandhi's Works and Interpretation of the Bhagavad Gita* (in 2 Volumes) (2009); *Gitapadarthakosh* (by Mahatma Gandhi), trans. into Hindi

(2010); and '*Historical background to Mahatma Gandhi's taking up Satyagraha against Salt Tax (1930), as the Key Issue for the Civil Disobedience Movement for Poorna Swaraj*' (published by Ministry of Culture, GOI, 2015, also by IIT, Mumbai).

After retirement, along with other colleagues I had also set up in 1994, 'GODHULI', an NGO for educating non-school going slum children in Delhi, and since then I have been functioning as its Chairman. At present, it runs four such centres and provides preliminary school education to over 400 children.

Conclusion

As explained above, I have had a very varied professional experience in multiple fields since I passed my degree in Civil Engineering from Punjab Engineering College, Chandigarh in 1955. I consider myself privileged to have had nearly 36 years' experience of service on Indian Railways, starting as an Asst. Engineer and retiring (on 31 December,1992) from the topmost position of Chairman, Railway Board. After retirement, I have remained deeply involved in both the professional and the Gandhian fields through my association with prestigious institutions/activities and my continuing studies. I have been a student throughout and continue to remain one. Throughout my service on Indian Railways as well as my professional involvements after retirement I have continued to learn and the learning curve continues to grow along with the experience, for which I remain deeply grateful to all institutions and to everyone with whom I have had the privilege to be associated.

Engineers' Moral Responsibility

Paritosh C. Tyagi

Introduction

If I say EMR, few may recognize it as Engineers' Moral Responsibility. But CSR is widely known as Corporate Social Responsibility. What makes EMR relevant and important today is the growing realization that much of the mess in the world has been created by the engineers and only engineers have the ability to clear it.

No one has denied, nor can anyone deny, the contributions made by engineers to the society. But it is also true that the contributions have created some unintended results that are adverse to environment, ecology and society. Let us take a few obvious examples:

- Waterlogging near canals
- Noise, effluent and emission associated with manufacturing activities
- Provision of water supply but without adequate arrangement for wastewater
- Man-made disasters in the form of structural collapse, earth slips and flooding.

Now let us go deeper and find what went wrong, why and how should it now be addressed.

Genesis

In Competition with Nature

Competition with each other and support for each other are two basic instincts in all living beings. So also in man. Man went further: he competed with Nature herself.

P. C. Tyagi (✉)
Flat No.0984, ATS Village, Sector 93-A, Noida, UP 201304, India
e-mail: paritya@yahoo.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_21

Thus if Nature has given our legs the strength to walk a distance of 6 km in an hour, man invented machine after machine to move faster and still faster. Likewise, man invented devices to see much more than eyes can see, grow more food than a field normally yields and started storing a variety of goods in warehouses. Associated with such activities are the problems we encounter, such as traffic jams, transport accidents and generation of large quantity of wastes and emissions.

Indiscriminate Provision of Goods and Services

Goods and services were identified by economists as wealth generated. Engineers participated enthusiastically in generating more and more goods and services, and marketing experts promoted consumerism to expand those goods and services. As a result, for example, we have far too many cars than our roads can carry, and we are badly short of place for parking.

Narrow Project-Wise Approach

Each organization has its own engineering outfit to get the proposed works implemented. These engineering outfits do not come in contact of each other during planning or implementation of their projects. The result is often experienced in successive digging up of roads for water supply, sewerage, gas, telecommunications, etc. Inconvenience, accidents, and extra costs are all possible to be mitigated to a significant extent by coordinated planning and implementation of proposed infrastructure.

Operational disadvantages apart, the worst effect of project-wise approach is the failure to anticipate and provide for mitigating their cumulative impact on environment and ecology. A cascade of dams and barrages on a given river gets clearance for construction when appraisal is done project-wise.

Focus on Beneficiaries

Cost have been a matter of concern to the engineer from the very beginning. Later, the economists focused their attention on the benefits to justify incurring the costs. This was picked up by the engineers, beneficiaries were identified, benefits were quantified, and the projects were justified. What was missed was the adverse effect on society and environment. Compensation for cost of land acquired found a place as an item of cost of proposed work's but social aspects like trauma of displacement, loss of livelihood, lack of ability to properly utilize the sums received as compensation were factors that were learnt only after bitter experience.

Ruled by Practice

Field engineers get used to thumb-rules and code of practice from the day they start to work as an apprentice. Seniors and superiors almost always like to see that the practice is followed. Sometimes they refer to the meaningful saying that in theory, there is no difference between theory and practice but in practice, there is. How practice rules is illustrated by public health engineers assuming a loss of 20% of water consumed even in housing estates in which sewage treatment plant is located in the basement and all sewage pipelines are watertight.

Indifference to R&D

By and large, engineers are a set of proud people. The field engineer is proud of what he calls his experience and the academician is proud of what he displays as his knowledge. A proud person is a happy person but is a very poor learner. So, the field engineer does not value R&D and the academician is more than content with the publication of his papers. The blame game starts: the field engineer thinks that the universities and research organizations are not bringing out anything practically applicable and the researchers pity the field engineers for their inability to pick up new applications. R&D suffers, at least the benefit it can bring is often lost.

Lack of Caution

Engineers seem to suffer from a fallacious notion that caution denotes lack of confidence. Perhaps that explains why public health engineers did not find the water quality problems caused by fluorides and arsenic until medical report confirmed the irretrievable damage to the health of affected population. Likewise, that is how urban sprawl became uncontrollable, floods were aggravated by arrangements to control floods, groundwater table was allowed to be lowered to unmanageable levels and waterlogging has repeated near unlined canals.

Fancy for the Spectacular

Politician, bureaucrat and engineer—each one wants to demonstrate his performance. That prompts them to go for large infrastructure projects that are spectacular. Such projects make a good impression that much has been or is being done. For example, what is certain to catch the fancy of decision makers is a project for construction of a large hospital rather than a project for disinfection of water though both have comparable effect for the public by either recovering health or by safeguarding against disease. Likewise, highways are made to look impressive with their signage and other appurtenant facilities, but the inadequacies in cross-drainage become known only after flooding is experienced. River valley projects, with a spectacular dam and reservoir, also have the same ready appeal, and undesirable ecological and hydrological consequences.

Staying Away from Innovation

Innovation has been the foundation of many path-breaking inventions and applications. Majority of innovators are non-engineers. Why do engineers stay away from innovation? First, there is a notion that innovation is sub-professional and a professional should go only for well-established practice. Secondly, engineers are particularly scared of failure and innovation seldom provides adequate assurance of success. Thirdly, the link between research and the field is, in general, too weak to carry ideas that could be tried out.

Perception of Conflict Between Environment and Development

The author recalls an early presentation of the proposal for interlinking of rivers. It was some twenty years ago. The word 'environment' came only once while referring to environmental clearance which was one of the topics under the heading named 'hurdles'. The term ecology did not come up at all. This was just a manifestation of the perception of conflict between environment and development.

In 1980s, much work was done to study the relationship between development and environment culminating in the report of the Bruntland Commission set up by the United Nations. The report is titled 'Our Common Future'. The conflict was seen as clearly resolved in the concept of sustainable development fully endorsed in the World Summit held in 1992. By now, nearly a quarter of century has passed without the concept becoming a norm for design and operation of large engineering developments.

Misconceptions About Development

There are three fundamental fallacies in conceiving development: first, all development projects are taken up as stand-alone while the impacts are always cumulative; second, development planning is resource-based while it should, in addition, be function-based and third, investments compelled by neglect are erroneously included in development. These are respectively illustrated below.

- Cumulative impact of diverse developments at the same place have great potential of compromising sustainability. The disaster that occurred at Kedarnath in Uttarakhand in June 2013 had roots in the cumulative impact of tourism, transport, building construction, disposal of muck and interference with the river in addition to intense rainfall.
- An example will illustrate the difference between resource-based and function-based development planning. Resource-based approach to river management will remain almost confined to water flow while a function-based approach will also encompass sediment transport and ecological habitat provided by the river.
- The third fallacy is illustrated by the booming bottled water industry, the domestic water purifiers, booster pumps and supply of water by tankers—all of which have been compelled simply by the neglect in maintaining safe quality of water at the tap.

Definition

No definition is readily available for EMR. An attempt to define EMR is stated below.

Engineers' Moral Responsibility is the collective and individual commitment by engineers to ethics, service to society and quality of life through forethought, research, planning, design, operation and closure, incorporating care for life and resources in all their contributions.

EMR Code

Engineers will need a code to guide them in the discharge of their moral responsibility in the various activities they get engaged in. A preliminary attempt for evolving such code is made below. It enumerates certain strategic policies which will need to be elaborated soon through a collaborative effort.

1. ***EMR should be measurable***. For this purpose, parameters have to be selected that are measurable and reflect the commitments stated in the definition, viz., ethics, service to society and quality of life. At present, ethics is covered by such regulations as Government Servants' Code of Conduct. Service to society is measurable in terms of performance and socio-economic benefits. Quality of life, as distinct from standard of living, is well defined by the United Nations in the principles for working out the index for human development. Improvement in this matter may be a never-ending process.
2. ***The impact of engineering projects should be equitable***. Equity is lost if a set of project- affected persons is deprived of the benefits of the project. Siting of hydropower station and alignment of high tension transmission line has required

acquisition of land from persons who are not included in the beneficiaries adopted in the project.

3. ***Engineers should not fail to learn from mistakes***. A glaring example of failing to learn is waterlogging caused by the Indira Gandhi Canal in Rajasthan, a relatively recent project, when the sad experience of waterlogging along irrigation canals had already been experienced on several projects constructed much earlier.
4. ***Concern for environment and compassion for all living beings should stay in the mind of engineer at all times***. These attributes are specifically mentioned in the amendments to the Constitution of India

    a. ***Article 51-A (g) under Fundamental Duties***: ***It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures***.
    b. ***Article 48-A under Directive Principles***: ***The state shall endeavour to protect and improve the environment and to safeguard the forests and wild life of the country***.

5. ***No defect no effect***. As propounded by Prime Minister Narendra Modi, engineers should translate the precept of 'no defect no effect' in all their activities. This shall encompass the quality of product to be the best possible as also the technology to be such as not to cause adverse impact on environment, ecology and public health beyond acceptable limits.
6. ***Innovation should be an integral part of engineering***. Despite shining examples of success achieved by some innovators (most prominent among whom is Steve Jobs), innovation has neither received the attention nor the respect it deserves. Admittedly, innovation does not lend itself to be codified and regulated. Quite often, established professionals look down upon innovation. There is need to establish a system that establishes provision for supporting and getting recognition for innovation. Indeed, there is plenty of scope of innovative applications in many areas, such as material science, product design and waste disposal.

Conclusion

Legal responsibility can be imposed but moral responsibility has to be voluntarily assumed. As the leading professional body among engineers, the Indian National Academy of Engineering and Fellows of the Academy have to step forward to set an example of being responsive towards moral responsibility. INAE has strived to strengthen the link between senior engineers and the young engineers. Through this link, INAE may invoke awareness and commitment towards EMR from an early stage in the career of engineers. In this manner, the commitment to discharge moral responsibility will be generated both by wisdom of experience and by emotion of duty.

Higher Technical Education in India: Need for New Initiatives

M. A. Pai

Introduction

Higher technical education in India started receiving priority after independence with the creation of five IITs at Kharagpur, Bombay, Kanpur, Madras and Delhi each with foreign collaboration. Then NITs were created in different regions. Today there are 22 IITs and 31 NITs with an annual intake of 10,000 and 18,000, respectively. There are over 20 Technical Institutions of comparable quality in the private sector. In addition, there are a large number of private engineering colleges whose quality has been questioned. The country graduates over a million students per year with a large number of them from these private engineering colleges. There are not enough jobs for these engineering graduates. There is thus a crisis in engineering education calling for an urgent need to control this growth and also retain quality. We discuss some of these issues and offer solutions, which to many may seem harsh. All the development schemes of the Government. starting from 'Clean India' to 'Digital India' to 'Start-up India' depend on good quality S and T manpower. In this task IITs, NITs and private Technical Institutions with a history of quality have key roles to play.

The IITs

There is a feeling that the country has too many IITs. A close look will reveal that there is nothing wrong with having many IITs, NITs and private institutions of quality for a country of 1.3 billion people. The State of California, for example, with a population of close to 40 million has 10 public universities in the UC system, and in addition

M. A. Pai (✉)
Department of Electrical and Computer Engineering, University of Illinois, 1406 W.Greet St., Urbana, IL 61801, USA
e-mail: mapai@illinois.edu

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_22

has private ones like Stanford, Cal Tech and USC. Each has its own reputation in certain niche areas of S and T. Hence, India, which is still in a stage of development in many areas, there is need for many good quality Technical Institutions. Thus, having about 75 quality institutions consisting of IITs, NITs and the reputable technical Institutions in the private sector turning around 100,000 undergraduates per year is a reasonable goal. This implies phasing out of poor quality engineering colleges in an orderly manner, a task that the HRD ministry and AICTE must take seriously.

We also need a different metric to judge the quality of our institutions. The original five IITs, IIT s at Roorkee and BHU along with IISc, are well past the developmental stage and in the opinion of many, they should be producing world-class research, and fundamental breakthroughs in S and T. They should aim to get into the top 100 Universities in the world. This is part of the debate that is going on now, and a very healthy discussion is needed. The total number of Ph.D.s produced in 2014 was close to 1000 with IITKGP and IITB, producing about 250 each and the remaining coming mostly from the other IITs. The newer IITs are also coming up. The total faculty strength in the five original IITs is over 2000. Hence, the turn out of Ph.D.s is thus quite comparable to research oriented US universities where the annual output of Ph.D.'s is roughly half of the faculty strength. Hence, within a year or two the country will produce a good number of Ph.D.s. This will translate into some significant impact both nationally as well as internationally. It is heartening to note that the newer IITs have a large number of faculty trained in older IITs. What is critical is that these Ph.D.'s be broadly trained in terms of course work in addition to the thesis part. This is a weakness that needs to be looked into. The newer IITs must ramp up their own Ph.D. programs very quickly. This is necessary to provide a pool of qualified faculty to other IITs as well as NITs and other institutions of good quality. In the long run the objective must be to bring the NITs at par with IITs in terms of funding based on performance and faculty quality. Looking ahead, about 75 institutions of quality should be the aim.

Controlling the Quantity of Undergraduates

India produces a large number of graduates in engineering to the tune of over 1 million per year for a population of 1.3 billion! That this is not matched by job creation. The quality of most of them is not good. In contrast USA produces about 85,000 graduates per year for a population of about 320 million. The number of Ph.D.s produced is about 8000 with about a third of the students coming from overseas.

The reform in technical education must start by both central as well as state governments acting together, particularly the latter. Historically, the rapid growth of private engineering colleges can be traced to two factors, namely, the quota system in the Central and State supported institutions as well as the inability of the IITs to take in more students on merit only. This led to the proliferation of large number of private colleges of dubious quality. Many IITs still regard student to faculty ratio of 10:1 as important whereas schools such as Berkeley and University of Illinois has it more like 20 plus. Optimum use of faculty and classroom space is critical. Since IITs admit students only once a year, labs are not utilized in the mornings and lecture halls not occupied in the afternoons. For example, IITs can easily admit students at the UG level in both semesters, a practice prevalent in all US universities. The same JEE results can be used for this purpose. Students at UG level need to share rooms all through their stay, a practice prevalent in Chinese universities. If access to these institutions is made easier, private institutions of dubious quality will close down.

Post Graduate Structure

About the large number of undergraduate students, one could draw a parallel between this and the 3-year liberal arts, science and commerce graduates that India produces. In sciences many go for the 2-year post-graduate work. One possible hope is that the same thing will happen in engineering too. It is here that the IITs, IISc, NITs and the well run private universities (referred to as Tier I schools) can play a key role. It is assumed that there will be about 50 tier I schools for discussion purposes. Hence, the intake for PG studies must be increased sharply. The Master's program should be of one-year duration consisting of course work plus a small project leading to a M.S degree. Perhaps the two-year M.Tech program may be phased out. This will encourage more students to go for Ph.D. This is critical for India in future. India has a respectable record in science research over the years, and it should be the goal to achieve an annual output of about 2000 Ph.D.s in engineering through the Tier I schools in about 5 years. The Government. must ensure that all Tier I schools must have a teaching staff with a Ph.D. who are available from abroad and the other IITs.

Course Structure and Faculty Teaching Loads

A major weakness in the Indian Ph.D. training is the lack of adequate course work. This is reflected later years when they start doing teaching and research as a faculty member or even in Industry. Minimum number of 6 courses beyond the proposed one-year of M.S degree is necessary with a good breadth outside the area of specialization, perhaps 2 courses. These courses must be at the graduate level from the science and Mathematics departments.

Ph.D. Thesis Evaluation

This is perhaps one area where the postgraduate education has failed in the IIT system, and perhaps in the country as a whole. Soon after a student finishes his thesis there is an elaborate process of sending it outside the country as well as inside the country. This basically prolongs the student's stay as well as the suspense attached. Anywhere from 6 to 9 months are wasted and a student does not know what to do. As a first step it is necessary to modify the practice of sending the thesis abroad. By sending a soft copy to examiners within the country and abroad the process can be shortened to a month. A student will be able to look for a faculty position even before he formally gets the degree. If he gets the degree within a month or two of the thesis submission, he can join a new institution quickly. It is hoped that he will publish a paper or two before he submits his thesis. The hiring practice must also a change. The IITs must accept applications all through the year. In this way the so-called faculty shortage issue will be solved. It is true in some ways that this resembles the US system. India has adapted to other features of the US system well.

Industry Involvement

Except for hiring good undergraduates, industry has shown little interest in hiring Ph.D.s. This is one of the reasons students do not go for PG work. There is need for discussion on how to change this situation. The answers are not clear at the moment. The public sector undertakings used to hire Ph.D.s in the 70s. The current picture is not clear since there is too much of reliance on FDI.

Faculty Teaching Loads

The current practice of faculty handling the tutorials must be replaced by letting the senior Ph.D. students handle them. Same thing goes for the labs except for some light supervision. By bringing down the teaching load, the faculty in an IIT can devote more time for research. An average of 3 courses per year is enough, provided that the faculty member has a sponsored project. Otherwise four courses should be the norm.

Conclusions

India can excel in engineering education by adopting many of the features of the US system. A new set of ideas mostly structural, has been presented in this article. There is need for quick implementation if the country wants to achieve the goals of a vibrant S and T country.

A Dream Comes True

T. K. Bera

I was born in a large middle class family in a remote village in the District of Bankura, West Bengal in 1954. My initial schooling was in the village primary school followed by high school in Bengali medium where English, Hindi and Sanskrit were taught from sixth the standard onwards. My father was a school teacher in the High school and also had the added responsibility of managing the village post office apart from looking after the agricultural fields and running his charitable Homeopathic dispensary. He was a simple, honest, hardworking person with the single motto of bringing up his children to the best of their abilities, sacrificing his own luxury and comfort. My mother was a homemaker with lot of love and care. Both of them taught us dignity of labour, honesty and dedication right from our childhood days.

I was an average type of student but passed out the Higher Secondary Examination in the first class which was a rare distinction for a village level school. I joined Garbeta Government college for B.Sc Honors course in Chemistry. Due to the turmoil of Naxalite agitation in West Bengal in the early 70s, and frequent stoppage of classes in the college, my father suggested me to go outside Bengal for my studies. Thus, I landed in Varanasi to join the Institute of Technology, BHU for a 5 years B.Tech course in Ceramic Technology.

The first year was agonizing due to frequent ragging, not knowing to speak proper Hindi and waiting for the money order to come every month to get my pocket expenditure. However, I survived the ordeal and grabbed a merit-cum means scholarship, and also managed to change my branch from Ceramic to Chemical Technology due to good score in the common curriculum for all engineering disciplines in the first two years. Thereafter, the journey for the next three years in the Chemical Technology Department was smooth and memorable due to some wonderful professors whose teachings and guidance made me what I am today. I still fondly recall Prof.

T. K. Bera (✉)
Rare Materials Project, Bhabha Atomic Research Centre, PO Yelwal, Mysore, Karnataka 571130, India
e-mail: Tk_bera@rediffmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_23

Gopal Tripathi for Fluid Mechanics, Prof. N. S. Garg for Thermodynamics, Prof. Umashankar for Mass and Material Balance, Prof. Tewari for Reaction Kinetics.

After passing out B.Tech with Honors in Chemical Engineering in 1976, the option was to go for higher education or for a job. I opted for the latter to give financial support to my family. Luckily quite a few job offers came in the way, namely, RIL, ONGC, RCF, INDAL and BARC. I opted for the last one on the advice of my father since it was a Central Government job and offers an opportunity to do work in a research oriented field in the frontier area of Science and Technology. I joined the 20th batch of BARC training and went through the one year rigorous training course in Nuclear Science and Technology with specialization in Nuclear Chemical Engineering. Thereafter, I was selected as a Scientific Officer 'C' and joined the New Activity Section of Chemical Engineering and Technology group in BARC, Trombay campus in the year 1977.

It was a small multidisciplinary group under the dynamic leadership of Shri B. Bhattacharjee that my journey in the Department of Atomic Energy began. The group was assigned with the task of developing a process for enrichment of Uranium (increasing the concentration of 235 U from natural 0.7% to higher value say 3.5% 235 U for Light Water Reactors or >20% for Nuclear Explosive Devices) wherein very little information was available in the published literature, a task that was considered near impossible for a country like India. The world enrichment at that stage was controlled by US, USSR, CHINA, FRANCE and UK through capital intensive gaseous diffusion process and the gas centrifuge process was in the initial stages of deployment in USSR, GERMANY, UK and Netherlands. Because of the potential of Enriched Uranium being used as a Nuclear Bomb (after Hiroshima & Nagasaki during 2nd world war) and to control the world enrichment market, the technology as well as all equipment and machinery connected with it were in the secret domain and embargo regime.

Under these circumstances, the quest for development of a suitable process for enrichment of uranium began in BARC, Trombay campus in the mid 70s. Initially it was scouring through scanty literature and patents that were available on the subject. After initial attempts on developing porous membranes and compressors for gaseous diffusion process, the focus was shifted to gaseous nozzle process, an aerodynamic process under development in Germany since it was a stationary wall device, easier to fabricate and experiment. However, development of critical components like Rotor, End caps, Drive motor, Bearings etc., for high speed gas centrifuge rotor continued in parallel since the gas centrifuge process offers higher separation factor and consumes relatively little power. We were faced with numerous challenges right from the initial days. Vacuum technology was not taught in our engineering curriculum, but was an essential part of any of the enrichment process. Therefore, we started learning about vacuum pumps, vacuum gauges and leak detectors. To design a vacuum system, we had to learn about suitable materials technology, type of joints and seals as well as welding technologies. A lot of effort went towards developing local vendors willing to manufacture and supply these components and systems. After initial learning of isotope separation technology through the separation nozzle setup using SF6 gas mixture, the focus got shifted entirely towards High Speed gas centrifuge process due to some promising initial results.

The initial breakthrough came in the form of a High Speed Rotor System with mechanical bearing at the bottom and an electromagnetic bearing on the top driven by a motor generator set. Gas entry and outlet scoops was arranged from the top through a hole in the end cap where there concentric tubes were inserted. Although the machine had a very short life, experiments on "U" isotope separation began with full earnest with in-house produced hex gas. With little or no experience in handling supersonic stratified gas dynamic inside a high speed rotor, the results were disastrous. But the tenacity to continue in spite of repeated failures and dogged determination to face the obstacles on the way soon got converted into a dream. In a short span of time we got an improved version of the High Speed Machine with pivot jewel non-contact bearing at the bottom and hysteresis induction motor drive as well as a molecular pump on the top. After struggling day and night for almost 3–4 years, the isotopic analysis of the product and waste streams showed that the high speed machine is truly capable of separating the 'U" isotopes. Soon various design of aerodynamic scoops as well as temperature control at the top and bottom yielded better results. The challenge was to multiply the effect and get some significant quantity of product. This too was realized soon from a five machine square cascade operating in a recycle mode.

I was pleasantly surprised when a few of us got an invite from the then Chairman, AEC Dr. Raja Ramanna to join for a celebration dinner at the famous Taj Mahal Hotel at Gateway of India, Mumbai. It was a memorable event for a young engineer like me at that time, but at the same time another dream was thrown into our mind; To build a gas centrifuge demonstration facility with few thousand machines sometime soon in the near future to qualify the technology as well as to produce some enriched uranium for various strategic applications of DAE.

During mid-80s the initial project work was initiated with site identified at a place in South India. We were still groping in the dark since the mechanism of separation inside the gas centrifuge was only partly understood and building a demonstration cascade of thousands of such machines working in a uninterrupted manner was a distant dream. However, once again we started working, making P&I diagram, layout, equipment design, writing specification in a feverish manner.

Many a times, the entire work as thrown into the dustbin to rework with a more feasible idea. It was a difficult ball game to work on a R&D project with so many unknowns and so much of uncertainty. Additionally, the difficulty in most of the multi- disciplinary engineering R&D project is that laboratory scale results are not enough, the concept must be proven at a scale where most of the engineering challenges are seen.

The Project site with an area of about 100 acres, was a barren piece of rocky land with hardly any green patches. We started visiting the project site from 1983 to 84, once the ground breaking started. Our first guest house cum office was an old bungalow type house belonging to the ancestors of Dr. Raja Ramanna. From 1985 to 86 recruitment of technical staff by holding interviews in the guest house started. We, a team about 10–15 engineers, were deputed to the project site to expedite the construction work and commission the project. In the initial years till the commissioning of the first cascade hall of the demonstration facility in 1990, the Project was under the administrative control of Indian Rare Earth limited, a PSU under DAE under the leadership of Shri R. K. Garg, CMD, IRE. We had a face a hostile neighborhood for almost a decade till we could convenience them about the zero discharge concept of effluent discharge to the environment from the project. Subsequently, many of our outreach programmes and social welfare activities won their hearts.

By 1989–90, within five years from the inception of the project, the first cascade hall of High Speed Rotors was commissioned. However, teething problems started arising one after another. The cascade could not be filled with hex gas since there was over pressure build up towards the enricher end and as a result machines were slipping away from synchronous speed. Occasionally machines will suddenly crash due to stress corrosion leading to leakage from vulnerable joints. The learning curve for cascade operation was very tedious and nerve breaking. By the time the teething problems were solved, the cascade life came to an end due to loss of a large number of rotors. But the lesson learnt out of this exercise revealed a lot knowledge about gas centrifuge cascade operation which no published literature on the subject provides and gave us the confidence to go ahead.

The process of building capacity by adding more and more cascade of high speed machines continued over the next two decades under the dynamic leadership of Shri B. Bhattacharjee inspite of strict embargo regimes, which was tackled with intense indigenous development efforts since the early 90s. Inhouse R&D gave us more and more advanced version of machines with higher and higher output, and they were also inducted on the way in a phased manner. Indigenous development efforts paid good dividends, particularly development of Special Vacuum Pumps and Gauges, Ultra Low Pressure Drop Mass Flow Meters, Hermatically Sealed Compressors, Helium Mass Spectrometer, Leak Detectors, Rare Earth Magnet Rings, Ultra Precision Contract Less Pivot Jewel Bearings, Molecular pumps etc. The production of indigenous enriched uranium opened up many frontiers of application which were not considered feasible earlier due to conditionalities that comes with imported material.

A two pronged expansion strategy was worked out during the silver jubilee celebrations of the project in 2009 under the guidance of Dr. Anil Kakodkar as Chairman, AEC and Dr. S. Banerjee as Director, BARC. An expansion of the existing Rare Materials Project during the XI and XII plan to take care of immediate needs of DAE and a long term commercial project plan at a new location to cater the fuel needs of Nuclear Power sector like AHWR/&IPWR and even imported PWR's.

The expansion project executed under the leadership of Dr. Banerjee is in the final stages of completion where commissioning activities have started. For the other long term objective a suitable land with an area of about 1800 acres has been acquired and first phase of project activities for building up the new facility has started after obtaining the Environmental clearance from MoEF.

I have superannuated from service in March 2014 with a sense of pride and fulfillment of a life time dream of taking up a technical challenge, and bringing it to a successful stage from where it can flourish further and serve the needs of the nation.

We feel proud that this project is based entirely on 100% indigenous technology, a truly “Made in India” product. Over the years, I have built a team of competent and dedicated scientists and engineers, who I am sure, will carry the torch forward and bring more laurels for DAE and the country as a whole.

I would consider myself lucky for being able to fulfill my deferred ambition of completing my higher education—Ph.D. in Engineering Science from Homi Bhabha National Institute during February 2014, and also to continue serving the department as a Raja Ramanna Fellow after superannuation.

I shall fail in my duty if I do not acknowledge the support and mentorship that I received although my career in DAE in achieving my dream from my colleagues and Gurus. I also thank my family for supporting me in all my endeavours particularly my wife Smt. Debi and sons Gaurav and Saurav. Lastly, I also acknowledge the support given by DAE in offering me the Raja Ramanna Fellowship to continue my intellectual pursuit that enabled me to write this article. Last but not the least, I thankfully acknowledge the contributions in drafting and typing the article by my erstwhile colleagues at RMP namely Shri R. Ravindra Kumar, Smt. M. S. Pushpa and Shri B. Pradeep.

Engineering the Human Mind and the External World

V. V. S. Sarma

विश्वं दर्पणदृश्यमाननगरीतुल्यं निजान्तर्गतं
पश्यन्नात्मनि मायया बहिरिवोद्भूतं यथा निद्रया ।
यः साक्षात्कुरुते प्रबोधसमये स्वात्मानमेवाद्वयं
तस्मै श्रीगुरुमूर्तये नम इदं श्रीदक्षिणामूर्तये ।।

The universe is like the reflection of a city seen in the mirror of one's own inner being. This witnessing of the external world is happening within the Atman through the power of maya (माया) as of a dream in sleep. This is experienced directly at the moment of spiritual awakening within the non-dual realization of one's own Atman. Salutations to Him, the inner Guru, who causes this illumination of awareness, who is personified as Dakshinamurti

Adi Sankaracarya

Cogito ergo sum (I think, therefore I am) — René Descartes

तत्त्वमसि (tat tvam asi, That you are) — Chandogya Upanishad

Introduction

Is the mind of an engineer different from the mind of any other human being? Does a decade of training spanning the period of one's BE, ME and Ph.D. programs affect the way a person thinks and acts? What does his experience teach him?

V. V. S. Sarma: deceased.

V. V. S. Sarma (✉)
#2182, SIVA, 8th Main Road, E-Block, Rajaji Nagar, 2nd Stage, Bangalore 560010, India
e-mail: Vallury.sarma@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_24

I felt that introspection is certainly going to be instructive. It is said "*mana eva manushyanam karanam bandha mokshayoh*" (मन एव मनुष्याणां कारणं बन्धमोक्षयोः). The ultimate source of all human endeavours is the mind and the purpose of engineering education is to train one to play the role of the designer of artefacts supposed to achieve specified goals or to serve some contingent purpose in a particular environment, say home, market place, factory or battle field. My interest in Artificial Intelligence, an endeavour to build systems displaying human-like intelligence, makes the quotes in the beginning become part and parcel of my ideas on engineering. Where does the mind begin and end? What is its capability and limitation? What is its relation to intellect, consciousness, knowledge, psyche, self and soul on one hand and brain on the other? These have been questions continuing to bother humans since ancient times, and still await complete understanding of the people working in diverse fields such as neuroscience, computer science, psychology, philosophy and religion. Brain is a physical material entity described with terms such as the grey and white matter. What is the ontological status of mind? The Sanskrit terms "*padam*" (पदं = word) and "*padartha*, (पदार्थ = meaning, denotation, category, matter etc.)" summarize the issue.

Beginning of the Journey

Earth has made more than 20000 revolutions since I joined the BE program in Electrical Technology in the EE section of the Power Engineering Department at the Indian Institute of Science (IISc) after my B.Sc from Andhra University (AU). I heard of two famous names connected with the IISc, before joining there; of legendary CV Raman and his protégé and the Institute's then director, S. Bhagavantham, who was to become the first SA to RM (GoI). Both of them were earlier associated with Visakhapatnam and AU. I had to choose between the M.Sc. (Nuclear Physics) program at AU or the BE at IISc. My cousin P. R. Rao who did his M.Sc. (Physics) at AU then working in Bangalore recommended IISc to me. I also preferred Bangalore to Visakhapatnam, though I had no clear idea about the scope of engineering and its relation with science, mathematics and the human. I realized much later that this confusion was universal and I strongly disagreed with one erudite director of the IISc, who declared in an editorial in a science journal that science and engineering were the two sides of the same coin. Engineering, like any other creative activity, is just a virtual reality (VR)[1] world view of our inner being, just like science, philosophy or literature. This article is my journey down the memory lane in the world of engineering education.

[1] Virtual Reality (VR), is multimedia experience of computer-simulated life projecting an environment that simulates physical presence in places in the real world or imagined worlds and lets the user interact in that world. Virtual reality artificially creates sensory experiences, which can include sight, hearing, touch, smell, and taste. Acarya Sankara says that the so called the ephemeral real world is also such an illusory vision of human consciousness.

Engineering—An Ancient Art

The words engine, engineer and engineering are related to a qualifying adjective "ingenious", its Latin root being *ingenerare*, which means "to create." God, the Creator, is obviously the first, the eternal and the best engineer creating and recreating the worlds (*lokas*) and the evolving beings inhabiting these worlds. Sri Krishna succinctly defined activities such as engineering as Yoga in his Bhagavad Gita (BG 2.50) as "*yogah karmasu kausalam*" (योग: कर्मसु कौशलम्). Action performed with skill and dedication is Yoga. The appropriate mind-set for action can also be achieved through Yoga. No wonder, the IIT at Kharagpur adopted this as its motto. Yoga practice may be termed "control engineering" of human mind and consciousness and the very first sutra of Patanjali Yoga Sutras, says that Yoga stills the fluctuations of the conscious mind (*yogah cittavrtti nirodha*, योगश्चित्तवृत्तिनिरोधः) through techniques such as breath control. The relationship between body, breath, mind, knowledge and bliss is a well-discussed problem of Indian philosophy. According to Taittiriya Upanishad the soul is visualized within the body in the form of a miniature inch-man (अंगुष्ठमात्र पुरुषः) representing a soul (जीव) covered with five sheaths (कोशः) made of—food (अन्नं), breath (प्राणः), mind (मनस्), knowledge (विज्ञानं) and bliss (आनंदः).[2]

God as creator is a transformation of an idea of creation (*samkalpa*, संकल्पः) arising of the attribute-less (*nirguna*, निर्गुण) Brahman dividing itself into Siva and Sakti or Purusha and Prakriti. This mutation is the starting point of creation. Theories of creation of *Darsana* literature involve a beginning, a transformation and an evolution, aptly described by Sanskrit terms such *Arambhavada* (आरंभवादः), *Parinamavada* (परिणामवादः) and *Vivartavada* (विवर्तवादः). God specifically as an engineer is represented in the Puranas by the divinity for architecture, Viswakarma (विश्वकर्मन्) and his Asura counterpart, Maya (मयः), the architect/engineer of the well-known palace Maya-Sabha in the Pandava Capital city, Indraprastha, identified with the modern city of Delhi in the Mahabharata. Asura Maya was also credited with the ancient Hindu Astronomy text "Surya Siddhanta" of Vedic Cosmology. Viswakarma was credited with many structures. He built the city of Lanka and the Pushpaka Vimana of Ravana in the Ramayana. Ancient civilizations (4000–1800 BCE) also boast of many civil engineering achievements. The Saraswati-Sindhu civilization, also known as the Harappan or the Indus valley civilization discovered in archaeological excavations is characterized by advanced town planning and water resources management applications. The sites such as Harappa (Punjab), Mohenjo-Daro (Sindh), Dholavira (Gujarat), Lothal (Gujarat) and Kalibangan (Rajasthan) are widespread in North West India up to Gandhara (modern Afghanistan) [1]. A recent (2007) paper in the Elsevier journal "Building and Environment" brings out elegantly the relationship between Hindu cosmology and the *vastu-purusha-mandala* (वास्तुपुरुषमंडल) in the 11th century Kandariya Mahadeva temple at Khajuraho, and explains the fractal geometry involved in the architectural design of the temple (Fig. 1) [2].

---

[2]Sivananda Murty, in his classic work "Katha Yoga", (Aditya Prakashan, New Delhi, 2009) gives an interpretation of Kathopanishad from the point of view of yoga. He explains the 5 sheaths of the inner man (the self) of anna, prana, manas, vijnana and ananda.

Fig. 1 Kandariya Mahadeva Temple, Khajuraho

The word "engine" in early English meant "to contrive". While military engineers worried about engines of war, the same principles are used by civil engineers (the term includes their mechanical, chemical, electrical, communication and aerospace counterparts) to design and operate the engineered artefacts in the service of the society. My own journey of half a century in engineering education was well within in the philosophical boundaries of civil and military engineering rather than in the development of a specific technology and its application in a single problem domain. In the Institute, my *alma mater* also, my own career as a teacher which commenced from the EE department (1967–73), went through ECE (1973–77) and settled in the School of Automation (now CSA) (1977–2012) and my 18 Ph.D. students and 6 MSc (by research) students from time to time were drawn from CSA, ECE, Aerospace, Mathematics and Metallurgy departments and engineers from organizations such as IAF, NAL, ISRO, DRDO, BHEL under the external registration program. My working together with them closely was on defining, modelling, representing and solving problems arising in a specific context in a satisficing (meaning satisfy and suffice) manner. Teaching or research in my view is constant learning for the teacher even more than for the student.

From Good, Old Fashioned Electrical Engineering to Cybernetics and Man–Machine Systems

After a colourful B.Sc program, which gave us under the then new regulations, a strong dose of English literature, general education consisting of economics, history and politics along with science subjects, MP and C, the BE course appeared rather a dull, colourless, tasteless and out-dated affair. Among seemingly disconnected and assorted subjects such as applied mathematics, applied mechanics, hydraulics, building construction, surveying, and machine tools in the first year, Electrical Circuit Theory was the only subject connected with the supposed main stream of study. While the Physics course of Electricity and Magnetism in BSc followed the historical route of electric charges, magnetometers, gold leaf electroscope, cells, solenoids and induction coils, Maxwell and Faraday, the EE course started with Ohm's and Kirchoff's laws, R, L, C circuits, voltage and current, both AC and DC. While the other courses generally followed British books, the lecturer of electrical engineering (who had an MS from Wisconsin) followed an American book, which had a better pedagogical approach. The lady, C. Lakshmibai, soon after earned the first Ph.D. awarded by the EE department of IISc. Even in our final year (1963–64) mostly vintage subjects such as electric traction, illumination, utilization, machines, wood pole and tower design and aspects of T&D of electric power were taught. Atkinson's Telephony and Gray's Electronics represented the electronics and communications part of the course. But changes were in the offing in the BE and ME programs of IISc by mid-sixties. The faculty of the department was much more research oriented than what the out dated BE program we went through, represented. The first head of EE, Alfred Hay's bridge circuit named after him and Yoganandam's method of current transformer testing (J of IEE, 1930) found their way into Golding's classic book on Electrical measurements in their time. From 1949 to late 1960s, the EE department's prized possession was an AC network analyser produced by GE. Before 1950, 30 such machines were in operation, 29 in USA and one at the IISc. All electricity boards in India simulated their power networks using it but this machine was out of bounds for students. The machine was a special-purpose analogue computer, used for power system analysis, power flow studies, short circuit calculations, and system stability studies till such machines were ultimately replaced by numerical solutions running on digital computers by 1980s. In 1958 IRE Transactions on Electronic computers published a paper on "A Novel Type of Isograph (Algebraic Equation Solver)" designed and built in the EE dept by P Venkata Rao and his student G Krishna, a special purpose analogue computer for accurate computation of roots of polynomials useful in analysing servomechanisms. Our own computing tool was a German made Aristo Studio slide rule.

By the time I joined ME (Power Systems) course in 1964, many visible changes have come into effect in the curriculum. Deekshatulu's Ph.D. thesis in nonlinear control with many publications in Transactions AIEE (constituent of later IEEE) established that high quality research could be done in India itself. Srinath, a Ph.D.

from University of Illinois, taught us control theory. His use of Lee's book on Statistical Theory of Communication for the course on Advanced Control brought out the relation between Control and Communication. In ECE department Rideout and Rajaraman built a differential analyser and Ramakrishna studied relative efficiencies of Indian languages for Morse code. His mention of Panini's name made me curious. Names such as Wiener, Shannon, Bellman, Kalman, Nyquist, Pontryagin and Lyapunov became the new *Sapta Rishis* (Ursa Major, the Great Bear) on the control sky.

Components to Systems

From components such as motors, generators, transformers, towers and transmission lines we encountered in BE, the study of power system was a different ball game. A huge system of hundreds of generators spread over a vast geographical area and considerations such as load flow, load frequency control, stability and operational economics come into picture. The control and management problems get entangled. The problem of power system ever since had become major techno-management problem implying a fundamental reengineering of electric utility and service industry aimed at achieving a smart grid today. A smart grid is an evolving system which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, energy efficiency resources, electronic power conditioning, e-commerce and control of the production and distribution of electricity with high quality of service and dependability.

I realized that general systems, be they transmission, transportation, water resources or communication systems, they were all being studied using a single methodology. I joined as a Ph.D. student working in control theory in 1966 under the supervision of Deekshatulu as a continuation of my ME project on power system control.

Deekshatulu asked me to work on Optimal Control Theory. Tou's book on Modern Control theory appeared just then with a chapter each on Calculus of Variations, Pontryagin's Maximum principle and Bellman's Dynamic Programming. They were like three formidable hills to be climbed and the literature looked like an intimidating forest. My guide had the stamina of a Bhagiratha to do exhaustive search on nonlinear control to come up with solvable problems with novel solutions to specific equations for his thesis but he himself was not much deeply involved in my topic. Luckily a text book on optimal control by Michael Athans from MIT appeared which evolved from his teaching of a course there. It contained many worked examples of optimal control and an exposition of the LQG (linear quadratic Gaussian) problem, showing that a linear control law derived from solving a Matrix Riccati equation as optimal with respect to energy-optimal quadratic criterion. With this work I was able to formulate some performance evaluation and sensitivity problems of optimal control. When the states are not measurable a state observer can be used to estimate the states from the input and output of the system. I was finding it difficult to conceive of some new problems. Thomas Kailath of Stanford was then spending his sabbatical year at the ECE dept of IISc. I attended his lectures on Wiener and Kalman filtering and on his advice I started work on stochastic optimal control and differential game problems and completed my thesis entitled "Some studies in optimal control with quadratic performance criteria". I did not like the title myself and I insisted my students that they should use titles that stress the main contribution of the thesis. Soon I had to find a problem and an approach for solving it for a research student who joined with me. I was awarded Ph.D. degree in March 1971 and Mansoor Alam joined with me in Aug 1971 and I decided that I would give a well-defined problem to him for research rather than suggesting an area of work as in our time.

We had a nice system then working at the IISc library. All the new journals received in the week were displayed in a hall on Friday evening. It has become a habit to me, learnt from my guide, which continued for a long time, of spending few hours in the library at that hour browsing through the new journals. Till my Ph.D. was over I was mostly referring to journals in Control theory such as IEEE Trans Automatic Control, International Journal of Control, Proc. IEE, J of Basic Engineering (ASME) and Automatica. After getting the degree, I was curious about the content of Management Science, Operations Research and other engineering and economics subjects. The terms control, manage and govern sounded similar to my ears. I located some papers dealing with machine maintenance, formulated and solved as optimal control problems, written by two American Professors from management schools at Carnegie Mellon and North-Western. The models were simple and the deterministic control theory they used was elementary. I was better equipped to use advanced control theory. I showed these papers to my student and told him that we can develop a unified theory, also taking into account the uncertainty in the system. We could formulate and solve the problem in a very short time. We wrote a paper and submitted the same to Management Science. The reply was prompt saying that our style of presentation was nearer to engineering than to management science and we were advised to submit the paper to an engineering journal. We sent it to the new IEEE Transactions on Systems, Man and Cybernetics. It was accepted as full paper in the first review. The model was generalized considerably soon using Markov and semi-Markov decision models and papers in IEEE transactions on SMC, Reliability, Automatic Control, International general of Systems Science followed. Alam submitted his thesis in July 1974 with more than 8 excellent publications. The work got him post-doctoral fellowships in UK and Canada in sequence and he is now a Professor and Chair of EECS in University of Toledo, OH, USA. In 1974 AK Rao of aerospace department saw the reports on this thesis in Senate proceedings and inquired me if our methods can be used to study the maintenance problems of aircraft. An air force engineer who completed his ME in Aeronautical Engineering would be able to register for Ph.D. and we could bid for a DRDO (ARDB) project to support the work.

After hours of discussions with the student Ramchand (I should call them domain knowledge elicitation sessions now) on maintenance problems of IAF aircraft and after visits to the flying stations and repair depots, I had an emerging mental picture of the issues at hand. The availability of a small fleet of aircraft in a flying-base, repair-depot combination was modelled and studied. A cyclic queue model showed the effect of the principal uncertainties in operation and repair and the consequent decrease in the availability of aircraft at the flying-base. This was published in IEEE Reliability. Queuing models were not unfamiliar to me. We encountered them in design of automatic telephone exchanges and they were developed by a Danish telephone engineer Erlang much earlier. We had seen some applications of cyclic queues in a Civil Engineering journal in an application concerned with earth moving. We adopted that model for our study. The perennial problem of resource allocation for fleet and facility build up that faces planners was modelled and solved as an optimal control problem. These models contain two "policy" variables representing investments in aircraft and maintenance/repair facilities. Interactions of major activities involved in air fleet operations, maintenance, and logistics were investigated in the framework of closed queuing networks with finite number of customers. An interesting by-product of this work is the use of spectrometric oil analysis program (SOAP) data from the Rolls Royce Gnome Engines of Westland Sea King helicopters of Indian Navy. I was told that Navy was sending SOAP data samples to London for engine maintenance decisions. We developed a decision theoretic model for health monitoring which was published in the AIAA Journal of Aircraft. Several papers in IEEE Transactions of SMC, Reliability and Simulation journals resulted from these studies. The reviewer of the thesis, Andrew Sage of Southern Methodist University (who was also the chief editor of the IEEE Trans SMC) wrote "the thesis was the best I had seen in recent years". The IAF officer later rose to be the Director of a DRDO laboratory, CABS (Centre for Air Borne Systems) and Mani, the project assistant subsequently became a Professor in Aerospace Engineering at IISc. My ideas on Systems Engineering as distinct from device technologies thus found their initial successes. Pedar from Electronics division of NAL joined for Ph.D. and his lab director, SR Valluri, wanted him to work on aerospace electronics. We discovered that the trend was fly-by-wire (FBW) aircraft. FBW system replaces the conventional manual flight controls of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires and flight control computers determine how to move the actuators at each control surface to provide the desired response. The FBW system also allows signals sent by the aircraft's computers to automatically perform control functions without the pilot's input, as in systems that automatically help stabilize the aircraft, or prevent unsafe operation of the aircraft outside of its performance envelope.

The aircraft computer is to be an ultra-reliability system and design of such Fault–tolerant systems was a special area in Computers on which IEEE transactions on computers was publishing special issues regularly. Pedar's work brought out the concept of phased mission analysis of aircraft flight and the architecture optimization of aerospace computer systems. The first paper from the study was published in IEEE Trans on Reliability and the second one was in IEEE Transactions on Computers. The later paper was republished by IEEE as a benchmark paper in the area of hard real-time systems. Pedar later spent some time in NASA labs as a guest scientist. Ramana from ISRO used queuing models for slotted ALOHA satellite channels. He then moved to INMARSAT (maritime satellite organization), London. His results appeared in Proc. IEE (London) and IEEE Trans A. C. Ramanjaneyulu (Ram Chakka), who worked for his M.Sc (by research) with me, proposed a model for server unreliability in closed queuing networks. Breakdowns and repairs of servers, assumed to be time-dependent, are modelled using virtual customers and virtual servers in the system. The problem is thus converted into a closed queue with all reliable servers and pre-emptive resume priority centres. The results were published in IEEE reliability 1989. He later completed his Ph.D. in University of New Castle UK and continued his excellent work in the same area and is a Professor of Computer Science, and Director of Research at MIET, Meerut now.

With my friends Viswanadham (IISc) and MG Singh of UMIST (UK) we completed a research monograph on “Reliability of Computer and Control Systems” published by North Holland in 1987. Viswanadham distinguished himself later as professor researching in Logistics and Manufacturing at ISB, Hyderabad and NUS, Singapore after voluntary retirement from IISc. Kanchana of CABS (DRDO) in the year 2000 did work on Software quality and dependability issues for the airborne surveillance platform. She used Taguchi methods of experiment design for software quality enhancement.

Move Towards PR and AI

Deekshatulu, after his sabbatical at IBM Watson Centre and the Environmental Research Lab (formerly, Willow Run Lab) at the university of Michigan, brought back ideas on subjects such as pattern recognition (PR), picture processing and remote sensing and started courses on such subjects. Around 1976 Deekshatulu left IISc to become director of NRSA Hyderabad where he played a key role in the popularization of remote sensing technology in India.

In the meantime my association with ECE department opened new horizons and also introduced constraints. The mind-set in ECE was a frequency based division of the universe. I had begun to look at signals along with systems that communicate them. Audio, Radio and TV and Microwave along with Tube electronics and transistor electronics were the faculty groupings. Colleague and friend, Yegnanarayana’s effort led to the development of an acoustics lab with anechoic and reverberation chambers. He is presently among our top-notch speech scientists now associated with BITS, Hyderabad after superannuation from IIT Madras and later at IIIT, Hyderabad. Speech signal processing and speech recognition were then being talked about. Atal, an alumnus of ECE, working in Bell Labs came out with the linear predicting coding of speech. Atal’s LPC scheme was, in fact, the discrete form of Wiener filtering.

In ECE, I used to teach Statistical theory of communication and Detection, Estimation and Modulation. I was also the first to teach a digital signal processing (DSP) course in IISc. With my control background and familiarity with Z-transform in sampled data control systems, DST posed no problems. Speech signal interested me. Languages developed as speech and writing was a much later affair. The phoneme set (varnamala, वर्णमाला) of Sanskrit perfectly matches with the speech production system of a human being (the vocal tract). Speech can be used for a variety of PR problems. Henry Dante worked with me on Speaker recognition. With the limited facility of digitization of speech available on a HP Fourier analyser we demonstrated accurate speaker identification for a set of hundred speakers. The 1979 papers on "Automatic speaker identification for a large population" were published in Acustica and IEEE Trans on Acoustics, Speech and Signal Processing. A paper entitled "A pattern recognition model of voice-based personal verification systems for forensic applications" appeared in IEEE SMC in 1980. I now see that ICICI bank and SBI are introducing "voice-banking" in India.

"Divide and conquer" was an age old problem solving paradigm, and it is considered a "weak" or "narrow" AI method. In stochastic control it takes the form of separation theorem. The estimation (or filtering) problem and the feedback control problem are solved separately. In PR the separation is between feature extraction and classification. In statistical PR with two classes, the classification problem is the binary hypothesis testing problem of statistics or the detection problem of communication. In medical diagnosis features or test results have associated costs and risks. My student Dattatreya looked at the problem of medical diagnosis as a hierarchical PR problem and his work with deterministic costs was published in IEEE Trans on Pattern Analysis and Machine Intelligence. He extended it to stochastic costs in a Trans SMC paper. Dattatreya was a professor at University of Texas at Dallas for two decades and is now a principal scientist in MITRE Corporation, an exclusive Systems Engineering and IT consultant firm for the US government. Bharathi Devi worked on Fuzzy pattern recognition and our IEEE Transactions SMC paper on "Fuzzy Clustering" was republished in a later benchmark paper volume.

In 1983 I visited my Guru Maha Mahopadhyaya Dr. K. Sivananda Murty at Warangal, a well-known Vedic scholar and Yogi. His interpretation of Kathopanishad in the light of Yoga Sastra is my reference text for Hindu philosophical issues touched in this essay. He suggested that I should look at Artificial Intelligence (AI) as an area for my further research work. In 1984 I went on sabbatical leave to the Centre for Advanced Computer Studies, University of South-western Louisiana (USL, now University of Louisiana at Lafayette). I started to teach AI at USL. AI was also called MI (machine intelligence) and the term artificial (meaning made in imitation) seemed to convey a negative connotation. Designing machines exhibiting human-like intelligence and smartness was the goal here. We encounter the philosophical questions of the mind-body problem, human rationality, logic, information and knowledge and consciousness issues and AI has strong interfaces with philosophy and psychology. In psychology computers provided an analogy for the mind-brain system I realized that AI books talk only of Aristotle and Greek Logic. The much deeper Indian contributions to logic, language and human mind find inadequate mention in the Computer Science literature. Very few have heard of Akshapada Gautama of yore or more recent (12–18 century CE) contributions of logicians of Mithila and Navadvipa such as Gangesa Upadhyaya and Raghunatha Tarka Siromani. While the Western logicians were still in the Aristotelian frame of mind, in Navadvipa (Nadia Dist, WB), the Navya Nyaya School of logic reached its peak. In modern times B. K. Matilal

(Kolkata and Oxford), N. S. Ramanuja Tathachar (Tirupati) and P. Sriramachandrudu (Hyderabad) excelled in Darsanas. At least I had the good fortune of meeting the latter two of them. While my thoughts were on the philosophy of AI, my students were working on engineering aspects of AI and incorporation of AI ideas in Systems design.

Computer scientists have already recognized the contributions of Sanskrit grammarians such as Panini, Patanjali and Bhartrhari to the study of generative grammars of languages. In computer science, BNF (Backus Normal Form or Backus–Naur Form) is one of the two main notation techniques for context-free grammars, often used to describe the syntax of languages used in computing, such as programming languages and drew inspiration from Sutras of Panini. Noam Chomsky undoubtedly derived inspiration from Panini. In fact there was some discussion in IEEE to name BNF as Panini-Backus form. This created in me an interest in Indian logic (nyaya, न्यायः and associated tarka, तर्कः) and its possible use in IT. My first encounter with India Logic was in an Encyclopaedia of Logic I saw it in the USL library and my first expository paper entitled "A survey of Indian Logic from the point of view of Computer Science" was in Sadhana (1994). A more recent one which touches Navya-Nyaya relations is in JNU's annual manual on Sanskrit Studies [3].

Computers and the Sciences of the Artificial

Cybernetics, which was defined as the science of control and communication in the animal and the machine by Norbert Wiener way back in 1948, later was defined by many variously as experimental epistemology concerned with the communication within an observer and between the observer and his environment (McCulloch) and science of effective organization (Stafford Beer) focussing on form, pattern, and metaphors of behaviours rather than on specific things. In the twentieth century the human being has become an integral part of the engineering system design. Human–Machine systems have become the order of the day. Design of an aircraft with a human pilot in the cockpit assisted by smart "phantom" flight crew makes the human being a subsystem rather than an external operator or the designer of the system. Mind, intellect and consciousness, the internal instruments (अन्तःकरण) of a human, in some form have to become a part of the engineered system as neuro-system models. Neuroscientists study how different neural circuits analyse sensory information, form perceptions of the external world, make decisions, and execute movements.

Over the last several decades, Cybernetics has evolved as a trans-disciplinary approach for studying self-organizing and regulatory systems. Today Cyber-Physical Systems consisting of collaborating computational elements controlling physical entities and systems are contemplated in areas as diverse as aerospace, automotive, chemical processes, civil infrastructure, energy, healthcare, manufacturing, transportation, entertainment, and consumer appliances. Social engineering and Political Engineering are meaningful terms for an engineer today. Easley and Kleinberg talk of reasoning methods in a highly connected society in their book "Networks, Crowds and Markets". Black money flows, money laundering, correlation of real estate business and general elections with cement factory production can all be modelled and studied using this basis. I wrote some introductory articles on these network topics in newspapers and magazines.

The term "artificial intelligence" was the brainchild of the Noble laureate (in Economics), Herbert Simon. In his classic work "The Sciences of the Artificial" [4] he observes "The world we live in today is much more human-made, or artificial, world than it is a natural world. Almost every element in our environment shows evidence of human artifice." He adds that a computer as part of a system makes it smart. This immediately raises the questions "Can machines think? Are they capable of rational behaviour? Do they display consciousness, sentience and conscience of some form?" The observation is that both the brain-mind system and the digital computer are information processing systems. At the first level, Simon introduces heuristic search, where brute force search is replaced by "search and reason" approach as a first thinking task solvable by computers in imitation of human intelligence. Simon observes that the most characteristic cognitive skill of human beings is the use of language. The key observation of Simon is "While the computer is embodied in hardware, its soul is a program." The similarity is that both work on symbol strings. A computer can provide a model for brain-mind system (an aspect of the mind-body problem) in specific intelligent tasks, such as playing games and solving puzzles. How far can "the emperor's new mind"[3] go, or is it similar to "the emperor's new clothes"?

Our AI Based Work

I asked my student Sunil Noronha to look at project management problems from the point of view of AI. The project evaluation and review technique (PERT) is well known. Normally such planning work is done before the project and date of initiation and PDC are given. But if there are delays as usual in the completion of activities and costs, The PERT chart does not help in on-line monitoring. There are lot of uncertainties in the information and knowledge available when the project is initially planned. Noronha developed an intelligent decision support system using imprecise information and knowledge structures called project influence graphs combining the power of PERT networks, influence diagrams and Petri nets. Our 1991 survey paper in a special issue on AI in management with some new material in IEEE Transactions on Knowledge and Data Engineering entitled "Knowledge-based approaches for scheduling problems: A survey" was widely cited. Our joy knew no bounds when

[3]The Emperor's New Mind: Concerning Computers, Minds and The Laws of Physics is a 1990 book by mathematical physicist Sir Roger Penrose. Penrose argues that human consciousness is non-algorithmic, and thus is not capable of being modelled by a conventional Turing machine-type of digital computer. Penrose hypothesizes that quantum mechanics plays an essential role in the understanding of human consciousness. This makes it closer to the Jaina logic of syadvada.

we saw the paper entitled "Artificial intelligence: where has it been, and where is it going?" by Herbert Simon, father of AI, in the same issue, preceding our paper. With an Iranian student, Mohsen Moshkenani, I did some interesting work on a less studied problem in expert systems. In his thesis "Knowledge teaching: An alternative strategy for knowledge-base (KB) development" we looked at the knowledge acquisition bottleneck in expert systems. In traditional systems a domain expert is constrained by the structures imposed by the knowledge engineer. In our scheme the computer is modelled as a student and the domain expert as a teacher with or without the intermediary of a knowledge engineer. All that can be expressed in a language by the teacher should find a place in the KB. We looked at dimensions of knowledge, knowledge types, whether knowledge is fully expressible in language, gaps and inconsistencies in knowledge, truth and its degrees and designed an interactive system for knowledge teaching where the domain expert is a teacher and the program a student. In retrospect, today I would apply Indian logic for testing the veridicality (degree of truth) of proposition. AI can handle only belief systems. Truth is only tentative and is a matter of degree. Language is always ambiguous. Knowledge coexists with ignorance in any human being. Knowledge, which is a created product of the mind, is always specified in relation with awareness of human beings. A proposition in Plato's dialogues views "knowledge as justified true belief". If we consider the proposition "Sun rises in the East", it is true for an observer on the Earth. For a traveller in space it has no meaning. A proposition justified true on the basis of sensory perception also need not be absolutely true. Thus means of arriving at correct knowledge (प्रमाण), thing to be studied (प्रमेय) and doubt or uncertainty (संशय:) are the first three categories of Indian logic according to the first aphorism of Gautama. Thesis of N Srinivas (1996) dealt with uncertainty handling in KBS (Knowledge-Based Systems) and Mohanvelu proposed expert systems for frequency management in ISRO. Another student Suresh Babu from BHEL worked on PROLOG technology for temporal reasoning in relational databases.

Vijay Rao from DRDO worked on quantitative software lifecycle modelling. An evolutionary process taking place in engineering systems is the shift from hardware to software and the role of software engineering is becoming more central. This shift represents a trend from a piece-meal vision of software development to a holistic, system-wide vision. The term "software crisis" of 1960s and 1970s was the observation that most software development projects end up with massive cost overruns and schedule delays. The growing complexity of software projects led to Waterfall, Spiral and other qualitative models to depict the software development lifecycle. We developed a generic, unified lifecycle model (ULM) integrating the product, process and project view of software development based on re-entrant lines, which are multi-class queueing networks. The techniques also included fuzzy and rough set concepts. Some of this work was recently published in 2014 Springer monograph on "Innovations in Intelligent Machines—5 (Computational Intelligence in Control Systems Engineering (Ed: Valentina Balas)).

R. Ravi's 2005 thesis is entitled "Intelligent Knowledge Based System for Hot Forging Process Design". Ravi worked with me and a physical metallurgist Y. Prasad for his Ph.D. in CSA department on expert systems for metallurgy. In any bulk metal working process, designing the process for forging is strongly dependent on human expertise, intuition, and creativity, and is an iterative procedure involving extensive and time consuming experimental work. A logical choice for realizing such a complex system is a hybrid intelligent system, consisting of an intelligent knowledge-based expert system and artificial neural network models. Ravi's thesis implements such a system resulting in considerable lead time and cost reduction. Ravi is a Principal Research Scientist in Material Engineering at IISc now.

The last student who got Ph.D. under my supervision in 2012 was Indra from ISTRAC/ISRO. Her thesis dealt with the architecture design of next generation smart satellites. Presently, most spacecraft are controlled from ground, which involves activities such as up-linking the daily operations schedule and monitoring the health parameters. Advanced space exploration systems demand intelligent autonomous spacecraft, which exhibit goal-directed and adaptive behaviour. An autonomy framework is defined with a six level structure comprising of the following capabilities—reflex, awareness, self-regulation, self-healing, self-adaptation and self-evolution. The last mentioned three theses were really engineering applications of AI.

Post-superannuation (2006–2016)

IISc and INAE supported me during 2006–2012 as honorary professor and distinguished professor respectively. I was able to study my favourite subject of interface between intelligent systems in engineering and Indian Philosophy. I have now greater appreciation of the four Darsanas: Samkhya, Yoga, Nyaya, Vaiseshika and some familiarity with Mimamsa and Vedanta. For exploring the limits of AI and smart systems on the one hand and for exploring the function of human mind in terms of thinking, memory, discrimination (viveka, विवेकः), knowledge, ignorance (अविद्या), consciousness, self, Atman and Brahman (as defined by *satyam jnanam anantam brahma*, सत्यं ज्ञानं अनन्तं ब्रह्म). Indian philosophy has the potential of clarifying the scope of AI and its boundaries. One of hobbies in this period is writing articles for general public in Telugu and English on topics of Indian philosophy, history, and society for some magazines and newspapers. Smart technology today has tremendous influence on the society. The impact of social networks such as Twitter and Facebook is one such example.

Studies by engineers can influence subjects such as history. Evidence combination methods of AI can check and question the credibility of historical narratives, particularly in the context of Indian history, where evidence from multiple sources is to be combined to get credible narratives. A less credible alternative is presented as a historical fact, such as the so called Aryan Invasion of India. Arun Shourie, an economist by training, could rightly question Indian historiography as the title of his book indicates.[4]

[4] Arun Shourie, 1998, Eminent Historians: Their Techniques, Their Line, Their Fraud.

Ethics for AI Systems

Ethics involves systematizing and recommending concepts of right and wrong conduct of humans living in a civilized society. In earlier days when it was called moral philosophy, religion and culture used to provide guidelines for acceptable social behaviour for humans by prescribing do's and don'ts. As societies become industrialized and as high technology becomes part of human life, many new ethical problems arise which need to be addressed by system designers and regulatory authorities. In the modern world, humans are constrained to coexist with artificial entities created by law such as organizations, companies and regulators on one hand and technological entities such as robots, driver-less autonomous vehicles, drones and even ubiquitous entities such as smart phone and i-pads interlinked to an Internet of Things (IoT). Laws, Regulations and Ethics are not keeping pace with the rapidly emerging new technologies such as AI.

Few examples where AI appears are sufficient to note its spread and widespread usage: ubiquitous computing, smart phones, mobile apps, mobile internet, Big data, social networks, autonomous vehicles (AV) and near AV, drones, internet of things, clouds, cyber physical systems (robotics) and smart cities. The ethics of artificial intelligence is the part of the ethics of technology specific to robots and other artificially intelligent agents and beings. Each domain listed above raises its own ethical concerns. While all the areas listed above have in the background AI programs, Intelligent Agents, Knowledge Bases, smart materials and subsystems, the regulatory policy and ethics have to be considered domain-wise. For example, what happens when a self-driving car has a software failure and hits a pedestrian, or a drone's camera happens to capture images of persons in a private swimming pool or an autonomous robot injures or kills a human? Contemporary ethical concerns about social networking services are privacy, the ethics of identity and community, friendship and values, democracy, freedom of speech and cybercrime. Recent discussions with members of a study group of ITU = ATP forum are summarized in this report [5].

Inner Hierarchical Structure of Mind

Human mind is defined in Western literature as the set of cognitive faculties that enable sentience, consciousness, perception, thinking, judgement, and memory. All these faculties constitute human intelligence. An intelligent engineering system on similar lines will have a perceptual system (sensors), a memory system, a processing system, a motor system (actuators), and so on. There is a need to consider knowledge and its representation. Is this knowledge trustworthy? There is a distinction between knowledge and belief and knowledge is the set of certified true beliefs. In view of the acceptability or otherwise of the certification process we may assume that AI deals with only belief systems. This is the view of Allen Newell in his paper "The

Knowledge Level".[5] There is a school which believes in brain-mind identity. Consciousness levels – Wake Up, Dream, Sleep, Anaesthesia and Coma consciousness are described with the body. Freud talked of id, conscious and subconscious levels. Jung distinguished between psyche and self. By psyche, he meant the totality of all psychic processes, conscious as well as unconscious. He defined self as a clearly demarcated functional complex that can best be described as a "personality".

Indian philosophy proposes a distinct inner hierarchical structure in the mind. At the lowest level mind (manas, मनस्) is felt only when there is thought. Mind manifests as thought. Thoughts arise when the sense organs make contact with the sense-objects. This contact is reported to the intellect (buddhi, बुद्धिः). Intellect consists in the use of discretion or discrimination taking place on the basis of past experiences known as memory (smriti, स्मृतिः). Memory spans everything in the past extending from the previous instant to remote past extending even to previous lives. Intellect projects its judgment or decision on to the consciousness (citta, चित्त) which is an impersonal non-discriminating reflector like a mirror. It is citta that propels the person (in fact, the core inner actor characterizing him) to action, right or wrong (karma, कर्मन्). It is this action (karma) which binds the actor or the doer to its chain of consequences. It is the actor that is called ego (ahamkara, अहङ्कार) or self (jiva, जीव). If citta through spiritual practice stops reflecting the intellect and is turned towards the ego, jiva becomes free of the separating consciousness and the jivatva is lost and the identifying tendency with respect to the body is lost. This is self-realization or being God (tat tvam asi). In the quote "I think, therefore I am" the first I is manas and buddhi and the second I is ego. In short, in the terminology of intelligent agents "the mind (manas) is the servant, buddhi is the reporter, citta is the observer and the ahamkara is the actor or owner. Indian logic is the logic of relations and the location-located relation is an important one. In this terminology, consciousness is the location of ego, which is what "I am conscious that I exist" means. This explanation clarifies the notion of mind considerably.[6] Stephen Phillips presented a paper on "The Mind-Body Problem in Three Indian Philosophies, Sankara's Advaita Vedanta, Gangesa's Navya Nyaya, and Aurobindo's Theistic Monism" at IIT Khargapur in 2002 and there is need for exploring this by AI researchers in India.[7]

[5] Allen Newell was among the pioneers of AI at CMU along with Herb Simon. This is from discussion in "Philosophical frameworks for understanding Information systems", 2007, IGI Publishing, Hershey, New York, (Ed) Andrew Basten, on Allen Newell's paper on The Knowledge Level.

[6] From unpublished lecture notes of MM K. Sivananda Murty.

[7] Infinity Foundation of Rajeev Malhotra was one of the sponsors of the International Multidisciplinary Conference on Mind and Consciousness during January 9–11, 2002, IIT Kharagpur and on his initiative Stephen Philips, professor of philosophy at U Texas, Austin presented this paper. Philips studied Navya Nyaya with Ramanuja Tatacharya of Rashtriya Sanskrita Vidya Peeth, Tirupati.

Conclusion

It is true that the smartness of machines is increasing at a high rate. Can a machine be ever made to reach the intelligence level of “the man who knew infinity”? Can quantum computers model brain functions or mental activities? Can “strong AI” (a machine with consciousness, sentience and mind) or “artificial general intelligence” (a machine with the ability to apply intelligence to any problem, rather than just one specific problem) realized in the near future. Probably the new generation researchers think about such things. A mental picture or thought is the specification of a future artefact. As it happens engineering always falls short of perfection and science always false short of truth.

References

1. Kulkarni RP (1987) Development of engineering and technology in India from 1000 BC to 1000 AD as revealed in Raja Tarangini. Indian J Hist Sci 22(4):316–327
2. Rian IM, Park J-H, Ahn HU (2007) Fractal geometry as the synthesis of Hindu cosmology in Kandariya Mahadev temple, Khajuraho. Build Environ 42:4093–4107
3. Sarma VVS, Gopal K (2004–2005) Indian logic (Nyaya) in modern information technology. In: Kapur K (ed) Sanskrit studies, vol 1, Samvat 2061–62 (ce 2004–2005). Special Centre for Sanskrit Studies, JNU, New Delhi and DK. Print World, New Delhi
4. Simon HA (1996) The sciences of the artificial, 3rd edn. The MIT Press, Cambridge
5. Sarma VVS (2016) Policy and ethical issues related to smart systems in diverse domains. In: Lecture notes. Indian Institute of Science

An Academic's Journey of Life Long Learning

K. P. Madhavan

As I reflect on various phases of my personal and professional life, I have come to realise how I have benefitted from diverse learning opportunities that came my way from time to time. My early life in a village in Kanjany, Trichur (Kerala) was an exciting learning experience of the unstructured kind. I learnt how villagers without access to modern tools could innovate and carry out their farming activities many of which are now done by machines. I had my first lesson in Physics watching my eldest brother construct an automatic water dispensing system for the poultry he was rearing. Perhaps one of the most exciting learning experiences was the unintentional demonstration of principle of applied mechanics by a team of coconut climbers in bringing down the heavy top of a coconut tree, which was hovering ominously over our house, along a safe trajectory away from the house. These early experiences underscored the importance of learning through such unstructured events, and making judicious use of available resources to achieve the desired goals.

School education opens up the structured pathway to learning. Here again one has to learn to mange the transition from one educational pattern to the next. This situation had happened to me in the early phase of my educational journey when I had to shift from the Government School near Kanjany, to pursue higher secondary education at St. Mary's High School in the mining town of Kolar Gold Fields. Learning to adapt to the urban life in Kolar and acquiring proficiency in Tamil and English were the challenges that had to be met. Access to quality reading material and inspiring tutelage from our Principal, Father Rajappa, helped me get a reasonable command of English. St. Mary's School had a well-structured academic programme, which did provide the base for me to go ahead in my academic career.

Transition to college education at the prestigious St. Joseph's college, Bangalore, was an experience to cherish. Since St. Joseph's had an array of excellent teachers in Mathematics and Chemistry and good lab infrastructure, learning was an exciting

K. P. Madhavan (✉)
3D, Anjaneya Cooperative Housing Society, Opp. Hiranandani Foundation School, Orchard Avenue, Powai, Mumbai 400076, India
e-mail: Kp_madhavan@yahoo.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_25

experience at this hallowed institution. On the personal side, this was the beginning of my hostel life. Despite the disciplinary constraints prevalent in such institutions, hostel life was a lesson in living harmoniously among a cosmopolitan student group. As my attempt to enter Government Engineering College in Bangalore after my intermediate (12th) proved abortive, pursuing B.Sc at St. Joseph's Bangalore remained the best option for me.

Post B.Sc, my relentless pursuit to pursue engineering bore fruit as I could get admission to the Chemical Engineering programme at AC Tech, Madras. The irony of the situation was that Electronics was my first preference for a career and I had no idea of what Chemical Engineering stood for. Despite these reservations, I decided to plunge into the area trusting my erstwhile learning and scholastic capability to help me embrace this unknown discipline. Since it was a two year post B.Sc programme there was imperative need to absorb the essentials of Chemical Engineering within the limited span of two years. We had the advantage of learning from Prof. G. S. Laddha (Director) who was one of the leading academics in Chemical Engineering of that era, and other inspirational teachers like Prof. A. P. Madhavan Nair and Prof. Murugamanickam. Prof. Murugamanickam had also marveled us with the display of a remote controlled car that he built in his garage. We found laboratory experiments in Engineering very interesting. Doing a B.Tech project on Design of Multicomponent Reactive distillation for the production of Butyl Acetate was one of the toughest assignments we had to handle. In 1958, when the only computational aid was the ubiquitous sliding rule, the plate to plate calculations we had to do were very arduous and time consuming. This initial tryst with distillation was the forerunner for many of other investigative work I could do on the topic in later years.

The compulsory three month industry training as a part of the curricular requirement for the B.Sc Tech degree did provide me an early exposure to industry. During my training at Travancore Cochin Chemicals, Alwaye (Kerala), I could get to study in totality the functioning of the Caustic Soda plant. While the early part of my training was mainly exploratory, I could get to work later on an investigative project of extracting mercury from the electrolytic cell mud waste. This promising project had to be terminated abruptly due to safety concerns of working with mercury without proper fume hoods. This was an early lesson about the paramount importance of safety in the plant and in the laboratory.

Without waiting for a 'dream job' to materialize, I took up the first option to get myself professionally engaged by taking up a one year Government of India Practical Training Scheme at Travancore Titanium Products Ltd., Trivandrum. In retrospect, this turned out to be a rich learning experience from an industrial perspective and opened the gateway for my professional career. While the plant had diverse unit operations, the most interesting among these were the huge RCC reactors, in which Ilmenite digestion with Sulfuric acid was being carried out. I could experience at first hand, the intensity of this exothermic reaction, which set of vibrations in the supporting structures also. There was much to be learnt by studying the operation of each of the unit operations in the plant. An interesting assignment I had undertaken was development of material and energy balance for the Titanium Dioxide plant, a task more demanding than the simple material and energy balance problems we solved in the classroom. I had to learn the art of extracting reliable information from myriad sources, which included plant operating personnel, laboratory technicians and plant records. I had also gained valuable experience by associating myself with the team involved in installation of a Sulfuric Acid plant and its commissioning. The startup sequence used in commissioning the plant was an interesting eye opener as such practical issues were seldom discussed in the class rooms. I was also impressed by the excellent quality and completeness of technical documentation provided by the German licensor of the Sulfuric Acid plant.

During the industrial training, the area, which caught my fancy was Instrumentation and control. I had the good fortune to get admission to IIT Bombay for pursuing Master's Degree programme in Chemical Engineering with specialization in Automation in Chemical Industries. This indeed was a turning point in my career. As I was among the first batch of students admitted to this specialization, there was considerable amount of self-learning to be done as there were no peers to reach out to. Most challenging was setting up a pH control system for my Master's Degree project. After graduation, the limited job offers that came in the area of Instrumentation and Control were not attractive. The enriching academic environment and the social life at IIT campus did entice me to continue for my Ph.D. During the early phase of my research, I had the good fortune to receive guidance from the Russian expert, Prof. Ivanov. He encouraged adoption of a research methodology, which required us to plan our own research independently. For researchers, there were several constraints with respect to the infrastructure, facilities and resources. Here again, the earlier lesson about judicious use of the available resources came into play. A typical instance of this was the development of a simpler Q meter equivalent to the Marconi Ecko Q meter for my Ph.D. work using the available Russian metering instruments and signal generators. Completing Ph.D. under these conditions was truly a lesson in endurance, optimism and self-belief to stay the course.

The academic ambience of IIT Bombay did provide a strong incentive for me to take up academics as my best career option. As a faculty joining the Chemical Engineering department in 1964, I had the good fortune to play a role in the development of the department in its growth phase. I was lucky to have Prof. Kamath as its astute Head who could play the role of a mentor, philosopher and guide. Besides his stature as a leading academic, he was also known for his prowess as an inspiring teacher with a mastery of the subject and excellent communication skills. While planning my own approach to teaching, I chose the option of reading as many of the books as I could on the subject and develop a course plan culled out of the material from these sources. Implied in this approach was also the need for continuous learning and preparation rather than the discrete approach of preparing learning material lecture to lecture. The first two subjects I got to teach were Instrumentation and Process Control. As things turned out, Process Control became the flagship course, which I could teach with relish to four generations of undergraduate students. Since the core material for this course was very analytical, there was challenge to develop easy to understand interpretation of the theory of some of the topics like stability and dynamics related controllability. Optimization was another course I enjoyed teaching at the Postgraduate level. In the initial years this course had attracted a good number of students from other departments also. I had to align my teaching plan to give equal attention to theory and applications drawn from various domains. I had also diversified my teaching to take up courses like Process Dynamics, Chemical Plant Simulation and Advanced Process control. Towards the fag end of my academic career, I was requested to take a new course on Artificial Intelligence in Process Engineering. I had to do extensive preparatory work to negotiate the course successfully. The lesson I learnt from this is "never lose an opportunity to learn new skills and knowledge even if it takes you out of your comfort zone ". I was also deeply involved in most of the departmental exercises in periodic curriculum revision and curriculum formulation for a Five Year Master's degree programme with specialisation in Process Systems Engineering. Converging on the final curriculum, in the face of divergent views, was often a delicate exercise needing patience and persuasive skills.

The development of teaching and research labs was a challenging task especially in a department in its growth phase. While the Russian aid had left the department with an impressive array of equipment and instruments and the Russian Technician had set up a functional Instrumentation and Controls lab, complete utilization of all these was hampered by inadequate documentation in English. In addition, much work had to be done to adapt them to teaching. Using a working knowledge of Russian to study the original Russian manuals and resorting to theoretical analysis, it was possible to get many of the instruments working. This included controllers, a wide range of measuring systems and an Analog Computer. Over the years the laboratories needed to be continuously updated to cope up with the transition pathway from pneumatic, analog, digital to microprocessor based systems. This included a versatile PC based pressure control system set up with the assistance of my Ph.D. student, Dr. Sachin Patwardhan (who later joined the department as a faculty) using the resources available in the lab. This was augmented with additional electronic and microprocessor based control systems procured from MHRD modernisation grants. There was much learning to be done to transcend from the analog to the digital world.

While the initial phase of my academic career was devoted to teaching, in subsequent years research became another equally engaging activity. Guiding research is always a learning experience especially when one has bright students who have the spirit of enquiry working under you. The choice of modeling, simulation, optimisation and control as the broad area of research did help me in getting motivated MTech and Ph.D. students to work with me. I had Ph.D. students from various backgrounds—IIT research scholars, teachers under QIP programme and scholars sponsored by R&D Organizations. I realised that besides providing guidance on technical issues, I needed to play the role of a mentor and a motivator rather than assuming the role of a relentless taskmaster. This approach of building of capability in them to do independent work seemed to work well with the assorted collection of students who had worked with me. Recognising the strengths and weakness of each student and shaping his/her career had been an enriching experience. My research topics for Ph.D. covered modeling, optimisation, and control issues of batch, azeotropic, divided wall distillation columns, exothermic semi-batch and laser photochemical reactors, hydrodynamics of jet type contactors, developing an integrated approach to design and control of chemical processes, model based control of nonlinear systems and heterogeneous and reconfigurable control structures. Two Ph.D. projects, which had great industrial significance in the Heavy Water manufacturing practice, related to Modeling of Heavy Water Cascade and Analysis of Jet loop reactors.

A new learning opportunity opened up for me when I got involved with setting up of a CAD Centre as part of an UNDP-DOE initiative for promoting computer applications in Chemical and Metallurgical industries. CAD Centre provided a good platform for me to engage in teaching and research in the emerging area of Computer Aided Process Systems Engineering. Another dimension to the learning was to develop the centre to act as a window to the industry with a mandate different from that of the academic departments. With proper planning and proactive activities of those associated with the CAD Centre, it could emerge as a unique model of a self supporting centre in the campus. Process Systems Engineering has also emerged as a dominant research area of the Chemical Engineering department.

A change in working environment can provide abundant opportunities for learning and understanding the professional world outside your habitual work place. During my visit to USA and UK in 1985 as an UNDP Fellow, I could get an opportunity to interact with leading research groups working in the area of Computer Aided Process Systems Engineering at universities of Purdue, Washington, Wisconsin, Carnegie Mellon and Imperial College, London. This helped me to know the state of art and the software tools available for supporting teaching and research in the area of Process Systems Engineering. During my second visit to Purdue as a visiting faculty in 1987, I could get to play a more active role in the academic activities of the department which included running and developing a hands on course on Computer Process Control using the real time IBM ACS control software. I could also do some developmental work, which included developing an integrated platform for fault diagnosis using IBM ACS/Expert system and developing computer based experimental systems for a distillation column, absorption column and a CSTR using the Camille Control System donated by DOW Chemicals to the department. My third visit to USA in 1993 was to Mobil's Research Centre at Princeton, New Jersey, to work on developing routines as per their software standards for integrating Mobil's Custom process packages with SIMSCI's Pro II simulation software. Through this association, I could get a first hand experience of the working style and professionalism of a global R&D organisation.

As a faculty, I felt that interaction with industry would provide an opportunity for me to work on real life problems. For industry consultancy and sponsored research assignments, I had soon learnt to chalk out a distinctive line of research, which would explore not only intellectually stimulating ideas but would also meet the project deliverables. I found by experience that successful industry targeted projects had a history of close interaction between the academia and industry. One such illustrative case was the long term R&D collaborative programme which IITB CAD Centre had with Honeywell Technology Solutions Ltd, Bangalore (HTSL). The collaborative project with HTSL had a high degree of complexity requiring an artful decomposition of the large scale problem to generate a tractable solution strategy. Another successful collaborative project CAD Centre had with a leading Sulfuric Acid manufacturer near Mumbai was the development of a Sulfuric Acid plant Simulator. Another challenging collaborative industry sponsored project was the development of integrated software environment for control system development for a process plant using the resources of a dynamic process simulator, control system design software and an Expert systems package. A unique learning experience opened up for me when I had the opportunity to sit on the Boards of Heavy Water (BARC) and Jopasana Software, Pune. The first organisation functioned in a strategic area with assigned targets and growth plans while the second one operated in a competitive business environment. I could get to understand the subtle differences in the way the respective boards looked at operational performance and future plans.

While the prime activity of a faculty is teaching and research, opportunities often come by faculty's way to participate in institutional developmental programmes. Though pursuit of these activities may take time away from research, I found that there were some administrative positions in the institute which could enrich one's background and vision. As Dean R&D, I could not only get a closer look at the spectrum of research done in various disciplines but also understand fully the ethos of academia –industry interaction. My experience as Dean R&D did help me to tackle a number of institutional developmental programmes that I was entrusted with. My association with the plan to start a Management School with focus on Technology and Manufacturing Management required me to develop a curriculum, which will embed these focus areas without compromising the essential facets of a general management education. For mobilization of funds for the School, I had the onerous task of preparing a proposal for financial support to be placed before the ICICI Board. With active co-operation of all concerned persons, I was able to prepare of a comprehensive document, which was not only academically sound but had also realistic estimates of infrastructural and funding requirements. I found this task a little more intimidating than writing up of a research proposal. The report was well received by the ICICI Board resulting in a sizeable financial assistance from ICICI for IITB Management School. This exercise was a unique learning experience for me as I could get an idea about the manner in which financial institutions addressed appraisement of developmental proposals. A few years after this exercise, I was again called upon called upon by the institute to explore options of integrating the Biotech and Biomedical academic divisions of the institute into a larger Bioschool, which could have a broader canvass for research. This required extensive efforts to bridge the engineering and science dichotomy and come up with a School which could provide a synergetic growth of the two disciplines the concept of such a school could only be evolved after protracted discussions with all the stakeholders. The lesson I had learnt from this exercise was that with frank and open discussions one could come up with a solution that could enable people with divergent views to work together in a harmonious manner. Another interesting assignment that I had to undertake for IITB was to co-ordinate the research of a multidisciplinary team working on the Mission Mode project on Integrated Design for Competitive Manufacturing. This required tactical handing of various research groups in the team and adopting a rational approach to resource allocation.

IIT Bombay provided me opportunities and freedom to pursue my professional interests in an unfettered manner. Chemical Engineering department provided me a warm and friendly atmosphere with my faculty colleagues and departmental staff supporting me in all the ventures I had undertaken. I am happy to see the emergence of the department as one of the leading departments in the country. It has been a privilege to work in such a dynamic department. While being at IIT Bombay, I had also the good fortune to come under the influence of many who have helped shape my professional career. Prof. Kamath was the ideal mentor who inculcated in me many qualities, which helped me to counter the highs and lows in my career. Prof. Kudchadkar pushed me to undertake assignments, which helped me broaden my spectrum of activities beyond the narrow confines of teaching and academic research. I had the good fortune to work closely with a succession of Directors holding the reins at IITB. Prof. De has been a great source of support to me both during his tenure as Director and thereafter. Prof. Nag gave me freedom to function as the Dean R&D. He had also entrusted me with some important institutional developmental activities. Prof. Sukhatme and Prof. Ashok Misra had also some interesting assignments for me to work on. I have learnt a lot interacting with them and these experiences have helped me become a more mature and complete professional. As resident of the Campus, I had realised the important position that students occupy at such a place. In my several roles of interaction with the students as faculty, supervisor, Head of the department and Chairman of Sports, I had always found excellent support and endorsement from the student community. I would cherish this as the greatest reward that I can get in my academic career.

After having worked for a long period in academic environment, my retirement in 2002 did not signal an end to my professional activity The professional engagements that came my way post retirement were as exciting as my earlier assignments. I could work with the R&D of some of the leading industrial organizations on a range of problems drawn from various domains. This called for extensive learning to understand the domain and develop solutions appropriate for the problems in the respective domain. A greater satisfaction that came out of these engagements was the mentor role I could play in nurturing the talents of the young engineers and scientists working on these projects.

As I conclude this narrative, I have come realise how the life of an academic can be an exciting journey of expedition with freedom to explore chartered and unchartered pathways providing abundant learning opportunities and professional challenges.

There Is Knowledge in Failure—If Followed by Root Cause Analysis

K. K. Vaze

Introduction

I obtained my B.Tech. degree in Mechanical Engineering from I.I.T. Mumbai in 1973 and joined the 17th batch of Bhabha Atomic Research Centre (BARC) Training School immediately thereafter. After completing the training, I joined Indira Gandhi Centre for Atomic Research (erstwhile Reactor Research Centre). After working for 15 years in the area of structural analysis and design of fast reactor components, I joined the Reactor Engineering Division of BARC in 1989. Subsequently I assumed the charge of Head, Reactor Safety Division and later Director, Reactor Design & Development Group. I retired in Sep 2014 after 40 years of service.

During my tenure at BARC I carried out extensive work in the areas of Nuclear Reactor Safety, Earthquake Engineering, Structural Integrity Assessment, Leak-before-break, Structural Analysis and Design, Fatigue, Fracture and Failure Analysis.

It so happened that around the time I joined BARC, there were quite a few failures in Indian Industry. For Root Cause Analysis as well as corrective actions, these were referred to BARC because of its eminence in structural analysis.

In this article I am going to talk about this single aspect of my work viz. Failure Analysis. This article is prompted by my reading of the book "The Mind of an Engineer" [1] in which many authors have pondered on the question whether the mind of engineer is different.

Dr. P.S. Goel in "Is an Engineer's Mind Different?" brings out that Engineer's mind ought to be different but most of our engineers do not possess that. Prof. Indranil Manna reflects on the dilemma "An Engineer or a Scientist?"

What better way than to learn from the Nobel Laureate Dr. Richard Feynman? After reading his memoirs "*Surely You're Joking, Mr. Feynman*!"*: Adventures of a*

K. K. Vaze (✉)
12, Pratik Regency, Sneh Paradise, Kothrud, Pune 411038, India
e-mail: kkvaze@barc.gov.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_26

Curious Character [2] *and* "*What Do You Care What Other People Think? Further Adventures of a Curious Character*" [3], one comes to an inescapable conclusion that he was a Scientist with the mind of an engineer. One area where the mind of an engineer distinguishes itself is the aftermath of a failure. The question that bothers him is "What is the Root Cause of the failure?"

The two stories in the memoires "He fixes radios by *thinking!*" *and* "Mr. Feynman Goes To Washington: Investigating the Space Shuttle Challenger Disaster" are masterpieces of Failure Analysis.

Another aspect that assisted us in our Failure Analyses was our assimilation of the ASME Boiler and Pressure Vessel Code, Section III [4] "Rules for Construction of Nuclear Facility Components" where the guiding principles are "Design by Analysis" and "Failure Mode Orientation" as opposed to the conventional approach of "Design by Rule" which provides design formulas, curves, charts and design procedures, which set the minimum required thickness and once this major parameter is fixed, the designer simply follows the rules for detailing of components such as flanges, heads, nozzles etc.

The rational approach for design adopted in Sec. III consists of:

(i) Identifying various failure modes,
(ii) Identifying the parameter causing the failure mode and its critical value and
(iii) Separating the operating value of the parameter from its critical value by appropriate factor of safety.

The key to the success in identifying the root causes in the case studies presented here lay in following the first two steps of this approach.

Case Study 1: Investigation of the Accident at a Gas Cracker Complex

Indian Petrochemicals Corporation Limited (IPCL) operated a gas based petrochemical complex at Nagothane near Mumbai, designed to produce 2.75 lakh tones of polymers. In Nov. 1990 there was an accident involving hydrocarbon leak followed by fire and explosion. A high powered Committee, headed by Dr. Mashelkar, constituted to investigate the accident, sought BARC's assistance in performing stress analysis of piping.

Process: A portion of the Ethane–Propane (C2–C3) feed to the cracker complex is diverted to Outside Battery limit (OSBL) plant where it is chilled and stored. Simultaneously the chilled liquid is sent back to main feed, exchanging heat with the incoming stream and getting preheated in the process. See Fig. 1 for Flow Sheet.

Incident: OSBL plant was being commissioned. First two stages of the four-stage chilling were commissioned successfully with chilling to −35 °C. Ethylene refrigeration system was valved in for further chilling. Temperature dropped to −100 °C. At that instant, massive leakage was observed forming a vapour cloud. There was an explosion followed by fire, extensive damage and loss of life. From the nature

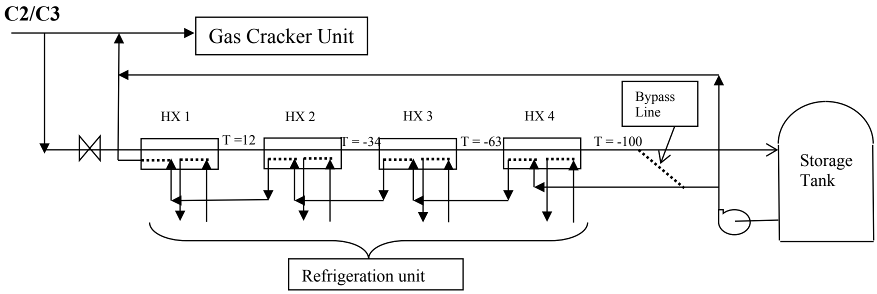


Fig. 1 Partial flow sheet

and spread of damage the source of initial leak could be pinpointed to one of the heat exchangers (HX 4 in Fig. 1).

Investigation

While commissioning, a need was felt to isolate the Storage Tank and for this purpose a bypass line was provided across the tank. A doubt was raised about the effect of bypass line on the overall stress picture of the pipeline. However, a detailed stress analysis showed only a marginal change in the stresses.

Two probable causes were investigated.

Weld failure hypothesis

The weld joining the aluminium flange to the nozzle at the suspected leakage location was found to be ruptured and metallurgical examination showed poor quality weld with extensive interpass porosity. However stress and fracture analyses showed that even the poor quality weld should have survived the operating stress once it passed the hydrotest because the operating stress is lower.

Alternate hypothesis

The piping uses low alloy steel studs for joining an aluminium flange to a carbon steel flange. The studs were tightened at room temperature and temperature was then lowered. The differential contraction between the flanges and studs, caused by the large difference in thermal expansion coefficient of aluminium and carbon steel, led to reduction in the gasket compression which in turn caused leakage. In support for this hypothesis, the following extract from Appendix XII of ASME Code Sec. III [5] can be cited.

> "DESIGN CONSIDERATIONS FOR BOLTED FLANGE CONNECTIONS
>
> A decrease in bolt stress, below any that may be due to internal pressure, might occur in service during startup or other transient conditions, or perhaps even under normal operation. This can happen when there is an appreciable differential in temperature between the flanges and the bolts, or when the bolt material has a different coefficient of thermal expansion than the flange material. Any pronounced decrease due to such effects can result in such a loss of bolt load as to be a direct cause of leakage. In this case, retightening of the bolts may be necessary."

The retightening or “Cold Bolting” was not followed in IPCL. In order to demonstrate that such a situation can indeed lead to leakage some tests were carried out in BARC.

Leakage Tests
Similar flange assembly containing air at pressure was immersed in methanol and leak tightness was demonstrated. Methanol was then cooled to −90 °C by liquid nitrogen. Extensive bubbling of air observed demonstrating possibility of leakage.

Root Cause
In view of the two facts: (i) The leakage quantity in the tests was not substantial and (ii) Whether the failed weld was the cause of the accident or the effect could not be established; it was concluded that the root cause was probably a combination of both.

Corrective Actions

- Use studs made of stainless steel whose coefficient of thermal expansion is between those of aluminium and low alloy steel. This reduces the differential contraction.
- Follow ‘cold bolting’ practice strictly i.e. tighten the studs after temperature change.
- Tighten the specifications for non-destructive examination of nozzle weld.

With these modifications, the plant was rebuilt and has been operating satisfactorily.

Case Study 2: Failure Analysis of Methanol Converter Vessel

Deepak Fertilizers and Petro Chemicals Ltd. is one of the largest producers of Methanol in India with an installed capacity of 1,00,000 MTPA at Taloja, near Mumbai.

Deepak’s low pressure methanol plant was built with know-how derived from ICI via one of ICI’s licensees, Davy. The plant was built between January 1988 and September 1991. It was commissioned in October 1991.

Process

- Synthesis gas ($CO + CO_2 + H_2$) enters the vessel through the bottom head (see Fig. 2).
- Rises through the tubes acting as a cooling medium and getting preheated in the process.
- Descends through the catalyst bed with following reactions.

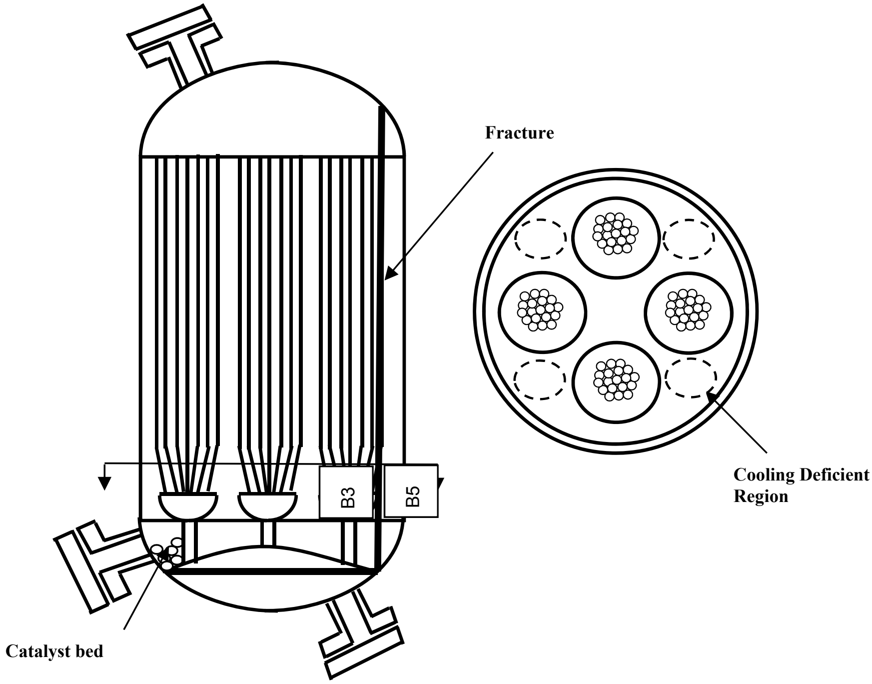


Fig. 2 Schematic view of methanol converter pressure vessel

$$CO + 2H_2 \Rightarrow CH_3OH + 91\ kJ/mol$$

$$CO_2 + 2H_2 \Rightarrow CH_3OH + H_2O + 50\,kJ/mol$$

- Other possible reactions

$$CO + 3H_2 \Rightarrow CH_4 + H_2O + 209\,kJ/mol$$

$$2CO + 2H_2 \Rightarrow CH_4 + CO_2 + 252\,kJ/mol.$$

Design Data

- Diameter 2270 mm
- Thickness 39 mm

- Thickness of hemispherical ends 39 mm
- Design pressure 90 kg/cm^2
- Operating Pressure 78 kg/cm^2
- Design temperature 325 °C
- Operating Temperature 325 °C
- Material 2.25 Cr–1 Mo steel

Incident

After about one year of operation, the 2.27 m diameter methanol converter vessel, designed for 90 kg/cm^2 internal pressure and operating at 325 °C, failed catastrophically. The vessel had split open and after flinging its contents, was catapulted to a distance of 80 m.

Investigation

- The failure was investigated from the following angles:
  - Stress Analysis
  - Fracture Mechanics evaluation
  - Metallurgical studies
  - Process Analysis
- Various hypotheses were postulated and examined in detail.

Different hypotheses examined

Postulate	Investigation	Result
Gross material error	Chemical analysis	Ruled out
Error in heat treatment	Tensile tests	Tests show low strength near B3, B5 (see Fig. 2) but not low enough to fail at op. pr.
Gross design error	Stress analysis	Ruled out as Codal limits were satisfied
Material defect	Fracture mechanics evaluation	Critical crack size depth = 19 mm, length = 130 mm, Too large to escape detection
Overpressure	Burst pressure calculation	Burst pressure = 259 kg/cm^2 against design pressure of 90 kg/cm^2 Pressure record does not show any increase
Internal explosion	Examination of fracture edges	Occurrence of bulge and extensive thinning suggests slow deformation

(continued)

(continued)

Postulate	Investigation	Result
External overheating	Burst pressure vs. temp. calculation	Temp. required for burst at operating pr. is ~700 °C. Requires sustained fire
Internal overheating	Burst pressure vs. temp. calculation	Temp. required for burst at operating pr. is ~700 °C. Possibility of local temperature rise due to methanation reaction

Findings—Accident Progression

- Due to the degraded catalyst, a part of the vessel was operating at a higher temperature
- This portion of the vessel was supporting methanation.
- Sustained high temperature resulted in lowering of strength.
- The temperature reached the threshold for a runaway methanation reaction.
- Local temperature rose to a value at which the UTS of the material was exceeded.
- Bulging and thinning followed by rupture near B3, B5.
- Unstable crack propagation through the length of the vessel.

Root Cause

- The failure was due to a local temperature excursion due to methanation reaction.

Lessons Learnt

- Consider worst case scenario i.e. runaway methanation reaction and guard against the same.
- Detect onset of instability by measurement of temperature at proper locations.
- Provide adequate margin between design and operating parameters.

Corrective Actions

- Avoid areas of cooling deficiency.
- Temperature measurement at more locations.
- Change the catalyst bed if it results in higher temp.

The plant has been rebuilt with these changes and has been operating satisfactorily.

Case Study 3: Failure Analysis of a Naphtha Storage Tank

Incident

In November 1988, a fire occurred on a naphtha storage tank (11 m dia × 8 m height, Fig. 3) of BPCL Refinery at Mumbai. The tank roof ruptured releasing a large amount of hydrocarbon vapour spread over an extended area and ignited; causing considerable damage and loss of life.

Design inadequacy was suspected to be the cause and in order to check this possibility, M/s BPCL had asked BARC to perform stress analysis of the tank and also carry out strain gauge instrumentation during a burst test they had planned to carry out.

Investigation

- Theoretical stress analysis was carried out using finite element method (Fig. 4).

The results showed significant deformation at the shell-roof junction and consequent localized yielding, which commenced at a pressure of 0.6 kg/cm^2. However, this is permitted by the codes and the tank, as designed, was safe for the design pressure of 1.0 kg/cm^2.

BPCL carried out a burst test on a similar tank. The tank and the roof were instrumented with strain gauges. The tank was gradually pressurized and the strain gauge

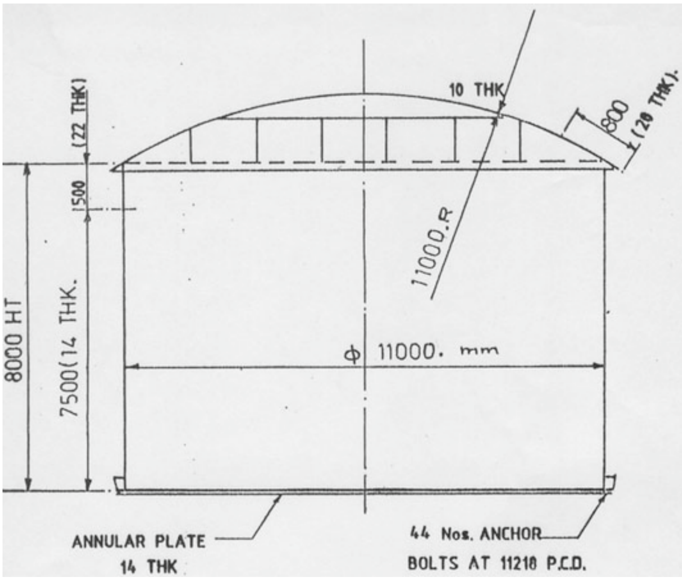


Fig. 3 BPCL tank geometry

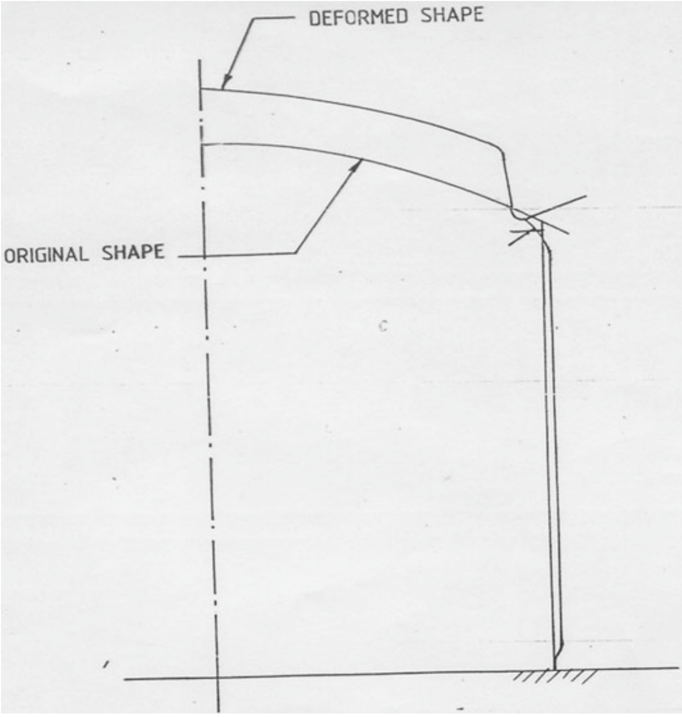


Fig. 4 Deformed shape

readings were taken at regular intervals. The measured and the calculated strains compared very well. Strain Gauges showed non-linearity at 0.6 kg/cm^2 pressure indicating initiation of yielding.

The tank actually failed at a pressure of 3.2 kg/cm^2, indicating a factor of safety of 3.2 over the design pressure.

Root Cause

- Failure was not due to any inadequacy in design.
- Further investigation revealed that the tank was overfilled and consequentially over pressurized because of the faulty indication by tank level gauge.

Lessons Learnt and Corrective Action

- Follow code rules for pressure relief.
- Avoid overpressurization during filling.

Case Study 4: Damage to Internal Shells of Exchange Tower in Heavy Water Plant

Heavy Water Plant at Baroda is based on monothermal hydrogen ammonia exchange. The synthesis gas which contains about 115 PPM of Deuterium is passed through isotopic exchange tower 12T1, operating at 640 kg/cm^2 pressure and −20 °C temperature In the presence of catalyst, potassium amide, deuterium from feed gas is transferred to liquid ammonia which is further enriched and processed for heavy water production. Exchange Tower-12T1 is a multiwall construction having outside dia 2660 mm and length 3122 mm and a thickness of 329 mm and weighing around 530 MT. Tower has 12 exchange stages.

Incident

During the annual shut-down in April–May 1991, tower was opened for maintenance; after it was depressurised purged and made ready for opening as per the procedure laid down for the purpose. Accordingly, the cover of the tower was lifted, kept aside and cable stage removed. When tower stages were removed one by one, stages 6th, 7th and 8th were found to be damaged. The damage was in the form of a 75 mm deep dent in each of the three shells [6] (Fig. 5).

Investigation

Causes such as explosion in the annular space, high differential pressure, mechanical damage due to impact during handling, explosion etc. were investigated but were found to be untenable.

During investigation it was discovered that a lot of water was sprayed inside the tower to wash residual ammonia. A postulate that the dents occurred because of freezing of water in the annular space was investigated analytically as well as experimentally. Although it could be verified that the quantity of water sprayed was

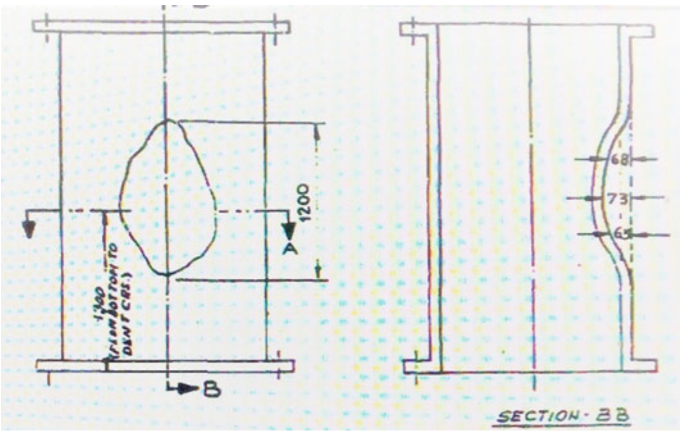


Fig. 5 Dent on stage no. 6

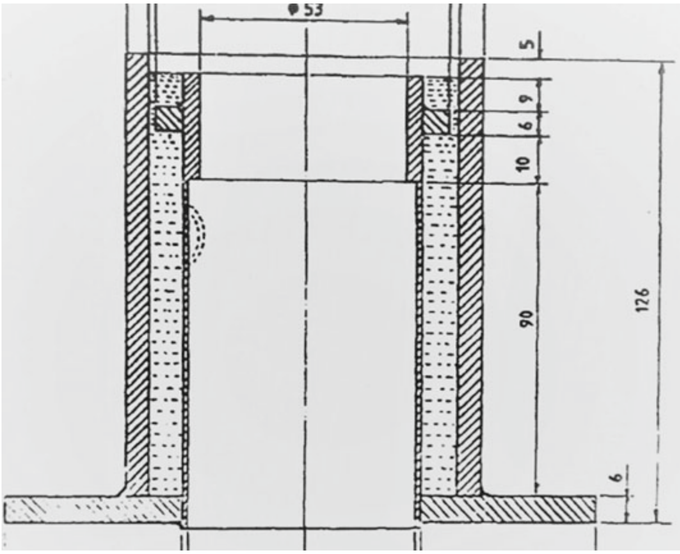


Fig. 6 Model for simulation of denting

sufficient to fill the annular space and had in fact frozen (the temperature was below zero °C); it was difficult to believe that a 30 mm thick shell could be damaged by this mechanism. To verify this, a scaled model of the tower-shell assembly (Fig. 6) was filled with water and put in a refrigerator. Next day, when the water in the annular space had frozen, the same dent appeared in the model. Thus it was conclusively demonstrated that this was indeed the cause.

A fitness-for-purpose evaluation was also performed using finite element method. It was found that for the intended service, the shells could be used without repair. The tower has since been put back into service and has been operating satisfactorily.

Lessons learnt

This is a textbook case. We have read about bursting of water-carrying pipes during winter. The lesson has been relearnt.

Case Study 5: Collapse of Dome of Kaiga Atomic Power Station During Construction

The containment building of a nuclear reactor houses the reactor, primary coolant and moderator systems, and other systems related to steam generation. Its function is to contain the radioactivity release in the event of a postulated Design Basis Accident so that the radiation level in the environment is within acceptable limits.

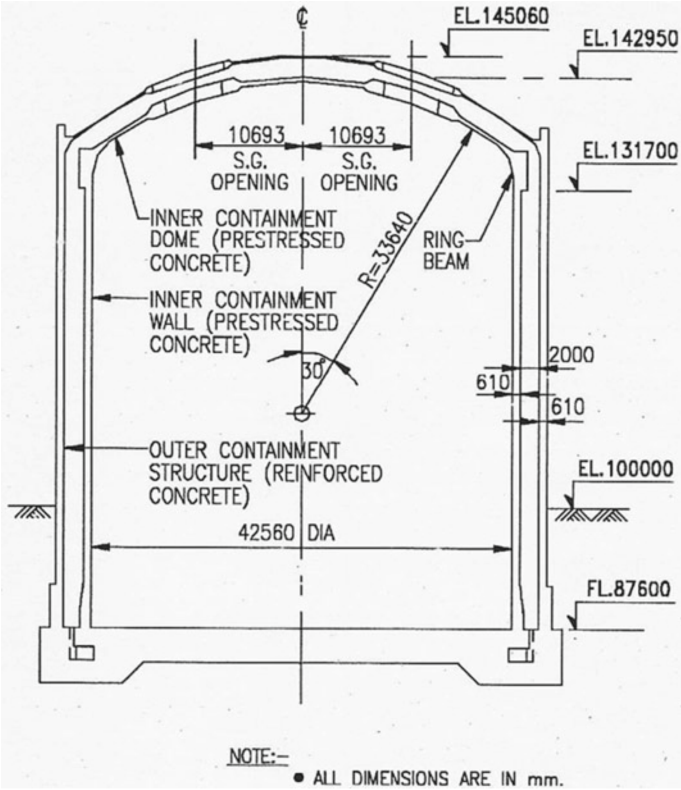


Fig. 7 Cross section of containment structure

The reactor building of the Kaiga Atomic Power Project, Unit-1 (Kaiga-1) has full double containment with an annular gap of 2.0 m between inner (primary) and outer (secondary) containment structures (Fig. 7).

The inner containment (IC) structure was designed as a prestressed concrete cylindrical shell (42.56 m diameter and 610 mm thick) capped with a pre-stressed concrete dome having 340 mm thickness.

Incident

On 13 May 1994, the inner containment dome of unit 1 of the Kaiga nuclear power plant collapsed during reactor construction. The dome itself had been completed but cabling and other tasks were being carried out. The failure was in the form of delamination. The under surface of the dome in the central portion delaminated and fell down completely. However, the upper portion had sufficient strength to hold itself in position under the action of its self-weight and whatever super-imposed load it had on it [7, 8].

Investigation

The nature of the delamination indicated that it occurred due to the action of radial tensile stress. For the normal operating condition involving dead weight and prestress, there is no external load which will cause net radial tensile stress; which is also the reason for not providing any radial reinforcement.

However, presence of local radial tensile stresses could not be ruled out; one of the sources being the stress concentration effect near an opening, Fig. 8.

Since these radial tensile stresses are localized in nature, there was hesitation in concluding that delamination was caused by them. In order to demonstrate that the radial stresses due to the stress concentration can indeed lead to delamination; an experiment was conducted using a Perspex sheet with two holes drilled into it (Fig. 9). The sheet can be visualized as a slice of the containment dome with the two holes simulating the sheath holes. The compressive load generated by the cables running transverse to the holes was simulated by clamping the sheet in a vice. On application of compressive load the ligaments between the holes and between the holes and the edges cracked, demonstrating the ability of the radial stress to cause cracking. The sheet however, remained as a single piece showing the secondary nature of the radial stress which disappeared on cracking.

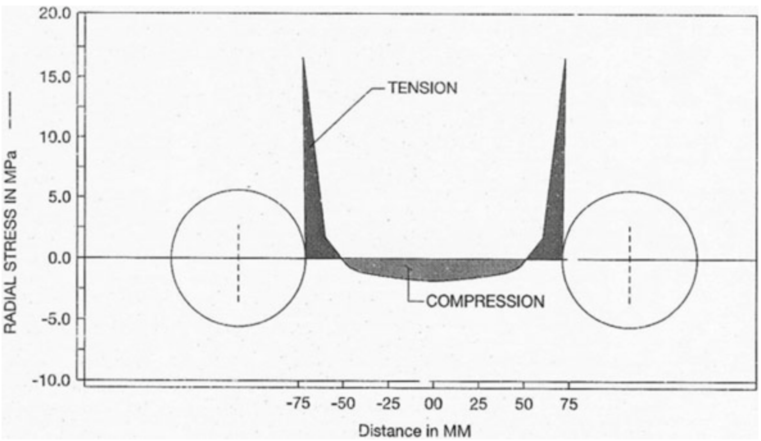
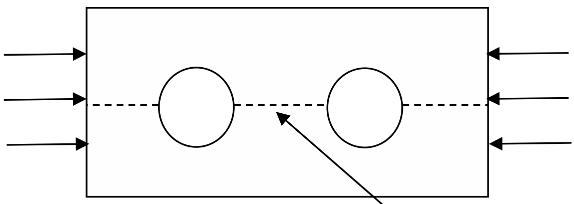


Fig. 8 Radial stress distribution near penetrations

Fig. 9 Simple experiment to demonstrate delamination phenomenon



Notwithstanding the difference between the two materials viz. concrete and Perspex, the experiment did show the possibility of delamination, in principle. The process of delamination is aided by short spacing between the two openings, which was the case at the location of delamination.

The fact that the sheet remained as a single piece showed that delamination alone may not lead to falling of the delaminated portion. That requires application of external load which will cause radial stress. In case of Kaiga dome, the hooks embedded in the dome were being used to lower the shuttering members. This created the radial stress which tended to separate the delaminated layers.

Root Cause

A detailed stress analysis which included the local changes in thickness and the openings for prestressing cables indicated occurrence of local radial tensile stresses because of some additional phenomena:

1. The in-plane compressive membrane stresses also generate radial stress near the hollow sheath in the thickness of shell due to stress concentration effect, as brought out earlier.
2. The curved prestressing cables exert pressure towards centre leading to development of radial stress.
3. The radial stress is also generated where the shell thickness changes within a short distance.

These radial stresses coupled with congestion caused by large quantity of reinforcement and closely spaced prestressing cables were identified as root causes of the failure.

Follow up

As a result of the investigation, a number of recommendations had been made for re-engineering of the delaminated dome [7]. Some of the major recommendations were:

(1) The intact portion of the dome to be demolished; extent depending on detailed examination.
(2) Measures to be taken in design;

    (a) increase of general thickness of dome from 340 to 470 mm;
    (b) to minimize the induced radial tension in the transition zones, the dome thickness to be increased gradually to the higher value of the thickened portion around the SG openings;
    (c) introduce radial reinforcement;
    (d) increase in minimum cable spacing from 108 to 225 mm to avoid congestion.

After incorporating the above, the dome was reconstructed and the inner containment structure was accepted after successful pre-commissioning proof test for structural integrity and leakage rate tests.

Epilogue

At this point, I revisit "Mind of an Engineer" [1] and refer to Dr. P. Ghosh who has aptly said "Engineers have a mind of a polymath: someone who knows something about everything and everything about something". The failure analyses described herein required exactly that kind of mind with *some* knowledge about many things and *expertise* in the core domain of structural analysis.

I hope I have been able to provide a glimpse into the mind of an engineer. The journey, though prompted by some unfortunate incidents, has been fruitful in the sense of providing answers. To borrow from Dr. Ghosh [1] again, "Mistakes strengthen engineers' self-confidence". It is hoped that the Root Cause Analyses and follow up recommendations did achieve that purpose.

There are many quotations on failure, especially ones pointing out how it is the path to success. But that hinges on Root Cause Analysis and the follow up. That is why I have named this article "There is Knowledge in Failure—If Followed by Root Cause Analysis"

In a Root Cause Analysis one can ponder over the question "How far should one go in finding the Root Cause"?

In engineering terms, it would suffice to identify "use of improper material" as root cause. But one can go deeper and identify "Lack of Quality Control in Design" or "Inadequate Knowledge" or "Improper Education/training" as the root cause.

That reminds me of a lecture on Failure Investigation which I attended. The excellent lecture was followed by a Question & Answer session. When I asked this question about where to stop in Root Cause Analysis, the lecturer admitted that the chain may indeed become too long to be meaningful. He cited the example of Challenger Disaster where the chain led to White House because of the instructions to fly the shuttle by certain date!

Acknowledgements In all of these failure investigations the investigating team was necessarily a multi-disciplinary one and consisted of: K.K. Vaze, V. Bhasin, K.M. Prabhakaran, D. Munshi, L.M. Gantayet, H.S. Kushwaha, A.R. Biswas, B.K. Shah, P.R. Vaidya, P.G. Kulkarni, S.C. Mahajan and Dr. A. Kakodkar.

As a postscript, I would also like to acknowledge the role played by the BARC work culture in my career. The complete absence of adherence to hierarchy was exemplified by the panel on the door of our boss Dr. Kakodkar, which proclaimed "Disturb". One could walk in with your problems and be sure to get a patient hearing or walk in with suggestions and be sure to get an enthusiastic audience. The willingness of others to share the knowledge/expertise was also contagious and if I were to summarize my innings in one sentence, it would be a quotation: "Choose a job you love, and you will never have to work a day in your life." I loved everything I did during those 40 years, it was done in the most congenial atmosphere and I did not have to *work* for even a day.

References

1. Ghosh P, Raj B (eds) (2016) The mind of an engineer. Springer, Singapore
2. Feynman RP, Leighton R (1992) "Surely you're joking, Mr. Feynman!" adventures of a curious character. Random House, New York

3. Feynman RP, Leighton R (2001) What do you care what other people think? Further adventures of a curious character. WW Nortan & Company, New York
4. ASME Boiler and Pressure Vessel Code. Section III "Rules for construction of nuclear facility components"; The American Society of Mechanical Engineers, New York
5. ASME Boiler and Pressure Vessel Code. Section III, appendix xii, "Design considerations for bolted flange connections", The American Society of Mechanical Engineers, New York
6. Gulati BS (1992) Deformation of stages of exchange tower- 12t1—a case study. In: National symposium on commissioning and operating experience in heavy water plants
7. Basu PC, Gupchup VN (2004) Safety evaluation of rehabilitation of delaminated containment dome. Nucl Eng Des 228:195–205
8. Roy R, Verma USP (2004) Design issues related to containment structures of Indian PHWRS. Int J Nucl Power 18(4):44–57

The Tale of an Engineer Teacher

Ranjit Kumar Ray

The steamer was jam-packed. Starting from Chandpur it was going to Goalanda, a small river-port on the other side of the Meghna river. The river was very wide at that point, looked almost like a sea. I, along with my parents, younger brother and sister was migrating from our house in Comilla town (in erstwhile East Pakistan) to the newly independent India. For a boy of slightly above five years of age, it was quite a traumatic experience.

I was so fond of our house in Comilla. It was a bungalow with gardens all around. My father, with the help of a domestic hand, planted a number of saplings, of mango, jamun and jackfruit. He used to tell my mother that we will have to wait for at least two to three years before we can eat the first fruit from those trees. My mother used to have a small vegetable garden, close to the kitchen. In one of the rooms I had a small desk and chair of my own in one corner, close to a big window. That was my study. There were no play-schools or kindergartens in those days, and so I studied at home. Of course, most of the time during the day, I was playing on my own, as there were hardly any other children of my age in the neighborhood and my siblings were too small. The road in front of our house led to the Ishwar Pathshala, a high school, a few hundred yards away. I later came to know from my father that this was a very renowned school in undivided Bengal. Every morning after breakfast I used to cross the road to the other side and sit down below a big jamun tree to run my own school with invisible students, till the time my mother called me home for lunch. What a wonderful time that was!

We had to leave all our possessions behind and my father could bring only two big suitcases, filled with mostly our clothes and my mother's little jewelry, on board the steamer. At that time I did not know the reason for our leaving the house so suddenly, but later when we were somewhat settled in independent India my parents gave me sufficient hint to make me understand that we were indeed very lucky to cross over

R. K. Ray (✉)
Apt.# 4C2, Glen Tower, Hiland Park, Kolkata 700094, India
e-mail: rkray@iitk.ac.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_27

to India alive, which many of our near and dear ones could not make. I became aware of the partition in a very rude way.

After living in two or three different locations on this side of the border for a little over two years, we finally settled down at Howrah, a satellite town of Calcutta, but on the other side of the Ganges. My schooling began here in the Howrah Zilla School, a Government school which started as early as 1845. I passed my School Final examination in 1958, standing 3rd in merit in the West Bengal School Board. When I look back, those were possibly the best years of my life. We had excellent teachers, who not only taught us various subjects, but shaped our character too. I would like to pay my respectful homage to all my teachers through this article. My eyes are filled with tears when I think of how much they gave us for so little they got from society. Where are those teachers now-a-days!

I was the eldest of the five siblings and both my parents used to keep a close eye on how I was progressing with my studies. They always used to tell me that if I were good in studies, my younger brothers and sisters would follow suit. I myself also became quite aware that financially we were not that well off as in Comilla, and life had suddenly become rather tough and difficult. The only way we could improve our lot was by studying really hard. I think that was the motivation that made me a hard-working person throughout my life. I would like to convey to my late parents, through this article, how much indebted to them I am for guiding me through all the trials and tribulations of my life.

My father, who was in Government service, cherished the ambition that his eldest son should work hard to be a member of the Indian Administrative Services. When I was in the seventh standard in school, he called me one day and told me how the administration was run in government departments and what a useful and honorable job the IAS officers performed. He even introduced me to his departmental Secretary, Mr. Ashok Mitra, who later became the Secretary in the Ministry of Information and broadcasting under Mrs. Indira Gandhi. My father's influence worked on me and I started making up my mind to try to become an administrative officer when I grew up. My ideas, however, started changing after I joined the Presidency College in Calcutta to do my Intermediate Science course (equivalent to the Higher Secondary course these days). It was while in Presidency College that I started realizing that administration was really not my cup of tea. Rather, I was drawn to the study of Physics and wondered if it would be a better idea to take up teaching and research in Physics as a career. A chance visit to the Bengal Engineering College (now IIEST Shibpur) on my way to the Indian Botanic Gardens, also kindled in me a possible career option in engineering. I mustered enough courage to tell my father that I was not interested in IAS, rather I would like to pursue a career in either science or engineering. He was a little bit sad, but told me that I was free to choose my profession. Since the family was going through economic hardship for obvious reasons, I decided that I would like to pursue a career in engineering, which came with more or less assured jobs those days.

I sat for the West Bengal JEE and also IIT JEE (there was just one IIT then, the one in Kharagpur) and made it to the list of successful candidates in both. It was a friend of my father, Late Professor SS Boral, Professor of Physics and Tele-communication

Engineering at BE College, who had advised me to opt for Metallurgical Engineering as the desired course of study. He told me, after I had a long discussion with him, that in this branch science and engineering are so inter-mixed that my passion for science and engineering will be satisfied simultaneously. He cited the case of Late Professor GP Chatterjee (once upon a time, Head of Metallurgy Department in BE College) who did two Ph.Ds simultaneously, in Physics and in Metallurgy, from the University of Pittsburgh, USA. At the same time, Professor Boral assured my father that I should get a very good job after graduating in Metallurgy since Hindusthan Steel (now SAIL) was putting up a number of integrated steel plants throughout the country and that there were only a very few metallurgists available, since this discipline was rather new in India. I opted for the Metallurgy course in BE College, which was then more than 100 years old, rather than going to the very new IIT Kharagpur.

BE College in those days was a first rate technical institution with a team of highly qualified and competent teachers. The college was a partner with eleven other American universities under the Technical Co-operation Mission (TCM) program. Under this scheme, eminent American Professors used to visit BE College for limited periods of time to teach and to help in guiding research. As a reciprocal measure, BE College teachers of high caliber could visit those American universities to pursue higher degrees. I spent a wonderful four year period in the Metallurgy Department, first learning the basic sciences and elements of the engineering profession in the first two years, followed by specialized Metallurgy courses in the remaining period. By the time I was in the fourth and final year of study, I knew perfectly what I would like to do for a job, once I finished my studies. I wanted to become a teacher and researcher in Metallurgical Engineering, for sure. It was while executing my Bachelor of Engineering thesis, I had a first- hand experience of what research was like. My teacher and thesis advisor, Late Professor AK Seal was very much instrumental to introduce me to the wonderful world of research. One day he called me to his office to tell me that he considered that I could be a good teacher and researcher in Metallurgy, and asked me to apply for a fellowship under the Technical Teachers' Training (TTT) program of the Ministry of Education, Govt. of India. According to this scheme, those who could qualify under the TTT program, would be allowed to enroll themselves for the Master's degree in an institution of their choice, and at the same time would be acting somewhat like a teaching assistant in US universities. On completion of the three year program, a lecturer's job in a good academic institution was assured. Accordingly, after my training period was over, I joined as a Lecturer of Metallurgy in my alma mater, BE College. I completed my Master of Engineering and then got enrolled for my Ph.D. under the Calcutta University with Professor Seal as my Guide in both the cases. The topic of my Ph.D. dissertation was the development of Fe–Mn-Ni based maraging steels. By the time the experimental part of my research work was complete, I was selected for a Commonwealth Scholarship to pursue Ph.D. in the University of Birmingham (UK) under the guidance of Professor RE Smallman, the renowned Physical Metallurgist. Since Professor Smallman, who was also the departmental head, could not give me sufficient time, Dr. WB Hutchinson, a bright young lecturer in the department, was made my co-supervisor. Professor

Smallman told me that the University received a substantial grant from the Science and Engineering Research Council (SERC) of the UK Government for procuring an AEI-EM7 High Voltage Electron Microscope (HVEM) for the department (Department of Physical Metallurgy and Science of Materials). This 1000 kV microscope had a reasonably large specimen chamber suitable for in-microscope experiments. Further, the much higher penetration of the electron beam would allow use of substantially thicker metal foils than was possible with the existing 100 kV electron microscopes. Thus, for the first time, it was possible, for example, to carry out in microscope heating experiments on heavily cold-worked and rather thick metal foils to study their recrystallization behavior. The use of thicker foils meant that the results obtained would be comparable to those from bulk samples. Previously quite a few attempts were made to study the recrystallization phenomena in situ in conventional 100 kV electron microscopes. However, the very fact that the foils that could be used in such microscopes had to be rather thin, and therefore not many deformed cells could be enclosed within the space between the top and the bottom surfaces of the foils, those experiments were total failures. I was quite fascinated with the idea that I could possibly be the first person to carry out in microscope recrystallization experiments in a HVEM. Therefore, I volunteered to take up a project on recrystallization studies on heavily cold rolled copper and copper alloys, using an HVEM, for my Ph.D. work. The results of these studies were beyond our expectations. The work was highly acclaimed by the scientific community. The impact of this basic work can be gauged from the following sentence. “Perhaps the clearest confirmation of the fact that the nuclei come from subgrains present in the deformed matrix is Ray et al.’s [R. K. Ray, W. B. Hutchinson and B. J. Duggan: Acta Met. 23 (1975) 831] direct observation by HVEM of nucleation in heavily rolled copper…., the first time apparently that nucleation events comparable to those occurring in the bulk have been observed in such detail.”[Ref. R. D. Doherty in “Recrystallization in Metallic Materials, Ed. F. Haessner, Dr. Riederer Verlag GmbH, Stuttgart, 2nd Edition (1978) 23–61]. After spending a year and a half in Birmingham, I took leave of about six weeks to come back to BE College. I wrote down the entire thesis of my Indian Ph.D. within that period and submitted the same before returning to Birmingham. I finally came back to India after completing my British Ph.D. in April 1973 and was immediately promoted to Assistant Professorship in BE College. Within a few days I sat for the oral examination for my Indian Ph.D. and therefore I received two Ph.Ds in the same year. The next year was a very important year in my life, since in January 1974 I tied the knot with my wife, Chhabi. I have no hesitation in confessing that whatever I have achieved in life is to a very great extent due to the fantastic support and understanding I received all throughout from my dear wife.

BE College used to be a state government-run institution those days. For the number of students enrolled every year, the number of teachers was abysmally few. Because of the total apathy, insensitivity and ignorance of the state politicians and the mandarins in the Writers’ Buildings, the secretariat, the infrastructure, both for teaching and research in BE College, deteriorated very fast and most of it became rather obsolete within the span of a few years. Thus, BE College, which once enjoyed the reputation of a premier academic institution in the country, soon became like a local college, both with respect to infrastructure and talent. As I found out that it was impossible to carry out any meaningful research in BE College, I started nurturing the idea of leaving BE College and join one of the newly created Indian Institutes of Technology in the near future. A few visits to IIT Kharagpur and IIT Kanpur convinced me that for doing good teaching and research, IITs would be the ideal places for me.

I was so determined to leave BE College that against all advice from my parents and well-wishers I joined IIT Kanpur, not with a promotion but at the same level as an Assistant Professor, in 1977. I could immediately see the gulf of difference between an IIT and a state government run engineering college, both teaching and research-wise. That difference only increased over the years and I could see the highly deplorable condition BE College fell into. The more I thought about it more I got convinced that in India if we want to produce first grade engineers, all engineering and technical institutions should be brought under the care of the central government. That will ensure that both teachers and students will come from different states of the country. This cosmopolitan fabric will not allow the local political goons to hijack the control of such important institutions, and at the same time will allow their healthy growth.

IIT Kanpur, during those days used to be a fantastic institution. I was highly impressed with the tremendous freedom and flexibility offered by the institute, in terms of academic curricula and courses, and research and teaching programs, which was quite unthinkable even in other IITs. Another very important aspect was the complete absence of hierarchy within the departments and in the institute. These were the attributes which made IIT Kanpur a completely different kind of academic institution in the country. I started getting, at a slow but steady rate, a number of brilliant M.Tech. and Ph.D. students, some of whom later distinguished themselves in their chosen careers. I am glad to mention here that a few of my former Ph.Ds turned out to be excellent teachers and researchers in some of the prestigious institutions in the country and abroad. While doing Ph.D. in Birmingham I learnt that crystallographic texture of materials, like their microstructure, affect the properties significantly. In fact, during those days, techniques of texture measurement were being developed and perfected in a select number of academic institutions and research organizations in several countries of Europe, a few organizations in the USA and in Japan. There was not a single institution in India where any serious research activity took place in the areas of crystallographic textures of materials. With my limited knowledge in textures I wanted to make a beginning in research in this area at IIT Kanpur. I started working with a primitive texture goniometer existing in the Advanced Centre for Materials Science in the institute. The operation of this equipment was totally manual and collection of texture data from one sample used to take almost a full day. I was still very happy that at least I could do some work in the textures area, using this equipment. I was awarded a Humboldt research fellowship in 1981 to work with Professor K. Luecke, Director of the Institute for Physical Metallurgy and Metal Physics in the Technical University of Aachen, in Germany. Professor Luecke was one of the two pillars of modern texture research, the other being Professor HJ Bunge of Clausthal University in Germany. My two years’ stay in Aachen has been extremely useful to me in learning the techniques and applications of crystallographic texture. After coming back to IIT Kanpur I built up a small facility for undertaking texture-related research (but still without a modern texture equipment). Using my wide network in Germany as well as in DMRL, Hyderabad I could manage to carry out critical texture measurements for my students' theses. Thus, possibly for the first time, meaningful texture research started in India in a moderate way. In 1997 I wanted to hold the first national seminar on textures in materials, to take stock of the pool of scientists and engineers in the country with active interest to work in this area. My idea did not get any response either at the departmental or at the institute level in IIT Kanpur, for some inexplicable reasons. Since my request to hold this meeting in IIT Kanpur was summarily turned down, I started looking for other alternatives. Fortunately for me, Professor Dipankar Banerjee, the then Director of DMRL Hyderabad, agreed to provide me all help for holding the National Seminar on the Application of Textures in Materials Research (NASAT) there. The seminar was a great success and was attended by about twelve overseas experts on textures, including Professor HJ Bunge, fondly known as the father of modern texture research. In addition, about thirty-five delegates from within India also participated. The proceedings of this seminar was published as a volume entitled Textures in Materials Research. This event singularly helped to put India firmly on the Texture map of the world. For pioneering texture research in India, I was made a member of the International Committee on Textures of Materials in 1999, the first and the only member from India. It was after the successful meet during NASAT-97, I started thinking about establishing a National Centre for texture studies in India. In fact, a number of prominent metallurgists in the country assured me of all help in this effort. However, it soon became apparent to me that, both in the departmental and in the institute level at IIT Kanpur, this proposition would be rather unwelcome. I therefore stopped nurturing this idea. I felt extremely happy when, after a few years, a national facility was indeed set up in the Materials Engineering Department of IIT Bombay with a grant from the DST, under young and energetic Professor Indradev Samajdar. By the time I retired from IIT Kanpur in 2005, texture research in India picked up in a big way and a large number of scientists and researchers, in academic institutions, national research laboratories and in the R&D laboratories in a number of industries, were engaging themselves routinely in texture studies on various materials. Thus, what I started single handedly about forty years ago, has now developed to such an extent that India is considered as one of the few countries in the world where high quality and meaningful research on crystallographic texture is being carried out on a regular basis. I must admit that this is the biggest source happiness and pride in my professional life. During the 15th International conference on Textures of Materials, held in 2008, I voluntarily relinquished my membership from the International committee, in favor of my younger professional colleague, Professor Samajdar, who was later inducted into the committee. In the same meeting I could convince the remaining members to choose Bombay as the venue of the next (16th) International texture conference in 2011, the first time this conference was held in India.

Although when I had joined IIT Kanpur, it was a fantastic institution of learning, over the years I noticed a steady and continuous decline in the academic culture of the institute. In the IIT system, a faculty member does not have to take many classes, as in case of other engineering colleges and universities. The faculty members are encouraged to put in sufficient time and effort in doing high quality research work, for which they have ample time. I must confess that going from a small state engineering college to IIT Kanpur, I had some kind of inferiority complex to begin with. I thought I was rather small in comparison to many of the faculty members there. However, I soon realized that excepting about some 40% faculty members, most of the others were really not that great. There were quite a few who neither taught well, nor did any worthwhile research. This kind of a situation is very fertile to breed dirty politics. As an elected member of the Board of Governors in IIT Kanpur for two years, I had ample opportunity of observing the working of the institute from close quarters. I was appalled at the extent of politics in almost all spheres, and this peaked during selection and promotion of faculty members. No wonder that the IITs do not figure within the top 100 academic institutions in the world. It is time to strictly implement a system so that only the most qualified and competent academicians are selected and promoted. There should be another system to monitor the academic and administrative output of every faculty member on at least a yearly basis. To start with, for the purpose of promotion to higher positions, the method followed in the Indian Institute of Science, Bangalore may be adopted. Again, the total contribution of a faculty member should be evaluated, on the basis of his/her teaching, research and administrative performances. Once it is ensured that only the good and deserving people can go to the top, all other problems of the institute will automatically vanish.

For the last ten years or so, all the academic institutions in the country, including the IITs, have been facing the problem of poor attendance in classes by the students. This is a terrible wastage of money, time and manpower for the nation. During the last few years of my stay in IIT Kanpur, I extensively interacted with many students. As per their version, the reasons for their poor attendance are: (1) poor teaching quality, (2) lack of motivation, (3) lure of high salary in the IT sector, for which just the engineering degree is needed, not any education, (4) easy availability of lecture materials through the internet and (5) urge for more freedom to choose the time and pace for learning a subject. Although this appears to be the biggest challenge for engineering education in our country, this can be turned into a very big opportunity. As we are all aware, the engineering education imparted in our country is highly deficient in the sense that here it is mostly bookish knowledge, as a result of which a graduate engineer hardly knows anything about practical engineering aspects. This has time and again been pointed out by the leaders of the various industries also. I would suggest a radical departure from the conventional engineering education as is practiced in India. On every subject high quality e-learning courses can be produced, through the auspices of NPTEL and/or some other agencies and the students may be given easy access to those courses. The students need not come to formal classrooms for learning, rather they can learn at their own time and pace. There should be a few formal contact hours with the teachers, when a student can clear up the deficiencies he/she may have by discussion with the teacher concerned. This will release a large amount of time for the teachers who can concentrate on research. Everyday a few hours should be set aside when a student will be taught the practical aspects of the relevant engineering course he/she is registered in, especially in modern manufacturing practices and design along with hands-on experience with sophisticated instruments. The marks allotted to these practical courses must have a substantial part based on attendance. This way we should be able to not only solve the problem of students' non-attendance in classes, but will also motivate and equip them better for future employment.

When I was near retirement from IIT Kanpur, I got an invitation to serve as a Visiting Scientist in the R&D Division of Tata Steel, Jamshedpur. My job description was to offer critical technical/scientific input on R&D research programs during the formulation and execution stages, to actively participate in specific projects undertaken by R&D, to hold special lectures on selected topics from time to time, to review the progress of research projects and to guide researchers so that they could write excellent research reports and technical/scientific papers and patents. In addition to these I was also requested to produce an e-learning course on X-ray Diffraction, with technical support from Tata Interactive Systems in Kolkata. After retirement from IIT Kanpur I started my work in Tata Steel full-heartedly. The Chief of R&D and Scientific Services of Tata Steel during that period was Dr. Debashish Bhattacharjee, an excellent technocrat and scientist with impeccable credentials. It was a wonderful time and I got into my task with the same vigor and purposefulness which I had in IIT Kanpur. Things went smoothly for the first few years when I was instrumental in getting a reasonably large number of papers published from the work done by researchers in R&D. I used to spend a lot of time discussing research problems with researchers and helped them in learning various techniques needed in research activities. In fact, I thoroughly enjoyed my job in Tata Steel. Then came a sudden change. The Tata Group bought Corus (a steel company with assets in both UK and the Netherlands) and Dr. Bhattacharjee left for Europe as Group Director of R&D Tata Steel with control over both Tata Steel India and Europe. A steady deterioration in R&D in the Jamshedpur plant started after the departure of Dr. Bhattacharjee, and it continued to become worse and worse. I finally left Tata Steel R&D in 2014. My ten years of service in Tata Steel R&D gave me a rare insight into the working of the top private sector steel plant in India. As a Visiting Scientist I used to send, after every two years, a critical report to the Managing Director, outlining the steps needed to improve things within R&D. I do not know what happened to those reports, however, I started having a feeling that the top management possibly was not that concerned with the health of R&D. They possibly were very happy that they, after all, had an R&D to give them some tax benefit from the Government. Tata Steel R&D those days had an excellent crop of very high grade researchers, coming from the IITs and the Indian Institute of Science, Bangalore. Compared to many of them, the group heads and the Chief of R&D appeared to be rather ordinary. The result was simple. Due to total apathy of the top brass in R&D these bright young boys and girls started leaving the R&D in large numbers. The vacant positions would be filled by new recruits, fresh from colleges. I brought these facts in my reports to successive MDs since I felt that the persons who left were the "value-added products", well versed in research and the new recruits were like "raw materials" and therefore no match for those who left. However, to my surprise I found that the Tata Steel bosses firmly believed that nobody was indispensable for the company and therefore no attempt was made to retain good researchers in R&D. This came as a big surprise to me. I was also shocked that Tata Steel R&D, which is the first industrial R&D in the country, and was more than 75 years old, lacked some of the basic equipment for research. Even now they do not have a vacuum induction furnace for melting experimental steels and a laboratory-scale rolling mill. It is high time they go for a total revamping of their facilities, otherwise nothing tangible will come out of that laboratory. As a result of all these, Tata Steel R&D is nowhere in comparison to the R&D departments of the major steel plants in the world, like Arcelor-Mittal, Nippon Steel and the steel companies in South Korea and China.

After my stint with Tata Steel finished in 2014, I joined as a Visiting Professor in my alma mater, BE College which has now become Indian Institute of Engineering Science and Technology (IIEST), administered by the central government. Life has turned a full circle for me. I started my career from BE College and now, at the fag end of my life, I am back again in the same institution.

When I look back, I think I am one among a handful of engineers (metallurgists) who worked both in academics and in industry. Surprisingly, I found plenty of similarities in both these types of entities. For example, politics reigns supreme in both, it is of course far dirtier in industry than in academics. A genuinely good and competent person faces lot of opposition from the mediocres (their number is obviously very large) who join in a formidable group and push the good one against the wall. The person concerned either leaves the organization or, if he/she can not leave due to personal or family reasons, gradually gives up and becomes a member of the mediocre group. As a country we really cannot afford this any more. The situation can change only when very bright and visionary persons are brought at the helm of affaires everywhere. It is indeed a matter of shame that bright young people who join an organization in India, find it extremely difficult to work and give their best. The same persons, when they go abroad, do wonderful work. The reason is very simple. In our country very small people unfortunately occupy very big chairs. This has to stop forthwith. If the top person is bright and first-grade, he/she will recruit only the first-rate persons. On the other hand, if the top person is second or third grade, he/she will keep on recruiting only the third or fourth grade people.

Our government over the last quite a few years has been emphasizing the need for quality research work in the country, in academic institutions, research laboratories and in the R&D laboratories in the various industries. From my limited experience I have seen how the top brass in an industry gives only lip service, so to say, for advancement in research. They are just bothered about how to maximize the profit of the company during the period of their tenure, and therefore, do not want to take any risk. The other most important point is that the top persons in most of the Indian industries are just graduates in engineering with a diploma or degree in business management. Because they have not done any research work during their life-time, they have absolutely no idea about what research is and what is essentially required for undertaking worthwhile research activity. Of course, there are very few exceptions also. But, by and large, this is the existing scenario. That is the reason why no landmark research has ever been carried out in the area of either product or process development, for example, in our steel industry laboratories. The remedy is to appoint very good and competent engineers, with substantial research experience, preferably a Ph.D. at the level of Managing Directors or Presidents of the companies. Our industry can only progress and become at par with the industries in the West, in China, Korea or Japan only by developing competitive technologies through sustained research. Otherwise, Indian industry will never be a leader in the world and will remain an inefficient follower all along. It is my fervent appeal to the Indian National Academy of Engineering (INAE) that they seriously start considering the measures necessary to improve the quality of engineering education in India, and at the same time start advising the industries on how to improve the quality of research, so that the country can forge ahead with high quality engineering manpower and knowledge (research) based modern engineering enterprises. INAE has to interact with the relevant Government departments, academic and research institutions and industries and roll out, after due deliberations, the way forward.

After spending nearly fifty years of my life in teaching and research, when I ask myself "are you happy?" the answer comes in a flash "yes, of course, because this profession is so fulfilling". I am a totally satisfied and utterly happy person, with no regrets whatsoever. Yes, it is true that I did not receive many accolades and awards, like many others, but that has nothing to do with my inner self, which is totally at peace and happiness. If I am asked to advise a budding engineer on which profession to choose as a career, I would definitely tell him/her always to consider teaching/research as a worthwhile option, although many will say "R.K. Ray is totally biased"!

Academic Life at the Indian Institute of Science (Bangalore, India) and Thenceforward Some Reminiscences

Y. V. Venkatesh

Before going up to the Indian Institute of Science (IISc), Bangalore (India), in 1963, I spent perhaps the most enlightening time in Sarada Vilas High School, Mysore (India), where I found myself in the challenging, but refreshing, company of students who, in stark contrast to me, came from special private schools meant for the society's elite in those halcyon days of royal Mysore. After passing through the portals of Sarada Vilas College (for the Pre-University program), I landed in the only engineering institute of Mysore of that time. It is appropriate to add here that, during the high-school and college years, my greatest teacher was my father who had been educated in England (Manchester) and to whom I wish to pay homage here at the outset.

The under-graduate engineering program at that institute lasted five years, viz. pre-professional + the four-year normal program—a consequence of the freshly introduced one-year duration pre-university (in Sarada Vilas College), replacing the two-year intermediate of earlier times—with specialization in Electrical Engineering confined to the final two years. My academic life at this institute was rank nightmarish.[1] But this period became, by and large, bearable, thanks mainly to the Government of India's (renewed) Merit Scholarship that had been first granted to me in high school earlier and continued in Sarada Vilas College, too. If only to give a

[1] Over the whole five-year period, I can only remember, with palpable relief, about five knowledgeable instructors, among whom the real standout was Professor M. K. Vamana Murthy, especially for the final year elective course on mathematics. Even with respect to crucial Electrical Engineering subjects (like Utilization of Electrical Energy, Electronics, and the important elective, Telecommunications), the students were literally left high and dry and to fend for themselves. It is no exaggerated bewilderment that I imagined myself, throughout the five years, pitted against the mighty Goliath of the *annual* (i.e., held only once in a year) engineering examinations of the University of Mysore. It is to be noted that, in those days, there was no concept of an examination in each "semester" or "term" (of four-month or so duration, which is the present norm).

Y. V. Venkatesh (✉)
521, 5th Cross, 8th 'A' Main Tata Nagar, Bangalore 560092, India
e-mail: yv.venkatesh@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_28

glimpse into the uneasy atmosphere I lived through at that time, I cannot resist mentioning just one event, an apparently traditional one—a farewell party—that took place at the end of a year. The then-head of a department (whose only expertise consisted of reproducing or, rather, regurgitating verbatim, material from a standard book) remarked maliciously and out of context that I was “earning while learning”, as though his finances were being drained, and seemed to grin with satisfaction over his choice of phrase. I hasten to add that such an insensitive and deeply hurtful utterance by the head of a department in a college was not endemic to an undergraduate institution. Fast forward, something similar, and of a more serious nature, was typical of events in an established, higher place of learning, too.[2] One may dismiss such events as inconsequential,[3] but they aren’t.

At the Indian Institute of Science

I was exuberantly relieved in May/June 1963 when I learned that I had been awarded the **Bowen Memorial Prize of the University of Mysore**. Soon thereafter, I arrived at the Indian Institute of Science (IISc), Bangalore, exhausted by the ordeal I had gone through in Mysore but enormously relieved to find myself in an atmosphere of intoxicating delight, and I reveled in it. The companionship was stimulating, and a few teachers (especially in Mathematics) were masters of their fields of activity with an uncanny ability to provoke thought while eliciting fun out of solving even standard problems on the blackboard with no notes in hand. This was absolutely unlike what I had experienced in the under-graduate engineering days in Mysore that, as I now strongly feel, I had barely managed somehow to come out of.

My research baptism at the IISc (hereafter called merely “Institute”) was presided over by **Professor B. L. Deekshatulu** (**BLD**) under whom I wrote a couple of papers on the analysis of linear, finite dimensional systems with (i) a time delay, and (ii) time-varying parameters.[4] As far as the first topic is concerned, the only accessible material at that time in the library of the Institute amounted to (a) the approximate results of N. Minorsky (gleaned from his voluminous, but classic, book on nonlinear oscillations); and (b) R. Bellman and R. Cooke’s treatise on differential-difference equations. The latter, with its theorems on existence and uniqueness conditions, was indeed terrifying, trained as I was in applied (or, rather, engineering) mathematics (where very little is taught in terms of existence and uniqueness of solutions to differential equations and their relevance to research investigations). In fact, in the mathematics classes even in the Institute at that time, no reference had been made to, for instance, E. Coddington and N. Levinson’s standard book. It should also be

---

[2]See item 1. in the section “Notes” at the end of the article.

[3]In my view, they do affect the idealistic view a sensitive mind conceives of a justifiably revered research haven.

[4]In retrospect, the results for the latter are inconsequential, while those for the former are inadequate, incomplete and unsatisfactory.

added that there had been no formal course on real analysis as such in the Institute. In fact, the instructors were literally from the Department of Applied Mathematics, as there was no separate Department of Pure Mathematics. Be that as it may, I came out with a new, non-standard expansion technique to obtain a recursive solution to a linear differential-difference equation with a small parameter, and demonstrated its practical usefulness by hand-computation using an old mechanical calculator installed in the corner of a big room occupied by Professor BLD. (My nearest access point to a computer was TIFR Bombay, and programming that computer was far beyond my field of view.) The paper with the proposed expansion appeared in an international journal.[5]

Feedback System Stability

I was disenchanted with the preliminary work on linear time-varying system analysis which was, much to my surprise, but rather alloyed excitement, duly published in some international journals. In apparent frustration, I turned to a more topical and challenging problem which concerned the stability analysis of feedback systems with a linear time-invariant forward block and linear/nonlinear time-invariant/time-varying gain in feedback.[6] I was motivated *post factum* by the intriguing behavior of solutions of the Mathieu equation, a linear second-order differential equation with a periodic coefficient having two parameters, α and β:

$$\frac{d^2x}{dt^2} + (\alpha + \beta \cos 2t)x(t) = 0, \quad t \in [0, \infty);\ \alpha > 0,\ \beta > 0. \tag{1}$$

This equation has been known for a long time, and the remarkable monograph [1][7] contains the $\alpha - \beta$ graphs of stability-instability boundaries, obtained from series expansions (in terms of the so-called Mathieu functions). In effect, McLachlan employs a quantitative approach to stability/instability, as against the current trend in qualitative methods which have been developed mainly for the stability analysis of higher-order and more general (including nonlinear) systems.[8] It is known that these *McLachlan-graphs* (or *stability-instability boundaries*) can be employed as a benchmark in the analysis (see Footnotes 6 and 7) of, for instance, the stability of oscillations in nonlinear systems by suitable approximation techniques. Moreover, there are physical systems like the parametric amplifiers which are inherently time-varying and periodic, too.

[5]Many years later, I saw its review, in a review journal, by, if I remember correctly, R. E. Kalman who very rightly criticized its numerical results.

[6]Many single-input-single-output (SISO) systems can be cast into this form, at least as an approximation; others, into a multi-input-multi-output (MIMO) form with the same feedback structure. The latter's stability conditions became the subject of my interest later.

[7]See references at the end of the article.

[8]See below for an outline of the more general problems.

Concerning the stability/instability properties of the solutions of Eq. (1), it is imperative to note the following: *whatever general techniques* (*of which the direct method of Lyapunov, in its original form or appropriately generalized, is one*) *have been developed to arrive at stability/instability conditions for second- and higher-order linear* (*and nonlinear*) *time-varying systems*, *these techniques when applied to* Eq. (1)*, can't reproduce the McLachlan stability-instability boundaries.*[9] In this context, note that Eq. (1) can be recast to describe the behavior of a feedback system with a (linear) time-invariant-block in the forward path and the time-varying gain $(\alpha + \beta \cos 2\mathrm{t})$ in feedback. A minor generalization of this leads first to an arbitrary time-varying gain, $k(t) > \varepsilon > 0,\ \mathrm{t} \in [0, \infty)$, in feedback.

Stage-by-stage further generalizations of Eq. (1) lead us to the following systems: (**a**) a feedback gain whose output is $k(t)\varphi(x)$, where $\varphi(.)$ is the first-and-third-quadrant nonlinearity (satisfying certain assumptions); with the same feedback gain $k(t)\,\varphi(x)$, (**b**) a higher-order (i.e., >2) finite-dimensional (time-invariant) linear forward block with a rational transfer function G(s).; and (**c**) infinite-dimensional (time-invariant) linear forward block (representing, for instance, distributed-parameter systems) having, in general, not necessarily a rational G(s). It is interesting to note that, even in the first case, i.e., (**a**), stability/instability boundaries (extending those found in [1]) are not known. Paradoxically, while many stability results[10] are known for Cases (**b**) and (**c**)[11] using Lyapunov or other frequency-domain-based methods (of which Popov's [2] is the most original) or even Zames's positive-operator theory [3], none of them when *specialized* to the special case[12] of Eq. (1), lead anywhere close to the stability boundaries found in [1].

For the general systems mentioned in cases (**b**) and (**c**) above, when we replace the nonlinear time-varying feedback gain by merely a linear constant gain, the frequency-domain stability conditions, which are necessary and sufficient, are attributed to Nyquist, and, as is well known, these conditions are, for finite-dimensional systems, equivalent to those that can be obtained from the Routh-Hurwitz criterion. What is, however, not immediately apparent is that the Nyquist criterion, for *both* finite- and infinite-dimensional systems, can be cast in terms of a multiplier-function, $z(j\omega)$, in the frequency domain: The system corresponding to cases (**b**) and (**c**) above, but with a constant feedback gain $K \in [0, K)$, is asymptotically stable, if there exists a frequency function, $Z(j\omega)$, such that $-\pi/2 < \arg Z(j\omega) < \pi/2$ and $-\pi/2 < \arg\{Z(j\omega)(G(j\omega) + 1/K)\} < \pi/2$, where "arg" denotes "the phase angle of'. Alternatively, $\Re\, Z(j\omega) > 0$, and $\Re\,\{Z(j\omega)(G(\mathrm{j}\omega) + 1/K)\} > 0,\ \omega \in (-\infty, \infty)$, where "$\Re$" denotes "the real part of'. One of the goals in research is to derive stability criteria for (linear and) nonlinear (time-invariant and) time-varying gain feedback systems that reduce to the *benchmark* Nyquist criterion when the feedback gain is linear and constant.

[9]See item 2. in *Notes* at the end of the article.

[10]One should mention here a few instability results obtained mainly in the Lyapunov framework.

[11]Note that Case (c) includes Case (b) as a special case.

[12]More correctly, its slightly modified version having some (arbitrarily small) damping to facilitate the formal applicability of the existing qualitative methods.

An important result attributed to many researchers is the **circle criterion**: A nonlinear time-varying feedback system (modeled by cases (**b**) and (**c**) above) is stable[13] if the multiplier function Z(jω) is simply unity, i.e., $-\pi/2 < \arg(G(j\omega) + 1/K) < \pi/2$, $\omega \in (-\infty, \infty)$. For simplicity in what follows, we set $K = \infty$. By a simple transformation, the results stated for $K = \infty$ can be reduced to those meant for a finite K by replacing $G(j\omega)$ by $(G(j\omega) + 1/K)$, and the feedback gain by an equivalent gain after an appropriate transformation.

Perhaps the most beautiful result for nonlinear time-invariant feedback gain systems, with a first-and- third quadrant non-monotone nonlinearity[14] φ (.) in the feedback path, is the celebrated criterion of Popov [2]: Re $(1 + j\alpha\omega)G(j\omega) > 0$, $0 < \omega < \infty$, where $\alpha > 0$ is a constant. A vast number of stability results have appeared over close to twenty-and-odd years, post-Popov, in the form of allowing monotone and other subclasses of nonlinearities in exchange for weakening the restrictions on the phase angle behavior of $G(j\omega)$. With this brief background, it is time to present my main contributions as applied to the stability/instability analyses of (linear and) nonlinear time-varying feedback gain systems.

The first major (and early) result [5] for the exponential stability of linear time-varying feedback gain systems was obtained in an extended Lyapunov framework by solving a differential inequality (in the manner of C. Corduneanu). The result of [5] reads as follows: If the linear time-invariant feedback gain system obeys the standard Nyquist criterion with an effective damping factor β, and the integral average of the positive lobes of $\{\theta(t) = \mathrm{d}k(\mathrm{t})/dt/k(\mathrm{t})\}$, is bounded for all finite time, but its asymptotic limit (i.e., as the interval of integration tends to ∞) is bounded from the above by 2β, then the system is exponentially stable.

Similar results have been obtained for the exponential stability of finite-dimensional nonlinear time- varying feedback systems (i.e., Case (**b**) above), with non-monotone and monotone nonlinearities, in the extended Lyapunov framework and once again by solving a differential inequality. However, the most general early result [6] for the L2-stability of nonlinear time-varying feedback gain systems [i.e., Cases (**b**) and (**c**)] with a monotone nonlinearity was obtained by an amalgamation of Zames's positive theory and Popov's Fourier transform-based framework. The multiplier function, which is a general (causal + anti-causal) function,[15] is due to O'Shea [7], and Zames and Falb [8]. The novelty of the L2-stability criterion is threefold: (i) The inverse Fourier transform of the multiplier function needs to satisfy an exponentially weighted integral inequality, with ζ as the exponent for the anti-causal function, and ξ as the exponent for the causal function. The exponent ζ determines the global (as t → ∞) lower bound on the integral average of the negative lobes of $\theta(t)$, and the exponent ξ, the global (as t → ∞) upper bound on the integral average of the positive lobes of $\theta(t)$. The finite-time averages of the integrals of the negative

[13]This is a misuse of terminology. In a Lyapunov framework, this implies, under certain conditions the system is asymptotically stable; and in the framework of positive-operator theory, L2-stable.

[14]This is the class ℵ of nonlinearities originally introduced by Lur'e and Postnikov. See [2, 4]. We write for simplicity φ (.) ∈ ℵ.

[15]For brevity, this is called hereafter the OZF multiplier function in honor of its originators.

and positive lobes of $\theta(t)$ need merely to be bounded. (ii) We can trade ζ with ξ. (iii) If we choose $\zeta = \xi$, then, for odd-monotone nonlinearities, there is no restriction on $\theta(t)$, which implies that *the stability criterion is effectively the circle-criterion for odd-monotone nonlinearities, but with a general multiplier function subjected to a constraint on the weighted integral of the inverse transform of the multiplier function.*

No such results are known in a Lyapunov framework (applicable in the existing form, as is well known, *only* to finite-dimensional systems), which also seems to imply that no counterparts of the Kalman-Popov-Yakubovich lemma [2, 9, 10] for general multiplier functions have been established. Even if one succeeds in discovering such a counterpart, its utility seems only to be only in non-stability domains, involving mere applications of the putative generalizations of the linear matrix inequalities (LMIs). More explicitly, a counterpart *may not* lead to any superior or new stability conditions for the problem under consideration.

The most recent result [11], while being a significant improvement over [5] but not entirely resolving the necessity-and-sufficiency conundrum of the Popov theorem, is the first ever result for the L2-stability of a nonlinear single-input-single-output (SISO) feedback system, described by an integral equation and with the forward block transfer function $G(j\omega)$ and a first-and-third quadrant, class $\aleph$ feedback nonlinearity, but employing the OZF multiplier-function.[16] In this sense, it is an improvement over the Popov theorem,[17] and is, interestingly enough, a veritable climax of a couple of my earlier results to be outlined later below for the sake of completeness.

More specifically, a novelty of the results of [11] is the employment of the OZF multiplier function (which had been originally suggested *only* for the class of monotone nonlinearities) whose time-domain L1-norm is constrained by certain characteristic parameters (CPs) of $\varphi(.) \in \aleph$, obtained from certain novel algebraic inequalities. If the nonlinearity is monotone or belongs to any prescribed subclass of $\aleph$, its CPs are reduced, thereby relaxing the time-domain constraint on the multiplier. An important special feature of the new stability results is a partial bridging of the significant gap between the Popov criterion and the stability results that appeared post-Popov in the form of considering monotone and other subclasses of nonlinearities in exchange for weakening the restrictions on the phase angle behavior of $G(j\omega)$. Extensions to time-varying nonlinearities more general than those in the literature are also presented in [11]. The background and motivation for such a surprising result seem to merit a recounting of *other* research efforts and interactions.

[16] Note the striking contrast with the Popov multiplier function $(1 + j\alpha\omega)$ already mentioned above.

[17] A possible generalization of the Popov theorem on the lines of the results of [11], i.e., with $\varphi(.) \in \aleph$, but with no characteristic parameters of the nonlinearities entering the time-domain constraint on the multiplier function, has been conjectured in the same reference. Another conjecture made in [11] is a similar generalization of the results of [6].

Background and Motivation for the Latest Result [11]

Early 1970, while in Moscow, I met the doyen of nonlinear stability analysis, Professor Mark Aizerman, at the then-called **Institute for Automation and Telemechanics** (now renamed as the **Institute for Problems of Control**), who is better known for his conjecture [12] than for his beautiful monograph [4]. The purpose of my visit to him was to discuss certain issues related to the work of his junior colleague (or assistant or whatever designation was appropriate in those days), Dr. E. C. Pyatnitskii, whose paper on the absolute stability of nonlinear time-varying systems had just then (January 1970) appeared in the Russian journal, Automation and Remote Control.[18] After a brief exchange of pleasantries, Professor Aizerman declared (in Russian) that research in stability analysis, according to him, was "Ne modna", which means "not fashionable".[19] He had by then already migrated to path-breaking work on pattern recognition in which he is known for the potential function method (leading to the "kernel trick").

Now fast forward to the year 2004 when I found myself in the National University of Singapore (NUS) where, among other things, I started interactions with the active group on control. In course of time, while participating in seminars on control at the NUS, given by visiting researchers (mostly from the US), I presented, during the discussion period, some unresolved stability (and stability-related) problems, including certain results which I had discovered to be faulty.[20] By and by, discussions with the control research group led gradually to the derivation of new L2-stability conditions for (monotonic and odd-monotonic) nonlinear periodic-coefficient (i) single-input-single-output (SISO) [13]; and (ii) multi-input- and-multi-output (MIMO) [14] systems. The former paper is a consolidation and detailed computational verification of [15]; and the latter, which entails the solution of certain novel matrix-algebraic time-varying linear and nonlinear inequalities, constitutes a significant improvement over the results of the literature, by *assuming no symmetrical time-varying feedback gain matrices*, along with the generalization of class $\aleph$ for vector nonlinearities, without the constraint of path-independence of integrals involving the vector nonlinearity as found in the literature (see corresponding references in [14]).

It has turned out that, for discrete-time linear and nonlinear time-varying feedback gain MIMO systems, the new L2-stability conditions [16] are not merely the *discretized* versions of those for continuous-time MIMO systems presented in [14]. For instance, the generalized circle-criterion of the former has no counterpart in the latter. A striking byproduct is that when the results of discrete-time MIMO systems [16] are specialized to be applicable to discrete-time SISO systems, the L2-stability conditions generalize those of [17] (after setting index $p = 2$), by being applicable to non-monotonic nonlinearities with the OZF multiplier function, thereby surpassing all the earlier results of Tsypkin, Jury and Lee, O'Shea and others (see references in [16]). For continuous-time systems, the paper [14], along with [18] for linear and

[18] See item 3. in *Notes* at the end of this article.

[19] See item 4. in *Notes* at the end of the article.

[20] See item 5. in *Notes* at the end of the article.

nonlinear feedback systems with constant and time-varying delays, is a culmination of recent efforts and seems to be the most general to date.

Aberrations in the Derivation of Stability/Instability Results

Lest one should lose sight of the forest for the trees, one needs to note that all the stability results have been obtained under the assumption (called for brevity **Assumption A1**) that the **basic linear time-invariant system with feedback gain** $K \in [0, \mathrm{K})$ is asymptotically stable, as determined by applying the Nyquist criterion or the Routh-Hurwitz conditions. However, all these stability conditions for linear/nonlinear time-varying feedback systems [Cases (**a**)–(**c**) listed above] are only sufficient. It is not known how to establish their necessity.

Analogously, instability results of the literature invoke, in general and in some form or the other, the method of contradiction to establish instability, but the end results turn out to be mostly either impotent or somewhat faulty [19]. The strange thing is that the derivation of instability conditions for linear and nonlinear time-varying feedback gain systems seems to be inextricably bound up with the assumption (called for brevity **Assumption A2**) that the basic linear time-invariant system with feedback gain $K \in [0, \mathrm{K})$ is *unstable*, as determined by applying the Nyquist criterion or the Routh-Hurwitz conditions. Set against such a background, I have developed a constructive method to establish instability conditions for linear and nonlinear time-varying feedback gain systems using a not-so-well known converse of the Cauchy-Schwartz inequality [20]. Further, invoking the converse Holder inequality, I have derived Lp-instability conditions for the same systems [21].

However, some of the unresolved problems seem to be the following: (i) With **Assumption A2** holding, replace the gain K by the time-varying function $k(t) \in [0, \mathrm{K})$, $t > 0$. In this case, do there exist *global constraints* on $k(t)$ and/or its derivative to *stabilize* the linear system? (ii) Again, under the same assumption, suppose the gain K is now replaced by the time-varying nonlinear function $k(t)\,\varphi(.)$, with $k(t) \in [0, \mathrm{K})$ for $t \geq 0$, $\varphi(.) \in \aleph$; and, for $x \neq 0$, $\varphi(x)/x \leq 1$. What are the global constraints on $k(t)$ and/or its derivative to *stabilize* the system?

The corresponding counterparts (of unresolved problems) for **Assumption A1** are obtained from the last paragraph by substituting the word "destabilize" for "stabilize".

Second Phase of Research at the Institute

The drastic change in my research interests was also inaugurated by **Professor BLD** who did not like my "getting lost in the unreal world of symbols". He had returned from IBM Labs in the US in early 1972, with stimulating ideas related to image scanning and processing, as also applications of image processing to remote sensing of agricultural areas by aerial color infrared (CIR) photography. Possibly inspired by Professor P. R. Pisharoty's work (in Kerala) on identifying coconut tree diseases from aerial photographs, and his own first-hand exposure to remote sensing experiments in Michigan which he visited during his US sojourn, Professor BLD managed to get financial support (around 1975/76) from (if I remember correctly) Space Applications Center (SAC), Ahmedabad—ISRO had not yet come into existence at that time in the present form—for aerial CIR imaging of sugarcane crops in Mandya (near Mysore) by mounting Hasselblad cameras (borrowed from SAC) on the Institute's Pushpak aircraft. There was, of course, a co-investigator from SAC, too. Since the color scanner needed for conversion of CIR images to digital format was not ready, we had to resort to manual interpretation of the acquired images.

In the middle of 1976, **Professor BLD** joined the National Remote Sensing Agency in Hyderabad. I was left alone to set up the **Remote Sensing and Image Processing Laboratory** (which was later called **Computer Vision and Artificial Intelligence (AI) Laboratory**, in which all the manual interpretation of the (Mandya Project's) CIR images of sugarcane and paddy crops was accomplished, along with the first attempts to develop a blue-green-red[21] LED-based scanner. In a project funded by ISRO, we developed all the basic software in Fortran on HP 1000 which had something of the order a few thousand bytes of solid-state main memory, and no tape drive[22] at all, for image processing and pattern recognition for resources estimates (on small patches of cultivated land). For any meaningful computational work, we had to reserve terminal time at the Computer Center of the Institute which had a DEC machine, but with no facilities for display of raw and/or processed image data. This necessitated the development of our own color image display using the Conrac monitor which I had managed to procure after more than a year of struggle with the mandatory formalities of 'clearances'.

Such formalities had been successfully completed for the purchase of a Printronix dot-matrix printer which was originally meant for a planned PDP 11/34, instead of the HP 1000.[23] It was felt unwise to cancel the printer's shipment from the US, fearing loss of time and hence, a possible refund of the sanctioned money to ISRO. Once the printer arrived, we had to develop appropriate interface (driver-) software to work with HP 1000 and Printronix.[24] In all these ground-breaking activities, the crucial contributors were Mr. Animesh Mukherjee who had registered for an M.Sc. (Res) degree and Mr. William Raymond.[25] I cannot adequately praise their whole-hearted devotion and achievements. The Computer Vision and Artificial Laboratory (along with its subsidiary, Remote Sensing Laboratory) owed—yes, it is past tense now—its existence primarily to them. And this place of my work in the Institute was *literally* my sanctuary (in the sense of a veritable *holy place*) until 2004.[26]

---

[21] See item 6. in *Notes* at the end of the article.

[22] This was because the Electronic Commission limit for Institute's purchases, Rs. 5 lakhs, without the so-called 'global tender' to be floated and decided on by the Government itself.

[23] This computer had no built-in interface for Printronix.

[24] The HP representative in Bangalore showed interest in 'buying' our Printronix driver software for HP.

[25] See item 6. in *Notes* at the end of the article.

[26] See Epilogue on p. 12 for a reference to this sanctuary.

The Subjective World of Image Processing

Any serious and thoughtful researcher will find that most of the literature in image processing contains purely ad hoc methods, with the number of papers on, for instance, edge detection running to thousands. In my Lab, we did implement quite a few of them, but always disagreed on how useful they were in the context of classification of, for instance, remotely sensed data. In fact, it would be quite relevant to know what an edge is. Is a 'mathematical edge' (as found in various books) applicable to what we, as humans, perceive something in an image as an edge? Is the much-harped-upon edge detection an end itself, implying thereby that we do not need to do anything else to an image to extract information from it? In my view, no! I am sure this could stir up an acrimonious debate among researchers still trying to write up yet another paper on edge detection, as Professor Azriel Rosenfeld would proclaim. For lack of space, I shall leave out the trials and tribulations of assembling a dedicated group of researchers to deal with challenging problems in vision.[27]

Professor David Marr, the author of the remarkable and influential book, *Vision*, was perhaps the first to attempt modeling the human visual mechanism for detecting boundaries among various objects in the image of a scene as cast upon the retina. Inspired apparently by the seminal work done by the Nobel Laureates, Professor David Hubel and Professor T. N. Wiesel, on the visual mechanisms of a mammalian visual system, and guided by the empirical findings on the bandpass characteristics of the (mammalian) visual system as obtained from flashing suitably calibrated bar-like patterns to it, Professor Marr proposed the existence of detectors of extremal points of gradients of intensity changes (in the visual scene) in the outputs of three/four bandpass channels, which were, in turn, obtained by using Gaussian filters with appropriately chosen variance parameters (to achieve a spread of an octave for each channel and partially overlapping with each other). He called them zero-crossing detectors. In effect, the human visual cortex stores the visual scene in the form of boundaries of objects in the scene, and apparently recalls the scene, as it were, in our imagination, based on *just* those boundaries. After all, the number of neurons in the human brain is limited, and the brain cannot possibly store all the information in a scene. This constitutes the background for *my* formulation of the first two of the three basic problems in vision that follow. The third problem is based on the fact that humans have been endowed with two eyes that facilitate depth perception.

Problem 1: Is it possible to construct an image of a scene using merely the zero-crossing points of the multiple channels of octave-width (or otherwise), which when theoretically assembled are supposed to give us contours of objects in the scene?
Problem 2: If we assume that the boundaries of objects contain all the required information available from a scene, how can we automatically recognize the objects in the scene?

---

[27] I may say that I was subconsciously goaded by the not-so-well-known remark by Einstein: "I have little patience with scientists who take a board of wood, look for its thinnest part and drill a great number of holes where drilling is easy." [P. Frank in 'Einstein's Philosophy of Science', Reviews of Modern Physics (1949)].

Problem 3: How can we automatically estimate a scene's depth information from the stereoscopic pair of images of the scene by extracting the boundaries[28] of objects from each image of the pair?

The above three problems acted as some sort of guideposts for work in the Vision and AI Lab.

The extensive work that is presently being done all over the world in image processing, vision and pattern recognition is an indication that no simple account can be presented here to give a reader some idea of the complexity of the problems under consideration and subjectivity surrounding each result that was obtained in our attempts. Note that there is absolutely no chance of mathematical purity and clarity of the type found, for instance, in the first part of this article. Moreover, any major description of the work I did (or was involved in) first in the Institute until 2004–05, and second, outside the Institute subsequently, would require a treatise which is not in order here. Therefore, only a bird's eye-view is provided below to give a glimpse of some contributions.

- **Problem 1**. By decomposing an image to scanned lines, I developed a new framework consisting of generalized Hermite polynomials, and dispensed with the standard, but unrealistic, assumption of bandlimitedness of (spatial) signals. The motivation came from Slepian's paper [22] in which he has introduced the concept of "effective time-spread" and "effective frequency-spread" for functions of time. This translates to corresponding spreads in the space-frequency domain for images. Invoking the special properties of Hermite polynomials, I established [23] that a unique reconstruction (except for scale factor) of a scanline is possible from its (real) zero-crossings,[29] given its space-bandwidth product or space-bandwidth ratio. Extension to images (considered as stacks of scanlines) involves space-bandwidth products or ratios (including cross-space-bandwidth products/ratios) in two dimensions [24]. The same framework can be used to reconstruct signals from other types of partial information of the type (i) Fourier phase only; and (ii) Fourier magnitude only. For an entirely different approach, involving the concept of a regularized solution for the reconstruction of images from points given arbitrarily near boundaries and gradient information at these points, see [25].
  Pro tem moving forward to the post-2004 period at the NUS (Singapore), during discussions (with the signal processing group) on compressive sampling, I came

[28]The assumption is that boundaries of objects are more reliable sources of information than the (raw) gray/color intensities of the images of the scene. This is because images are naturally affected by noise, but boundary detection operators are supposed to be less susceptible to noise.

[29]What are complex zero-crossings as applied to an image? If one assumes that the zero-crossings in an image are obtained as maximal/minimal gradient points of a Gaussian-filtered—to simulate multiple (octave-width?) bandpass channels of the human visual system—image, how does one label them as real and complex zero-crossing points, if any? These are questions which seem to be still in need of clarification.

across a more striking problem of reconstruction of assumed sparse digital (sampled in time, for instance) signals,[30] from partial information sampled from, say, its Fourier transform. During some preliminary studies on this topic, I happened to come across a paper in which the Gini-index (developed in economics) was being used to characterize sparsity. Employing such a definition and using the (discrete) lq-norm (with $0 < q < 1$) along with simultaneous perturbation stochastic optimization (SPSO), we came out with a more efficient and more accurate reconstruction algorithm [26]. Note that this has no counterpart in the modelling of human visual system because it seems most unlikely that the human brain stores compressive samples of images of scenes for reconstruction during recall.

Problem 2. At the Institute, we first explored many algorithms of the literature on two-dimensional pattern detection and recognition (for images with no occlusion). The process involved extraction of boundaries which were mostly broken, thanks to the inevitable use of thresholds at various stages of processing. Of course, we invoked ingenious tricks suggested by a few authors (incl. Azriel Rosenfed) to 'close' the broken boundaries, and then employed strategies (like relaxation labeling) to segment the image. None of these were satisfactory in our preliminary goal of detecting even a card-board cube in a synthetic lab scene. To cut the story short, disenchantment led to my foray into an application of artificial neural networks, and, more specifically, the multilayer perceptron (MLP).

The first major study was an attempt to implement Fukushima's Neocognitron, a neural network to recognize characters. After a significant number of experiments with it to identify English alphabet and numerals, we found it to be unsatisfactory. This is the origin of our paper [27] which presents a significant modification of (and improvement on) the Neocognitron.

The standard MLP treats a two-dimensional pattern as a stacked 1-D vector, and hence two similar patterns shifted by even one-pixel are regarded as two different patterns. For the same reason, invariance to scale and distortion cannot be achieved satisfactorily. Inspired by the retinal structure of the human visual system, we were motivated to develop a radial encoding of two-dimensional patterns which was successfully used to recognize patterns of non-overlapping characters. The first step was to generate synthetically many patterns of each of the characters subjected to distortions (within limits) in scale and rotation, and affected by controlled amounts of noise. These patterns were then fed to Kohonen's self-organizing neural network (SONN) by way of checking the possibility of finding clusters (in feature space) for the characters. Excited by the output of the SONN, we developed some efficient algorithms not only to recognize characters and numerals, but, with some novel modifications depending on the applications, to boundary/contour extraction, face detection and recognition, multispectral data classification, among others [28–38]. The unresolved problem in this context is the recognition of partially overlapping characters (and objects).

[30] Sparsity is normally expressed in terms of the number of elements in the signal having either zero magnitude or negligibly small values.

Lest one should get the impression that the problem of face detection and recognition from images has been resolved satisfactorily in the ever-growing literature, it is advisable to note here that none of the algorithms reach the remarkable efficiency and accuracy of the (trained, wherever required) human visual system. The same is true of the classification of human facial emotions from images. Even with three-dimensional facial data, success with recognition of faces and their emotions has not been satisfactory.

Application of neural networks to three-dimensional face recognition is quite a complex issue, apart from the fact that a huge database needs to be created and processed. While processing a publicly available three-dimensional database (of limited size) of human faces, we found that the data points were irregular samples, and were not amenable to direct analysis for face (and facial expression, as one of eight basic emotions) recognition. After applying a data resampling strategy, we developed a modified form of principal component analysis to recognize (three-dimensional) faces and their expressions [39, 40] with an accuracy better than what is reported in the literature. The fact is that the same approach (after all the necessary modifications or changes) gives *highly unsatisfactory* results on other databases. A universal (and reliable) solution to the problem of face (and facial expression) recognition, independent of the origin of the datasets, is most unlikely anytime soon.

Problem 3. It is known that stereoscopic image analysis deals with the reconstruction of a three-dimensional physical scene (containing objects of interest) from at least a pair or, as is currently the practice, multiple images of the scene captured from different locations. Most of the literature contains (area-, feature- and diffusion-based, Bayesian and the like) algorithms for matching corresponding points in the images under the assumption of epipolar geometry,[31] the points being the projections of the same scene point on the images. If we assume that the geometry of image acquisition is given, we can use the matched points to compute the depth information in the scene. When applied to calibrated scenes, these algorithms have been found to be generally unsatisfactory. Even artificial neural networks have been tried out.

However, motivated by the self-organizing (i.e., so-called unsupervised) model proposed by Kohonen to imitate perceptual mechanisms of the human brain, we employed a modified self-organizing network to match the corresponding points in a stereo-pair of images. Quite distinct from the existing algorithms which, typically, involve area- and/or feature-matching, the network is first initialized to the right image, and then deformed until it is transformed into the left image, or vice versa, this deformation itself being the measure of disparity. This novel approach, which dispenses with the standard assumption of epipolar geometry, has been successfully tested on synthetic and natural (including random-dot stereograms and wire frames) and distorted stereo-pairs [41]. Such an application of the principle of self-organization to extract depth information in a scene from stereo-pairs of

[31] An assumption of epipolar geometry implies that the corresponding points lie on the same scanline in the stereo-pair under consideration.

images seems to be the first of its kind. Generalization of the proposed approach to multiple images of the scene remains to be accomplished.

- **Other Research Contributions**: Apart from the above, additional work was done in my Vision and AI Lab on certain aspects of image representation (quadtrees), optical flow, image fusion and modeling the human visual system. These topics do not, in general, relate to what was presented above as three basic problems. Since it would take a significant amount of space to describe these contributions, I thought it advisable to merely list some of them [42–47], while hoping that their titles give an idea of their contents.

I wish to end my article with a reference to Turing's much-debated paper (1950) [48] with the title, *Can a machine think*? As is well known, lots of issues engendered by an interpretation of Turing's question have not yet been settled satisfactorily. In 1950, Turing declared: "I believe that in about fifty years' time it will be possible to program computers, with a storage capacity of about 10^9, to make them play the imitation game so well that an average interrogator will not have more than 70 percent chance of making the right identification after five minutes of questioning. I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted." Many mathematicians and philosophers opine that his claim has been shown to be mistaken. See, for instance, [49, 50].

With the above formidable history related to thinking machines, can we venture to ask for a machine that can "see"? Is it the case that *thinking* and *seeing* are analogous processes? If a machine can think, can it also see, provided it is subjected to appropriate inputs? Answers to these questions could hopefully trigger a stimulating debate among those interested in classical versus modern-AI controversy. As a first step to grapple with the imbroglio, what tests, involving the use of cameras and computers, are to be designed to set goals for the realization of a possible vision-machine? Are there arguments analogous to, for instance, Searle's *Chinese Room* [51] as fundamental objections to (or in support of) the very concept of a vision-machine?

Epilogue

I wish to place on record my deep gratitude to my teacher, mentor and father-figure, **Professor BLD**, for his ever-benevolent association with me all these years, and to **Professor M. A. L. Thathachar**, my former teacher and later colleague, for his crucial role and providential help rendered in the early stages of my work in stability analysis.

All in all, I consider my academic life at the Institute to be mostly glorious and occasionally ecstatic. I would, of course, be delighted to live it once again if there were an opportunity. However, I cannot but end these reminiscences without quoting William Blake's poem, *The Defiled Sanctuary*:

```
 I saw a Chapel all of gold That
none did dare to enter in,
 And many weeping stood without,
Weeping mourning, worshipping.
 I saw a Serpent rise between
The white pillars of the door,
 And he forc'd and forc'd and forc'd;
Down the golden hinges tore,
 And along the pavement sweet,
 Set with pearls and rubies bright,
All his shining length he drew,
 Till upon the altar white
Vomiting his poison out On the
Bread and on the Wine.
 So I turned into a sty,
 And laid me down among the swine.
```

Notes

1. There entered, in the early 1970s, a new, foreign import to the Indian Institute of Science (IISc), at the level of the highest academic position. This event was a very precious fruit of the efforts of a special committee set up in the late 1960's which literally scoured the world, interviewing candidates with the goal of bringing in "specialists from abroad", to ostensibly "avoid inbreeding" and, at the same time, earnestly hoping that frontier research work would be launched by them at the Institute. This person of significance (with apologies to Nikoloi Gogol, the Russian novelist), soon after coming over to the Institute from a place not exactly on the map of distinguished places of higher learning, began his activities by forcing himself on junior members of faculty who were teaching graduate courses, and sat in some of the classes—much to their chagrin and disgust—as though to grade them. He used to pass unsolicited judgement on their teaching standards. In one such case, in fact, when he felt his blatant claim as the sole authority on a certain course-subject was in question, he *wrested* the "custody", as it were, of that course, wagged his first finger (as teachers used to do in middle school in those days) at the hapless instructor, and verbally threatened him with dire consequences on his promotion.
   There were other unpleasant events associated with the same person. Once, in his seminar, which was widely announced, he wrote on the blackboard some mathematical expressions. A mathematician of high caliber in the audience was bold enough in bringing to the speaker's attention inaccuracies in those expressions. The speaker's fury stunned the audience, especially when he shot back: "Have you worked on the problem?"
2. I have recently discovered that a much-quoted and beautiful stability result of Lyapunov [52] when applied to Eq. (1) does not *seem* to exhibit the set of stability regions in the $\alpha - \beta$ graphs of [1]. More simply, there are (α, β) values inside

the McLachlan stability boundaries which do not obey the Lyapunov condition for stability. I wish to add, however, that I haven't succeeded in accessing M. G. Krein's (Russia) papers (on the type of differential equation considered by Lyapunov [52]), and collected in AMS Translations, which are supposed to contain an improvement over Lyapunov's result. I am left to wonder whether these results of Krein can reproduce the $\alpha - \beta$ graphs of [1].

3. I was told about this paper by another well-known researcher (from the same institute), Professor Ya. Z. Tsypkin, the author of a book on adaptive control, as also of a paper in Doklady Akademii Nauk SSR (around 1965 or so) on the extension of the Popov theorem to discrete-time nonlinear time-invariant feedback gain systems. (This paper will figure in later in the article.) I used to have regular meetings with him in Moscow either before or after his lectures on learning systems. Once he gushed with pride to tell me that Dr. Pyatnitskii had applied Pontryagin's maximum principle to solve a stability problem. When I responded by pointing out that Professor Roger W. Brockett had already done (or rather attempted) it in 1964—see item 5. below—he was unimpressed.
4. For the sake of completeness, I wish to add, however, that at the end of those discussions, in which I harped on the need for a comparison of any stability criterion as applied, wherever possible, to the Mathieu equation, with the $\alpha - \beta$ graphs of [1], we found ourselves in disagreement.
   By the way, *control* as a discipline in India began a steep descent around this time. Except for some indirect references to control in power electronics and the like, there seems to be no discernible research interest, in India, in control theory and practice per se. Contrast it with what the Russians have done to Aizerman's institute—they have christened it the **Institute of Problems in Control**.
5. The fact that it [53, 54] is a faulty result I discovered [55] in early 1975 when I was at the University of Karlsruhe, Karlsruhe (Germany), interacting with my German colleague, Dr. Gerhard Siffling, on the stability analysis of a discrete-time FSK oscillator. It is appropriate to mention here that Brockett did not *actually* employ Pontryagin's maximum principle for the system governed by the linear second order differential equation,

$$(d^2x/dt^2) + 2(d\,x/dt) + k(t)\,x(t) = 0, \quad t \in [0, \infty),$$

   where the time-varying gain $k(t) > 0, t \in [0, \infty)$. His technique, in fact, amounted to choosing a k(t) for $t > 0$, such that the phase-plane trajectory starting from, say $x(0) = 0$, $(dx/dt)|\_\{t = 0\} = 2$, results in the *limiting-case* of a closed loop trajectory having the largest intercept on the x-axis. In this context, it seems pertinent to pose the following problem related to a possible application of the Maximum Principle to the Mathieu equation whose stability/instability boundaries in terms of $\alpha - \beta$ plots are known, as mentioned earlier: What is a typical performance criterion to be maximized in terms of parameters α and β?
   In this context, see [19] for other instances of faulty results, including the one in which what is to be proved is assumed. And, interestingly enough, one such

faulty result has been *extended* by a researcher to Marcinkiewich space without even verifying its correctness.

6. While in Germany in 1975, I had managed to contact the division of Siemens where blue and green LEDs were being manufactured for the first time. They were kind and generous enough to send me gratis a couple of their samples. Along with the Hewlett-Packard HEDS unit, the standard red LED and the blue and green Siemens LEDs were ingeniously assembled by my newly-acquired assistant, Mr. William Raymond (who had just a diploma in electronics) and mounted on the movable carriage of an old lathe in the department. The spindle of the lathe provided the rotary motion for a cylindrical drum on which a CIR image print could be stuck. And so was created the first solid-state scanner in India. We did succeed in scanning a couple of black-and-white and color images just to demonstrate the possibility of conversion of a hard copy color image to digital format.

   (It behooves me to add here that we also manually digitized a few color infrared frames using the microdensitometer of the Department of Metallurgy (IISc) for preliminary computer classification of sugarcane and paddy crops. A technical paper on the results obtained were presented in an international conference on remote sensing held in Freiburg i. Br. (Germany) in 1978.).

   There is a lot more of bumpy history associated with the indigenous design and development of our planned LED-based color scanner which cannot be presented here. Thanks to the facetious remarks by some members of the project monitoring committee, no refinements of LED scanner for research purposes could be attempted. A typical remark was that it was *simpler* to buy an (American) Optronics scanner or a (French) laser scanner! Yes, it was perhaps the case for other organizations. In stark contrast, this was a time when anything to be bought (by the Institute) from abroad had to be *mandatorily* cleared by the Electronics Commission. An unenviable consequence was this: by the time any equipment arrived in Institute after a delay typically of the order of years, the model would be outdated, as it did in fact happen with respect to the Hewlett Packard computer HP1000 (already referred to earlier) which required superhuman efforts just to get formally cleared by the various authorities of the Government. This computer, which was bought from ISRO project funds for image processing, had, at the time of the purchase order, a certain type of fragile disk drive. When the computer did at last arrive at the Institute, it was already outdated. By the way, it was the first *modern* computer in the department which claimed to be almost 75 years old.

Getting back to the story of the French laser scanner imported by the Government agency, when that scanner stopped functioning, it could not be repaired for more than one year. We subsequently learned that the device soon fell into disuse!

References

1. McLachlan NW (1947) Theory and applications of Mathieu functions. Oxford Press
2. Popov VM (1962) Absolute stability of nonlinear systems of automatic control. Automation and Remote Control 22(8):857–875
3. Zames G (1966) On the input-output stability of time-varying nonlinear feedback systems, parts 1 and 2. IEEE Trans Autom Control 11:228–238 465–476
4. Aizerman MA, Gantmacher FR (1964) Absolute stability of regulator systems. Holden-Day, San Francisco
5. Venkatesh YV (1971) Global variation criteria for the stability of linear time varying systems. SIAM J Control 9:431–440
6. Venkatesh YV (1978) Global variation criteria for the L2-stability of nonlinear time varying systems. SIAM J Math Anal 19(3):568–581
7. O'Shea RP (1967) An improved frequency time domain stability criterion for autonomous continuous systems. IEEE Trans Autom Control 12(6):719–724
8. Zames G, Falb P (1968) Stability conditions for systems with monotone and slope restricted nonlinearities. SIAM Journal on Control 6:89–108
9. Kalman RE (1963) Lyapunov functions for the problem of Lur'e in automatic control. Proc Natl Acad Sci 49(2):201–205
10. Yakubovich VA (1962) The solution of certain matrix inequalities in automatic control theory. Dokl Akad Nauk SSSR 143:1304–1307
11. Venkatesh YV (2015) On improving Popov's criterion for nonlinear feedback system stability. Syst Sci Control Eng Open Access J 3(1):211–229
12. Aizerman MA (1948) On one problem concerning the stability in the 'large' of dynamic systems. Usp Mat Nauk 4(4):186–188
13. Huang Z, Venkatesh YV, Xiang C, Lee TH (2014) Frequency-domain testability conditions for switched linear and nonlinear SISO systems. Int J Syst Sci 45(3):682–703
14. Huang Z, Venkatesh YV, Xiang C, Lee TH (2014) Frequency-domain testability conditions for time-varying linear and nonlinear MIMO systems. Control Theory Technol 12(1):1–22
15. Venkatesh YV (1974) On the stability of nonlinear systems with periodic coefficients. Proc IEEE 62:278–279
16. Venkatesh YV (2014) On the L2-stability of time-varying and nonlinear discrete-time MIMO systems. Control Theory Technol 12(3):217–241
17. Venkatesh YV (1988) Riesz-Thorin theorem and the Lp-stability of nonlinear time-varying discrete systems. J Math Anal Appl (USA) 135:627–643
18. Venkatesh YV (2016) Frequency-domain stability criteria for SISO and MIMO nonlinear feedback systems with constant and variable time-delays. Control Theory Technol 14(4):261–282
19. Venkatesh YV (1977) Energy methods in time varying system stability and instability analyses. In: Lecture notes in physics, vol. 68. Springer, Heidelberg
20. Venkatesh YV (1977) Converse Schwarz inequality and an instability-related property of feedback systems. Int J Syst Sci 8:339–352
21. Venkatesh YV (1988) Converse Holder inequality and the Lp-instability of nonlinear time varying feedback systems. J Nonlinear Anal Theory Methods Appl 12(3):247–258
22. Slepian D (1976) On bandwidth. Proc IEEE 64:292–300
23. Venkatesh YV (1992) Hermite polynomials for signal reconstruction from zero-crossings, part 1: one-dimensional signals. IEE Proc I Commun Speech Vis 139(6):587–598
24. Venkatesh YV (1998) Generalized hermite polynomials for image reconstruction from zero crossing contours. In: International conference on image processing, Oct 4–7, 1998. Chicago, Illinois, USA
25. Ravi D, Venkatesh YV, A new framework for reconstruction of images from boundaries. SIAM J Appl Math (USA)
26. Zonoobi D, Kassim AA, Venkatesh YV (2011) Gini-index as sparsity measure for signal reconstruction from compressive samples. IEEE J Sel Top Signal Process 5(5):927–932

27. Murthy CG, Venkatesh YV (1996) Modified Neocognitron for improved 2-D pattern recognition. IEE Proc-Vis Image Signal Process 143(1):31–40
28. Murthy CG, Venkatesh YV (1998) Encoded pattern classification using constructive learning algorithms based on learning vector quantization. Neural Netw 11:315–322
29. Shanmukh K, Murthy CG, Venkatesh YV (1999) Applications of self-organizing networks to spatially isomorphic patterns. Int J Inf Sci (USA) 114:23–39
30. Venkatesh YV, Rishikesh N (2000) Self-organizing neural networks based on spatial isomorphism for active contour modelling. Pattern Recognit 33:1239–1250
31. Rishikesh N, Venkatesh YV (2001) Shape recognition using an invariant pulse code and a hierarchical competitive network. Pattern Recognit 34:841–853
32. Koh LH, Ranganath S, Venkatesh YV (2002) An integrated automatic face detection and recognition system. Pattern Recognit 35:1259–1273
33. Ong SH, Yeo NC, Lee KH, Venkatesh YV, Cao DM (2002) Segmentation of color images using a two-stage self-organizing network. Image Vis Comput 20:279–289
34. Venkatesh YV, Raja SK (2003) On the classification of multispectral satellite images using the multilayer perceptron. Pattern Recognit 36(9):2161–2175
35. Yeo NC, Lee KH, Venkatesh YV, Ong SH (2005) Color image segmentation using the self-organizing map and adaptive resonance theory. Image Vis Comput 23:1060–1079
36. Venkatesh YV, Raja SK, Ramya N (2006) Multiple contour extraction from gray-level images using an artificial neural network. IEEE Trans Image Process 15(4):892–897
37. Gu WF, Venkatesh YV, Xian C (2010) A novel application of self-organizing network for facial expression recognition from radial encoded contours. Soft Comput 14(4):113–122
38. Gu W, Xiang C, Venkatesh YV, Huang D, Lin H (2012) A facial expression recognition using radial encoding of local Gabor features and classifier synthesis. Pattern Recognit 45(4):80–91
39. Venkatesh YV, Kassim AA, Murthy OVR (2009) A novel approach to classification of facial expressions from 3D-mesh datasets using modified PCA. Pattern Recognit Lett 30:1128–1137
40. Venkatesh YV, Kassim AA, Yuan J, Nguyen TD (2012) On the simultaneous recognition of identity and expression from BU-3DFE datasets. Pattern Recognit Lett 33(13):1785–1793
41. Venkatesh YV, Raja SK, Jayakumar A (2007) On the application of a modified self-organizing neural network to estimate stereo-disparity. IEEE Trans Image Process 15(4):2822–2829
42. Unnikrishnan A, Venkatesh YV, Shankar P (1987) Connected-component labelling using quadtrees—a bottom-up approach. Br Comput J 30:178–182
43. Goel V, Venkatesh YV (1992) On an optimal and faster construction of quadtrees from raster-scanned images. Br Comput J 35:A073–A083
44. Sobey PJ, Nagle MG, Venkatesh YV, Srinivasan MV (1994) Measurement of complex optical flow using an augmented generalized gradient scheme. J Opt Soc Am 11:2787–2798
45. Li Y, Venkatesh YV, Ko CC (2000) Multi-sensor image fusion using influence factor modification and ANOVA methods. IEEE Trans Geosci Remote Sens 38(4):1976–1988
46. Li Y, Venkatesh YV, Ko CC (2001) A knowledge-based neural network for using edge-maps. Int J Inf Fusion 2(2):121–133
47. Rishikesh N, Venkatesh YV (2003) A computational model for the development of simple-cell receptive fields spanning the regimes before and after eye-opening. Neurocomput 50(1):125–158
48. Turing AM (1950) Can a machine think? Mind 59:433–460
49. Churchland PM, Churchland PS (1990) Could a machine think? Sci Am 262(1):32–37
50. Copeland J (2000) The turing test. Minds Mach 10:519–539
51. Searle JR (1980) Minds, brains, and programs. Behav Brain Sci 3:417–457
52. Kaplan W (1962) Operational methods for linear systems. Addison-Wesley (Chapter 8)
53. Brockett RW (1965) Optimization theory and the converse of the circle criterion. Proc Natl Electron Conf (NEC) 21:697–701
54. Brockett RW (1967) Variational methods for the stability of periodic differential equations. In: Hale J, LaSalle JP (eds) Differential equations and dynamical systems. Academic Press (1967)
55. Venkatesh YV (1977) A survey of some recent results in the stability and instability analyses of time varying systems. Int J Non-Linear Mech 12(4):251–268

An Engineer—Academic Looks Back

Prem Krishna

This article attempts to connect and correlate the various aspects which influence the life and career of a person, in this case, more specifically, an engineer. These include the factors that dictate the formation of one's attitudes and character, namely, the opportunities offered, and the environment—social, political and professional. Although the traits in the character of a person may be dictated largely by nature—genetics and inheritance, the exposure and contacts of the early years, with parents, family and teachers go a long way in forming attitudes towards life. In this article, the writer has used himself as the example to construct one possible model of an engineer's life. While going through this journey it is imperative to understand the factors that made it what it has been, it is not out of place to recount any contributions one may have made to the profession or the national development. This enables an understanding of the total package.

Since my birth in March 1938, the narrative relates to three specific time windows. The first till the completion of formal education in 1964, the next, the period of regular employment as an academic at the University of Roorkee, from 1965 to 1998, and lastly, the period post retirement from 1998 onwards. As I look back before writing this narrative, I am convinced that providence has so far been most kind to me.

My father, Professor Jai Krishna, whom the fellows of the INAE will also identify as their Founder President, joined the Thomason College of Engineering at Roorkee as a Lecturer in 1939, and then the family joined him in 1940, with me a toddler. The College set up in 1847 by the British for formal engineering education, being one of the first globally, was spread over a sprawling (for those days—today with almost ten thousand students that aura has diminished considerably) campus. It was a serene environment with tall green trees. There was quietness and life was organised. Transportation was restricted to walking or a few bicycles, and, the air was clean. The snowclad Himalayan peaks could be seen from the campus. Growing up a little

P. Krishna (✉)
B-033, Raheja Atlantis, National Highway 08, Sector 31-32A, Gurgaon 122001, India
e-mail: pk1938@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_29

further, I began to notice the unmistakable traits of a highly disciplined civic life—there was punctuality, tidiness, regular participation in sports, utmost regard for seniors, and, so on. There is a reference to this aspect later too. At this point it will suffice to say that a growing up youngster was bound to be affected by this environment.

Although this was too early in years for me to carry any impression of the highly significant political developments going on in those years, the sense of turbulence was noticeable, and the coming of Indian independence in 1947 was obviously too important an event to escape any Indian. There was a mixed feeling—joy for getting independence but sorrow created by the turmoil due to partition of the country. The status of engineering education and development was not much to write home about. The change in status of the country opened the gates for growth. The Thomason College was converted into the University of Roorkee in 1949. The Indian Institutes of Technology were set up—5 to start with—at Kharagpur, Bombay, Madras, Kanpur and Delhi. Projects such as the Bhakra Dam (Mr. Nehru's temples of modern India), setting up of India's space and Atomic Energy program, and, the establishment of the Council of Scientific & Industrial Research (CSIR), are only some examples of the initiatives taken.

On the personal front, I obtained admission to a Public School at Nainital, a touristic destination in the hills in UP, in 1948. This had been an English medium institution till 1947 and was taken over by the Birlas and converted into the first Hindi medium Public School in India. More relevant to the tenor of this article is the fact that during the four years of my schooling at that institution, there was exposure to the same spirit of discipline, punctuality, regularity, tidiness, and, civility, as I had observed while growing up at the Roorkee campus. Added to that was another experience that left an indelible impression on my mind. This was the total commitment of the teachers towards the welfare and education of the students. The hostels were a home away from home! Next at a College at Mussoorie, another town in the Uttar Pradesh, a public school run by Irish missionaries, the experience of Nainital continued.

The exposure of these early years, must have played an important role in forming me as a person. Besides this, growing up on the Thomason College campus, with its reputation as an outstanding place for education in this subject area, must in all likelihood have created an attraction to become a Civil Engineer. Admission to the University of Roorkee even in those early years was difficult, though not as tough as today. Therefore, my admission to the Civil Engineering degree programme in the year 1956 was not only a matter of great satisfaction for me, it was a great privilege, since this programme at the University of Roorkee was highly rated amongst the young students aspiring to become engineers. At that time I could not have asked providence for more.

The three years spent at the University of Roorkee as an undergraduate student, were very significant in providing a direction to my professional as well as personal life. Besides directly experiencing the special features of life at this institution, mentioned earlier too in the article, there were a few other things that need to be mentioned. The faculty were not only of sterling quality technically, their commitment to producing outstanding graduates, and their welfare generally, is remembered even today by the alumni of that era. Another point that characterised our education was the obvious mandate to make the students as self—reliant as possible, as well as to prepare them for serving the cause of National development. An anecdote narrated by one of our teachers, Professor O. P. Jain, who also was a student at Roorkee in the early 1940s, is most illustrative in this respect. His class was assigned to design a railway bridge over the Ganges canal. The task was to be completed in two weeks, and, no other information or data were given by the teacher. When approached by the class for this additional information, the teacher told the class—you are going to become engineers, please go and find the answers!!

Furthermore, the Roorkee graduate was exposed to the 'grass roots' of Engineering practice, while being imparted with fundamental knowledge required to remain a self—learner throughout life. Those were the years when students could have a brush with real life engineering through 'shramdan' besides the structured summer training, which was part of the curriculum. For better or for worse, our engineering education seems to have veered away substantially from this philosophy, which was central to the programme in those early years at the University of Roorkee, and, from what one can see, it served the cause of National development very well. The training packaged into the 3-year programme provided a good start to our engineering careers.

Another aspect worthy of mention, for the decade pertaining to the schooling at Nainital up to graduation from the University at Roorkee, was the compulsory participation in sports and games. It is my belief that sports help to teach a person about team spirit and also give him a capacity to take defeat. The young generation today is faced with harsh competition, and sports can help them to get de-stressed to a good extent.

After a stint as a graduate trainee at the Bridge & Roof Co. at Howrah for a year, there was another year at the University of Roorkee pursuing a Masters course in Structural Engineering. The B&R specialised in design and fabrication of industrial steel structures. These two years added to my preparedness for a professional career. The next very significant turning point that followed was my admission to the postgraduate programme at the Imperial College of Science & Technology, London (affiliated to the University of London), with the objective of getting a doctoral degree. This again one would consider a fortunate opening, since the "Imperial' as it was called, had a great reputation for its quality of research in the area of Structural Engineering. Their higher education programme required a student to enter through the *Diploma of Imperial College* (*DIC*) course, before registration for research for a degree. Then, a research scholar was first registered for the M.Sc. degree before being moved on to the doctoral programme, if found fit. A very prudent arrangement! Having had the benefit of obtaining a master's degree from a reputed college, I was exempted from the requirement of going through the DIC course after attending it only for a few weeks, and, could utilise the time that thus became available to me, for a few months of excellent experience in a Structural Engineering consulting firm. Subsequently, admission to the research programme came through in July 1962, leading to a doctoral degree in November 1964.

Although my technical education in India was from a top-rated institution, the research and training experience in the UK was comparatively more intense. The ethos was different, but there was similarity in the emphasis on self-learning and achieving excellence, besides many other attributes. A blessing was in having a supervisor in Professor S. R. Sparks, a brilliant experimentalist, and a great human being. Our discussion on my research was held on barely 7 occasions, though I had the pleasure of meeting him socially very many more times. There was often a feeling of having been pushed into a pool at the deep end to learn how to swim.

When leaving India for studies in the UK, research in the subject of *Suspension Bridges* was contemplated. Infrastructure development was beginning to grow in the Country, and, it was anticipated that as the hilly regions will open up, there will be a need to build many suspension bridges. However, when work was started at the Imperial College, it was suggested to me that within the general area of cable suspended structural systems, it could be even more exciting to work on cable suspended roof systems. It was a fascinating experience to explore this entirely new area of research. Barely any back up literature was available which dealt with such roof structures. This allowed plenty of scope for original thinking, and explore new vistas. This was a training of mind which stood with me in the subsequent years of my professional life.

There was also a new exposure to the use of digital computers, which were in the early stages of their development—something that has changed the pattern of life on this planet beyond imagination in the decades that have followed. In 1962, solving 5–6 simultaneous equations seemed to be quite a task. By the time my Ph.D. work was completed, two years later, a number running into hundreds was a clear possibility. Thus, as the technology for computer hardware continued to improve, solving thousands of equations (that too in quick time) did not remain a challenge. This revolutionised the very manner of looking at numerical work and engineering analysis. On the other hand, and in parallels, the electronic revolution completely changed the entire field of communications. In the 50 years that have since elapsed, the world has become smaller!

Reverting back to my journey, the Doctoral degree from the University of London, completed my formal degree requirements, upon which I returned to India. India had been independent politically for more than 17 years, and for most of these it was under the visionary leadership of Jawahar Lal Nehru. There had been effort all around to lay the foundations of a modern Nation, embracing a scientific temper in its multifarious development. However, for a person like me returning to India, the difference between the western world and India (in fact most of Asia) was stark and huge, even somewhat depressing. However, what helped greatly was the determination to anchor my heels fully in India to make the best of whatever training had been received in the foregoing years to build up a career, and indeed to give back to the country to my utmost capacity. Providence was kind to me in upholding the decision.

There were opportunities to make a career in *Academia, Research, or, the Industry.* However, there was little to debate, as the privilege of accepting the offer from the Civil Engineering Department of the University of Roorkee provided an obvious choice. There were several plusses perceived. The University flaunted some of the best known peers in Civil Engineering in the country, and Structural Engineering was without doubt the strongest nationally and comparable internationally. As an Academic at the University of Roorkee, with its reputation, one could hope to get a good exposure to sponsored field work and carry out applied research, besides teaching. It turned out to be a very good decision, and permitted a balanced combination of all three. The period of 33 years (1965–1998) was mostly utilised at Roorkee.

Soon after joining the University of Roorkee, there was a welcome opportunity to go abroad to accept offers of visiting assignments for two years (1968–1970)—first at the University of Illinois, Urbana in USA, and, in the next year at Imperial College, London. Although both these stints provided invaluable experience in their own different ways, the US assignment gave a completely new dimension, in that this gave me an opportunity to understand the US system for the first time. The department of Civil Engineering, rated the best in that country, had a faculty of 105 which included some of the best known names in the discipline, led by the redoubtable Professor N. M. Newmark. I felt humbled, and made my best efforts to learn as much as possible during the limited time I had there. In a significant development, it was possible for me to initiate the project for writing the first book on *Cable-Suspended Roofs,* under the banner of the McGraw-Hill Book Co., New York—add to the text substantially in the following year at London, and, complete it later upon my return to Roorkee.

Late, temptations came for going to the West as well as the middle eastern countries, but better sense prevailed. There was indeed no lack of opportunity within the Country. The model followed was to keep in touch with the developments abroad through visits for conferences and exchange programmes (*besides the two years for teaching assignments mentioned above*), but keep the anchor at Roorkee. Assigned to teach *Structural Mechanics,* and, *Design of Steel Structures,* I built up specialisation for these, besides the non- conventional area of *Cable Supported Structures*, a legacy from my doctoral research. *Cable Supported Structures* led to a logical interest in the subject of *Wind Engineering.* In the mid—seventies, my father, Professor Jai Krishna, who had championed the cause of establishing *Earthquake Engineering* Research, Development and Extension in India, nudged me to plunge more seriously into developmental work on *Wind Engineering*. He envisioned that as the country grows into a modern nation, it will build many tall as well as wide span structures, besides power systems of different types. These will often consist of slender and wind-sensitive structures. Thus capacity building in wind engineering was required. It is gratifying to record that Roorkee became a destination for sponsored work related to both the last named specialisations of cable structures and wind engineering.

In fact, for the developments in *Wind Engineering*, Roorkee attained a leadership position in India. Pioneering steps were taken to set up the first large boundary layer wind tunnel in India, in the early 1980s, at the University. Incessant effort was made to strengthen this field of engineering. The first Symposium on Wind Engineering to cover the Asia Pacific region was held at the University of Roorkee in 1985, and has since established itself as a 4-yearly event. I was privileged and honoured, to have been elected President of the International Association of Wind Engineering for the period 1991–95 (the only Indian so far), and India organised the 4-yearly

International Conference on Wind Engineering for the first time (and only time so far) at Delhi, in 1995. An Indian Association of Wind Engineering was set up in 1993. Significant contributions were made towards wind disaster mitigation efforts of the country.

During the period being addressed at the University of Roorkee, there was ample interaction with the industry which was personally very satisfying, since it enabled exposure to problems related to complex structures often requiring a novelty of approach for their solution. Some of these worthy of special mention are, the work on several cable stayed bridges, the TIFR Giant Metre Wave Telescope system, numerous power and communication structures tested in the wind tunnel, and, so on. The year 1996–97 provided a unique excitement as the Institution celebrated its 150th year. *Soon after, in 2001, the University was converted to an IIT.* It is needless to mention that the most enjoyable and rewarding task of all was to teach the undergraduates, and, to notice the sparkle in their eyes when they grasped a point well made.

It may surprise the reader, but the nearly 20 years post retirement from Roorkee have brought for me as much challenge and excitement, as perhaps the 20 years in the pre-retirement period. Part of the reason for this ongoing opportunity is the globalisation mentioned below. The experience gained in earlier years has enabled me to contribute to some iconic engineering projects—to name a few—membrane roofs; cable bridges; a 115 m high Shiva murty (under construction); a 486 m span railway arch bridge over the river Chenab (under construction), which will be one of the highest in the world; a state-of-the-art wind tunnel being constructed at Guna (MP) by JAYPEE Associates; a major Rail Road bridge under construction over the river Ganga at Ghazipur (UP). Of equal satisfaction has been the association in the INAE work, in earnest after 2008, the first 6 years having been as its Vice President. An opportunity to mentor the research activities of the Central Building Research Institute at Roorkee as the Chairman of its Research Council for the last 7 years has provided me with an entirely new dimension. There were awards and recognitions, but the one most cherished was the Distinguished Alumnus award 2012 of the IIT Roorkee.

Opening up of the Indian economy and globalisation from mid 1990s onwards brought about a sea change in all round growth, including that related to Engineering and Technology. We as engineers have been playing a commendable role in contributing to this growth*. I feel proud to have been part of this fraternity, and feel that this has given me a life well lived. Some industries such as the one dealing with Information Technology, gave a great fillip to the economy of the country. Similarly, there has been enormous progress in departments such as aerospace making the country proud. The Civil Engineering profession has served the goals of development well and steadily, but perhaps there is not enough glamour so as to get better recognition.

The problems of our country have varied and have enormous proportions, whether these be political, societal, or, developmental. The world order, economic or political, is not making things any easier. There is often much turbulence experienced. It is nevertheless a good augury that the dynamics has given rise to a positive direction to the growth of the Nation.

In the final count, for me as an individual, life so far has proved Swami Vivekanand's words, whose essence is that, God does not give what you want but gives all you need.

See "*Glimpses of Indian Engineering Achievements*", *A Coffee Table Book, INAE, 2012*.

Industrial Research—Academia—R&D Management

E. C. Subbarao

I was born 8th August, 1928 in a middle-class family. My parents had 4 sons and 2 daughters to raise and educate on my father's low monthly salary. We all studied in Board High School, Nidadavol, West Godavari District, Andhra Pradesh. This village had no running water or electricity. I studied with a kerosene lamp. Our batch was the first to write the high school examination in our school, in 1944. There was a function held in our school in late 1944 with the Education Minister of undivided Madras state as the Chief Guest to award a medal to me for topping the pioneer batch in our school. Since all our siblings studied in that school, when I liquidated two plots of land we had in that village, I donated that money to build a set of classrooms, since the class rooms collapsed in a recent cyclone and the students were studying under trees. The classroom building was dedicated to the memory of my late parents, Eleswarapu Sriramamurthy and Eleswarapu Neelaveni.

For Intermediate (or PSU), I went to Government Arts College, Rajahmundy for two years. Some years ago, when this college celebrated its centenary, our Physics teacher contributed a chapter to the commemoration volume. That chapter covered 10 alumni of the college during the past 100 years who made outstanding contributions to India and he included me as one of those ten. The values of a family can move mountains even if money is limited.

E. C. Subbarao (✉)
Tata Research Development & Design Centre, 54B, Hadapsar Industrial Estate, Hadapsar, Pune 411013, India
e-mail: ecsubbarao@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_30

College

I joined the College of Technology at Banaras Hindu University (BHU) in 1946 and received B.Sc. Tech degree in Glass Technology in 1949. It was a memorable period of BHU, when the founder Pandit Madan Mohan Malaviya and the Vice-Chancellor Dr. Sarvepalli Radhakrishnan were staying on the campus. In early 1947, all the national leaders including Pandit Jawaharlal Nehru, Mahatma Gandhi, Sardar Patel, Maulana Abdul Kalam Azad, Sarojini Naidu, Jayaprakash Narayan among others, visited the campus and addressed the students. Dr. Radhakrishnan delivered Gita lectures every Sunday, attended by students and staff. On one occasion, he announced that there will be no Gita lecture next Sunday since he has been asked to speak to the nation at 1130 pm on 14th August 1947, just before Pandit Nehru gave his famous "Tryst with Destiny" lecture just before midnight when India became independent. On a later occasion, Dr. Radhakrishnan announced at a Gita lecture that he was reluctantly leaving the University because Pandit Nehru appointed him as the first Indian Ambassador to Russia. The intellectual ambiance created by luminaries leads the way to following in their footsteps to serve the nation.

As part of my engineering undergraduate education, I had spent summer and puja vacations in industrial training in Ogale Glass Works, Ogalewadi, Maharashtra and in Ganga Glass Works, Balawali, U.P. This was a valuable exposure to actual shop floor industrial operations, which unfortunately is no longer a required component of Indian engineering education.

Recently, by combining the Colleges of Engineering and Technology, BHU Indian Institute of Technology was created. Immediately, BHU IIT Global Alumni Association was formed. In its first meeting in June 2013, I was honored with an Award for Excellence in Research in a memorable function in Bangalore. This was 64 years after my graduation from BHU!

First Factory Job

My first job in 1949 was in the Parry Pottery works in Ranipet, Madras state with a starting monthly salary of Rs. 75 plus dearness allowance. I was on shift duty and was supervising from raw materials, processing, fabrication of pottery articles, drying, firing in a tunnel kiln and finally packing for dispatch. An engineer's education is not complete without exposure to these industrial practices, preferably in the early stage of his career. Since I wanted to go abroad for higher studies, I left this job in August 1951.

Studies in USA

I got admission with an Assistantship at the University of Washington, Seattle, USA. I travelled by ship from India and joined the University in September 1951. Since my BHU degree was of 3 years duration, I studied for one year to earn a B.S. degree in Ceramic Engineering and after another 15 months, received M.S. Degree in Ceramic Engineering.

Soon after arrival, I entered a research paper competition and I won a prize and the paper (my first) was published. I won a prize in same competition in the following year, leading to my second publication. My professors were impressed with this, being the first for the department.

Professor James I. Mueller was my thesis guide and unforgettable mentor at the University of Washington and he enabled me to integrate with the American educational and social scene and to do my best.

I helped a consultant by carrying out the necessary experiments and it was a valuable experience in tackling real world problems, besides giving me a welcome income. An open mind to opportunities is needed to learn.

My Ph.D.

As I was completing my M.S. degree, I applied to MIT and Pennsylvania State University (Penn State) for Ph.D. admission. Both admitted me and MIT gave a half time Assistantship ($128 per month) and Penn State gave a three quarter time assistantship ($192 per month). Since, I wanted my wife and daughter to join me from India, I accepted Penn State offer (inspite of the greater reputation of MIT) and joined there for my Ph.D. in January 1954 and my family joined me in December 1954.

I worked with Prof Hummel for a year and published two papers. Then I shifted to Prof. W. Buessem as my Ph.D. thesis guide and worked on "Domain Effects in Ferroelectric Barium Titanate Ceramics". Dr. Buessem was the Director of Siemens.

Research in Germany before and during the World War II. He joined Penn State as a Professor in early 1950s. I was his first Ph.D. student. I published two papers from my Ph.D. thesis, one in the U.S. and the other in German in Germany.

As I was completing my Ph.D. thesis, I applied to four major US companies for a research job. After interviewing, I was offered jobs by all the four. I evaluated them in terms of my priorities and finally accepted the one from Westinghouse Research Laboratories, Pittsburg, PA headed by Dr. Clarence Zener. I felt that Westinghouse offered better opportunities to learn and grow, though it paid the lowest starting salary of the four offers. I joined in November 1956 and worked mostly in two areas - Ferroelectrics and Solid Electrolytes for Fuel Cells. I came up with a family of Ferroelectrics with higher Curie temperatures than the 560 °C which was the limit so far. This breakthrough attracted a lot of international attention. The work on Solid

Electrolytes was of great relevance to Westinghouse since work on solid oxide fuel cells was being pursued actively at that time. With excellent mentoring available for me at Westinghouse, not only the quality and relevance of my research on industrially significant problems blossomed but also conveying my research results in the form of publications in reputed journals. In fact, my papers were getting accepted as submitted even in the best Journals.

Dilemma and Resolution

Life is a perpetual motion machine. After establishing a successful research career, some things cropped up. We had two more children (a son and a daughter). My wife wanted to raise our children in India to become acquainted with life and relatives in India and that it should be done before they become too grown up to adjust easily. So, she wanted it to happen before end 1963 (when the children were 13, 5 and 4). At that point, Dr. P. K. Kelkar, Director of the newly established IIT, Kanpur visited Carnegie Institute of Technology and Westinghouse Research Laboratories in Pittsburg (the latter to get an idea of industry oriented research in the US). Dr. Zener wanted me to show Dr. Kelkar around our lab and then Dr. Kelkar impressed us with his vision of the kind of institution that he wants IIT K to be. On his return to Kanpur, he sent me an offer of an Associate Professorship and long letters about why he wants me and others like me to come and join and shape IIT K.

As a follow-up of my brief visit to India in 1960 when I delivered some lectures, I had attractive offers from some of the prominent labs in India. When Mr. Sethuraman of W. S. Insulators Ltd, Chennai visited Westinghouse to finalize a collaboration, he met me and wanted me to join them because of my long association with Westinghouse.

Thus, I ended up with four offers in India. Again, by evaluating them using my priority criteria, I chose IIT Kanpur, though again it paid the lowest salary and I had no teaching experience. Again, I am glad that my criteria and choice were right.

Having decided to join IITK, I informed Westinghouse that I am leaving US to return to India. They pointed out that I am fully integrated and very productive in the US and that I will be lost in India. When I did not budge, they said, as a special case, they will give me one year's leave, because they were sure that I will be back within 3 months. I thanked them, but added that I want to get there with both my feet and try my best to settle down. If things did not work out, I hope that either Westinghouse or some other organization in US will hire me. This obviously is due to my desire to serve the nation. Lo and behold, 54 years after 1963, I am still in India.

IIT Kanpur

I reported to Dr. Kelkar at 10 am on 3rd November 1963 to join. He was gracious and emphasized how happy he was about my joining IIT K. After discussing for 30 min, he went to a meeting, to select the first set of Ph.D. students in Philosophy in IIT K. He took me along. I was amazed that when he had a million things seeking his attention in Institution building, he gave enough importance to students' selection. This was the first of several surprises to me about the wonderful person that Dr. Kelkar is.

I never taught before and hence I had to spend a great deal of time preparing for each one-hour class. The students are brilliant and this adds to the challenge.

The faculty became involved in all aspects of institution building and operation. For example, I was made Chairman of Equipment Committee with several members including one from Kanpur Indo-American Program (KIAP). KIAP is a consortium of nine leading universities in the US to help develop IITK. In addition, US Government provided about $10 million for purchase of equipment, to be dealt with by the Equipment Committee. Some of the equipment was for the teaching labs but more of it was for research. In order to make specialized, expensive equipment available to all faculty members, it was placed in Central laboratories instead of departmental laboratories. For example, IITK had the first computer in any educational institution in India and it was a central facility.

As soon as I joined, I was made the Head of the Metallurgical Engineering Dept. Five months after I joined, I was promoted as a full Professor. When Dr. Kelkar created and appointed the first two Deans (one for Faculties and the other for Research & Development), it was a new initiative among the IITs. I was appointed the first Dean of Faculties, with responsibility to hire quality faculty for each department and to look after their needs. As Dean of Faculties from 1966 to 1972, I had played a key role in adding over 200 faculty members to IITK, a large number of them from abroad, mostly USA. For this purpose, I used to make trips to US to meet potential candidates and their referees and to provide information about IITK to them.

As Dean of Faculties, I realized that most of our faculty are trained abroad and have little or no exposure to Indian industry, its level of development, nature of its problems etc. As a solution to these lacunae, a novel programme, High Level Summer Opportunities for Faculty in Industry, was conceived and developed. I went around to various companies to explain the goals of this Programme, which is a win-win for all concerned and then sought some problems the Company would like to have a fresh look at and come up with implementable solutions. Thus, I collected a set of industrial problems, matched them with the background and interests of the faculty and if the identified faculty agrees, his (or her) name is proposed to the Company. The Company then sends an offer to the concerned faculty member. The work gets done, and a report is presented to the Company. Nearly half of the Engineering faculty participated once or more in this Programme in the first few years. This has influenced the teaching material of such faculty and also the projects they assign to students. Many Companies participated in this programme in successive years.

Another major contribution of mine to IITK and Indian academia at large is the introduction of Materials Science as a discipline for teaching and research. It started with a 10-day conference on Materials Science Education at IITK in 1966 with many teachers and also engineers from industry as participants. Three prominent materials science educators from the US had attended. Now Materials Science appears in the curriculum of all engineering colleges in India. I set up an inter-disciplinary programme in Materials Science leading to M.Tech. and Ph.D. degrees where the students as well as faculty are drawn from many engineering and science disciplines. This was followed by creating an Advanced Centre for Materials Science to house sophisticated equipment for materials research as a Central facility.

In the early years of IITK, there were not many Ph.D. students, particularly in the Engineering disciplines. Therefore, nearly all the research was carried out by B.Tech. and M.Tech. students. But the brightness of these students ensured that the quality of research was good and the results of such work is published in leading international journals. This helped the B.Tech. students to get into the best engineering schools in the U.S.

Engineering colleges in India, by and large, use text books written by well-known authors abroad, but reprinted as Indian or Asian editions, and sold at affordable prices. In the early stages itself, IIT K faculty undertook to write text books. This effort was assisted by creating a textbook cell with typists, draftsmen etc. As a pioneer in Materials Science Education in India. I undertook and wrote “Experiments in Materials Science”, together with four of my young colleagues. This book, in cyclostyled form, was used in the one-month summer courses for engineering teachers under the Quality Improvement Programme of the Government of India. The book was published by McGraw Hill Publishing Co. as submitted and with no alterations. It has been used at all leading Universities in the US. Simultaneously, it was brought out by Tata McGraw Hill in India, with support from National Book Trust to market at a lower price. It was soon translated into Portuguese for the South American students. This was the first of 10 books I wrote or edited.

Because of my being away in US from 1951 to 1963, I was practically an unknown person in academic and professional circles in India. However, soon after joining IITK, I was called upon to participate in a number of high level national and international activities, possibly due to the reputation of IITK rubbing off on me. Examples are: the first Science and Engineering Research Council (SERC) of Department of Science and Technology; the first Committee of the Electronics Commission; Indo-US sub-commission on Science and Technology with six members from each country to identify areas of common interest to be carried out by experts in both countries. For example, in the first SERC, there were 2 members from academia out of a total 8 and they were Prof C.N.R. Rao and me, both from IITK. The Working Group chaired by me in the Electronics Commission recommended establishing Central Electronics Ltd., and I had to present it to the Committee of Secretaries and convince them, which approved it and the company came into existence. In the Indo-US Sub-commission on S&T, I was the only non-government member. Once when the sub-commission was meeting in Delhi, Prime Minister Indira Gandhi wanted us to meet her and report the progress of our work. When the Regional Engineering Colleges were completing their first decade, a committee to examine their progress and future directions was appointed, with me as a Member. The Committee made Bharat Darshan visiting all the RECs from Srinagar to Trichy and made recommendations, which were accepted by the Government.

I was also nominated as a Member of Board of Hindustan Zinc Ltd. and UP Electronics Corporation, which proved to be a very interesting experience for me.

Another Transition

By 1981, another transition was surfacing. Since my three children, for whose upbringing in India we shifted from US to India in 1963, have all got their degrees and returned to the US, I suggested to my wife that we also should go back. She was not in favour of it.

At that time, Mr. F. C. Kohli of Tata Consultancy Services, invited me to meet him in Bombay. We had known each other, since Mr. Kohli was actively involved in the development of IITK through his participation in faculty selections, setting up the computer center and taking a number of faculty during summers into TCS. He briefly outlined to me his idea of an R&D Centre in the private domain to carry out meaningful R&D for Indian needs. He mentioned that he discussed this idea with Professors at the University of Waterloo in Canada. He wanted me to participate in this idea. This is the beginning of the next transition in this engineer's career.

Birth of TRDDC

After the initial discussion with Mr. F. C. Kohli, a team of 3 professors and Deans from University of Waterloo visited India to meet Government officials, business leaders and Tata Management and then submitted a report. I was involved in these discussions. Then Prof. Norman Dahl of MIT was commissioned to prepare a report on private R&D institutions in the US and he covered four of them, following which he visited India for discussions with the Tata Management. I was fully involved in these discussions. There were consultations with the Indian Government at a high level. The Tata people who fully participated in these discussions in 1981 were Mr. J. R. D. Tata, Mr. Nani Palkhivala and Mr. F. C. Kohli. Then I was asked to prepare a final document on the goals, location and modus operandi of the proposed R&D institution. I prepared such a document which was discussed and approved. Since, I was still inclined to shift to US, my wife was persuaded by Tata management about my role. The rest is history.

Thus, Tata Research Development & Design Centre (TRDDC) was born in Pune in 1981 with me as the Founder-Director. The word "Design" was added at Mr. Kohli's insistence, since research and development are incomplete unless it assumes a form through "Design".

The mission of TRDDC is "to use the existing knowledge for the benefit of our industry and our people", in the words of Mr. J. R. D. Tata. Translating this statement into reality was the challenge before me. The tasks undertaken were based on the stated needs of the end user. This required establishing communication with the beneficiaries of our work and develop a partnership relation. The quality of work has to be the best possible which translates into using the best advances in science and technology. For this to happen, one has to have people with a deep understanding of their subject and willing to put in the hard, dedicated work needed to get the desired end results.

The best trained and motivated young people from abroad as well as India were recruited and given maximum freedom to accomplish the best results. Problems to tackle were arrived at by discussions with the end users - Tata Consultancy Services for software and Computer science areas and industries in the TATA group and other private and public-sector companies for others. There were projects funded by Government departments as well as international collaboration projects. The benefits that accrued are new products, improved productivity and reduced energy consumption. A number of patents and published papers in leading journals (many with joint authorship with the beneficiary company) are additional outputs. Based on their work in TRDDC, many people received recognition through election to the prestigious professional bodies, academies here and abroad, awards, publications in leading journals, etc. For example, the benefits which accrued to the beneficiary company were such, that the Chairman of a company included the contribution of TRDDC in his annual report to the shareholders!

As examples of use of science and technology for the benefit of our people (as mentioned in the mission statement), one might cite a low cost, very efficient, well-engineered water filter based on rice husk ash, for the rural people. Another example is low cost decentralized Bio-gas plants using a wide variety of agro-industrial wastes while achieving a high rate of bio gas production by employing specially developed, highly efficient microorganisms.

Some of the other unique features of TRDDC which added to the competent human resources of India are: a number of researchers were encouraged to receive their Ph.D. degrees in India and abroad; a number of faculty from Indian educational institutions served as Consultants on the industrial problems pursued by TRDDC; a number of academics from abroad spent their sabbaticals of a few months to one year at TRDDC.

My gratification is that a wonderful mission statement could be converted into reality with tangible, heartwarming results. The close interactions in accomplishing this with three wonderful mentors—Mr. J. R. D. Tata, Mr. Nani Palkhivala and Mr. F. C. Kohli—is my eternal memory and reward. For example, what amazed me about my interactions with Mr. J. R. D. Tata and what I learnt from them was: Considering that he is the Head of over 100 companies, his humility is unbelievable. The undivided attention he gives you when you are discussing something is incredible. The sound advice he gives you based on his vast experience floors you.

Summary

What are the main ideas or leads stand out from this engineer's mind journey. Clearly, a person's success and contribution depends mostly on one's clarity of mind and dedication to quality of work than on one's family limitations. One should always seek and grab opportunities, the more demanding the better. Interacting with young students and colleagues to enable them to reach greater heights is one of the most gratifying satisfactions. Learning from your mentors and mentoring the next generation of achievers is an important goal and contribution. Institution building calls for an open mind, cooperation of all involved, nurturing values, dedication to best quality and meeting or exceeding targets. Value of service to society and of learning takes precedence over monthly income. The latter is likely to follow. Building partnerships is always more fruitful then going solo. Similarly, multi-disciplinarity is the need of the hour than limited expertise.

Lastly, I am grateful for the opportunities available to me, and the wonderful mentors that groomed me, and to my family.

R&D in Indian PSUs: My Experience

P. V. Ananda Mohan

At Andhra University

I was initiated into research at Applied Physics Laboratories, Andhra University to work in the area of thin films with specific task initially on the development of a thickness monitor for films formed using vacuum evaporation. In those days, universities did not introduce transistors in the curriculum. Only circuit design using vacuum tubes used to be taught and laboratories were equipped with the needed electronic components. The problem was to use reflectance of thin films as measure of thickness when aluminium is being deposited. Unfortunately, the light from the tungsten filament was much more than the reflected light of a source. In order to distinguish these two, one signal and another noise, the reflected beam needs to be made different in some way. One known solution was to use modulation for the source being beamed on the thin film on glass substrate by chopping it. Thus one is having a frequency component depending on the motor speed and number of holes on the circular disc connected to the axle of the motor through which light is sent to fall on the device under test. The job was to design a bandpass filter to select he needed frequency component and reject the huge noise (light from the filament). The whole process happens in few seconds to take the aluminium or other metal like tin, copper in a crucible kept in the heated filament.

The library of Andhra University was perhaps the best in India at that time. The author had to browse through Journal of Scientific Instruments, Review of Scientific Instruments, Wireless world, Electronics and other magazines to look for designs of filters. At that time, the research trajectory in my career was perhaps defined. Then some design was implemented using vacuum tubes and it was working quite well meeting the requirements. I had to discontinue research at Andhra University his

P. V. Ananda Mohan (✉)
CDAC, 1, Knowledge Park, Bayapanahalli, Old Madras Road, Bangalore 560038, India
e-mail: anandmohanpv@live.in

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_31

due to some differences with research supervisor and had to join NSTL, Visakhapatnam as a Junior Scientific Assistant. The laboratory was newly started, and I could procure bipolar transistors and build some circuits picked from some journals—a relaxation oscillator using a SCR like device using a PNP and a NPN transistor. I could thoroughly understand the operation and design.

At I.I.Sc., Bangalore

I was keen in pursuing Ph.D. programme and applied to I.I.Sc., Bangalore, and was interviewed by Prof. B.S. Sonde and the I.I.Sc. selection committee, and was selected to work with Prof. Sonde. Interestingly, the topic was Negative Resistance in Bipolar Transistors. The training given by Prof. Sonde included: asking me to read classic papers on bipolar transistor modelling, books on VLSI technology by Motorola, SEEC six volumes, selected IEEE Papers etc., This has really changed my understanding of the subject. He then asked me to build a test set for studying negative resistance phenomena without killing the transistors-pulse based testing. He used to give me variety of transistors which were based on various fabrication technologies-alloy, alloy-diffused, planar epitaxial etc., and to find out whether anything interesting breakdown phenomena was observed. I had to conduct experiments and whatever interesting anomalous behaviour I used to report everyday evening at 6 PM–8 PM, based on his free time. He used to then ask me to explain what could be the reason for that anomalous behaviour. Most important idea was asking me to investigate negative resistance in inverted mode operation of the transistor. This led to significant results. Then of course, at the end of two and half years, he asked me to start writing the thesis. I had asked him: have I done enough work? He said that while writing the thesis, you know the gaps and then actually you will do the real work, tie up lose threads, which was found to be true. He advised me to join ITI limited. He was insisting that he wanted his students to serve the industry. I learnt how to draw circuits meticulously, using pen on paper as though they were printed and how to analyse circuits.

At Indian Telephone Industries Limited

I must stress that ITI limited was a great company. When I joined the Electronic Switching System Group, Space Division telephone exchanges using reed relays were being used which occupied lot of space for the switching matrix. I was asked by the then Executive Director Shri M. S. Jayasimha, a visionary although just a B.E. from Madras Institute of Technology, to develop a semiconductor version of the switch in place of reed relay. I had then first used PNPN diodes of ITT and the supply voltage needed was very high due to large breakdown voltage of >5 V, but concept was proven. Then, suddenly I got an idea why cannot I use NPN PNP transistors in inverted mode an extension of my Ph.D. work and build a PNPN diode.

This had resulted in the invention of a new PNPN diode which needed a breakdown voltage of 7 V for switching [1]. This device was manufactured by Semiconductors Limited, Pune and Continental Devices India, Faridabad using two transistors in a single package, and was extensively used for 50 line telephone exchanges where 700 devices were assembled on one card. Then PCM came into existence for switching. ITI had meanwhile used PAM based TDM exchanges a forerunner for today's E1 based trunks. In those days, multiplexed codec chips were available and Filters were realized outside. No chips were readily available. ITI limited thought of having Active RC filters. My passion for filter design made me design Active RC filters and new techniques for sinx/x correction were envisaged and these were published as design ideas [2]. Next, I was asked to design line cards using these filters made in Thick film hybrids, design of SLIC without using bulky transformers. Small exchanges using Microprocessor based stored program control were designed by my colleagues using 8008 processor (used in Indian Navy ships) initially, then using 8080, later 8085 based processor cards. My passion for Filters continued as a parallel effort. The author has published many papers on tuning [3, 4], some even on fundamental theoretical aspects [5] since there was a need for designing Voice Input filters for FDM equipment which had stringent requirement on low noise, low pass-band ripple, steep cut offs. I designed several filters for Thick film hybrids which did not need any post tuning other than using laser trimming for resistors, and using low tolerance capacitors. These filters used low noise opamps and scaled low value resistances, and were fabricated by ECIL and at ITI limited facilities. Defence services have used these extensively in their Voice plus data multiplexers using FDM technique. Numerous papers have been published in Proc. IEEE letters. Unfortunately, with the arrival of numerous transactions catering for different areas, the letters section was discontinued.

During 1980s, India had outstanding researchers in the area of Active RC filters who had the foresight to investigate new techniques. Notable was the use of opamp finite bandwidth to advantage. Following the trend, I worked in partially Active R filters, Active R filters [6, 7]. Experimental results were included in the publication due to the availability of devices, ease of assembly and testing.

At Concordia University, Montreal

During 1980–1983, I was offered a post-doctoral fellowship at Concordia University, Montreal to work with Prof. M. N. S. Swamy and Prof. V. Ramachandran. They asked me to work in an emerging area Switched capacitor filters. At the beginning, I was rather scared to work in a new area but the urge to contribute otherwise being considered as not good made me to pursue deep into this area and within one year new results have been obtained; numerous papers were published in reputed journals, jointly with Dr. Swamy and Dr. Ramachandran.

Then I got an idea to write a book that was published by appeared from Prentice-Hall, London in 1995 [8]. Meanwhile, in 1983, I had to returned to India and continue in ITI Limited. The research in SC filters was continued and I could adapt to new areas such continuous-time filters [9], OTA-C filters [10], current-mode filters [11] etc.

At ITI Limited

During 1987, there was need for Indian army to introduce a new communication network using the first integrated voice and data switch with full media encryption on digital microwave links. Again Shri M.S. Jayasimha picked me amongst all the R&D engineers of ITI limited, and assigned this task. I built an outstanding group of algorithm and hardware designers with knowledge of Telecom interfaces to build state of the art systems. In those days, FPGAS were not available. Building a massive encryption hardware was a problem due to space constraints. The then Director R&D of ITI Limited Dr. Prabhakar had taken up the challenge of designing and fabricating ASICs totally in ITI limited foundry (now SITAR). About fifteen thousand ICs of about 2500 gates each using 0.8 micron technology was used to set up the army network. This network was first of its kind in India with comprehensive distributed network management system, redundancy to yield a fail safe network. The Army Generals described it as a Force Multiplier.

The work in encryption continued at ITI and numerous solutions for Satellite networking, optical fibre links etc. later using FPGAs. I had to inspire the teams to add novelty in design, new features, cater to higher and higher bandwidths up to 622 Mb/s. During this time, I was studying public domain algorithms for encryption, Authentication and digital signatures etc. Several papers on Architectures and implementations were published. Research in residue number systems was a by product. Noticing the absence of a book on Residue number systems after the one published in 1967 by Szabo and Tanaka, I has published a book on the same with Kluwer Academic Publishers in 2002 [12]. ITI limited was encouraging original research and I was deputed to several IEEE annual International symposia on Circuits and Systems at Hesinki, Japan, Port land USA, San Jose U.S.A., Munich.

At ECIL, Bangalore

Later in 2003, I has resigned from ITI Limited and joined ECIL at Bangalore. The work on Encryption continued and numerous products for the Armed forces were developed and supplied. The two research tracks were followed in analog filter design and in Cryptography and Residue Number Systems. Two books on Analog filters-current-mode VLSI analog filters from Birkhäuser, Springer in 2003 [13] and VLSI analog filters in 2013 [14] were published. These involved hard work in compiling information, designing examples, problems and sharing knowledge with the readers. I was delighted to be elected as a IEEE Fellow in 2005 and FNAE in 2010.

Concluding Remarks

I was delighted to work with numerous young engineers, inspire them to be creative and create leaders, and quickly deliver the results to the customers. I feel that self-motivation is needed to excel in research. R&D institutions belonging to Indian Government sector have done much for the development of indigenous technologies in Space, Atomic research, encryption, telecommunication and Digital Electronics. Much of my work in cryptography could not be published due to strategic reasons. Government funding for scientific research shall be enhanced and methodologies to attract and nurture talent, inspire them need to be thought of. I truly enjoyed working in India and I am grateful to institutions like ITI Limited, ECIL and Indian Armed Forces for their trust in Indian capabilities in strategic areas.

References

1. Ananda Mohan PV (1975) Inverted transistors in a low-voltage PNPN device. Electronic Engineering, London, p 17
2. Ananda Mohan PV (1983) Design of PCM filters and sinx/x correction. Electronic Engineering, pp 31–32
3. Ananda Mohan PV (1975) Precision tuning of RC parallel-T notch filter. Proc. IEEE 63:1730
4. Ananda Mohan PV, Jayakumar V (1976) Distributed RC null network tuning. Proc. IEEE 64:362–363
5. Ananda Mohan PV (1976) The definition of Q of RC notch networks. Proc. IEEE 64:1439–1440
6. Ananda Mohan PV (1979) A novel band-pass filter using the amplifier pole. IEEE J. Solid-State Circ 14:649–651
7. Ananda Mohan PV (1980) Novel active filters using the amplifier pole. Electron Lett 16:378–380
8. Ananda Mohan PV, Ramachandran V, Swamy MNS (1995) Switched capacitor filters: theory, analysis and design. Prentice-Hall International, London
9. Ananda Mohan PV (1987) New structures of MOSFET-C filters. Proc. IEEE 75:957–960
10. Ananda Mohan PV (1990) Generation of OTA-C filter structures from active RC filter structures. IEEE Trans CAS 37:656–660
11. Ananda Mohan PV (1995) New current-mode biquad based on friend-deliyannis active RC Biquad. IEEE Trans CAS Part II 42:225–228
12. Ananda Mohan PV (2002) Residue number systems: algorithms and VLSI architectures. Kluwer Academic Publishers, USA
13. Ananda Mohan PV (2003) Current mode signal processing. Birkhauser, USA
14. Ananda Mohan PV (2012) VLSI analog filters: active RC, OTA-C and SC. Birkhäuser, USA

Nurturing Engineering Talent in the Aerospace and Defence Sector

K. Venkataraman

Outlook of India's Aerospace and Defence Sector

The Indian aerospace industry has become one of the fastest growing aerospace markets in the world, primarily due to the increase in defence spending and a growing commercial aviation market. The rapid growth of this industry has attracted major global aerospace companies to India and has boosted the confidence of domestic aerospace players to increase and deepen their operations.

India's defence industry which has seen a steady growth in recent years, seems poised for even better days. Growth in domestic demand looks promising and the Government has a clear vision for an indigenous defence industry. The defence companies across the globe are increasingly looking at India as a lucrative sourcing hub in order to remain globally competitive. India has a tremendous potential for exporting engineering services and component manufacturing capacity in these sectors.

With the Government of India now encouraging indigenous development in the Aerospace & Defence (A&D) sector in a big way through its "Make in India" initiative, huge investments are expected in the A&D sector in the areas of manufacturing. India is rapidly building capabilities to emerge as a preferred destination for manufacturing of aerospace components. India's real and sustainable advantage lies in demonstrating our expertise in the entire process, beginning right from the initial design to final manufacture. The industry is surely poised for an exponential growth in the coming years.

The A&D sector in India is now being looked at as the sunrise sector and it has the potential to generate a large number of engineering jobs in the years to come. One of the major challenges ahead for the Aerospace and Defence (A&D) organizations is: how to effectively manage this engineering talent. Organizations are in need of science, technology and engineering talents to cater to the future

K. Venkataraman (✉)
Larsen & Toubro Ltd., L&T House, Ballard Estate, 400001 Mumbai, India
e-mail: kv@larsentoubro.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_33

growth. They require engineers with highly specialized skill sets to cater to their niche requirements. Attracting and retaining critical talent is increasingly viewed as a top strategic issue by the senior management and human resources executives in this sector.

Addressing these challenges requires a comprehensive transformation, the requirement of which stems from the challenges that the A&D industries face due to the mismatch between their requirements and the skills with which the aspiring engineers join these organizations. There is a need for a radical change in the present style of pedagogy being employed in many of the engineering institutes. On the other hand, there is an equally important need for a change in the working style of A&D industries to overcome their existing workforce challenges. Hence, there are efforts and steps required from either side, from the industries and the institutes, so as to better orient the engineering workforce with the industry requirements.

Engineer's Mind and Aspirations

An engineer's mind is highly inquisitive. Engineers have the tendency to question the actual physics behind any process. Young engineers, who are fresh pass-outs from the institutes, are high on inquisitiveness and creativity quotient. They are fascinated to see how the machines are being designed and built to achieve magnificent goals and how modern technology influences our day–to–day life. Young engineers enjoy taking up challenges. They are driven by the desire to apply the lessons they have learnt in the classroom to the outside world. Engineers today are expected to think out of the box, examine and analyze things critically and come up with solutions and improvements which would have been considered unattainable even a decade ago.

However, when it comes to choosing organizations where they would aspire to work, we normally come across one category of engineers who are driven more towards what we may call an AC–PC (office room with an AC and a PC) kind of work culture. They do not seem inclined to take up the rigorous work at site or in shop-floor. But there will always be young engineers who get excited by things where they see a purpose, get motivated by a formidable challenge and work which would give them a sense of pride and great professional satisfaction. Working for projects like the "First indigenous nuclear submarine built in India" or "First Indian PSLV to travel on lunar mission" get them excited more than anything else.

It is indeed very heartening to see the recent trends, which indicate that the present generation of engineers are more drawn towards organizations which provide them with opportunities to work on grass-root innovations, big challenges or social sector applications where they get to implement their ideas through the high–end technology or digital platforms.

Need for a Radical Change in Engineering Pedagogy

At engineering colleges we are taught how things work, but as practising engineers we have to understand how things can fail as well. Bringing reliability to a product is nothing but to understand the underlying failure mechanisms and generate methodologies to mitigate the failures. Engineering curricula must, therefore, be able to bring such practical orientation into academics and offer budding engineers a true "feel" of the reality outside the classroom.

To be successful as an engineer in this age, one needs to have the technical competence and excellence which comes from a combination of a sound theoretical knowledge imparted through classroom teaching and applied knowledge which comes from industrial exposure and industry-oriented training. It is a good sign that some engineering institutes are introducing "practice schools" for final-year engineers, in place of traditional academic projects.

The purpose of engineering education is to develop the candidate's abilities of analysis, design, application and engineering judgement, while deepening the understanding of engineering fundamentals. The pedagogy currently followed in many universities has the following shortfalls.

> Many engineering students find some courses including design courses difficult to grasp or understand in totality, primarily because most of the instructors lack the necessary practical experience to relate fundamentals to practice, and to give a real-life orientation to learning. This hampers the student's ability to handle practical problems. Many educational institutes lack requisite computer hardware and the latest engineering software tools presently used in the industry. This makes the students feel "alienated" when they come out in the industry and are required to use such tools in a big way. Some universities cannot set up laboratories because of the shortage of funding and the lack of specialized teaching staff. These factors also attribute to incomplete understanding of engineering fundamentals. In traditional teaching methods, students study fundamentals according to predefined steps to acquire certain results and to prepare for examinations based on a well-defined pattern. The teaching methodology rarely encourage independent thinking or application-based learning. This makes it difficult to nurture innovation and creativity.

Therefore, it is necessary to reform the current teaching methods by focusing more on application of learning, out-of-box thinking together with innovative and entrepreneurial outlook. Wherever possible budding engineers need to be encouraged to develop a holistic view. For instance, engineers need to realize how the scientific principles derived from basic research, as depicted in Fig. 1, attribute to developing the technology and know—how through applied research and how such know—how translates into tangible products and processes. It is imperative for young engineers to implement this value-chain in practice so as to make a visible impact in their professional career.

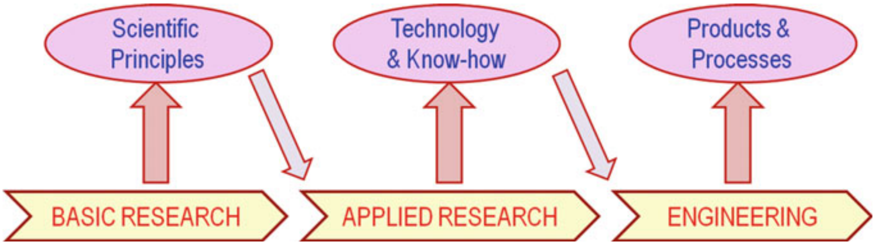


Fig. 1 Clarity on interdependence to be offered by engineering education

Industry Requirements Versus Output from Academia

Engineering excellence has always been the critical capability for aerospace and defence. The nature of the work assigned to our engineers is constantly evolving with changing requirements and with varying magnitudes of complexity. It calls for a multi-disciplinary approach and additional soft skills which is not what our engineers are normally trained for. It calls for speed and continuity to execute complex projects associated with these A&D programs, which have longer life cycles and tend to drag indefinitely at times. Today, be it any industry including A&D, only fraction of the workforce is completely trained and qualified to carry out the work that they do. Employers have to invest considerable time, effort and money to make the fresh engineers “job-ready” and readily “billable”. We need to face the reality that majority of the graduating engineers today are not directly “employable” and both Industry and Academia need to collaborate effectively to bridge the gap between Industry requirements and the output coming out from academic institutes. The *National Knowledge Functional Hub* (NKFH) initiative—a collaborative framework between Industry and Academia with a national footprint—launched by the Federation of Indian Chambers of Commerce & Industry (FICCI), is actively addressing this critical issue.

Managing the Engineering Workforce

The A&D industries, like any other sector, face several typical challenges when it comes to managing the engineering workforce. These include: having the required number of engineers on board, developing the engineering capabilities needed for future competitiveness attracting and retaining the engineering talent. having the required number of engineer on boards developing the engineering capabilities needed for future competitiveness attracting and retaining talent.

Having the Required Number of Engineers on Board

Given the growth anticipated in the A&D industry and with changing demographics (specifically, with a large number of existing senior staff approaching retirement), there is a concern about sustaining the core engineering talent. Though the optimal number of engineers the companies should have is not static, they need to ensure a relatively steady intake of engineers looking at the series of long lead A&D programs in pipeline. As one program ends, a new one begins. As a result, a sufficient base will have to be maintained to absorb the engineering capability and the new engineers will have sufficient time to "cut their teeth" before they get fully engaged with live projects.

Developing the Engineering Capabilities Needed for Future Competitiveness

The landscape in A&D is evolving, which has significant implications for the industry's engineering needs. Some of the biggest development programs are now moving into production and other programs are likely to follow, which call for enhanced design and manufacturing skills. There is a tremendous emphasis being laid on necessary skill and capability development, which is one of the driving factors behind "Make in India" initiative.

Attracting and Retaining Talent

A&D industry's twin challenges of sustaining a mature engineering workforce and meeting intense competition for younger talent from other industries are well known. A common situation in A&D engineering departments today is a shortage of early and mid-career talent to compliment the experienced engineers.

Looking at the prevailing situation, the imperatives for the A&D sector should be to recruit more creatively, create a well-designed career track for top talent and implement a formal knowledge transfer mechanism from experienced to young engineers, particularly tacit knowledge and experiential learning.

Towards Better Industry-Academia Alignment

As already mentioned, the engineering institutions and universities produce graduates with basic academic qualification as per prevalent curriculum, but their skills and capabilities often do not meet the current industry requirements. Key shortcomings appear to be the inability to relate class-room learning to practical situations, adopt innovative ideas to face unfamiliar problems and display required “soft skills”, specially the people management abilities. Some of the obvious expectations from young engineers are that they should be creative and able to work well in teams, communicate effectively, define problems, consider alternatives, come up with innovative solutions and appreciate the uncertainties of “real world” environment, where not everything is well-defined or well-understood.

Industry and Academia need to collaborate to ensure that fresh engineers are equipped with the necessary technical capabilities as well as “soft skills”. Both the entities can play a key role in helping the future engineers with active support in the following areas.

Improving the “Soft Skills”

To address the need for students to acquire soft skills, some engineering institutes have already associated with the industry and consultants to understand the factors associated with soft skill development. The idea is to create a teaching environment that fosters holistic development of students by making them work in teams, do hands-on projects in institute as well as industry and actively engage with professional societies.

Maintaining the “Right Balance”

Today’s engineering students face the challenges of a demanding curriculum, long study hours and a heavy course load. These are particularly daunting for first-year students, most of whom are also required to adapt to the challenge of being away from home for the first time and being responsible for more than just their academics. All this can lead to poor academic performance and stress-induced problems, requiring professional counselling.

One successful model for helping students not only cope but also thrive forward is by maintaining the right balance between the “course load and pressure of exam performance” on one hand and the opportunity of “Learning and Application” on the other hand. This can enable the students to face their academic challenges in a proactive and relaxed way and also inculcate “learning by doing” habit right from the beginning of their professional life.

Introducing "Real World" Engineering

For most engineering students, understanding theoretical concepts and applying these to practical situations with the right context is critical to their success in the classroom and eventually in the workplace. Industry and Academia can join hands in developing a curriculum that allows engineering minds to relate the theories to practice and appreciate the challenges and uncertainty in real-life applications.

Encouraging "Internships" and "Industry Projects"

It is encouraging to see that most of the leading academic institutes today are emphasizing the need for student internships and industry-based projects as a mandatory part of their curriculum, with assigned credit points. This can be a key enablers for young engineers to appreciate their classroom learning better and to understand how the industry functions and what it takes to succeed as a practising engineer. A spin-off benefit from such initiative is that faculty members also get better tuned to the industry realities and get an opportunity to enrich their teaching and research work to make these better aligned with industry requirements. This in turn benefits the students in the long run.

Skill Development and Innovation

Skill Development is being viewed today as a necessity at the national level in order to transform the "Make in India" dream into reality. While this applies to all industry sectors and all the professions, the need is even more acute for the skill-building of our engineering talent in A&D sector. The movement is essentially a collaborative, multi-dimentional engagement process with many stakeholders, as shown in Fig. 2.

Industries need to facilitate the creation of a well-defined set of "Occupational Standards" for the engineering profession, together with appropriate innovation ecosystem. The Academia, on the other hand, needs to ensure that the identified skill sets are being adequately covered in engineering curriculum. Enhancing the efficiency at all levels of operation and sharing of knowledge across stakeholders will be the key to success.

Going beyond Skill Development, institutionalizing an "Innovation Culture" will involve additional considerations, as shown in Fig. 3. If it is our aspiration to see future engineering talent in Aerospace & Defence sectors as the drivers of innovation and entrepreneurship, then the enabling process should necessarily start in the classroom itself.

Fig. 2 Making 'make in india' a reality

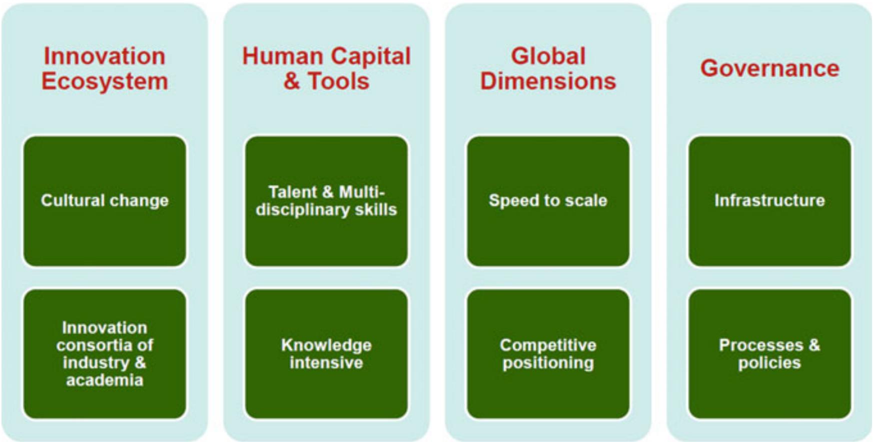


Fig. 3 Innovation pillars

Conclusion

Going forward the A&D sector is poised for a steady growth, driven by the indigenous development and manufacturing aimed by the "Make in India" campaign. Managing the engineering talent to take up the speed and scale required to keep up to the targeted growth in the sector is going to be the most crucial factor. Recognizing the issues and implementing necessary changes to better align the engineering pedagogy with the external industrial needs is of paramount importance. It is equally important to overcome institutional inertia and enable sustainable improvement in processes dealing with teaching, training and nurturing young engineering talent. Industries in the A&D domain must create a better value proposition for talent and instil a culture of performance management. Organizations that effectively pursue and maintain such transformation will be able to create a competitive advantage with respect to the engineering talent they possess. We in India have the potential of harnessing the best engineering minds in the world, but it will require a quantum shift in our mindset towards engineering education and a committed and sustainable effort among all stakeholders.

Underground Metro Construction, Development in India

Mangu Singh

Introduction

Development of Metro System in the country Started with Construction of Kolkata Metro in Mid 70s. Kolkata Metro 16.5 km long North–South Line was predominately underground with only two terminal Stations being at grade. The construction was carried out with limited local technical and engineering expertise as was available.

The construction of the Metro System in Delhi is partly underground, and has been done very successfully and many more Cities of the Country like Bangalore, Chennai are constructing underground systems. I have been fortunate to have been involved in construction of Kolkata Metro, Delhi Metro and also in planning of Metro Systems in other cities like Chennai, Bangalore, Jaipur, Mumbai and Kolkata East–West Line. I can, therefore, claim that I have witnessed the entire development of construction of Underground Metro Systems in the country. The construction of Kolkata Metro was very remarkable in view of the fact that we had very little technical and engineering experience and skill to execute such projects and also access to International Technology was limited. However, the Project had many civil engineering Challenges, and the execution of civil engineering works was not free from deficiencies. Since I was fully involved in execution of civil works in most difficult part of Kolkata Metro, i.e., section between Esplanade and Shyam Bazaar, gained very valuable experience and was in a position to take care of these deficiencies in subsequent Planning of Delhi Metro and other Metro Systems in the Country.

Before we go into the deficiencies, let us understand the exact nature of civil works involved in an Underground Metro System. The Kolkata Metro Underground Section involved construction of Stations approximately every k.m. and Tunnels connecting these Stations. Both Stations and Tunnels were largely done by Cut & Cover Method

M. Singh (✉)
Delhi Metro Rail Corporation, Bungalow no.1, Metro Enclave Road, Pushpa Vihar, 110017 Delhi, New Delhi, India
e-mail: mdmetro@dmrc.org

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_34

except a small Section between Shyam Bazaar and Belgachhia Stations which was done by Tunnel Boring Machine.

Cut & Cover Station

A typical station involved constructions of 2 story rectangular building under ground. Constructing this underground structures required excavation up to depth of about 17–18 ms, and in order to support the soil temporarily, diaphragm walls were first constructed along with parameter of the station, and while excavating the soil between Diaphragm walls, the diaphragm walls were strutted. Number of layers of struts were placed as excavation proceeded to the final level. The Base Slab of this rectangular Station box was constructed first and then side walls, Concourse Slab, and Roof Slab constructed progressively from Bottom to Top. The struts are also removed in sequence.

Cut & Cover Tunnel

The construction of Cut & Cover Tunnels connecting two Stations involves similar operation as construction of station except that the structure is single story long box connecting two stations. In addition to above Main Structures, number of Ancillaries Structures like Entry/Exits and Ventilation Shafts are required to be constructed normally in a same way as Main Station Box.

Typical Kolkata soil is silty clay with poor bearing capacity and with high water table. Number of difficulties and deficiencies noticed in civil works construction and how these have been taken care of in the subsequent Metro Constructions: are enumerated below.

The construction of Diaphragm wall was planned as a temporary structure and the Main Box was planned to be constructed inside these temporary diaphragm walls. The Diaphragm wall Panels went out of verticality and therefore, two adjacent Panels were not in the same plain and sometimes forming a Window/gap which was potentially risky for soil loss and heavy leakage during excavation. In fact, in some cases, the Diaphragm wall panel went out of plumb to the extent that it infringed the permanent RCC box. This led to serious problem during excavation. Apart from the modification of the Box design and huge chipping and cutting involved in Diaphragm wall, it created big problem in casting the side walls while water was leaking from the Diaphragm walls' joints/gaps. This problem was been resolved as in subsequent planning in Delhi and elsewhere, the Diaphragm wall has been planned as a part of the permanent structure and the quality of the concrete as well as the geometry of the Diaphragm wall had improved drastically. Verticality of the Diaphragm wall Panels was ensured during construction by mapping the trench for the verticality before the concreting. In case of any deviation in the verticality, the trenching was redone. With the advancement of the Technology it was now possible to introduce water seals between two panels of the diaphragm wall. With these provisions, the diaphragm wall joint had virtually being made water tight and also the two adjacent Panels had been in perfect alignment to form the rectangular wall without leaving a gap between two panels.

Number of Utilities crossing the Station Box or Cut & Cover Tunnel Box created special difficulties in casting Diaphragm wall Panel at the utility locations. The correct way was to complete the Diaphragm wall Panel in the adjacent stretch and divert the utilities on to the completed Panels, and then take up the diaphragm wall Panel at original location of the utility. In Kolkata, however, this could not be made possible at number of locations and therefore, the works were planned keeping the utilities in position and leaving a gap in Diaphragm wall at the utility location with the intention that this gap would be closed progressively with the help of steel plate lagging while doing the excavation. In practice, however, this proved to be very risky affair because of the type of soil there was hardly any standing time and with the excavation even before placing the steel plate to cover the gap, there used to be soil movement causing settlement in the utilities. With this settlement, utilities start leaking particularly, storm water drain and high pressure water pipelines. This leakage water found easier way into the excavation area taking soil along with it causing further settlement and more leakage leading ultimately to collapse of the utility. In many cases, taking away huge amount of soil into the excavation area creating huge collapse, sometime very near to the buildings. Number of buildings have suffered serious damages on this account.

This has been taken care of as no gap was left in the Diaphragm wall and utility diversion if required, was a must in Delhi. The responsibility of diversion of utility is also taken by Delhi Metro. This had ensured that no collapse occurred on this account during construction of underground Metro in Delhi.

Problem of Severe leakage from the Base Slab

Since the soil has low permeability, it was not possible to lower the water table before casting the Base Slab and in most of the cases, the water seepage from base could not be stopped. This seepage water under heavy head used to penetrate and form water channel in the Green concrete which ultimately lead to heavy leakage into the structure.

This problem was taken care of in Delhi Metro that in case it was not possible to lower the water table below the base slab level to facilitate casting of the slab, a pervious filter is introduced below the base slab and over that the base slab was caste. The percolating water finding easier path in the filter did not penetrate the green concrete of the base slab ensuring setting of concrete without any risk of leakage.

Bottom upheaval was quite common in Kolkata Metro, particularly at final level of excavation because of very heavy earth pressure and surcharge outside the Diaphragm wall and bearing capacity of the soil being poor. This used to cause severe settlement outside the Diaphragm wall and number of building affected due to this differential settlement, being more near to Diaphragm wall and less beyond the Diaphragm wall. It appeared that the depth of Diaphragm wall below the final excavation level did not have much margin of safety. A typical embedment length in Kolkata Metro was about 4 meters beyond the final excavation level. This problem had been resolved in Delhi by providing adequate embedment length typically 8 meter or so. This had ensured no upheaval at Delhi and no major settlement to cause damage to buildings adjacent the work.

Environmental Issues

Number of environmental issues like spilling the muck on the road, poor upkeep of the work sites, large scale movement of construction vehicles/equipments and large scale activities at the site in congested area led to great inconvenience to the public. For Metro Line in Delhi, a strict regime detailing to take care of these problems was worked out, and made part of the contract conditions to ensure the compliance of the regime. This ensured that the Contractor was allowed to work in the designated area properly barricading and segregating the public area from the construction area and Contractor not allowed to encroached upon the public area. Similarly, Contractor to transport the excavated earth in good condition vehicles, cleaning the tyres and vehicle under frame before leaving the site to avoid defacing the roads. The construction vehicles movement restricted to allow in night hours mainly. The activities at sites were minimized by enforcing major activities like Fabrication, Concreting, Pre-casting, etc. done off the site, not allowing the Contractor to use work site for labour camps, using only good condition machines and equipments causing less noise, vibrations, etc.

Speed of Construction

Speed of construction at Kolkata Metro was extremely slow and a line of about 16.5 km took more than 22 years to complete. The whole city was put to inconvenience for long. It was, therefore, considered necessary to plan and execute the project in Delhi and subsequent other cities in more expeditious manner so that this inconvenience is greatly reduced. The best construction practices and management practices to execute such projects, available internationally, were adopted. With the result in Delhi we were able to develop network of about 190 km (Phase I and Phase II) in about 10 to 12 years time. Further in Phase III, about 140 km is under implementation which will be completed by December 2017. The development of network at such a rapid pace has on one hand reduced the inconvenience to the public during construction and also has provided great relief to the city traffic.

Traffic Management

During construction very heavy traffic congestion was encountered due to reduced road width available for traffic and addition of construction related traffic of heavy vehicles and equipments etc. In Delhi, this problem was taken care of by suitably diverting the traffic after detailed Traffic Study and also making improvements to the adjacent roads for diversions. The movement of construction vehicles was restricted mainly during night times only and avoiding completely during peak hours. Deployment of trained Traffic Marshals to guide the Traffic has also helped greatly.

Conclusion

The experienced gained at Kolkata Metro proved to be very useful, and the difficulties faced during construction of underground Metro in Kolkata has been duly taken care of by deploying suitable technology and Project Management Practices in subsequent Metros. With this, not only the construction of underground Metro Systems but also the construction industry, in General, has improved drastically in India.

To Fight Power-Cuts, Do Not Agitate. Install Rooftop Solar Panels

Surjit Singh

The Scourge of Power Cuts

Unscheduled power cuts can ruin an industry. While loss of productivity and idle manpower are the obvious consequence, there are processes in which material gets wasted, and machines suffer damage. The larger industrialists are forced to install 'standby' diesel generating sets at enormous cost. Farmers are unable to irrigate their fields, and most of them have no means to run their tube-wells. They suffer in silence. The lay citizen is hit the hardest during the long Indian summer. On a sultry day, when the power cut occurs, they are unable to run their air-conditioners, and that leaves them fuming in anger.

In India, generation and distribution of electricity is largely controlled by the government. The tariff and availability of electricity turn into a political issue, and the fortunes of politicians are often decided by their ability to assure reliable power supply. When they are unable to keep their promises, people take to the streets and agitate.

Some recent technological developments have made it possible for us to solve the problem by helping ourselves. The price of the photo-voltaic cells has been dropping exponentially, and it has now become economically viable to install roof-top panels to bridge the gap between the supply and the demand of power. I am reminded of a Zarathustra quote which reads as under:

"To fight the darkness do not draw your sword. Light a candle."

We might soon be able to say, "To fight power cuts, do not agitate politically. Install roof-top solar panels!"

S. Singh (✉)
#1192, Sector 34C, Chandigarh 160022, India
e-mail: Surjit97eme@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_35

In Praise of the Sun

The sun gives us light and energy. There would be no life on the earth if the sun did not rise, day after day, without a single day's rest. People of many civilizations have worshiped the Sun as God since times immemorial. But during the tropical summer, it emerges with brutal fierceness and saps life. Productivity drops to an abysmal low, and those who can afford it, escape to the mountains for a bit of cool air. A hundred odd years ago, air-conditioners were invented, and the rich acquired a new device to save themselves from the fury of '*suryadevata*'. In due course, the price of air conditioners dropped and even the middle class could afford to buy them. The flip side of this phenomenon was that we did not have the electric power needed to run these cooling devices. Power cuts, scheduled and unscheduled, ensued. People felt '*powerless*' and invented nasty swear words to express their anguish. The gap between supply and demand began to widen and, soon, this became a political issue.

The light radiated by sun can now be economically converted into electricity, and the system is so simple that you can install it on your own rooftop. I have done it and the details of my system are given below.

Functioning of a PV System

A solar PV power plant converts sunlight into electricity. It does so without any moving parts (unless it has a tracking system) and without generating either noise or pollution. A solar PV system can be installed at any un-shaded location such as on rooftops of buildings, car parking sheds, empty land, or even on top of canals and roads. A typical rooftop solar PV system for a household is between 1-10 kW. A solar PV system consists of the following key components.

1. Solar PV array (group of modules)
2. Solar inverter
3. Battery
4. Interconnecting devices (junction box, cables, distribution box).

Picture of the PV system installed in our house are given below:

This is a 2 Kwp system. There are eight modules.

Some Fundamental Principles

The PV array consists of solar modules interconnected with each other. The modules convert the energy from sunlight, are held on structures made of galvanized iron, mild steel or aluminum and are inclined at a horizontal tilt, facing either south or east-west. The modules are designed to generate power at either 12 or 24 V. Inverter models can differ in their input voltage requirements in the range of 12–1000 V. A junction box connects the modules in series or parallel to achieve the optimum voltage required by the inverter.

Solar modules produce direct current (DC). Almost all electrical appliances in India, however, require alternating current (AC) to operate. The function of converting DC to AC is carried out by the inverter. In the case of a battery backup system, the inverter is also connected to the batteries and is responsible for managing the charging and discharging of the batteries.

The output point of the inverter is connected to the distribution box, which consists of a meter, fuse, a miniature circuit breaker (MCB), and load connections. Cables connect the solar modules, junction boxes, inverters and distribution boxes.

The capacity of the solar PV system depends on the amount of electricity (kWh) required per day by a consumer and the shadow and obstruction free space available on the rooftop. For example, a 2 kWp load operating for 10 h requires a PV system of 5 kWp. Further, 1 kWp of solar PV requires 10 m^2 of shadow free area. Therefore, a 5 kWp system would require 50 m^2. In addition, if the consumption occurs during non-sunshine hours (6:00 p.m. to 6:00 a.m.) or in case the consumption is not uniformly sufficient throughout the day, batteries to store energy must be added.

Another factor, which affects the system design, is the timing of electricity consumption. For example, residential consumers in Chandigarh have a peak demand during the morning (6:00 a.m. to 10:00 a.m.) and evening (6:00 p.m. to 10:00 p.m.). These are not peak sunshine hours (10:00 a.m. to 4:00 p.m.). Residential demand tends to be lower during the day as household members become engaged in daily activities, mostly outside the house (e.g. adults going to work and children going to school). Thus, the peak power production of a PV system does not match the peak demand of residential consumers. For industrial and commercial consumers, on the other hand, solar generation coincides more closely with peak demand as most of these sites operate through the day.

Solar PV systems could be sized to not exceed the load demand during the day. If they are larger, and solar power is being generated that exceeds consumption at that point in time, wastage can be avoided by storing the excess power. Alternatively, excess power could be injected into the grid. In this case, metering would be required to measure energy transactions between the PV system and the grid.

The Need to Resurrect DC Appliances and Gadgets

Electricity first came in the form of 'Direct Current' and even as late as 1960, we were on DC. It was generated locally and distributed by the municipalities. There was no 'grid' system. Around that time, it became necessary to transmit power over long distances, and that is when the AC arrived. In the beginning, we used electricity mainly for lights, fans and radios. There were very few gadgets at that time. The AC counterpart of these devices appeared in the markets, and some smart manufacturers came up with AC/DC devices, which could operate on both forms of power.

Solar arrays have added another dimension to this process. The panels produce DC, ranging from 12 to 48 V. A large number of our domestic appliances like computers, music systems and mobile phones operate on DC. The new LED lights need DC, and batteries of ALL devices need to be charged. We are likely to waste a lot of power and money in the process of converting DC to AC and re-converting it to DC for our appliances. Time has come to give a fresh look to the entire energy scene. When the panels become sufficiently efficient, it is possible that we shall revert to 'distributed' generation. Several households might actually become 'net-free' (they may be able to generate ALL the power they need from solar panels or a hybrid of solar and wind power). In such cases, the power will be stored in DC batteries, and therefore they would best served by DC appliances. It may be noted that the automobiles, aircraft and even the railways operate exclusively on DC.

Rooftop Solar PV with Storage

Storage in solar PV systems is required to provide stable backup power when the solar energy is not available (at night) or not adequate to meet the entire load demand. Solar energy is an intermittent source of power. The power generation can vary with a change in sunshine due to, for example, a sudden cloud cover. Batteries can be used to store solar power to safeguard against a short-term fall in solar power generation. Intermittency can also be avoided by connecting the solar PV system to the grid. In this case the grid provides the extra energy at times of inadequate sunshine.

Another application of storage is to protect against grid outages. During an outage it is possible that solar generation is inadequate to meet the load demand (e.g. if it occurs outside sunshine hours). In such a case, the stored energy can be utilized to provide a stable output of power. If the grid condition is good and power outages are rare, batteries would probably be avoided as they add about 25% to the system cost. Batteries also need to be replaced every three to five years. Since we do not experience long power cuts in Chandigarh, batteries need not be an essential part of the PV system.

Rooftop Solar PV Array with Net Metering

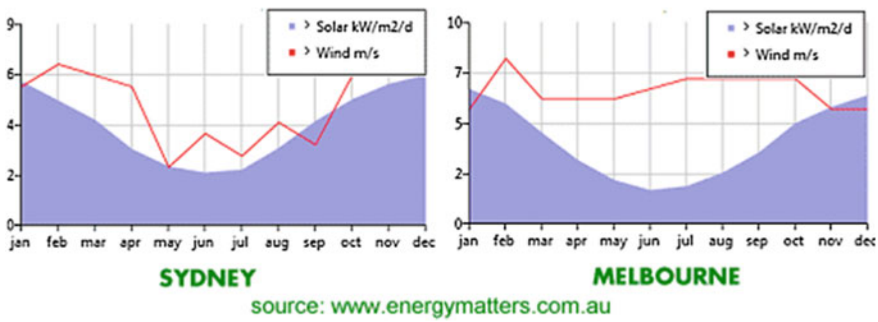
There are two common ways in which owners of kW-scale rooftop solar PV plants can be compensated for feeding electricity into the grid: FiTs and net metering. For FiTs, solar power generated and fed into the grid is measured through a separate meter and then given a price (the FiT) through which the owner is compensated for the electricity generated. The advantage is, that the price for solar power and the amount of solar power generated can be determined independently. This method is useful where either the cost of solar power far exceeds the cost of grid power and/or where the generation of solar power far exceeds the on-site consumption needs. A risk is the potential for fraud through channeling non-solar power through the solar meter and thus inflating the amount of power for which the—usually high—solar FiT is paid. A household-level FiT is offered in, for example, Germany.

Under net metering, on the other hand, conventional electricity and solar electricity are traded at the same tariff. The billing in this case is based on the net energy imported (energy consumed minus energy generated and fed into the grid). In case more energy is generated than consumed, the utility can adjust the excess in a future billing period (this would be akin to "banking" the power), rather than giving a monetary compensation, as in the case of FiTs. However, over the long term, the amount of solar power that can be generated and monetized through net metering will be limited by the amount of power consumed, where, at most, the consumer can feed as much power back into the grid as he draws from the grid so that the electricity bill is “zero”. Net metering is popular in, for example, the USA and Japan.

The Central Electricity Agency (CEA) has initiated steps to set standards and guidelines for the integration of solar PV systems into the grid. A report on grid connectivity of solar PV is under formulation at the CEA. A draft is to be shared with the public for comments by end-June. The CEA’s move is based on its acknowledgement that decentralized solar PV can play a key role in bridging the country’s energy deficit and is set to take off now. During our interactions with senior officials at the CEA, we were told that “solar PV is the future for this country, and we have to make sure that there are standards and guidelines in place to support its integration with the grid”. Various metering arrangements covering grid interaction of a PV system with battery, without battery, with different load battery back-ups, with different load DG back-ups, and with DG and battery back-up combinations, have been laid down in the draft report.

The Economics of Rooftop Solar Systems

The conversion efficiency of solar panels has been improving during the last ten years, and the prices are gradually diminishing. In my case I had to erect a steel structure to obtain sunshine all through the day. This added to the cost, a bit. In normal circumstances, a system should cost Rs. 1 lakh per Kwp capacity. Larger systems are cheaper because the power controller price drops. It is my estimate that a 5 Kwp system can be erected at a cost of under Rs. 4 lakhs. The quantum of power generated varies with the seasons. During winter, the days are short and the sun is at a low angle. Consequently, the power generated in a day may be less than one-third of the yield during the summer. On a day when the sky is overcast, the power generated may drop to as little as 15% of the capacity. A study done on the seasonal variation carried out by the Australians is given below.



Please remember that in Australia, Jun-July is winter. Notice the seasonal pattern of solar power. Consequently, the capacity is based on the annual yield of a system.

Estimate of Power Expected and ROI

As per the current estimate, that a 1 Kwp system can produce 1300–1750 Kwh of energy during the year. Thus I can expect to sell about 3200 units of power out of my 2 Kwp system. The current rate is Rs. 8.51 per unit for those who have not sought subsidy from the government. Thus, on my investment of about Rs. 2.15 lakhs I can hope for a return of over Rs. 27,000 per year. There being very little maintenance cost (other than cleaning the panels periodically), the ROI works out to more than 12%. This is better than the yield on fixed deposit in banks.

Routine Maintenance

There being no moving parts and no deterioration with time, operation of the solar system entails no running expenses. Just about the only thing which you need to do is to clean the panels whenever dust forms on them or raindrops settle on their surface. For that, we have erected a ladder and steps to access the panels.

Our system was ‘commissioned’ on 18 Jan 2016. The sky was overcast, and so during the first five days, we got very little power. But after clouds left, we started getting 5–6 units of power.

The Future of Solar Power in India

From whatever I have observed and read, India is at the ‘take off’ stage in the field of solar power. If the current events are any indication, solar panels are likely to become as common as mobile phones.

An incidental advantage of installing a rooftop system is that it **cools** the house, since the solar panels absorb heat. According to some estimates solar power is expected to grow from 18 to 20,000 MW by 2022. This is a massive growth, by any standard!

The Timeline

I started this project on 11 Sep 2015, and estimated that I would be able to commission the system by 15 Oct 2015, since I had gone into considerable detail. In actual fact, it took three months longer. The electricity board created some hassles while clearing the design and they took unduly long in certifying the meter. I really do not blame them because they were new to the game themselves. My contractor *claimed* to have installed several systems, but they were in a different configuration (where the power is used to charge the user's own inverter) and therefore the government grid did not come in. So all in all, we were all breaking new ground. However, by the time I finished, it became clear to us that for small rooftop solar systems, government approval of the design of the structure is not necessary. As a result of the noise we made, orders have been issued that rooftop solar systems up to 5 Kwp do not need government sanction. In my view, we will proceed much faster if *all* controls are removed. In the NDA, we were taught that, 'The best government is the one that governs the least'

Conclusion

Solar power systems are coming. No one, not even our bureaucracy, can stop them. The need of the hour is that many of us should install them and talk about our experiences. These systems will succeed the most in cases where the system can operate on DC. And if it can be used at the very time it is generated, the cost gets slashed. I am told that a student of IIT Bombay has designed a bicycle where the traction of the pedals is assisted by a solar module. In all probability, he is using a dc motor, which draws power the moment it is generated. So he neither needs a battery nor an inverter. And, of course, he needs no sanction from the government! With a little more sophistication, this concept can be used for short distance commuting. There can be no better solution to pollution.

Finally, I am tempted to insert a picture. It depicts a pre-historic young man trying to 'tame' the Sun. It was not possible then, but appears to have become technological possibility now.

Acknowledgements I wish to place on record my debt of gratitude to my life-long friend, Wing Commander J Thomas, VM for his valuable inputs for this paper.

Development of HVDC Transmission Technology in India

K. R. Padiyar

Introduction

High Voltage Direct Current (HVDC) power transmission made a modest beginning in 1954 when a 100 kV, 20 MW DC link was established between Swedish mainland and the island of Gotland. The converter stations utilized mercury arc valves which were problematic due to the problem of arc backs. Yet, 6000 MW of HVDC links (including the Pacific Intertie in USA and Nelson River Bipole 1) were built using mercury arc valves till 1972. The thyristor valves were first installed in a Back to Back (BTB) HVDC link at Eel River in Canada which interconnected Hydro Quebec system and the New Brunswick electric power system. Thyristor valves did not have the problem of arc backs in mercury arc valves which prevented fast control of power in the DC link. Also, the thyristor valves are made up of series connection of thyristor devices and permitted the choice of the voltage and current ratings of the HVDC link for a specified power flow. Further developments in the technology involved microcomputer based converter control, light triggered thyristor (LTT), capacitor commutated converter (CCC) and UHV DC transmission (at ±800 kV).

The advantages of HVDC transmission are primarily due to (a) elimination of reactive power requirement for the DC line which implies elimination of reactive power compensation (b) asynchronous connection between two systems (c) the fact that, for similar and voltage and current ratings, two DC conductors can carry approximately same amount power as three conductors in an AC line and (d) fast controllability of power flow which can be used to stabilize AC systems. The first advantage is useful for applications in sea crossing while the second advantage dictates its use when the nominal frequencies are different (as in different islands of Japan). The third and fourth advantages are useful in long distance bulk power transmission and HVDC

K. R. Padiyar (✉)
306, 18th Cross Road, Malleswaram, Bangalore 560055, India
e-mail: krpyar@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_36

ties for system interconnection. There are at present, more than 1,30,000 MW of power flow in over 140 HVDC links in the world.

In this article, I describe the introduction of the HVDC transmission technology in India and an account of my involvement with it which lasted till 1994.

Introduction of HVDC Transmission in India

The development of HVDC technology has been slow to start although there was awareness about the advantages of HVDC transmission for specific applications. For example, the possibility of a HVDC interconnection between Sri Lanka and India was discussed. However, when I returned to India in 1976 to take up a faculty position at IIT Kanpur, not much activity was going on. As a matter of fact, some electricity boards opposed the introduction of HVDC transmission as it was considered High Technology and not appropriate for India. It was felt that the introduction of HVDC technology may not happen in the 20th century!

However, I was keen to initiate research activities. I introduced a graduate course on HVDC power transmission and started guiding M.Tech and Ph.D. students on topics related to modelling and control of converters for stability enhancement in AC-DC systems and issues related to AC-DC system interactions involving sub-synchronous frequencies. The research activities were supported by a small grant from CSIR and partially from a DST sponsored project. We could buy a small HVDC (physical) Simulator for academic use. Couple of M.Tech theses were based on the experimental work using the Simulator. Lectures were also organized in short term courses for the benefit of engineers from power industries and teachers from Engineering Colleges. There were also invitations for Lectures on HVDC transmission in Conferences and Seminars.

I came to know in early 1982 that DOE,-BARC-BHEL had teamed up to prepare a proposal to set up an Experimental HVDC Line. I also met Mr. M. S. Vasudeva in DOE and Mr. Seshadri in BARC (Reactor Control Division) who also had interest in developing power electronic controls for Indian Railways and also for power transmission equipment. In the latter half of 1982, there was a meeting of Planning Commission chaired by Dr. M. G. K. Menon to discuss the proposal and the Directors of three academic institutions—IIT Kanpur, IIT Bombay and Indian Institute of Science, Bangalore were invited. I had the privilege of attending this meeting on behalf of the Director of IIT Kanpur. In this meeting, a decision was taken to initiate the National HVDC Project with the experimental line as the major component. This project was cleared on 1st October 1984 by the Government of India with following objectives:

(1) To build up knowhow for the design and construction of the various hardware components constituting the HVDC system
(2) To develop better understanding of the hardware and software involved in HVDC systems, enabling scaling up to higher voltage and power levels.

(3) To become conversant with the installation, commissioning and operation of HVDC systems, which will act as a basis for the same purpose for commercial HVDC lines.

In the first phase of the project, one of the two 220 kV AC circuits linking Lower Sileru in Andhra Pradesh with Barsoor in Madhya Pradesh will be converted to DC by bunching the 3 conductors into a DC pole, which will be used to transfer 100 MW at 100 kV DC with ground return covering a distance of 196 km. It was planned to further augment the capacity of the system to 200 MW at 200 kV DC monopole in phase II, The entire system including System Engineering, software and hardware was handled by a multi-disciplinary team of Indian engineers and specialists, and involved agencies like DOE, DAE. DPE, DOP, DST, NTPC, CEA, CPRI, Planning Commission, APSEB, MPEB, CSMRS, BHEL, Suppliers both in Public and Private Sectors, and Research and Academic Institutions.

Initiation of Research & Development Activities

Even before the project was approved (in 1984), activities were initiated by DOE to invite experts. One of the first expert to visit DOE was Dr. Narain Hingorani, Vice-President of Electric Power Research Institute (EPRI) at Palo Alto, California. He had obtained his Ph.D. from University of Manchester, Institute of Science and Technology (UMIST) and his thesis (which was published jointly with his guide Prof. Colin Adamson) was the first book on HVDC in the English language. He was later invited by the Bonneville Power Administration (BPA) to commission the first HVDC (long distance) link, the 'Pacific Intertie' in United States (from Celilo in Oregon to Sylmar in California, transmitting 1440 MW at ±400 kV over a distance of 1372 km). I had the opportunity of meeting him in December 1982 at DOE office and discussing some issues. Later I had the opportunity to talk to him in detail at his house when I was a Visiting Scholar at University of California Berkeley in the summer of 1983… I also met Dr. John Vithayathil at BPA in 1983 again (I had met him earlier in the summer of 1982) and he was very helpful in answering my queries and showing me the facilities of BPA (the energy control centre and the high voltage test facilities). Both Dr. Hingorani and Dr. Vithayathil were kind enough to send me the technical literature published by EPRI and BPA respectively. I had also visited IREQ (Hydro Quebec Research Laboratory) in Montreal in 1980 and 1982. I could meet and interact with Drs. P. C. S. Krishnayya, P. S. Maruvada, V. K. Sood, H. Nakra and visited the laboratories where significant work on the HVDC line effects and modelling issues were being investigated. I also met Dr. Suresh Kapoor who was working at General Electric on HVDC projects. In 1980, I also visited University of Waterloo and met Prof. John Reeve and his students who were working on control problems. Subsequently, in 1981, two of my M.Tech students at IIT Kanpur were selected for the Ph.D. program in HVDC transmission at Waterloo. One of them Dr. Ram Adapa is presently in Electric Power Research Institute in charge of HVDC and

FACTS program. The other could not take up the offer at Waterloo due to personal reasons, but left a year later to University of Manitoba, Winnipeg and obtained Ph.D. degree under the guidance of Prof. R. M. Mathur and subsequently returned to IIT Kanpur as a faculty member.

In the summer of 1982 also, I had visited San Francisco to present an important paper on the representation of converters based on graph- theoretic approach for the simulation of two and multiterminal HVDC systems. Interestingly, Mr. Woodford from Manitoba Hydro also had presented a paper on the Digital simulation of DC links based on EMTP (Electro-Magnetic Transients Program) type approach. Subsequently, the Manitoba HVDC Research Centre situated at University of Manitoba brought out a program called EMTDC which is a commercial computer program under the title 'PSCAD'.

Visiting Professor at Indian Institute of Science

After the Planning Commission meeting in 1982, I received an invitation by Professor Joseph Vithayathil (who was my teacher during my M.E. student days) at Indian Institute of Science, Bangalore, to join as a Visiting Professor for a year. I accepted the offer and joined the EE Dept. as a Visiting Professor in August 1983. I took sabbatical leave from IIT Kanpur for a year. My stint at IISc was very fruitful. I gave a set of lectures on HVDC Power Transmission. These were attended not only by the students and some faculty members (from EE and HV departments), but also by engineers at BHEL and CPRI. Dr. Arunachalam and Mr. Baldev Raj from BHEL had several discussions with me and an outcome of these discussions was a request to assist in the design of HVDC valves under a consultancy project with participation by Prof. K. Parthasarathy, Prof. Ramakrishna Iyengar and Dr. V. T. Ranganathan in the EE department. The project started towards the end my stay at IISc, but I continued to participate even after I returned to IIT Kanpur towards end of July 1984.

I also participated in two Workshops, one organized by Profs. K. Parthasarathy and H. P. Khicha, on "Electromagnetic Transients" and other by Prof. D. P. Sen Gupta on "Power System Reliability". Prof. H. W. Dommel was the visiting expert from University of British Columbia, Canada in the former Workshop and Prof. M. P. Bhavaraju from U.S.A was the visiting expert in the Workshop for the latter. Incidentally, I was teaching a course on Reliability based Power System Planning at IIT Kanpur. I also was studying the reliability issues in HVDC power transmission. I gave an invited lecture in New Delhi (organized by IEEE section) in January, 1984, describing the reliability issues in HVDC transmission systems. I recall meeting Mr. Jain, Chairman, Central Electricity Authority who appreciated the presentation and advised his Chief Engineer to interact with me. However, that did not materialize except on formal occasions.

After Dr. M. Ramamoorty joined CPRI as Director General in January, 1984, I also had opportunity to give lectures at CPRI and interact with the engineers, particularly from the power system division.

Visit to Canada and U.S.A. in Summer of 1984

Towards the end of my stay in IISc, I had an opportunity to attend an International Conference on DC Transmission in Montreal in June 4–8, 1984. There was a large contingent from India with engineers from BHEL, CPRI, DOE, SEBs etc. who attended. There were several papers presented in addition to a panel discussion at the end. There was a visit to the newly commissioned Chateauguay HVDC BTB (Back To Back) converter station which had a SVC (Static Var Compensator) to regulate the bus voltage as the station was connected to a weak AC system. It was a very useful visit and the Conference gave an opportunity to discuss with Engineers from utility and manufacturing industries in addition to experts from academic and research laboratories. After the Conference, I visited several places including University of British Columbia (where Prof. Dommel was my host and one of my M.Tech student was registered for Ph.D. under his guidance), University of Manitoba (where Prof. R. M. Mathur was my host and Dr. P. K. Kalra was doing his Ph.D. under his guidance). I gave lectures at both universities and met some of the young faculty members including Dr. A. Gole. The highlight of my visit to Winnipeg was the visit to the two Nelson River bipoles side by side (one with mercury arc valves and the other with thyristor valves). I could collect useful literature on the detailed converter control systems for the converter station which I passed on to Engineers at BHEL-ED. I was told later that this information was very useful in designing the controllers for the National HVDC project.

I also could get an invitation to visit GE at Schenectady in New York State because of Dr. Suresh Kapoor who was my contemporary at University of Waterloo. I visited the HVDC Simulator facility used for the design of control and protection.in converter stations. I also met my friend Dr. R. S. Thallam who provided me the literature on DC arrestors used for valve protection. I was staying with Mr. K. J. Rao (who did M.Tech from IIT Kanpur) was also working at GE and was hosting me officially! The entertaining part of my visit was the lunch at Schenectady where a Sales Engineer tried to impress me by talking about the GE technology. He also tried to insinuate that a rival company tries unethical methods to win projects. He mentioned a major project in Brazil which GE lost, and perhaps assumed that Indians may also be lured in a similar fashion. At this point, I had to ask him why a recent major project in the Western U.S. was awarded to the rival company. The reality is that GE was still marketing air-cooled thyristor valves while European companies had switched over to water cooling, which resulted in reduced losses.

Return to IIT Kanpur

At the end of July 1984, I returned to IIT Kanpur as my sabbatical leave got over. Although I was offered (by invitation) a Professorship at IISc, I could not accept as I had signed a bond to serve at IIT Kanpur for 3 years after returning from the sabbatical leave. During my absence, Dr. Sachchidanand (who was my Ph.D. student) had been selected as an Assistant Professor. We applied for a major project from the Department of Electronics (as IIT Kanpur was one of the three major academic institutions selected for Research & Development under the National HVDC Project). It took some time to get the project sanctioned and start ordering for equipment. I continued to teach the elective course on HVDC Transmission which had a good response from research students. J. Senthil joined as a Ph.D. student and started work on the electro-magnetic transient simulation of AC-DC systems that also included study of Sub-Synchronous Resonance (SSR).

After the NHVDC project got approved in 1984, Workshops were being conducted every year on HVDC where experts from abroad were also invited. In January 1985, the first Workshop was held in Bangalore, organized by CPRI. The second Workshop was held in early 1986 at IIT Bombay and in January 1987, we organized the third Workshop at IIT Kanpur. Drs. Narain Hingorani and John Vithayathil were the experts who attended. Dr. Hingorani gave a spell binding lecture on the State of the Art in HVDC technology which lasted about 3 h! It was a brilliant performance and also offered insight into the power semiconductor technology research, which can revolutionize the HVDC technology in future. Dr. Vithayathil gave lectures on HVDC breakers and the issues involved in the clearing DC faults.

Transition to IISc

I received the offer from Indian Institute of Science towards end of 1985, but I could join as Professor in the Department of Electrical Engineering only on 31st July, 1987 due to my constraints. After joining, I applied for projects from two sources—Ministry of HRD and DOE. Since it takes time to process the applications, I got busy with writing the book on ‘HVDC Power Transmission Systems’ for Wiley Eastern Publishers (who had accepted my proposal in 1985). I could finish the manuscript by end of July, 1989 and it was published in March 1991. I was nominated a Member of the Project Review and Coordination Committee (PRCC) for the experimental line project, chaired by Dr. M. Ramamoorty, DG, CPRI. The meetings were held primarily at the Project sites (Lower Sileru in Andhra and Barsoor in Chhattisgarh). The experimental HVDC line between Lower Sileru and Barsoor transmitted power first time on 3rd October, 1989. This was the first HVDC line India.

I also started teaching the elective course on HVDC Transmission and guiding M.E. projects and research students. Three of my Ph.D. students who had registered in IIT Kanpur started visiting me for consultations. Two of them, Dr. Rajiv Varma (presently at University of Western Ontario in Canada) and Dr. S. Senthil (presently at Power Technologies, Schenectady, U.S.A.) also conducted experimental work on the HVDC Simulator in CPRI. The results based on the physical simulator were used to authenticate the system models and the analysis. The work carried out was published in journals.

The research activity picked up after the projects got approved in 1989. The DOE project was aimed at the study of Multi-Terminal DC (MTDC) systems which were under consideration in N. America. The research work related to developing a systematic approach to the study of power flow, stability (including synchronous and voltage stability) of AC systems interconnected by MTDC systems. In particular, the work required development of suitable software. Specifically, an electro-magnetic transients program called DISIPACK was developed to study the transients in two and multi-terminal DC systems. Utilizing the concepts of Object Oriented Programming and graph-theoretic representation of converters, the computer time was reduced significantly and the program could run on PC-AT with 20 MHz clock. This work was presented in 1990 NPSC (National Power Systems Conference) held in Mumbai. A simpler version of the program was applied for the understanding of the response of HVDC converters for various disturbances. A short term course was conducted in 1992 which was attended by faculty from engineering colleges and engineers from industry including State Electricity Boards. In 1991, after my HVDC book was published, I got an invitation from Prof. M. A. Pai at University of Illinois, Urbana, to give a set of lectures spread over 3 weeks, based on the book. The lectures were attended by research students and the faculty in the power area. I also visited Massachusetts Institute of Technology at the invitation of Professors George Verghese and Marija Ilic and I gave two lectures. In September 1991, I attended the IEE Conference on ‘AC and DC Transmission’ to present two papers and visited the Sellindge terminal of the Cross Channel Scheme transmitting 2000 MW power (from France to U.K.). I also visited Liege University in Belgium at the invitation of Prof. Mania Pavella and delivered a lecture (and interacted with the power group there).

By 1996, two of my Ph.D. students working on Voltage Stability and Harmonic Interactions in HVDC-AC systems, completed their work and published their work in conferences and journals.

Epilogue

I consider the National HVDC Project as a mission oriented project was a successful experiment and introduced the HVDC technology for power transmission in India. The attitude of system planners in Indian Electricity Boards changed drastically and the first commercial scheme of a BTB HVDC link at Vindhyachal interconnecting Northern and Western Regions was commissioned in 1988. Subsequently, 6 more BTB links among regions and 5 Bipoles are in existence. A UHV DC, three terminal scheme is being built to transfer 6000 MW of hydro power from North east to load centre around Delhi. There is also a private HVDC bipole transmitting 2000 MW power from Gujarat coast to Haryana. HVDC interconnections are also being built between India and Bangladesh, India and Sri Lanka.

In 1994, I introduced an elective on FACTS Controllers. Dr. Hngorani had given the concept of FACTS (Flexible AC Transmission Systems) in 1988 which involved the application of power electronic controllers to enhance power transfer, improve voltage regulation and system security of AC transmission systems. The first generation FACTS Controllers are SVC (Static Var Compensator) and TCSC (Thyristor Controlled Series Capacitor) based on thyristor valves. The second generation of FACTS Controllers are based on the application of VSC (Voltage Source Converter) using IGBT valves. A STATCOM (Static Compensator) is an advanced version of SVC which has better technical performance with smaller foot print. FACTS Controllers can also be applied in distribution systems to improve Power Quality (PQ). Such devices were labeled as Custom Power Devices by Dr. Hingorani in 1995. Interestingly, just as HVDC technology resulted in the development of SVC and TCSC, the STATCOM technology led to the development of VSC-HVDC which has several advantages over the LCC (Line Commutated (Current Source) Converter) based HVDC technology. VSC-HVDC (which was first applied in 1997 with a modest rating of 3 MW) is now being applied for transfer of power from Off-Shore wind power plants. Since 2010, with the development of Modular Multilevel Converters, the ratings have gone up to 1000 MW. There is convergence between FACTS and HVDC in that two STATCOMs connected in parallel can be used as a BTB connected VSC-HVDC scheme. Incidentally, at the persistent request from my publisher in Delhi, I revised the HVDC book thoroughly incorporating the later developments in the second edition published in 2010. A subsequent revision published in 2014 includes the topic of MMC based VSC-HVDC.

There were several Masters and Ph.D. students who worked on FACTS for system stability improvement, based on designing appropriate locations and control strategies for voltage regulation, prevention of blackouts, damping SSR and improving power quality. Couple of students also worked on VSC-HVDC. I had three DST projects to support the activity and in 2007, published a book on “FACTS Controllers in Power Transmission and Distribution”. While it was a pleasure to teach and guide students in new technologies and their applications, it was also very satisfying to be associated with the development of the HVDC technology through NHVDC Project in India. Two of my Ph.D. students, Prof. Rajiv Varma and Anil Kulkarni were consultants in the SVC and TCSC projects developed by BHEL in the nineties.

Structural Integrity: A Technological Term Synonymous with Safety

B. Dattaguru

Introduction

Way back in 1972, on a nice sunny Wednesday (considered auspicious day in Karnataka), I submitted my Ph.D. thesis at the Indian Institute of Science, and stared into the sky thinking what future has in store for me. The mind of a young engineer who completes his Ph.D. program at a reputed University finds the research world to be of wider scope, vast, but hazy. Gone are the nice days when one was a student working with and guided by a distinguished Professor. The guide would define the problem, periodically keep track of the progress, change direction of work when the need arose and help when the student is stuck. Having received the degree, the student would have to look for a career in industry or academic career in an academic institution/research laboratory. In industry or research laboratory the work is many a time governed by the organisation depending upon where funding is available and only a few could successfully take up research lines of their own choice. In an academic institution where there is no hierarchy the young researcher needs to relate his/her program of work to possible funding sources for acquiring minimum scientific infrastructure. The present faculty are lucky that they get a substantial start-up grant, but this was completely absent in our days in 1960s.

Now the struggle starts for the young faculty. I remember always the words of my brother who is a distinguished Professor of Bio-Physics in USA and a Fellow of US Academy of Physics. He said that "when your supervisor is correcting your thesis do not concentrate on somehow to finish your thesis, but learn how to guide and bring your student's thesis to an acceptable level in future". The wisdom and advice from my mercurial Professor and Supervisor, Prof. A. K. Rao, that "in particular in a developing country like ours, at least some of us should concentrate on research lines which directly should benefit the Indian industry". These two have been my

B. Dattaguru (✉)
79, 3rd Main Road, Amarjyothi Layout, Cholangar RT Nagar (P.O.), Bangalore 560032, India
e-mail: datgurb@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_37

total guidelines when I started my research career. I later passed on these sentiments to my students.

I looked up to two areas among many needing considerable research inputs for the scientific and technological developments in the country. One is structural integrity covering "Fracture Mechanics as the Science and Damage Tolerance as the Technology". The second is Wave Mechanics with several applications to NDT, rock mechanics, earthquake engineering… etc. At that time I moved towards fracture mechanics which seemed to be of direct relevance to the then aerospace programs. In later years I found many of my colleagues have made tremendous in roads into the wave mechanics using Mini-, Micro- and Nano sensors to identify defects and monitor their growth in primary structural components in both off-line and on-line (during the flight) situations. Structural Health Monitoring (SHM) and Integrated Vehicle Health Monitoring (IVHM) have become buzz words, and research to successfully implement them is considered to be necessary to ensure aviation safety.

Integrity of Structural Joints

Joints are one of the critical parts of an aircraft in ensuring safety in design and operational phases. The configurations which threaten the structural integrity of large scale structural systems are structural joints causing concern to engineers conducting design. These structures are often made in parts and assembled using joints such as fastener, riveted, adhesively bonded or welded. The last one is preferred in steel structures whereas the aerospace adopts other types. Fastener and riveted joints are preferred in metallic structures. Bonded joints are used in a limited sense in metallic structures. With the advent of composite structures as primary material for aerospace vehicles bonded joints have become extremely popular. All these joints are discontinuities and are potential sources for crack (or de-bond) initiation and their growth leading to structural failure. Many of these problems are non-linear of different variety, but can be handled by the well-developed Finite Element (FE) software.

Fastener joints exhibit loss of contact along bolt-hole interface and material nonlinearity in some cases of interference joints. Bonded joints get into large deformations due to eccentricity of load path and material non-linearity due to low yield stress for the adhesives. These nonlinearities can be handled with finite element software even when more than one type of non-linearity occurs together. Ultimately, combining non-linear analysis with fracture mechanics poses challenge in both conceptually and in keeping the computational time to be reasonable. These problems are handled using iterative and/or inverse formulations and there is considerable ingenuity required to save computer time. We were aware a well knit group was required for success. Self and my colleagues Prof. T. S. Ramamurthy and Prof. C. R. L. Murthy became the nucleus around which we built the activity in fracture, fatigue, finite element methods and NDT.

"The strength of a chain is the strength of its weakest link" is a well-known statement. Similarly in structures with large number of joints, the strength of individual components is the strength of the weakest joint. The safety regulations during design and during operational phase are stringent and need be followed strictly by the operators. If the health monitoring becomes mandatory in all flight vehicles, the joints will be the sites needing continuous monitoring. A wide parametric study conducted by our research students showed the effect of joints on the stress distribution and maximum stresses which cause crack initiation and growth. Misfit parameter values (negative corresponds to clearance fit, positive to interference and zero to push fit), elastic modular ratio of pin to the plate, Poisson's ratios, Interfacial friction (zero corresponding to smooth, infinity corresponding to rough/bonded or interfaces with finite friction) are the parameters of considerable interest to designers. Among these the interference joint is known to increase fatigue life.

When I was in Air India as a summer visiting faculty in 1970, Boeing replaced many major joints with interference joints. The concept used is a taper lok. This certainly impressed us and later it has been a pleasure to see the influence of geometric and material parameters from our work is being picked in the real design exercises in some of the industries. The greatest happiness for an engineer is when he sees his research contributions find a place in design procedures and/or data sheets published for use in design. Technological innovation sometime went ahead of the computational/analytical developments. The innovative minds of engineers have intuitively predicted higher fatigue life due to introduction of initial stresses using interference bolt in fastener joints much before such a benefit was analytically estimated. Besides interference and interfacial friction play an important role in predicting fretting fatigue failures in fastener joints.

Adhesively Bonded Joints

Adhesively bonded joints were used in a limited sense in metallic structures in several non-aerospace industries. Classical work by L. J. Hartsmith of Mcdonnel Douglas corporation, USA brought out several advantages of bonded over conventional fastener and riveted joints. The clear ones are less sources of stress concentration since cracks starting from riveted holes have been a major worry for designers and operators. However, only in 1980s with the advent of composite structures adhesive bonding method of joining became more popular. USA conducted in 1980s a US National program PABST (Primary Adhesively Bonded Structures) program to resolve certain crucial issues such as Damage Tolerance of large area bonding in aero-wing type of structures. I had the benefit of working at NASA, Langley those years and contributed to computational methods to estimate de-bond growth. A team of scientists including me developed software known as GAMNAS (Geometric and Material Non-linear Analysis of Structures). This software is available on COSMIC where all the US Government funded softwares are stored. The type of defects and their growth in bonded joints are distinctly different from fastener joints, and require special attention for detection (diagnosis) and growth (Prognosis).

Growth of Fracture Research at IISc Along with National Programs

This is the background which created the enthusiasm in some of us to pursue research & development activity in the field of fracture and fatigue. Dr. K. N. Raju of NAL developed facility for full scale testing of aircraft. We learnt a lot related to fatigue and fracture from him. National Aerospace Laboratories (NAL) and Defence Metallurgical Research Laboratory (DMRL) have become centres of this activity under the exceptional guidance of the then Directors Dr. S. R. Valluri and Prof. P. Rama Rao. ICF 4 (International Congress on Fracture) was brought to India and was conducted in 1984. NAL Organised the International workshop on Fatigue, Fracture and Failure Analysis. It was soon evident that given reasonable funding and facilities, India will be soon be self-reliant in handling the Fracture Control in Design of Pressure vessels/Rocket casings, Launch vehicles and the other Indian aero-vehicle programs covering fighter aircraft, helicopter and missiles without depending on the West. Aeronautics Research and Development Board (ARDB) sanctioned large number of projects to academic institutions and research laboratories from 1973 in all areas of significance to aeronautics. Their contribution to generation of large competent scientific man power was outstanding. This helped immensely the National programs which were launched in later years. Dr. A. P. J. Abdul Kalam who moved from ISRO to DRDO started Joint Advanced Technology Program (JATP) in 1983 at IISc and funded projects of relevance to DRDL programs in all branches of Aerospace. Around the same time ISRO started Space Technology Cells (STC) at several Institutions including IISc. This was the beginning of a "Golden era" for Indian Aerospace and the young engineers were bubbling with great enthusiasm to conduct research in certain novel areas and as well contribute to the national programs. Fracture Mechanics is one of these areas which designers were keen to get inputs into their vehicle programs. We could see the initiation of DRDO Aircraft programs like LCA and Missile programs through IGMDP, Space programs including SLV, ASLV, PSLV and GSLV, HAL Helicopter program ALH and it is clear that aerospace received the most important boost.

VSSC organised a task force in 1985 to bring together fracture Scientists with a mandate to bring out the procedure for the fracture analysis of Pressurized components. The procedures set by this committee were subsequently used in defence and aerospace programs. Generally, everyone is satisfied with the progress till then for their projects. However, both Aeronautics R&D Board (AR&DB) and Joint Advanced Technology Program (JATP) supported research in this area including emerging technology of Acoustic Emission for online monitoring of aircraft in flight. The use of Acoustic Emission for incipient detection of failures during ground fatigue testing of structural components seems to be well understood by then.

Early Research Lines

As young faculty members at IISc, we were not satisfied by participating only in projects though they are of national importance. IISc mandate certainly includes conducting research of national and International importance and place the institution at a high pedestal.

To help these national projects we developed certain novel research lines in finite element techniques to accurately determine the fracture parameters SIF and SERR in all the three modes of fracture. Modified Crack Closure (MCCI) technique is known in literature, but limited to simple constant strain triangular, and linear quadrilateral elements. We developed the technique to exploit MVCCI to be applicable for several singular and non-singular elements in both 2-D and 3-D cracked fields. Later for higher order elements a numerically integrated crack closure technique has been successfully implemented. This removed any issues in applicability of the technique to certain elements and made it more versatile to handle all situations. The MVCCI equations developed by us for the singular elements have been adopted in the famous FRANC2D software of Prof. Anthony Ingraffea of Cornell University.

Experimental programs were carried out with collaboration from National Aerospace Laboratory. Dr. K. N. Raju and Dr. R. Sunder of NAL wholeheartedly helped IISc students to work on the excellent facilities in their laboratory. Crack closure measurement with striations developed with special closure fatigue cycles, fatigue failure in structural joints and explanation of crack growth retardation and the effect of temperature exposure on the retardation were some of the topics where collaborative work was carried out. IISc Aerospace department soon became an integral part of the teams on fracture and damage tolerance on most of the National programs. IISc acquired a Fatigue testing machine and primary work done on this machine was combined with NDT techniques. Prof. C. R. L. Murthy pioneered research on Acoustic Emission (AE) when major attempts were being done all round the world to adopt this technique for online monitoring and for incipient damage detection. As a technique AE at that time got accepted as an online monitoring technique during the ground test of components or full scale testing of aircraft. Many more years later with the advent of micro and nano-sensors, I do find this technique is being developed further.

These projects have resulted in several accomplishments. (i) Failure of one of the pressurised air bottle is detected much before the actual failure using AE. The project Director was very happy and he exclaimed "your project budget is 1.8 lakhs and the cost of the project is paid for since we saved one vessel which costs more than the cost of the project", (ii) Several proof tests on pressure vessels in non-aerospace industries were cleared with AE monitoring, (iii) Software is developed for estimating the Stress Intensity factors (SIF) and Strain Energy Release Rates (SERR) in different modes of fracture, (iv) Certain critical thicknesses in high technology components had to be marginally changed to accommodate both fracture and DT criteria and (v) permissible crack sizes were determined in several critical situations.

Damage Tolerance to SHM

Last couple of decades have seen a distinct change with the scientific revolution leading to the availability of micro- and nano-sensors. Fibre reinforced composites as primary structural material also changed the approach of designers in safety critical structures such as in aerospace industry. Micro sensors can be embedded in layered composites and the diagnostic methods are based on wave propagation in the structure. I could not visualise in my younger days the potential of wave mechanics, but extremely delighted that many of my competent younger colleagues have been exploiting this technique quite extensively for damage detection.

National programs NPSM and NPMASS headed by Prof. V. K. Aatre gave a tremendous fillip to the emerging micro sensors and systems, and put the safety aspect into a different perspective. It is possible to continuously monitor the structures and possible to detect cracks as they occur and grow. The information can be used in two ways: (i) If the damage or cracks detected are critical this information can be used for online Structural Damage Mitigation i.e., temporarily mitigate damage till you land and (ii) allows the cracks to be attended off line and provides prior information to MRO operations where the cracks have occurred. The later saves considerable time in diagnosing the damage locations.

Currently, we are working at the International Institute for Aerospace Engineering and Management (IIAEM), Jain University on prognostic aspects of crack growth in critical components. Crack growth in standard configurations can be handled using well-known software such as NASGRO. On the other hand when one needs to investigate prognostics of crack growth in problems such as structural joints where non-linearity is prevalent, special methods need be adopted, and these are the aspects dealt with in the studies at IIAEM.

Structural Health Monitoring (SHM) and Integrated Vehicle Health Monitoring (IVHM) have become buzz words for all operators of high technology and safety critical structures. "Can we decrease the stringent requirements of Damage Tolerance if we continuously monitor the structure" is the natural question asked by the LCA chief designer Dr. Kota Harinarayana. I would love to see his anticipation for the future flight vehicles come true.

Working Closely with Industry

Industry obviously needs reliable answers to their problems involved in safety critical components. They would depend on premier institutions with strong research base for this. Generally, the problems faced by them do not need inputs from cutting edge research, but simple calculations done by institutions with strong research base will be accepted with confidence. Many of times we realise that there is a need to approach industrial problems with simple theories, and use common sense than jump into complex methods and solutions. Engineers must carefully groom their minds to pick the right approach for the problem at hand. Design of every bracket need not be done with fracture mechanics and damage tolerance approach. I would like to highlight a few examples to bring out how problems are solved.

1. Some industry had to reproduce a bolt to be used under tension. Their reproduction was perfect including the material and dimensions. Among the dimensions they reproduced the length and shank accurately. However they did not bother about the bolt head dimension to be of any significance made it marginally bigger for operational advantage. The bolt was failing at much lower fatigue cycles than the original bolt. It was a mystery till it was discovered that the dimension considered to be unimportant viz., bolt head size is the main cause. When a given load is distributed over longer length, the root bending moment is larger. 15% larger bending stresses cause loss of 70–80% of fatigue life. It did not require further fatigue testing and the modified bolt worked. Typical example when an engineer's mind should be alert and often complex looking problems have simple solution often based on strength of materials only.
2. A crack was discovered in a solid propellant couple of days before it was to be fired. We were rushed to the spot in view of the time constraint. The main issue is to profile the crack and later standard equations could be used to check the integrity during firing.
   We worked hard for a period of 4–6 h to complete the job and declare the crack to be safe. The firing justified our conclusions.
3. The first time I had an opportunity to use fracture mechanics knowledge along with my distinguished colleagues was in an event happened in a major power generating station. In a rainy season a large size mud block flowed in a semi-liquid form on to a pen stock and pushed it out of its anchors. It was contemplated to replace a few hundred meters of the penstock, but there was a delay in carrying it out. In the mean a team from IISc consisting of myself and another 7 distinguished Professors visited the site. The crucial point which was identified by the team is that during the type of loading such as the one which occurred in pushing the pen stock off the anchors, only very few circumferential joints would have been damaged. Just as sugar cane breaks at one or two junctions when one tries to break it using bending load. When one or two joints break, there will be stress relief everywhere and this makes the other joints to remain intact. This logic made it possible to think of restoring the pen stock and carryout required repairs instead of replacing large section of the penstock. Then the program was to identify the damaged joint/joints using NDT, re-gouge and re-weld it and push the pen stock back to the original position and anchor it. While refilling the pen stock we used Acoustic Emission monitoring to check on the structural integrity. This operation took 3–4 months and it was a success, and 30 years later we did not find any report of further damage on the restored pen stock.
4. A company used bonded joint in their road driven vehicle. They observed frequent failures at the end of lap length and this was spreading inside. When we looked at the configuration, the first comment we made was that the adherends should be tapered. The industry man said" Yeah, I should have thought about it myself"

and he was about to go. We asked him to wait to allow us to estimate what taper angle to be given, using fracture calculations on Strain Energy Release Rates. In particular, the peel mode causes early failure and we recommended a 60° which brings the peel effect to near zero value. It was implemented and no further failure has occurred. I have given this example to show how one should combine the use engineering sense to computational structural mechanics to arrive at the optimum answer.

Conclusion

I narrated four examples, but there were many. If we consider the entire IISc, the faculty would have dealt several cases of this type. My narrating these here is to emphasise that an Engineer is a bridge between science and technology. In bringing these together he needs to also use "engineering sense" (some may call it common sense and there is not much difference between these) to successfully implement. Ultimate proof is successful implementation. Development of correct theory is necessary, but not sufficient till it works and also stands the test of time. The mind of an engineer has to assimilate the theoretical part and spend considerable time to realize it.

Safety of operations is needed in every engineering field to protect their structures. Appreciation of all methods of safety could save disastrous loss of human life and money for the state. In each one of the problems there are no common solutions. This is the reason why damage tolerance is called a strategy which has to evolve for each case. As such now continuous monitoring of structures is the scientific method which could be the front end of this approach. SHM and IVHM will generate enormous data, and the next few years need to concentrate on how to handle Big Data Analytics to isolate and pick the signals of warning from continuously generated huge data.

Necessity is the Mother of Innovation—An Example

A. Sanatkumar

Introduction

In the context of technology development, 'invention' may be seen as creation of a hitherto unknown concept, design, material, or process etc., through the all-important one percent inspiration 'gifted' to the inventor (seeker of answers) by evolutionary processes of Nature, and who subsequently by his/her own ninetynine percent 'perspiration', successfully achieves the end result. Inventors are rare persons, born too few and far between, although their inventions can have tremendous impact on society and mankind. By contrast, 'innovation'[1] is a work-around for any obstacles that we may face in the way of technology development. It is generally a case of developing an alternative design, material or manufacturing process when indigenising a component or system for which we do not have in our country, industrial infrastructure to the same extent as our collaborator's designers from whom we obtained the design. Problem solving innovations are more commonplace than inventions, and are being implemented all the time around us if only we take the trouble to recognise them—often yielding huge positive outcomes. This article is about a small innovative idea[2] which although might look simple and obvious in retrospect, did result in saving a make-or-break situation.

[1] Innovation (Wikipedia) is the process of making changes to something established by introducing something better and, as a consequence, new.

[2] 'One small step for Indian PHWR!' (with due apologies to Mr. Neil Armstrong http://www.nasa.gov/mission/pages/apollo/apollo11/audio.html).

A. Sanatkumar (✉)
Flat C-4, Building 25, Kendriya Vihar CHS Sector 38, Nerul, Navi Mumbai 400706, India
e-mail: lskask@gmail.com

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5_38

Innovative Idea

Because of their ability to effectively use limited resources of Natural Uranium, the Pressurized Heavy Water Reactor (PHWR) concept, based on the CANDU reactor system developed by Canada, has been chosen to be the basis for nuclear power in our country. Collaboration agreement (1960s) between India and Canada envisaged almost complete Canada-supply for the first Unit at Rajasthan (RAPS-1). Recognising the importance of achieving self-sufficiency in these high-technology areas, Dr. Bhabha and his associates had included in the collaboration agreement, provisions for increased India-supply of materials, equipment and components for RAPS-2. Further, the agreement envisaged that India could use the Canadian designs, even beyond RAPS-2 (with further indigenous innovations and adaptations) for constructing more PHWR units at Kalpakkam (Tamil Nadu) and elsewhere in India.

PHWRs are well-known for their neutron economy, contributed to a large extent by the on-power refuelling capability that the design is endowed with. Fuel in the form of half a metre long 'bundles' are placed inside horizontal tubular assemblies called Coolant Channels (Fig. 1).[3] Heavy Water at high pressure and temperature flows through each of these channels, picking up the (heat) energy liberated as a result of nuclear fission in the fuel.

In order to refuel the reactor without shutting it down (that is, to carry out on-power refuelling), it is necessary to gain access to the fuel bundles inside each Coolant Channel. Two remotely operated, automatic, computer controlled Fuelling Machine (FM) Heads, functioning in unison, are used for this purpose. The first FM Head, clamped to one end of a channel, gains access into the Coolant Channel by removing

[3]Figures 1, 2, 3, 4 and 5 are at the end of the article.

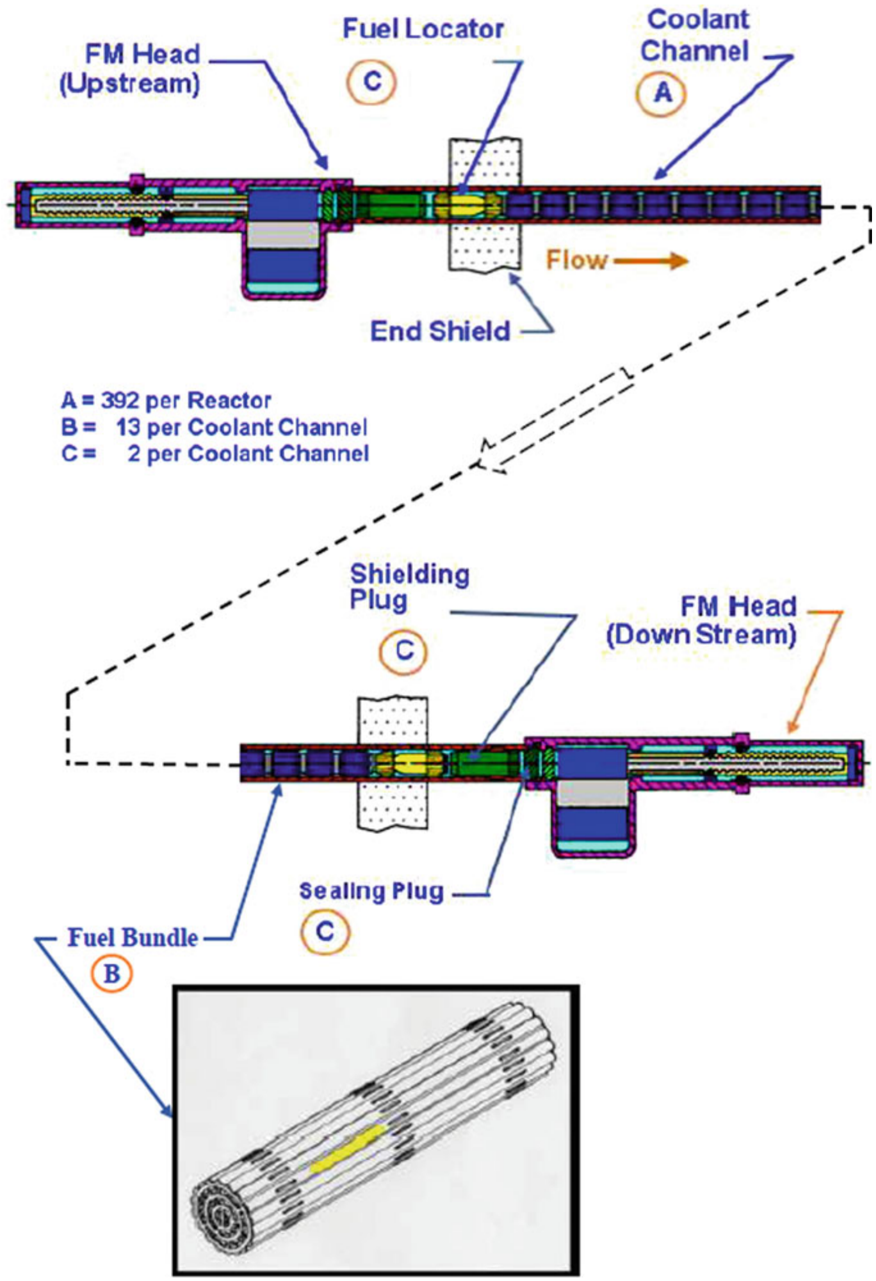


Fig. 1 540 MWe PHWR coolant channel

the Canada-invented, ingenious, self-energised[4] sealing mechanism (called Sealing Plug), and subsequently removing another similar mechanism used as a shield against nuclear radiations streaming axially from the channel (called Shielding Plug). Sealing and Shielding Plugs are identified in Fig. 1, as are the Fuel Bundles. The FM Head at the upstream end, then pushes new fuel into the channel while the second FM Head, clamped to the downstream end of the same channel, after removing identical Sealing and Shielding Plugs at that end, receives the spent fuel. Fuel received in the downstream FM Head is subsequently discharged to the Spent Fuel Storage Bay for safe underwater storage. When refuelling operations on a channel are completed, the FM Heads safely reinstall the Shielding and Sealing Plugs at both ends before unclamping and proceeding to refuel the next channel. All the operations have to be carried out remotely and automatically in order to ensure utmost reliability and safety. The Fuel Handling System comprises of several complex systems and sub-systems involving almost all aspects of engineering, including high precision mechanical engineering, advanced oil and water hydraulics, computer control etc.

Design and safe operation require the Sealing Plugs to be precision engineered and manufactured. A cross section of a typical Sealing Plug (in this case for 540 MWe PHWR at Tarapur 3&4) is shown in Fig. 2. Sealing Plugs for 220 MWe PHWRs are slightly smaller, but utilise the same principle of operation.

The Sealing Plug Assembly, as installed in the End Fitting of the Coolant Channel is shown in the top half of the cross sectional view in Fig. 2. In this condition, it is required to withstand hydrostatic loads acting on the Seal Disc (Item 5 in Fig. 2) which provides sealing against high pressure coolant heavy water. For this purpose, a set of six Jaw Segments are expanded into a groove (with one side of it being conical) in the End Fitting, by pulling the Spider outwards using three telescopic co-axial Rams in the FM Head. To withstand the high hydrostatic force and share the load equally, the Jaw Segments need to move uniformly outward. Moreover, the conical surface at the outer periphery of the Jaw Segments (see Fig. 3) should bear uniformly against the conical face of the groove in the End Fitting. To uninstall the Sealing Plug from the End Fitting for refuelling, the FM Head Rams push the Spider inwards to collapse the Jaw segments. Lower half of the cross sectional view of the Sealing Plug Assembly in Fig. 2 shows the Jaw Segments in the collapsed condition. Again, the Jaw Segments must move uniformly inwards, so as to ensure that in the fully retracted condition, none of them are projecting into the groove in the End Fitting and are well inside the outer diameter of the Sealing Plug. Clearly, to achieve uniform, smooth movement of the Jaw Segments and to safely withstand the high forces operating on the Sealing Plug, apart from use of high strength stainless steel material and robust design, they must also be manufactured to high precision.

In order to achieve their uniform and precise movement, each of the six Jaw Segments of a set are provided with a contoured non-circular hole (commonly referred to as a 'slot') comprising of two straight sides, connected at the top and bottom by

[4] 'Self-energising' refers to the capability of the sealing element to automatically generate increasing gasket seating force with increasing pressure of the fluid being sealed, thereby ensuring that when fluid pressure increases, leakage past the sealing surface does not increase.

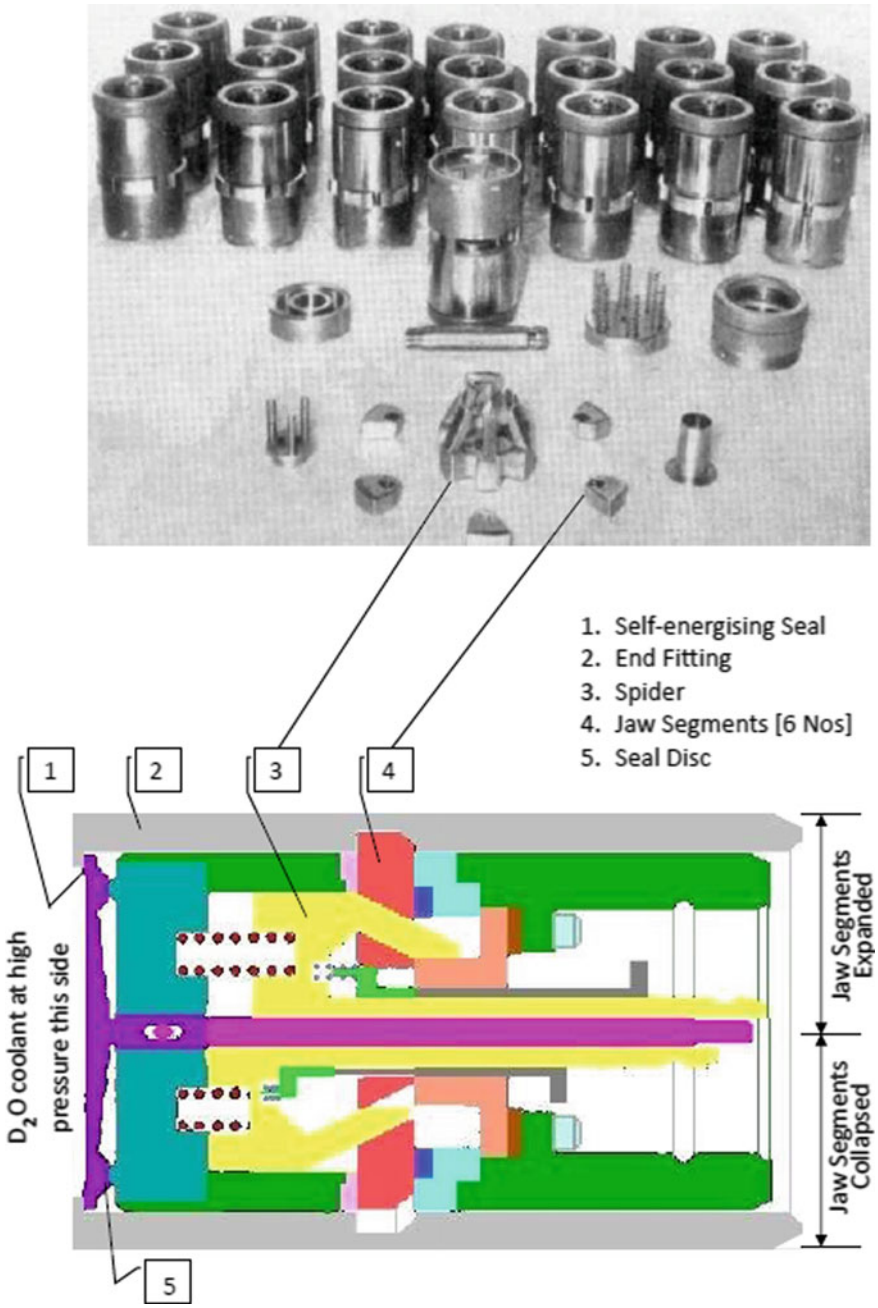


Fig. 2 Typical seal plug assembly

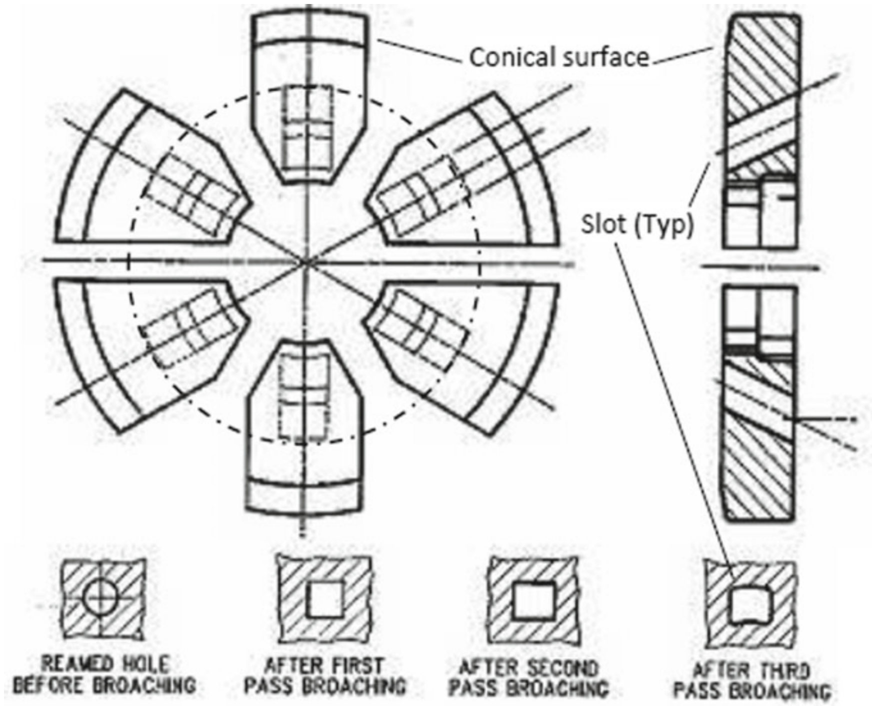


Fig. 3 Jaw segments and broaching passes

two concentric circular arcs as shown in Fig. 3. Size of each slot is approximately 13 mm wide by 10 mm high by 18 mm long. It is essential that all the slots are located such that their common pitch circle is concentric with the conical surface at the outer periphery. Furthermore, all the internal surfaces of the slots need to have a smooth finish in order to minimise friction during their movement. Finally, the angle at which the slot (which engages with the 'finger' of the mating component, namely 'Spider'—see item 3 in Fig. 2) must be identical in all the Jaw Segments. The design envisages that the six Jaw Segments are not interchangeable; that is, all six Segments must stay together during manufacture and assembly. One Segment from a set is not to be interchanged with another of a different set. The Jaw Segments are made of Precipitation Hardened Stainless Steel, as are most of the other parts.

The Shielding Plug is similar in construction to the Sealing Plug, but is smaller in overall diameter, and has a set of only three Jaw Segments. Although this article mainly describes certain manufacturing aspects of Jaw Segments of Sealing Plugs, similar requirements and constraints are applicable to Shielding Plugs too.

How the 'Necessity' Arose

We started our efforts towards indigenous manufacture of Sealing and Shielding Plugs in early 1970s. Readers may please keep in mind the very limited extent of nascent industrial infrastructure, particularly for precision manufacture, that existed in our country at that time.

Our efforts in indigenous manufacture began with attempts to use the manufacturing process sheets furnished by the Canadian Supplier of Sealing and Shielding Plugs for RAPS-1 as per the requirements of the Purchase Orders placed on him. From the beginning we realised that the manufacture of Jaw Segments could become be a critical path activity. Very soon it became evident that the processes used by the Canadian manufacturer could not be followed in India, because he had used spark erosion technique whereby all six slots were 'sunk' simultaneously using six electrodes moving in unison.

Hectic efforts to locate manufacturers in India having spark erosion machines of the required capacity were not encouraging. Extensive trials undertaken to make prototype pieces, limited only to the slot, just to determine the different spark erosion parameters, were unsuccessful in terms of achieving accuracy and surface finish. Time required to complete even a single slot and electrode wear were other major issues. There was no question of sinking six slots simultaneously as was done in Canada for RAPS-1 because spark erosion machine having the requisite capacity was not available at that time.

Thus, broaching became the selected method for making the contoured non-circular slots. When contacted, the initial reaction of the supplier of special purpose broaches in India (who also had an appropriate broaching machine so that he could be given single point responsibility not only to supply the broaches but also carryout the broaching operations) was: "we have never machined stainless steel nor have we supplied broaches for use with this material". However, they subsequently agreed to work with their foreign collaborators and attempt indigenous manufacture of the required broaches.

Sustained discussions with the broach manufacturer brought to light that their collaborator's effort in the past to manufacture broaches for this application was not very successful since the broaches, even though properly designed and made of the highest quality tool steel available at that time, frequently tended to break during the broaching operation. This, apart from increased cost of tooling and decreased productivity, often additionally resulted in unacceptable damage to the component being broached. It was this feedback from the broach manufacturer which presented the 'necessity' that led to our 'innovation'.

The 'Eureka!' Moment

Feedback as above was indeed very discouraging. Having failed to develop spark erosion technique, inability to make the slots even by the second alternative, namely broaching, would mean that in order to complete manufacture of Sealing and Shielding Plug assemblies in India, at least the finish machined Jaw Segments need to be imported. This was not found desirable, since, we could be faced with difficult-to-resolve issues due to potential incompatibility with mating components manufactured by a different manufacturer, when the Jaw Segments are finally put together with their other mating parts, to make up the respective Plug Assemblies. The only other alternative appeared to be to import complete Sealing and Shielding Plug Assemblies, manufactured abroad. Not only would this have been a more costly proposition, but would also have meant that remaining machining operations that could otherwise have been carried out in India are actually done abroad. These scenarios would have led to big setback to our resolve to develop indigenous capability to manufacture precision machined components, considering that construction of many more PHWRs to follow RAPS-2 were on the anvil.

We were quite determined to spare no efforts to make a success of indigenous manufacture of the Sealing and Shielding Plugs.

In pursuance of this aim, a detailed analysis to find out the possible reasons why frequent failure of the broaches took place, was undertaken along with the broach manufacturer, who incidentally, was also quite keen to participate in our Nuclear Power Programme. Apart from (a) normal tool wear and (b) mishandling of the broach during use, we felt that there might have been some non-optimal features in the broaching process itself that led to frequent failures experienced by the foreign collaborator.

Some of the requirements dictated by the design and dimensional constraints of the slot are:

(a) As previously described, to get the required dimensional accuracy, the slots for all six Jaw Segments must be made while they are integral as a single 'Jaw Blank'. The Jaw Segments are to be parted from the Jaw Blank only as a final operation after the slots and all other related features have been finish machined.
(b) The broaching tool would be slender and hence a pull-type broaching machine is to be used. No problem here since such a (horizontal) machine of the requisite capacity was available with the broaching manufacturer.
(c) In order to reduce the load on the broach, and to achieve the final surface finish as specified, each slot is to be made using a set of multi-pass broaches, whereby only limited material is removed from the slot surfaces in each pass (see Fig. 3). Also, coolant/lubricant oil to be supplied at the tool-and-job-interface in copious quantity, should be carefully selected, having requisite properties.
(d) In order to enable accurate insertion of the shank of the broach through the component and grip it in the chuck of the broaching machine, precisely located drilled and reamed circular pilot holes need to be pre-machined for each slot.

It is in this requirement (d) above that we located a potential cause for frequent failure of the broaches. Drilling and reaming of the six pilot holes in the Jaw Blank, corresponding to each slot, was being carried out in a vertical drilling/reaming machine using an indexing fixture that would allow successive location of the centre of each of the six holes to be machined, concentric to the spindle of the drilling machine.

On the other hand, broaching of the slots in the Jaw Blank was being made in a different machine (essentially a setup which is distinctly different from that for drilling and reaming) using a different indexing fixture. Even if both the fixtures are made to high accuracy, because they were different from each other, due to tolerance stack-up, indexing operation at the broaching machine may not have positioned the pilot hole at the ideal position with respect to the axis of pull of the broaching machine ram. This misalignment might have caused the broaching tool to bend to an unacceptable extent (even if only small in terms of dimensional errors), resulting in failure of the broaching tool.

Once this issue was identified as a possible cause for frequent broach failure, we suggested to the broach manufacturer that he should design and use a unified, precision manufactured, indexing fixture that can be mounted on a vertical drilling/reaming machine as well as on a horizontal broaching machine (see Fig. 4).

Agreeing to give it a try, he designed and manufactured such a fixture in addition to a prototype set of multi-pass broaches. Needless to say this effort proved successful, although the special coolant/lubricant used in the broaching operation needed to be imported, as it was not available in India at that time. Tool wear and tear and broach breakages were brought down to acceptable levels. A similar strategy was adopted for the manufacture of Shielding Plug Jaw Segments too (Fig. 5).

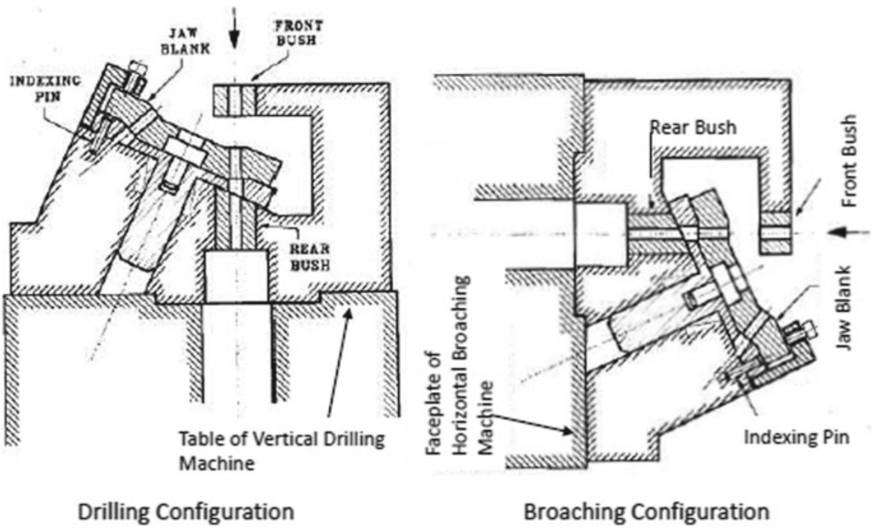


Fig. 4 Drilling and broaching fixture (conceptual)

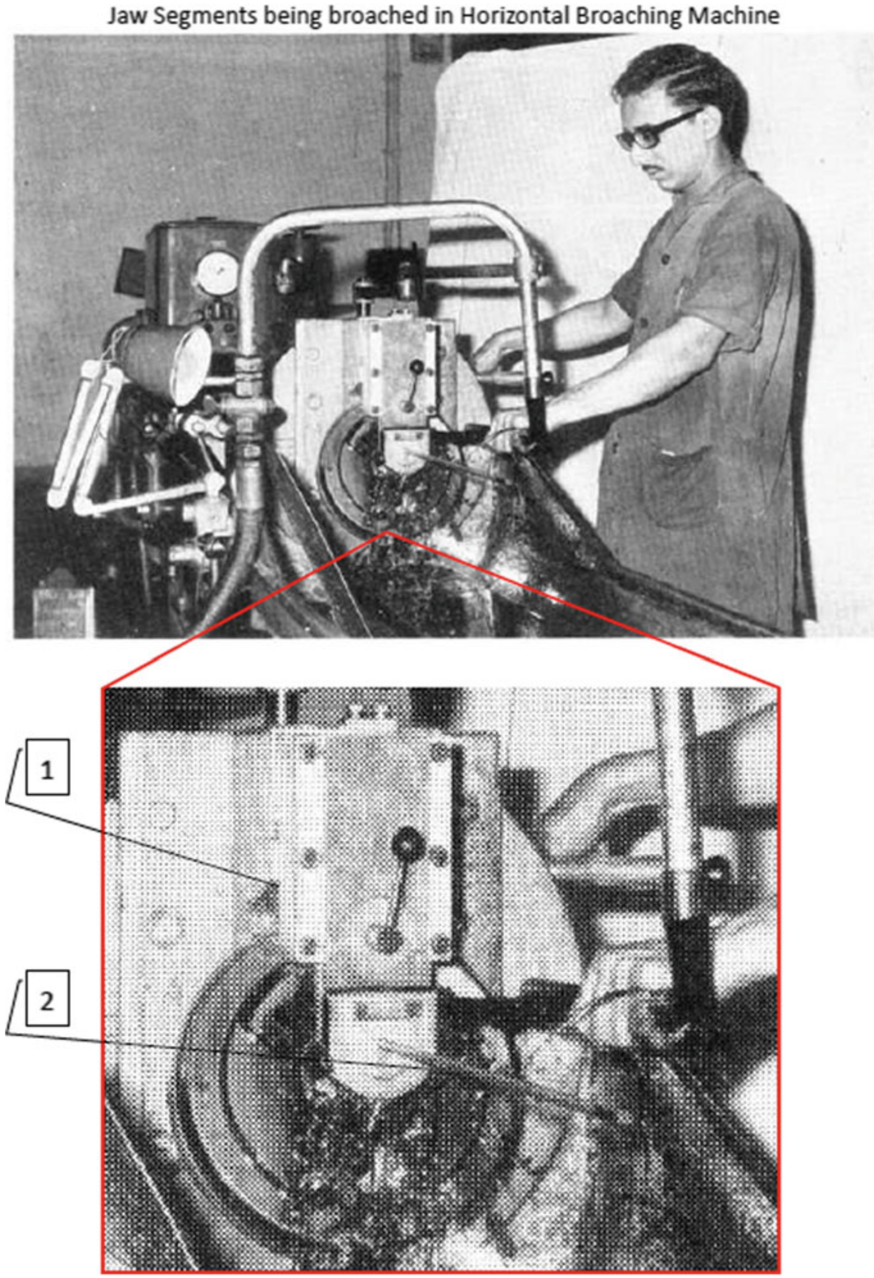


Fig. 5 Enlarged view of fixture [1] and broach [2]

Conclusion

Implementation of the concept of combined Drilling-plus-Broaching Fixture went a long way in enabling us to satisfactorily manufacture Sealing and Shielding Plug Assemblies for the first time in India.

Since then, using this combined fixture concept, a total of nearly 19,000 Jaw Blanks (of Sealing and Shielding Plugs put together) for 14 reactors have been successfully broached.

Of course, there were several other technology-related problems too, not discussed in this article, which needed to be resolved and overcome in economically achieving our goals.

Among many examples, big and small, involved in indigenous technology development of on-power Fuel Handling Systems for PHWRs, is the development of Precipitation Hardening Stainless Steels by MIDHANI which has given us, to a very great extent, independence from having to import this important raw material.

Certainly, technology development is not static. By about 2005, several Indian manufacturers had acquired suitable Spark Erosion/Wire cutting machines. At the present time, slots in the Jaw Segments are spark eroded/wire cut, much as it was done in Canada for RAPS-1.

Acknowledgements The Author is grateful to Shri A.B Ghare who reviewed the manuscript and gave valuable suggestions for improvement.

Author Index

P. Ghosh (ed.), *The Mind of an Engineer: Volume 2*,
https://doi.org/10.1007/978-981-15-1330-5