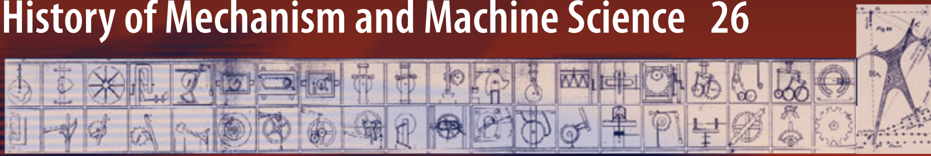
History of Mechanism and Machine Science 26



Marco Ceccarelli *Editor*

Distinguished Figures in Mechanism and Machine Science

Their Contributions and Legacies, Part 3

Springer

History of Mechanism and Machine Science

Volume 26

Series editor

Marco Ceccarelli, Cassino, Italy

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This technical approach is an essential characteristic of the series. By discussing technical details and formulations and even reformulating those in terms of modern formalisms the possibility is created not only to track the historical technical developments but also to use past experiences in technical teaching and research today. In order to do so, the emphasis must be on technical aspects rather than a purely historical focus, although the latter has its place too.

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Editor

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Preface

This is the third volume of a series of books whose aim is to collect contributed papers on figures in Mechanism and Machine Science (MMS). This latest volume follows the first, published in 2007, and the second, published in 2010, both of which also represented a combination of very ancient and very recent scholars with the dual goals of both lending an encyclopedic character to the project and also emphasizing the significance of MMS through time.

The uniting characteristic of the project is that the papers all recognize persons whose scientific work resulted in relevant technical developments in the historical evolution of the fields grouped today under the banner of MMS. Biographical notes describing the efforts and experiences of these persons are included as well, but a technical survey is the core of each contributed paper. This third volume was made possible thanks to the invited authors, who have enthusiastically shared this initiative and have spent time and effort in preparing the papers in due time.

The stand-alone papers cover the wide field of the History of Mechanical Engineering, with specific focus on MMS. I hope that readers will take advantage of each of the papers in this book and future ones as an opportunity to gain further satisfaction and motivation for their work (historical or not).

I am grateful to the authors of the papers for their valuable contributions and for preparing their manuscripts on time. I also wish to acknowledge the professional assistance of the staff of Springer Science+Business Media and especially Ms. Anneke Pot and Ms. Nathalie Jacobs, who have enthusiastically supported this project with their help and advice in the preparation of this third book.

I am grateful to my wife Brunella, my daughters Elisa and Sofia, and my son Raffaele. Without their patience and understanding, it would not have been possible for me to work on this book and the dictionary project.

Cassino, September 2013 Marco Ceccarelli

Contents

Allievi Lorenzo (1856–1941)

Marco Ceccarelli

Abstract Lorenzo Allievi is best known for the Water hammer solution, which he proposed in 1903. But he also contributed to Mechanism Design with the milestone work 'Cinematica delle Biella Piana' (Kinematics of Planar Couplers), published in 1895 as an original work from application of the Burmester Theory. His lifetime's professional activity cemented him as a Captain of Industry, as he experienced success in many Italian enterprises and organizations.

1 Biographical Notes

Lorenzo Allievi, Fig. 1, was born in Milan on 18 November 1856 and died in Rome on 30 October 1941.

He was the son of Francesca Bonacina Spini and Antonio Allievi, who was a Senator in the Italian Parliament in the recently established Italian Kingdom. Lorenzo started school in Como but when his father was appointed Senator in 1871, the family moved to Rome where he completed college and got an Engineering degree on 24 October 1879. His thesis on 'Internal equilibrium of metallic pylons according to elastic behavior', Fig. 2, was also published in 1882 in Rome and was circulated successfully in Italy, as indicated by the fact that it is stored in the libraries of several Italian Royal Schools of Engineering. He received a grant

This Chapter is an expanded version of the journal paper: Ceccarelli M., Koetsier T., "Burmester and Allievi: A Theory and Its Application for Mechanism Design at the End of 19th Century," Journal of Mechanical Design (Vol.130, July 2008, pp. 072301-1:16), http://link.aip.org/link/?JMD/130/072301 (DOI: 10.1115/1.2918911).

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M. Ceccarelli (ed.), *Distinguished Figures in Mechanism and Machine Science*, History of Mechanism and Machine Science 26, DOI: 10.1007/978-94-017-8947-9_1,

Fig. 1 Portrait of Lorenzo Allievi (1856–1941)

as a visiting scholar in Germany and was subsequently appointed to a temporary position at the Royal School of Engineering in Rome, where he mainly worked on studies of TMM. During this period he also put effort into other design problems, such as the Metro system in Rome and the railway line to Castelgandolfo.

On 31 August 1885 Lorenzo Allievi married Anna Brenna, who later gave him three children: Francesca, Raimondo, and Antonio.

In 1893 he left Rome to take the position of Director of the industrial enterprise ‘Risanamento di Napoli’ in Naples, where he promoted industrial development until 1901, after which he came back to Rome. There, he took up several positions in a number of industrial enterprises (Carburo Calcio, Risanamento della Romana Gas, Anglo-Romana, Terni, Romana Elettricità, Banca Commerciale, Meridionale di Elettricità, Electrochimica, Saline Eritreee), resulting in his appointment as President of the Association of User Electrical Companies. This success led to further appointments as President of the Industrial Union of Region Lazio and later Vice-President of the Italian Industrial Union.

Particularly interesting is his activity at the Elettrochimica company, for which he designed plant enlargements in Popoli, although primarily he studied problems in the plant at Papigno in Terni, where in 1902 a hydraulic pipe exploded, causing great damage to the structure. Following that, Allievi put considerable attention towards the study of perturbed motion of water in pipelines, working mainly at night after his daytime duties for the industrial companies. He often remained at home, surrounded by the smoke of his cigarettes, absorbed in the study of hydraulic phenomena in an attempt at rigorous formulation for design and operational purposes.

The study of Hydraulics was always of interest to him, even after he addressed the problems in the Papigno plants by solving the regulation of the Water hammer, as detailed in his first publication in 1902, reprinted in 1903. Figure 3 shows the

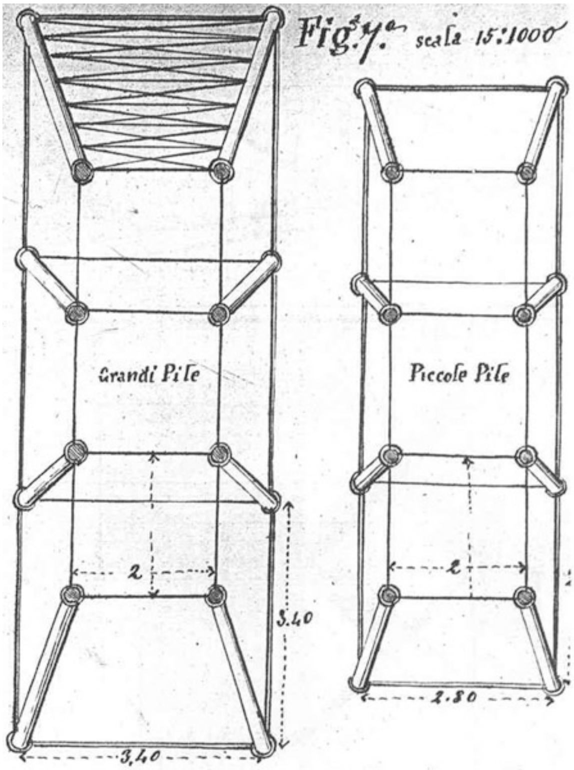


Fig. 2 Schemes of pylons in the thesis for an Engineering degree by Lorenzo Allievi (Courtesy of Mirta Lancellotti)

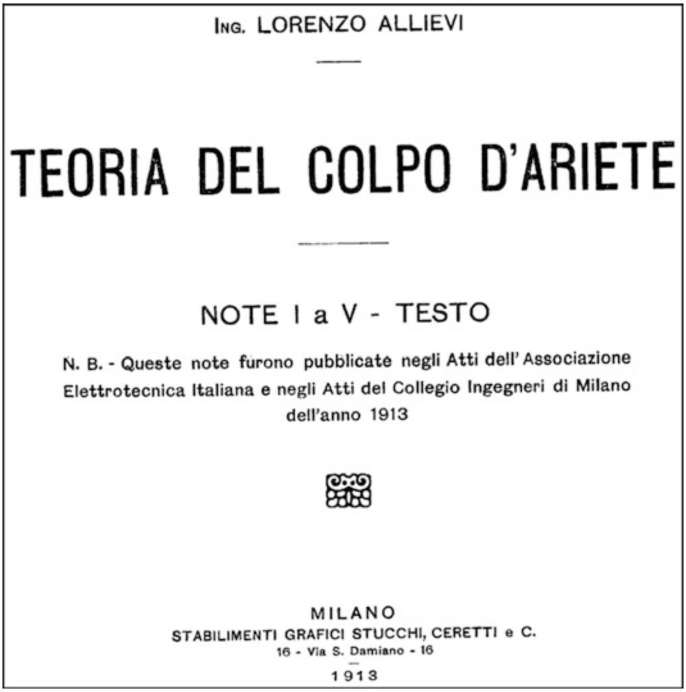
title page of the most widely distributed version from 1913. He continued to work on the theory of the Water hammer but never again considered problems of the Kinematics of mechanisms, the subject of his first scientific publication (Allievi 1895).

In his activity as an engineer and industrial manager, he also always paid attention to the satisfaction of the employers, since he considered the work in its entirety to be fundamental for achieving the scheduled goals of the company and the job being undertaken. Since he was also involved in economic aspects, Allievi addressed subjects of Finance in articles that were published later in 1918 in Rome in a volume entitled 'Spunti polemici di attualità'.

Despite all of this, he never neglected his family, to whom he dedicated attention and time, mainly in the holy day periods in Anzio (Fig. 4).

Lorenzo Allievi enjoyed success as both a professional engineer and industrial director. But the activity that brought him international fame was his scientific study of the Water hammer, which he addressed in several publications from 1902 until 1936 (Allievi 1902, 1913, 1932, 1933, 1934, 1936), a subject he was still investigating when he died in 1941.

In the hydraulic plant in Papigno, a large marble plaque stands as a monument to his contributions (Fig. 5) (ENEL 1996).


ING. LORENZO ALLIEVI

TEORIA DEL COLPO D'ARIETE

NOTE I a V - TESTO

N. B. - Queste note furono pubblicate negli Atti dell'Associazione Elettrotecnica Italiana e negli Atti del Collegio Ingegneri di Milano dell'anno 1913

MILANO
STABILIMENTI GRAFICI STUCCHI, CERETTI e C.
16 - Via S. Damiano - 16
1913

Fig. 3 Title page of the 1913 publication of the theory of water hammer by Lorenzo Allievi

His approach, still known today as Allievi's Theory, gained him several prizes, both in Italy, such as the Jona Prize for Industrial Engineering achievements, and abroad, including immediate translations of his publications into French, German, and English. Significant is the Award that ASME, the American Society of Mechanical Engineers, gave him as a recipient for Honorary Membership in 1937 (ASME 1937), during a period of great international tensions before the Second World War.

Today, he is still honoured, his name having been bestowed upon technical schools and even streets in several Italian cities, particularly in Rome and Terni.

Several biographies have been written on Lorenzo Allievi from several viewpoints and at different dates, such as (Angelini 1992; Anonimus 1952; Marchetti 1941; Enciclopedia Italiana 1960; Marzolo 1942; Evangelisti 1956; Roger 1995; Roger Allievi 1980).

2 List of Main Works

Lorenzo Allievi published few works, since his primary activity was in Industrial Management. The most important ones, listed in the references with bibliographical data, are:

Fig. 4 Lorenzo Allievi with his grandchild AnneMarie in Rome during celebration of her first communion on 9 March 1929 (Courtesy of Mirta Lancellotti)

- Cinematica della biella piana (Kinematics of Planar Couplers), published in 1895.
- Teoria del colpo d'ariete (Theory of Water Hammer), first published in 1902 and then in several other more complete publications up to 1936.

3 Review of Main Works on Mechanism Design

In this chapter, the focus is on Mechanism Design, and therefore we will only address Allievi's book on Kinematics of Planar Couplers, whereas the presentation and historical significance of his work on the Water Hammer is celebrated in other

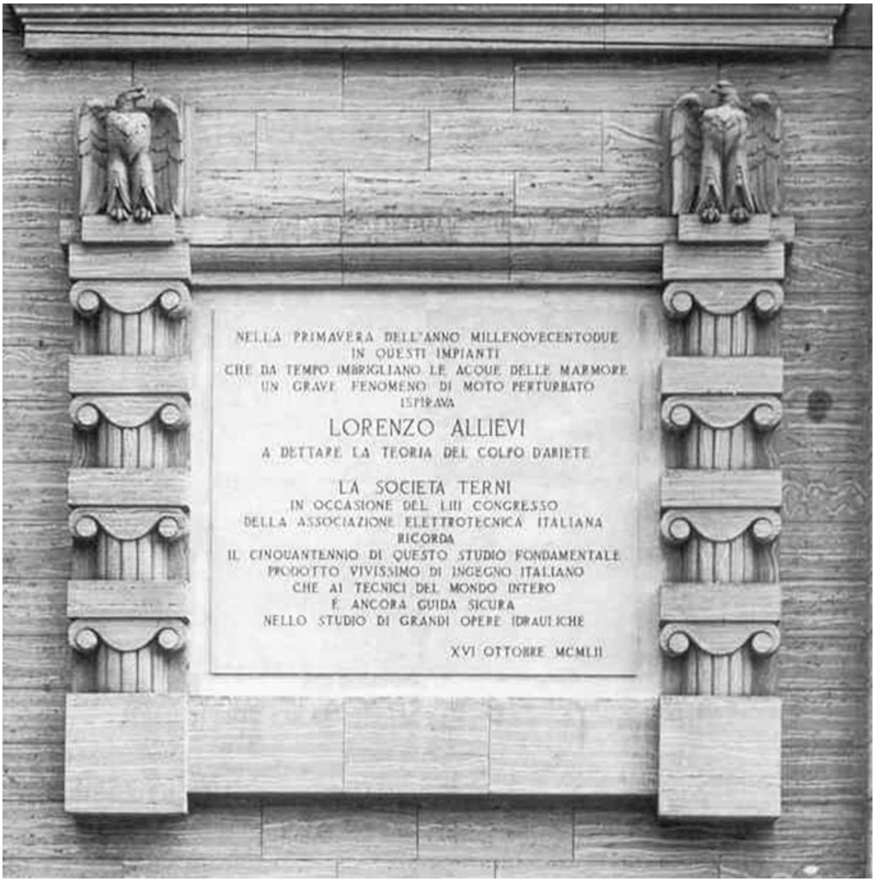
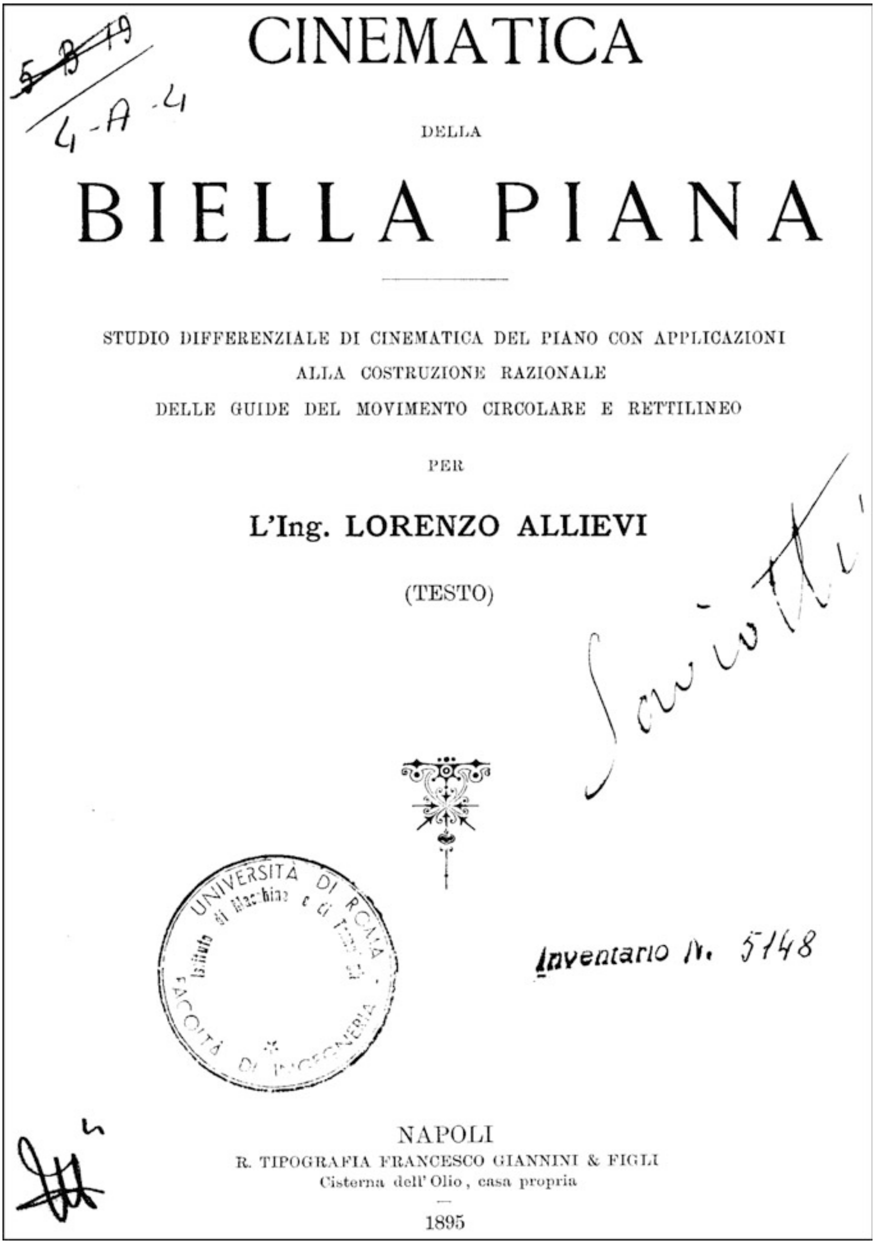


Fig. 5 The marble plaque acknowledging Allievi's contributions to the water hammer at Papigno plant in Terni

specific publications on the History of Hydraulic Engineering, like for example in (Anderson 2000).

Allievi wrote the treatise 'Cinematica della Biella Piana' (translated as Kinematics of Planar Couplers), Fig. 6, in Rome in 1892, most likely as a consequence of his experience in Germany, but he only published it in Naples in 1895 after he had already left his academic position. In several of Allievi's biographies, this treatise is considered to be a minor work and is often not even cited.

The treatise (Allievi 1895) is presented as a survey of Kinematics of planar motion as applied to mechanism design with a specific reference to the works (Burmester 1888 a,b) and (Schoenflies 1886) , as well as an original contribution by Allievi himself. Allievi refers to Burmester's book with the date 1886 (instead of 1888), since he probably got an early edition of the book during his stay in Germany.



CINEMATICA

DELLA

BIELLA PIANA

STUDIO DIFFERENZIALE DI CINEMATICA DEL PIANO CON APPLICAZIONI
ALLA COSTRUZIONE RAZIONALE
DELLE GUIDE DEL MOVIMENTO CIRCOLARE E RETTILINEO

PER

L'Ing. LORENZO ALLIEVI

(TESTO)

NAPOLI
R. TIPOGRAFIA FRANCESCO GIANNINI & FIGLI
Cisterna dell'Olio, casa propria

1895

Fig. 6 Title page of treatise "Cinematica della biella piana" by Lorenzo Allievi as published in 1895

The treatise by Allievi is organized into seven chapters: the first five chapters introduce a general theory and the last two chapters are related to the application of the theory in design solutions of mechanisms. In the preface, Allievi stresses the novelty of his work, both with theoretical arguments and design applications for a rational classification of mechanisms for planar motion and particularly for approximate straight-line and circular guides.

In the Introduction, a survey is presented on the correlation between points and lines as generators of geometric loci in planar motion. Characteristics of coupler curves are analyzed in terms of singularities through a mathematical characterization from Differential Geometry and a graphical characterization from Descriptive Geometry. This systematic analysis gives a complete classification of stationary singularities in coupler point trajectory that are called cusps (cuspidi in Italian), inflections (flessi in Italian), cuspidates (cuspidazioni in Italian, which are arcs due to p cusps with infinite curvature or very short cusps), undulations (ondulazioni in Italian, which are due to q inflections with long inflected trajectory or with zero curvature), falcates (falcate in Italian for the sickle shape, which are due to p = q as cusps with finite curvature and concavity of trajectory branches that are oriented in the same direction), and their iper-shapes as a function of the order p of cusp and degree q of inflection, as well as a function of their generation and shape. This classification is clearly summarized in the Table shown in Fig. 7. This classification is still a novel way to classify mechanisms in a very elegant and general way for planar mechanisms.

In the first chapter, there is a survey of theories on trajectory curvature; the circles of inflections and cusps are introduced; and an expression for curvature analysis is derived from a quadratic transformation that can be useful for a new synthetic classification of mechanisms for trajectory generation. Formulations are presented in simple expressions all throughout the treatise by means of synthetic methods that nicely mix approaches from Analytical Geometry and Descriptive Geometry.

Although the treatise is directed to four-bar linkages, Allievi approaches the generality of planar motion by also considering mechanisms that can be derived from four-bar linkages when their fixed and mobile joints are constrained on suitable trajectories by modelling different planar kinematic chains. Besides the common revolute and prismatic joints, he defined as head-cross (testa-croce in Italian) a joint with straight-line mobility when it is connected to a fixed joint that is located at infinity and as link-block (glifo in Italian) a joint whose center of motion is at infinity. He identifies six families of elementary mechanisms that are the basis of the study and are represented in Fig. 8, reproducing Figs. 10–13 of the treatise, namely four-bar linkages, slider-crank mechanisms, crank-slider mechanisms, slide-cross-head mechanisms, cross-sliders mechanisms, and the so-called Oldham Joint.

For each mechanism type, a simple graphical procedure is outlined to determine the circles of inflections and cusps, which are useful for computing the curvature of any point of the mobile plane through the Euler-Savary equation.

The second chapter deals with Kinematics of two infinitesimal movements. A calculus of the curvature variation gives a mathematical characterization of the

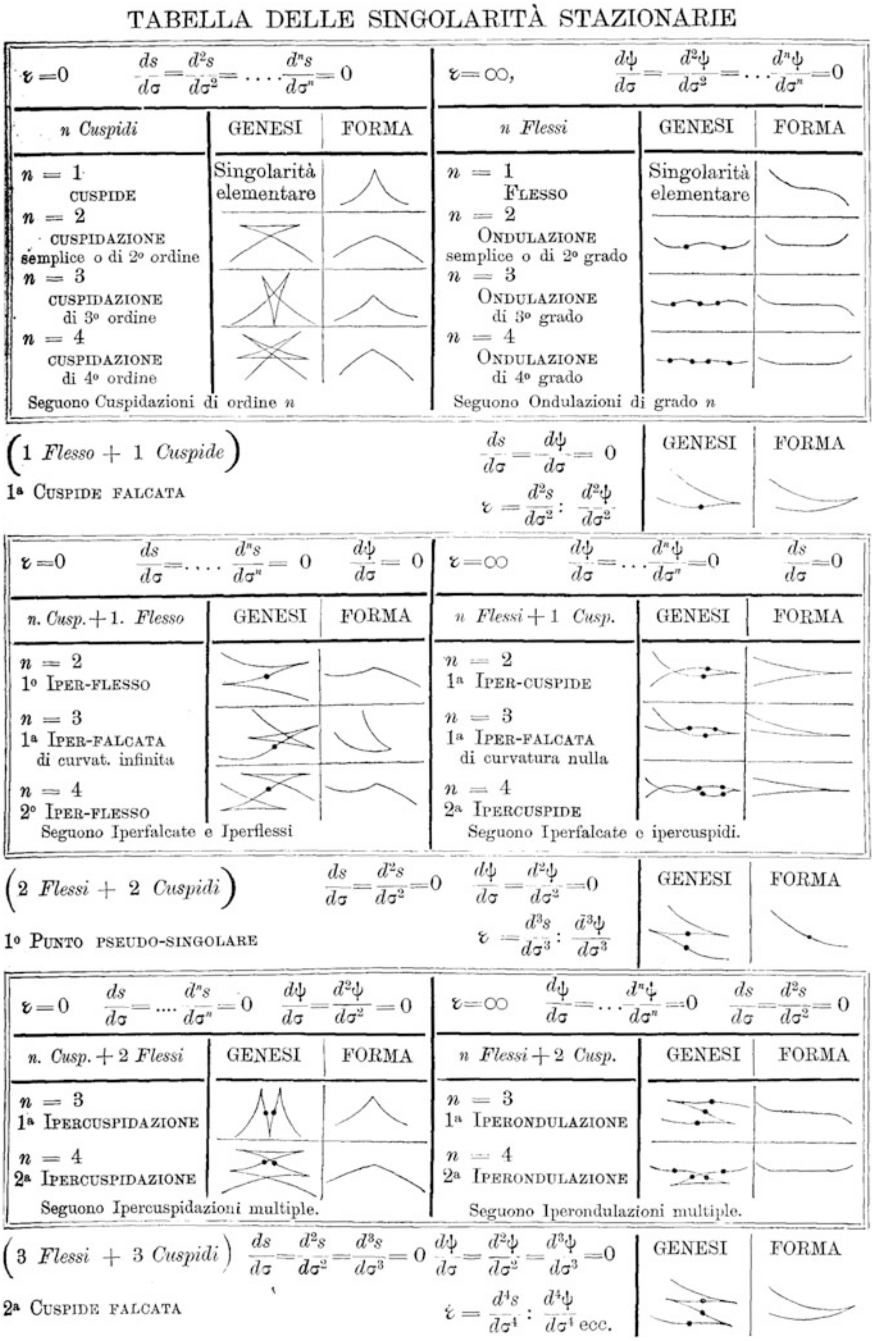


TABELLA DELLE SINGOLARITÀ STAZIONARIE

$\varepsilon = 0 \quad \frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = \dots \frac{d^ns}{d\sigma^n} = 0$

n Cuspidi	GENESI	FORMA
$n = 1$ CUSPIDE	Singolarità elementare	
$n = 2$ CUSPIDAZIONE semplice o di 2° ordine		
$n = 3$ CUSPIDAZIONE di 3° ordine		
$n = 4$ CUSPIDAZIONE di 4° ordine		
Seguono Cuspidazioni di ordine n		

$\varepsilon = \infty, \quad \frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = \dots \frac{d^n\psi}{d\sigma^n} = 0$

n Flessi	GENESI	FORMA
$n = 1$ FLESSO	Singolarità elementare	
$n = 2$ ONDULAZIONE semplice o di 2° grado		
$n = 3$ ONDULAZIONE di 3° grado		
$n = 4$ ONDULAZIONE di 4° grado		
Seguono Ondulazioni di grado n		

(1 *Flesso* + 1 *Cuspide*)

1ª CUSPIDE FALCATA

$\frac{ds}{d\sigma} = \frac{d\psi}{d\sigma} = 0 \qquad \varepsilon = \frac{d^2s}{d\sigma^2} : \frac{d^2\psi}{d\sigma^2}$

GENESI FORMA

$\varepsilon = 0 \quad \frac{ds}{d\sigma} = \dots \frac{d^ns}{d\sigma^n} = 0 \quad \frac{d\psi}{d\sigma} = 0$

n. Cusp. + 1. *Flesso*	GENESI	FORMA
$n = 2$ 1° IPER-FLESSO		
$n = 3$ 1ª IPER-FALCATA di curvat. infinita		
$n = 4$ 2° IPER-FLESSO		
Seguono Iperfalcate e Iperflessi		

$\varepsilon = \infty \quad \frac{d\psi}{d\sigma} = \dots \frac{d^n\psi}{d\sigma^n} = 0 \quad \frac{ds}{d\sigma} = 0$

n Flessi + 1 *Cusp.*	GENESI	FORMA
$n = 2$ 1ª IPER-CUSPIDE		
$n = 3$ 1ª IPER-FALCATA di curvatura nulla		
$n = 4$ 2ª IPERCUSPIDE		
Seguono Iperfalcate e ipercuspidi.		

(2 *Flessi* + 2 *Cuspidi*)

1° PUNTO PSEUDO-SINGOLARE

$\frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = 0 \quad \frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = 0 \qquad \varepsilon = \frac{d^3s}{d\sigma^3} : \frac{d^3\psi}{d\sigma^3}$

GENESI FORMA

$\varepsilon = 0 \quad \frac{ds}{d\sigma} = \dots \frac{d^ns}{d\sigma^n} = 0 \quad \frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = 0$

n. Cusp. + 2 *Flessi*	GENESI	FORMA
$n = 3$ 1ª IPERCUSPIDAZIONE		
$n = 4$ 2ª IPERCUSPIDAZIONE		
Seguono Ipercuspidazioni multiple.		

$\varepsilon = \infty \quad \frac{d\psi}{d\sigma} = \dots \frac{d^n\psi}{d\sigma^n} = 0 \quad \frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = 0$

n Flessi + 2 *Cusp.*	GENESI	FORMA
$n = 3$ 1ª IPERONDULAZIONE		
$n = 4$ 2ª IPERONDULAZIONE		
Seguono Iperondulazioni multiple.		

(3 *Flessi* + 3 *Cuspidi*)

2ª CUSPIDE FALCATA

$\frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = \frac{d^3s}{d\sigma^3} = 0 \quad \frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = \frac{d^3\psi}{d\sigma^3} = 0 \qquad \varepsilon = \frac{d^4s}{d\sigma^4} : \frac{d^4\psi}{d\sigma^4}$ ecc.

GENESI FORMA

Fig. 7 Table summarizing stationary singularities in planar coupler curves from Allievi's treatise

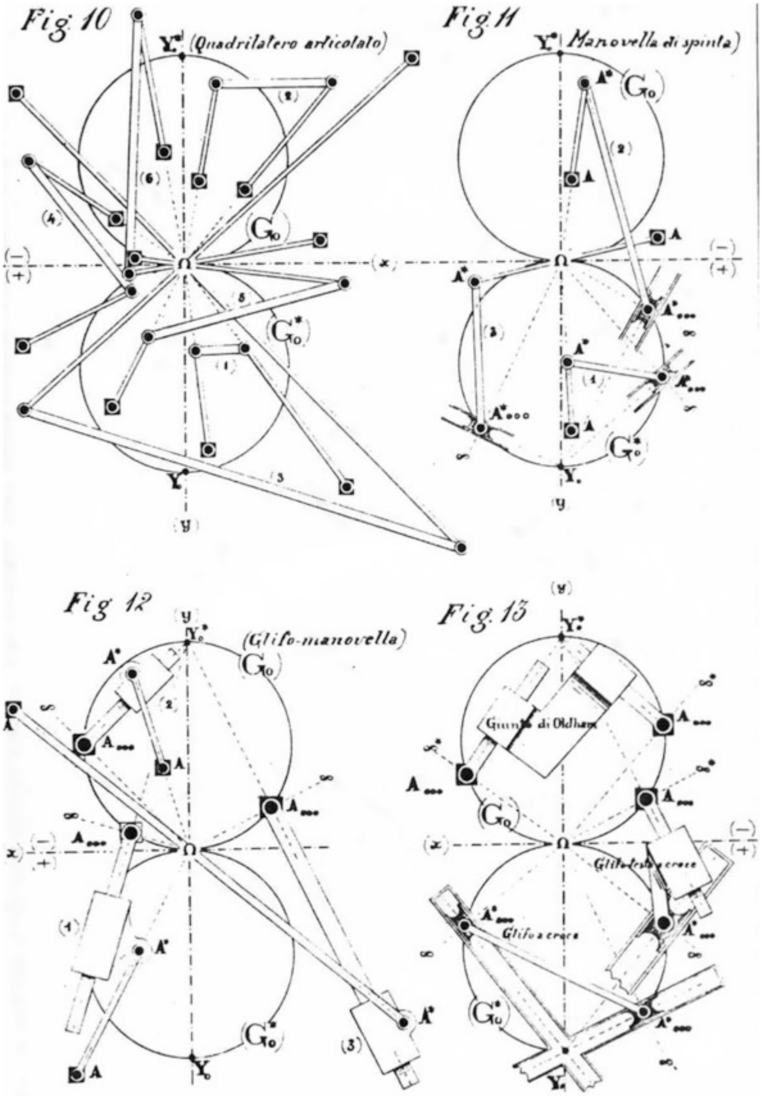


Fig. 8 Six elementary mechanisms for generation of planar coupler curves from Figs. 10 to 13 in Allievi's treatise

circles of inflections and cusps as loci of trajectory points with stationary curvature and of curvature centers of trajectory points with stationary curvature, respectively. The example in Fig. 9, reproducing Fig. 27 of the treatise, graphically illustrates such a characterization.

The loci of the points with stationary curvature in a fixed plane and a mobile plane can be expressed as the cubics in Eq. (12) of the treatise written as

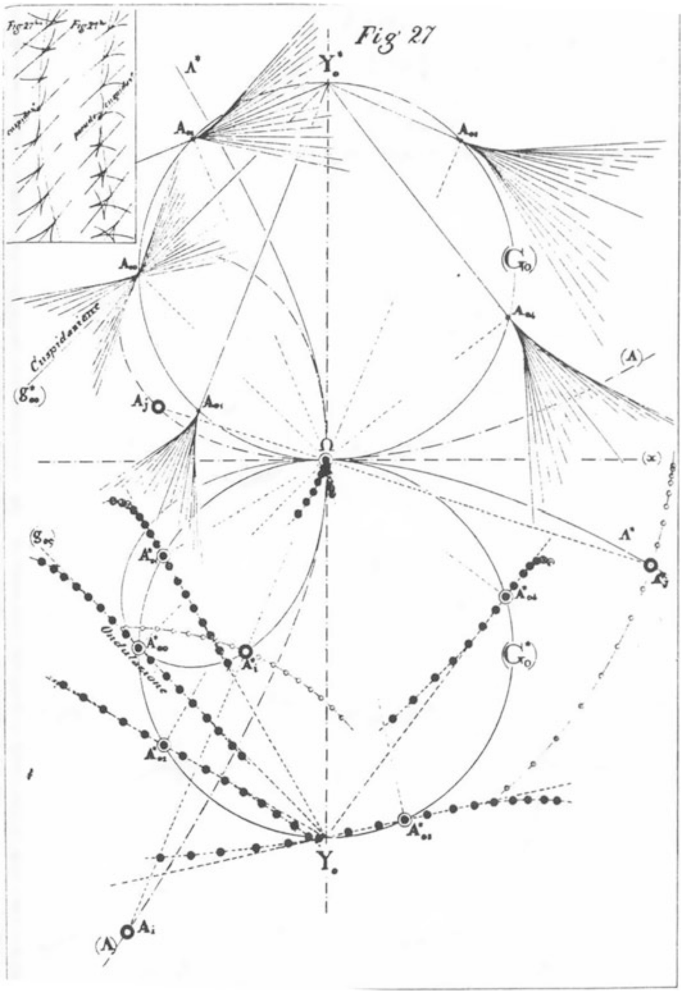


Fig. 9 Graphical representation of characteristics of points of inflection and cusp circles, from Fig. 27 in Allievi's treatise

$$
\begin{aligned}
\left(x^2+y^2\right)\left(\frac{1}{Ry}+\frac{1}{Sx}\right) &= 1 \\
\left(x^{*2}+y^{*2}\right)\left(\frac{1}{Ry^*}+\frac{1}{Sx^*}\right) &= 1
\end{aligned}
\tag{1}
$$

in which R and S, R* and S* are coefficients representing diameters of osculating circles in the acnode of the cubic, as shown in Fig. 10, which reproduces Fig. 22 of the treatise.

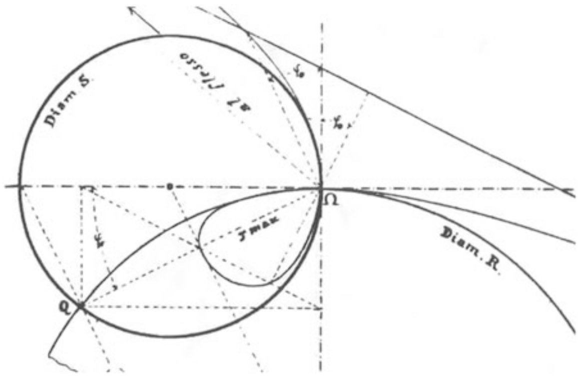


Fig. 10 Graphical interpretations of coefficients in the cubic of stationary curvature, from Fig. 22 in Allievi's treatise

In addition, manipulating the cubic expressions of these loci in Eq. (1), Allievi gives a proof and lemmas for kinematic characterizations of undulations and cuspidates that are correlated to the continuous motion, explaining: 'the loci of successive points of undulations and cuspidates are the loci of the successive intersections among the inflection circles and cusp circles, respectively, for successive motions' (pg. 43). Those mathematical arguments finally led to graphical procedures of a generation of the loci 'by means of the use of squares only' (pg. 48), as outlined in the construction of Fig. 17 of the treatise.

In the third chapter, Allievi extended the study to the case for three infinitesimal motions in order to characterize so-called pseudo-undulations and pseudo-cuspidates that are points with stationary curvature with multiple contacts with osculating circles. This characterization is obtained by discussing Eq. (20) up to its form (23) in the treatise, which are additional manipulations of Eq. (1), reproducing Eq. (12) of the treatise. In particular, in this short chapter, Allievi has shortened the original heavy treatment of instantaneous Kinematics by Burmester, extended by Schoenflies, to the case of continuous motion for determining the four cyclic points. In fact, Allievi outlines a handy procedure for graphical constructions by using analytic differentiation of (r–r*) with r and r* radii of polhodes, leading to Eq. (20) of the treatise.

In chapter four, degeneration of the loci of points with stationary curvature is discussed by using the cubic expression in Eq. (1) (Eq. (12) in the treatise) from chapter two. Degenerations into circles and straight-lines are analyzed through conditions on the cubic coefficients and corresponding kinematic relations for the motions they represent. Five classes of degenerated mechanisms are identified, as reported below.

In the first class, for $1/S = 0$, each cubic becomes a circle and a straight-line giving three series of mechanisms depending only on the location of their joints. In the first series, the relative location line of fixed joints gives only four-bar linkages, the cranks being convergent, crossed, or diverging. These mechanisms can show pseudo-undulations and pseudo-cuspidates or double undulations and double cuspidates. In the second series, with joints on circle and line, mechanism types are related to crack position giving four-bar linkages with two followers and slider-crank mechanisms, as shown in Fig. 32 of the treatise, with the possibility of having pseudo-undulations or pseudo-cuspidates expressed by a simplified expression of the cubic in the form of Eq. (31). The third series, with joints on a line only, is composed of mechanisms of the previous series at dead-lock configurations.

In the second class, with 1/S = 1/R = 0, a duality of series is identified as corresponding to the case in which a cubic degenerates into either the inflection circle or the cusp circle with a line joining their centers. In this class, there is a great variety of mechanisms with symmetric and asymmetric motion capability. Those mechanisms with symmetric motions are related to the possibility of having symmetrical motions of cyclic and paracyclic types. All the mechanisms can show several types of stationary singularities that are discussed with mathematical and graphical characterizations by using algebraic manipulations of Eq. (20) and illustrations from Figs. 34 to 45, which are then summarized in a synoptic view from pg. 92 to pg. 98 of the treatise.

A third class is identified by the condition 1/R = 0 or 1/R* = 0, which corresponds to the case in which one of the loci does not degenerate and the corresponding mechanism types are characterized as having pseudo-cuspidates and pseudo-undulations in the coupler curves. Those mechanisms are illustrated with their typical structures in Figs. 46 to 49 of the treatise.

In the fifth chapter, a fourth class of mechanism is introduced as deduced from degeneracy of the cubics due to the location of the instantaneous center of rotation at infinity. Therefore, possible mechanisms like four-bar linkages and slider-crank mechanisms are configured with parallel cranks, as shown in Figs. 52–54 in the treatise. The corresponding coupler curves are characterized by having iper-falcates and iper-undulations.

In the last two chapters, detailed analyses are reported for mechanisms with coupler curves for approximate circular and straight-line guides, respectively. The discussion is also focused on practical design with constraints using the proposed classification in classes and series. Practical solutions for design with very detailed graphical representations are shown in Figs. 56 to 107, referring to the last part of the treatise.

An example of the rich graphical details is shown in Fig. 11, which reproduces Fig. 89 of the treatise for a case of straight-line guide mechanism in the second class as an example in which the coupler curve of point Ω shows a falcate.

In particular, at the beginning of chapter six, the mathematical structure of synthesis problems is formulated and discussed in terms of available equations and conditions in order to make it possible to determine the eight design parameters that correspond to the coordinates of the four joints of a mechanism for planar motion. Allievi outlines that, in general, it is possible to design guide mechanisms for point trajectory up to the fourth order, and in the case of guiding two points, up to the third order so that the variety of stationary singularities in the proposed Table in Fig. 7 can be used to obtain suitable coupler curves.

As an example of the practical design-oriented approach of Allievi's treatise, the case of the Watt mechanism is shown in Fig. 12, reproducing Figs. 105–107 of the treatise.

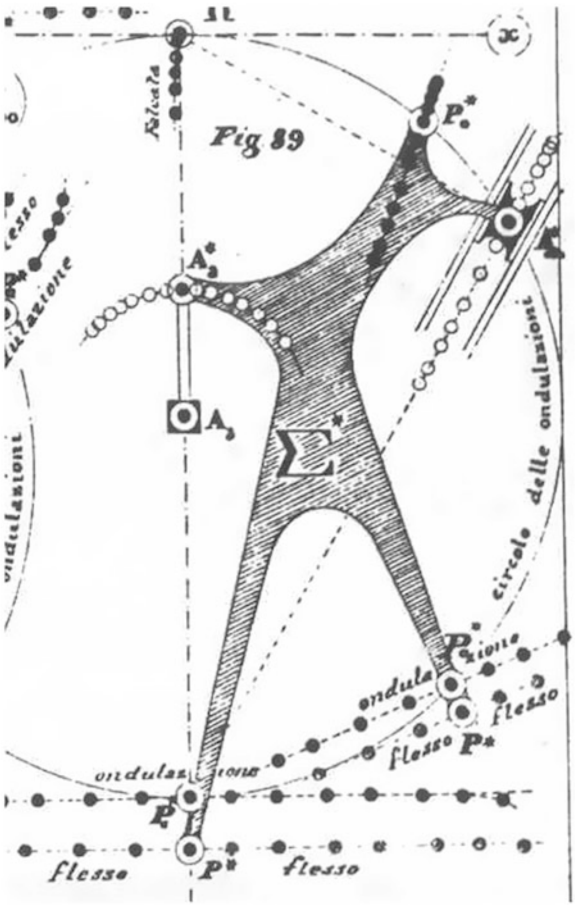


Fig. 11 An example of detailed design solutions for guide mechanisms from Fig. 89 in Allievi's treatise

The Watt mechanism of Fig. 106 is a mechanism whose coupler curve is used with three inflections coinciding at a point to give pseudo-undulations. The three inflections can be separated by means of enlarging or shortening the cranks, as stated by a proposed mathematical characterization of the corresponding mechanism series, and therefore it is possible to obtain an excursion of the approximate straight-line trajectory as long as required for a design application. In particular, considering Fig. 105 in Fig. 12 and referring to the table in Fig. 7, Allievi deduces the following proposition: 'once the inflections are separated, if the cranks are fixed with length $(m^2 + n^2)^{1/2,}$ the two extremity inflections are located at a distance $\pm$ n from the central inflection, by being m the crank length and 4n the distance between them' (pg. 150). Similar considerations can be applied to a slider-crank mechanism of the fourth class to obtain the solution in Fig. 107 of the treatise as an efficient alternative to the Watt mechanism in Fig. 106, as shown in this Chapter's Fig. 12.

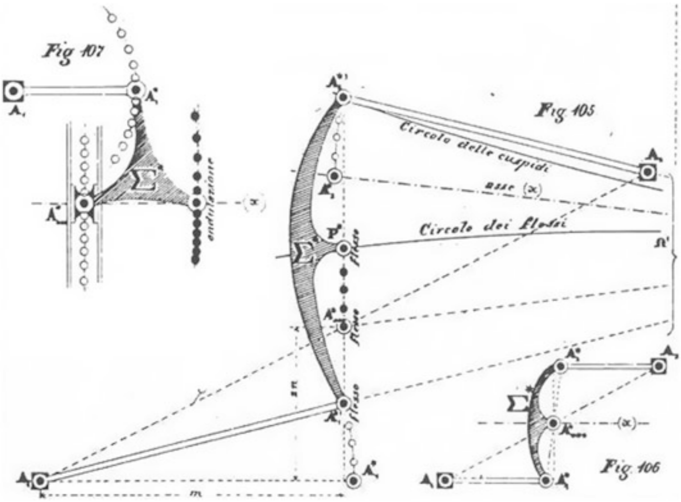


Fig. 12 Schemes and solutions for a practical approach to designing an approximate *straight-line* mechanism with a *Watt coupler curve* from Allievi's treatise

4 Modern Significance and Circulation

The work of Allievi can still be considered of modern significance and even of practical interest, both for investigation and application in Mechanism Design. In fact, the treatise on Kinematics of Planar Couplers is still known worldwide nowadays and is cited in research reports as a background or inspirational source.

After a period of oblivion, the work by Allievi has come to be considered some of the most brilliant results of the vigorous activity of Italian kinematicians in the 19th century, as pointed out in Ceccarelli (2000).

Just after its publication, the work circulated mainly within Italian circles, largely because of the language barrier. But it was soon forgotten for a long period, at least as an explicit reference. However, it was subsequently rediscovered, mainly because of international studies, and came once again to be appreciated as a significant contribution.

Since the 1940s, it has been considered as a basic reference, mainly in the German literature. For example, Richard De Jonge cited 'Cinematica della biella piana' with great emphasis in De Jonge (1940, 1943), and thus brought this reference to the attention of the U.S.A. As a result, Allievi's work was reconsidered and circulated all around the world, as indicated for example by the references to it in Hain (1967), Hunt (1978) and Nieto (1978).

The importance of Allievi's treatment has been recognized in its analytical developments, mainly for the derivation of the Burmester points in four-bar mechanisms, both from an historical viewpoint, as in (Nolle 1974), and as technical modern formulation in (Freudenstein and Sandor 1961). The work has garnered great attention and stimulated further investigations into the stationary points of the coupler points of coupler curves, even though it has not been explicitly cited.

Nowadays, 'Cinematica della biella piana' is still referenced from an historical viewpoint, as for example in (Angeles 1997, Ceccarelli 1999, 2001 and 2004). Emblematic of this renewed interest is the fact that it led to an anastatic reproduction of Allievi's treatise by CFR (FIAT Research Center) in 1999, (CFR 1999), an indication of the significance of Allievi's approach even in the modern field of industrial applications.

The work of Allievi has been influential in the development towards a modern discipline of Mechanism Design, as recognized in the edited book (Erdman 1993) celebrating Professor Freudenstein. Even today, it is considered an inspiration, as indicated in textbooks, for example, (McCharty 2000), in journal papers for example (Pennock 2008), and conference events, for example (Chicurel 2011).

5 Conclusions

Lorenzo Allievi was an engineering practitioner with a strong formational background in MMS and a life-long interest in the theory of mechanical engineering aspects. Allievi's book on Kinematics of Planar Couplers is a milestone work in modern Mechanism Kinematics with its rigorous theory, complete with applications in practical mechanism designs.

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Leonid Assur (1878–1920)

Alexander Evgrafov and Denis Kozlikin

Abstract Leonid Assur solved a great challenge. He devised a classification system of planar linkages with lower pairs based on the theory of mechanisms. This system turned out to be remarkably productive, as it described not only all of the hinge mechanisms known at that time, but also showed how to form the new ones. After Assur's death, his ideas were further developed in the works of his fellow Russian and foreign researchers.

1 Biographical Notes

Leonid Vladimirovich Assur was born on March 31, 1878 in Rybinsk (Yaroslavl province, Russian Empire). Leonid's father, Vladimir Fyodorovich Assur, worked as a customs officer at the Railway Administration. Leonid had two younger brothers: Andrey (born in 1881) and Vladimir (born in 1883). His mother, Lyudmila Andreevna, died when Leonid was seven years old. After his mother's death, his father sent the boy to live with his aunt in Vezenberg (Estonia). Another aunt, the older sister of Leonid's father, Adel Fyodorovna Assur, also lived in this house. She was a gymnasium teacher and she gave Leonid a primary school education at home. Leonid spent seven years in Vezenberg, after which he entered straightway into the fourth form of the gymnasium in Warsaw in 1892. In 1895 Leonid moved back with his father, who lived in Grodno in those days. Being in Grodno, Leonid (Fig. 1) entered the seventh form of the gymnasium and graduated

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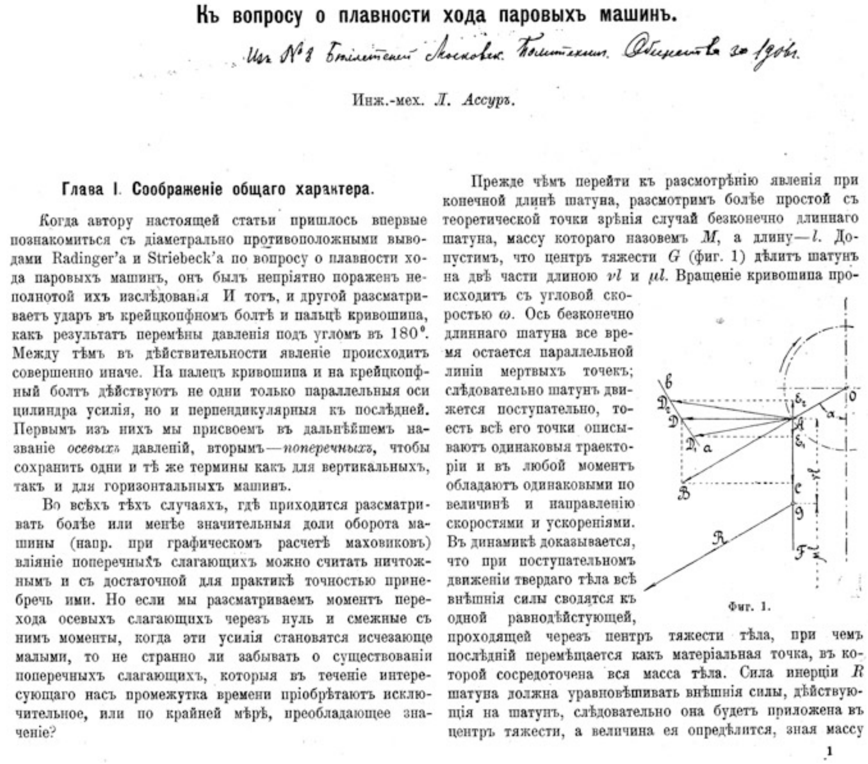
M. Ceccarelli (ed.), *Distinguished Figures in Mechanism and Machine Science*, History of Mechanism and Machine Science 26, DOI: 10.1007/978-94-017-8947-9_2,

Fig. 1 L. Assur—in gymnasium (This photograph is from Ivan Assur's family archive. A copy of the photograph was given to one of the article's authors. Ivan Vladimirovich Assur (1929–2006) is the son of Leonid Vladimirovich Assur's younger brother, Vladimir Vladimirovich Assur. The photograph was published for the first time in Scientific Review The theory of mechanisms and machines, 2004, No. 1(3). Vol. 2.)

cum laude in 1897. By that time Leonid had a good command of Latin, Greek, French and German. Later he learned English. Apart from his genius for foreign languages and exact sciences, Leonid inherited a talent for music: he played piano and wrote original compositions (Biographical data was taken from Artobolevski and Bogolyubov (1971).)

In the autumn of 1897 Leonid moved to Moscow where he entered the Department of Mathematics of the Physic-Mathematical faculty of Moscow University. Teaching mathematics at Moscow University was a very highly sought-after professional position. Professor N. E. Zhukovsky (1847–1921) was teaching mechanics at the University at that same time. The vast sphere of Zhukovsky's academic interests also covered the theory of mechanisms, to which he had dedicated several of his works. Zhukovsky had a great influence on Assur. Some of Zhukovsky's ideas had become an impetus for Assur's analysis of topological issues.

In 1901 Leonid Assur graduated from Moscow University. At the recommendation of Zhukovsky, Assur had immediately entered the second course of the Department of Mechanics of Moscow Technical School (nowadays—Moscow State Technical University, named after N. E. Bauman). Theoretical mechanics was taught by N. E. Zhukovsky. The course of applied mechanics was worked out and taught by N. I. Mertsalov (1866—1948). Mertsalov's academic interests included the study of hinge mechanisms. He explained engineering mechanics on



Къ вопросу о плавности хода паровыхъ машинъ.

Инж.-мех. *Л. Ассуръ.*

Глава I. Соображеніе общаго характера.

Когда автору настоящей статьи пришлось впервые познакомиться съ діаметрально противоположными выводами Radinger'а и Striebeck'а по вопросу о плавности хода паровыхъ машинъ, онъ былъ непріятно пораженъ неполнотой ихъ изслѣдованія. И тотъ, и другой разсматриваетъ ударъ въ крейцкопфномъ болтѣ и пальцѣ кривошипа, какъ результатъ перемѣны давленія подъ угломъ въ 180°. Между тѣмъ въ дѣйствительности явленіе происходитъ совершенно иначе. На палецъ кривошипа и на крейцкопфный болтъ дѣйствуютъ не одни только параллельныя оси цилиндра усилія, но и перпендикулярныя къ послѣдней. Первымъ изъ нихъ мы присвоемъ въ дальнѣйшемъ названіе *осевыхъ* давленій, вторымъ—*поперечныхъ*, чтобы сохранить одни и тѣ же термины какъ для вертикальныхъ, такъ и для горизонтальныхъ машинъ.

Во всѣхъ тѣхъ случаяхъ, гдѣ приходится разсматривать болѣе или менѣе значительныя доли оборота машины (напр. при графическомъ расчетѣ маховиковъ) вліяніе поперечныхъ слагающихъ можно считать ничтожнымъ и съ достаточной для практикѣ точностью пренебречь ими. Но если мы разсматриваемъ моментъ перехода осевыхъ слагающихъ черезъ нуль и смежные съ нимъ моменты, когда эти усилія становятся исчезающе малыми, то не странно ли забывать о существованіи поперечныхъ слагающихъ, которыя въ теченіе интересующаго насъ промежутка времени пріобрѣтаютъ исключительное, или по крайней мѣрѣ, преобладающее значеніе?

Прежде чѣмъ перейти къ разсмотрѣнію явленія при конечной длинѣ шатуна, разсмотримъ болѣе простой съ теоретической точки зрѣнія случай безконечно длиннаго шатуна, массу котораго назовемъ M, а длину—l. Допустимъ, что центръ тяжести G (фиг. 1) дѣлитъ шатунъ на двѣ части длиною νl и μl. Вращеніе кривошипа происходитъ съ угловой скоростью ω. Ось безконечно длиннаго шатуна все время остается параллельной линіи мертвыхъ точекъ; слѣдовательно шатунъ движется поступательно, то-есть всѣ его точки описываютъ одинаковыя траекторіи и въ любой моментъ обладаютъ одинаковыми по величинѣ и направленію скоростями и ускореніями. Въ динамикѣ доказывается, что при поступательномъ движеніи твердаго тѣла всѣ внѣшнія силы сводятся къ одной равнодѣйстующей, проходящей черезъ центръ тяжести тѣла, при чемъ послѣдній перемѣщается какъ матеріальная точка, въ которой сосредоточена вся масса тѣла. Сила инерціи R шатуна должна уравновѣшивать внѣшнія силы, дѣйствующія на шатунъ, слѣдовательно она будетъ приложена въ центръ тяжести, а величина ея опредѣлится, зная массу

Фиг. 1.

1

Fig. 2 The first page of L. V. Assur's first published work «about the question of the steam machine's smoothness of movement»

the basis of application of geometrical methods such as analysis and synthesis. He also gave the solutions to several specific problems of the synthesis of hinge mechanisms.

During that time L. V. Assur was interested in the issues of the dynamics of machines and in the problems of kinematics and kinetostatics of hinge mechanisms. In 1906 he had published his first work «About the question of the steam machine's smoothness of movement» (Fig. 2) (The Proceedings of Polytechnical Society that took place in the Empire Technical School, No. 8, pp. 341–352). In the same year L. V. Assur graduated from the Moscow Technical School, entitling him to use the moniker of "mechanical engineer". Having been unable to find a job in Moscow, he moved to the capital—Saint Petersburg.

Most Russian technical schools were located in Saint Petersburg. Nevertheless, L. V. Assur couldn't get a job as a teacher at first, and he subsequently became employed as an assistant to the head of the urban public bridge-construction workshops. He was engaged in construction planning and material support for bridge construction, working on the Alarchin, Panteleymonovsky, and Mikhailovsky Bridges.

In 1907 the Board of Academics of the Saint Petersburg State Institute had announced admission for studies at the Department of Mechanics for the first time. A job opportunity having opened up, L. V. Assur soon received an offer of employment at the Institute as a teacher of mechanical drawing in the Department of Mechanics.

In 1908 L. V. Assur was charged with conducting exercises in theoretical mechanics and applied mechanics. Lectures on applied mechanics were read by Professor V. L. Kirpichev (1845–1913), and lectures on theoretical mechanics were read by Professor I. V. Meshchersky (1859–1935). The lectures by I. V. Meshchersky were closely related to the sub-disciplines of applied mechanics, which students studied later on. Since 1907 I. V. Meshchersky had been composing tasks on theoretical mechanics that had concrete technical content. Colleagues of I. V. Meshchersky were also involved in this work, including L. V. Assur. The resulting book featuring different tasks met with exceptional success: it was eventually republished 50 times (the 50th edition in 2010).

V. L. Kirpichev had organized a scientific-technical circle at the Polytechnical University that brought young lecturers together. L. V. Assur had become a regular member of that scientific circle (Assur 1909a). In 1908 at one of the circle meetings Assur delivered his paper «Analogues of accelerations and their appliance to dynamic analysis of the planar linkages» (Assur 1909b). In 1909 Assur presented his second paper, a logical sequel to the first one—«Basic attributes of analogues of accelerations in analytical presentation». Full texts of these papers were published in the «Proceedings of Saint Petersburg Polytechnical Institute».

In these works, L. V. Assur outlined his theory of the analogues of accelerations. He came to a conclusion that «acceleration is a particular case of a more general concept—the analogue of acceleration. Therefore, every theorem derived for analogues of accelerations implies a corresponding theorem for accelerations». Assur had pointed out the possibilities of application of his theory. Among other factors, he had devised the foundations of the graphical analysis of mechanisms with several degrees of freedom. This problem has not only theoretical but also practical importance, especially in our day, and it was Assur who first raised this problem as well as finding the solution to it.

In 1911 Assur took a break from his work on the theory of analogues of accelerations. He had published two text-books for students, one right after the other: «Velocity and acceleration vector diagrams of planar mechanisms» and «Graphical methods for determination of the moment of inertia of a flywheel» (Assur and Roerich 1911). The Assur family picture shown above was likely taken in the same year (Fig. 3).

At the same time he passed examinations and began to work on a doctoral dissertation that had become his life's work: «Research of planar linkages with lower pairs on the basis of their structure and classification».

In 1914 in the «Proceedings of Saint Petersburg Polytechnical Institute» the first part of his work was published—«Teaching about normal multi-arm chains and their role in the formation of mechanisms» (Assur 1914a). In 1915 the second part was issued: «Application of the teaching on normal chains to the general theory of mechanisms» (Assur 1914b). The same year Assur went to Moscow

Fig. 3 Family picture (sitting: at *left*—V. F. Assur, at *right*—E. M Assur with son Vsevolod; *standing at right*—L. V. Assur) from the family archive of S. V. Assur—L. V. Assur's grandson. Published for the first time

where he showed his dissertation to N. I. Mertsalov and N. E. Zhukovsky. On February 13th, 1916 at the meeting of the Scientific Council of Saint Petersburg Polytechnical Institute L. V. Assur presented his Ph.D. defense. The official opponents were leading scientists who dealt with the different issues of applied mechanics: professor of Moscow University and Moscow Technical School N. E. Zhukovsky, professor of Kazan University D. N. Zeiliger (1864–1936) and professor of applied mechanics and the dean of the department of mechanics A. A. Radzig (1869–1941). The defense was successful and Assur got a degree of adjunct in the Department of Applied Mechanics. The following picture of L. V. Assur was taken at that time (Fig. 4).

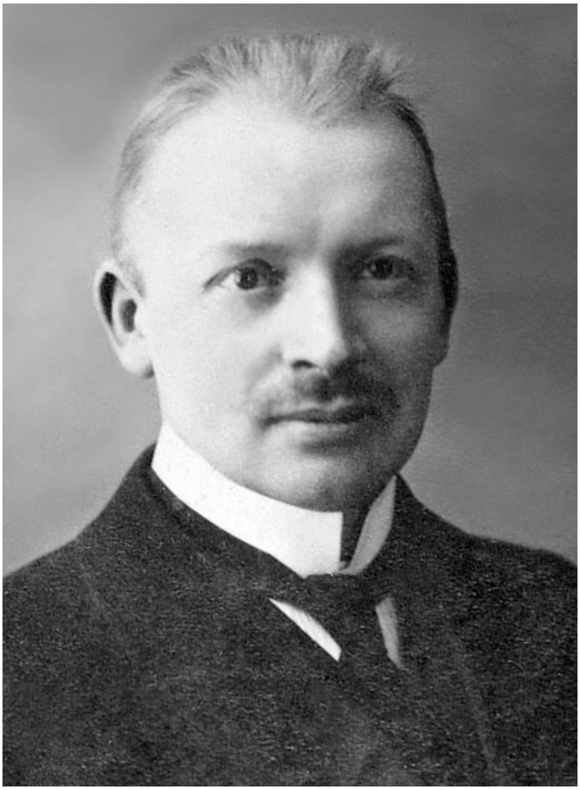


Fig. 4 Photography of L. V. Assur from the family archive of S. V. Assur—L. V. Assur's grandson. Published for the first time

After his Ph.D. defense, Assur couldn't be engaged in scientific work with the same intensity as he had been. In 1914 World War I began. Russia's involvement in the war led in May 1916 to Assur being enlisted to work on the Petrograd Military-Industrial Committee for front assistance. Engineers working on this committee had very high qualification. Assur conducted the project planning for different systems of military assets.

After the Revolution of 1917 and with the beginning of the Civil War, food supplies and provision of necessities had deteriorated significantly. Some lecturers left the city. Assur had to teach at two institutes: at the Polytechnical Institute and the School of Forestry. His teaching load had increased greatly, taking up time that could have been spent on scientific work. As time went on, Assur's health was ruined. In June 1919 Assur went to Voronezh where his family lived. He planned to return to Saint Petersburg (called Petrograd in those days) by the beginning of the new semester, but owing to the conditions caused by the civil war, he didn't get a chance to do that. Assur's health never improved. In May 1920 he went into the hospital, where he had two operations. After the second operation, on May 19th he died without regaining consciousness.

L. V. Assur was married to Elena Mikhailovna Mindrina.[1] They had three children: Olga (1907–1909), Vsevolod (1910–1987) and Elena (1913–2001). Olga died tragically at the age of two. Vsevolod and Elena lived long lives and worked as lecturers. The grandchildren and great grandchildren of L. V. Assur live in Moscow, Saint-Petersburg and Paris.

Assur's manuscripts didn't survive. According to family legend, the manuscripts were bought by a nameless scientist, but the authors of this article were unable to find the proof to substantiate that legend.

2 List of Works

About the question of the steam machine's smoothness of movement 1906.

Analogues of accelerations and their appliance to dynamic analysis of planar linkages 1908 Finished 1909.

Basic attributes of analogues of accelerations in analytical presentation 1909.

Velocity and acceleration vector diagrams of planar mechanisms 1911.

Graphical methods for determination of the moment of inertia of a flywheel (co-authorship with K. E. Roerich) 1911.

Die Methode der characteristischen Kurven als Beitrag zur graphishen Auswertung mehrfacher Integrale 1912.

Research of planar linkages with lower pairs on the basis of their structure and classification:

Part 1. Teaching about normal multi-arm chains and their role in the formation of mechanisms 1914

Part 2. Application of the teaching on normal chains to the general theory of mechanisms 1915.

An addition to the second chapter of the first part 1915.

An addition to the first chapter of the second part 1918.

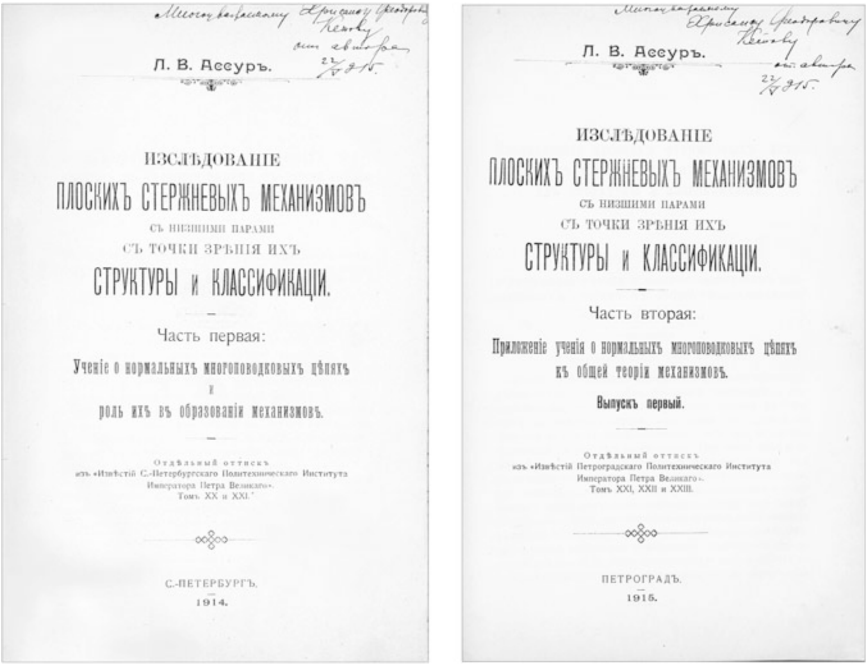
Geometrical construction schemes of some curve lines 1916.

3 A Review of the Treatise by Leonid Assur

Undoubtedly, the work most assuring Assur's place in the history of science is «Research of planar linkages with lower pairs on the basis of their structure and classification» (Fig. 5).

The book consists of two parts: Part 1. Teaching about normal multi-arm chains and their role in the formation of mechanisms (published in 1914); Part 2.

[1] In the monograph by I. I. Artobolevski and A. N. Bogolyubov «L. V. Assur», the surname of Assur's wife is printed as Mindlina by mistake.


Л. В. Ассуръ.

ИЗСЛѢДОВАНІЕ

ПЛОСКИХЪ СТЕРЖНЕВЫХЪ МЕХАНИЗМОВЪ

СЪ НИЗШИМИ ПАРАМИ

СЪ ТОЧКИ ЗРѢНІЯ ИХЪ

СТРУКТУРЫ И КЛАССИФИКАЦІИ.

Часть первая:

Ученіе о нормальныхъ многоповодковыхъ цѣпяхъ

и

роль ихъ въ образованіи механизмовъ.

Отдѣльный оттискъ
изъ «Извѣстій С.-Петербургскаго Политехническаго Института
Императора Петра Великаго».
Томъ XX и XXI.

С.-ПЕТЕРБУРГЪ.
1914.

Л. В. Ассуръ.

ИЗСЛѢДОВАНІЕ

ПЛОСКИХЪ СТЕРЖНЕВЫХЪ МЕХАНИЗМОВЪ

СЪ НИЗШИМИ ПАРАМИ

СЪ ТОЧКИ ЗРѢНІЯ ИХЪ

СТРУКТУРЫ И КЛАССИФИКАЦІИ.

Часть вторая:

Приложеніе ученія о нормальныхъ многоповодковыхъ цѣпяхъ

къ общей теоріи механизмовъ.

Выпускъ первый.

Отдѣльный оттискъ
изъ «Извѣстій Петроградскаго Политехническаго Института
Императора Петра Великаго».
Томъ XXI, XXII и XXIII.

ПЕТРОГРАДЪ.
1915.

Fig. 5 Title pages of the book «research of planar linkages with lower pairs on the basis of their structure and classification», parts 1 and 2, autographed by the author. Published for the first time («To dear Chrisanph F. Ketov from the author, 22/V 915». C. F. Ketov (1887–1948) at the time this book was signed in 1915 was a young professor at Leningrad State Polytechnic Institute (now St. Petersburg State Polytechnic University) and would later become Head of the Department of «Theory of Mechanisms and Machines». The book belongs to the Fundamental Library of SpbSPU.)

Application of the teaching on normal chains to the general theory of mechanisms (published in 1915). Later additions were made to chapter 2 of the first part (1915) and to chapter 1 of the second part (1918).

The first part opens with an introduction in which the author gives a short summary of the systems of classification of mechanisms developed by his predecessors: G. Monge (1746–1818), A. Ampere (1775–1836), Ch. Laboulaye (1813–1886), F. Reuleaux (1829–1905) and some smaller contributions by other researchers. Giving preference to the classification of Reuleaux, Assur notes that it nevertheless does not embrace all the existing practices of creation of new combinations and forms of the time. At the end of the introduction, Assur formulates the problem with the research:

«The only theory which may claim scientific value is that which is in a position to specify the ways toward practice: the concern of science is to specify all that is possible, the concern of practice is to choose the practical from the possible. The author hopes that his work will serve as a contribution promoting a scientific

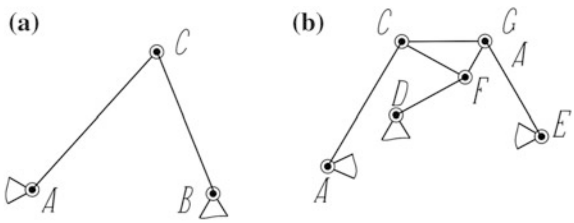


Fig. 6 Two-arm (**a**) and three-arm (**b**) groups

viewing of that area of the theory of mechanisms, which it directly concerns, and that the reader will find in it the aforesaid general scheme».

Chapter 1 is called «Survey of the existing methods of formation of new mechanisms». Assur looks for the method (though obviously does not specify it) through which the questions of the synthesis of mechanisms, their structures and classification are organically related. Knowing the place of a mechanism in the classification, it is possible to select the most convenient method for its calculation. The author examines the works of L. Burmester (1840–1927), F. Reuleaux, A. Ampere, M. Grübler (1851–1935) and others. However, Assur did not find a method which would meet his demands. Therefore he puts forward a problem for working out such a method.

In this chapter, Assur sets out the formulation of his classification. He considers the mechanisms with multi-arm open chains of normal types, correlating their structure to the method of their formation. Assur approaches one of the elementary methods of formation of mechanisms: the Silvester dyads are attached to the existing mechanism (Fig. 6a) (Assur calls them two-arm groups). A new mechanism is formed. A dyad consists of two links and three joints, the degree of freedom equal to zero. In the same position of extreme joints, the central joint (and, accordingly, the two links of a dyad) can occupy two positions (we would call it two ways of linkage now). If all three joints (and two links) are placed in one straight line, the dyad gets into a special position (at present they often call them singular). The method also works when any of the joints are replaced with translational pairs (the author excludes the case of three translational pairs).

Further, Assur increases the number of links in a connected chain (group) by means of his method of arm development. The main condition of the formation of such a chain is its degree of freedom being equal to zero. In this case, the chain is statically determinate. Assur referred to this as a normal type chain.

The method of development of the arm consists of the following. To get a new chain, one of the arms (for example, BC in the Silvester dyad) is replaced with a two-arm link (this is a system of three links: DF, EG and CGF). A three-arm chain of normal type is formed (Fig. 6b). Sequentially and repeatedly joining the three-arm groups, one can form new mechanisms.

Applying the method to three-arm chains, Assur builds a four-arm chain, then a five-arm (Fig. 7), etc. Assur comes to an important conclusion: setting an initial configuration of a chain (the way of joining), we define the movement in an

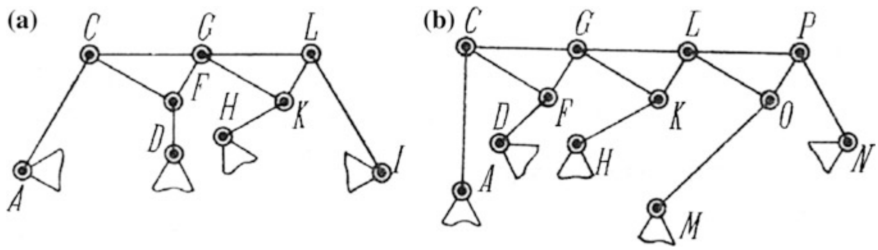


Fig. 7 Four-arm and five-arm groups

absolutely unique way. Here, Assur shows the way to define special (singular) chain positions.

Thus produced, multi-arm chains (group) possess the following property: being fastened to an unchangeable basis (frame), they form a rigid connection, i.e., such a chain has a zero degree of freedom. Such groups, being joined to the mechanism, always give rise to a new mechanism more complex than the original. Assur formulates the essence *of the method of stratification*: the formation of mechanisms by consecutive joining of a series of normal type groups.

Assur begins the classification with Class I mechanisms. In this classification, Class I mechanisms are all the mechanisms derived from a crank by consecutively adding simple open multi-arm normal type chains. He defines the order of Class I mechanism by the number of arms of the most complex multi-arm chain of the mechanism. Thus, the majority of known mechanisms are the Class I mechanisms of the second order. The mechanisms containing three-arm chains (Stephenson guide, Gutch guide) belong to Class I mechanisms of the third order. The Heisenherr guidance mechanism is the only realized Class I mechanism of the 4th order.

Developing chains of 5 and more arms, Assur discovered the chains with branching (Fig. 8). These are special formations, clearly distinguishable from the other types of chains. Assur called such chains *complex* open multi-arm chains of normal type.

Assur defines a Class II mechanism as any mechanism which can be reduced to a crank by separation of only multi-arm open chains of normal type, just complex or both simple and complex.

The chains lying in the basis of the formation of Class I mechanisms are what Assur calls Class I chains. The other chains forming Class II mechanisms are Class II chains. The difference between Class I and Class II chains is only that the Class II chains have central links adjacent to more than two neighboring links.

Having considered the possibilities of building Class I and Class II chains, Assur proceeds to the further development of the method. In Chapter 3, he considers simple multi-arm closed chains of normal types with simple and expanded arms. Assur detached the extreme links of an open chain from the frame and connected them between themselves, forming a closed chain (Fig. 9).

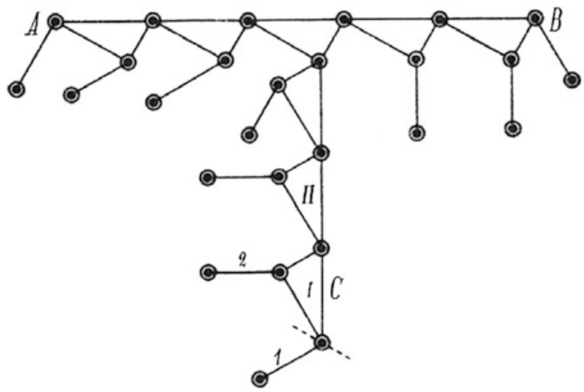


Fig. 8 Complex open multi-arm chain of normal type

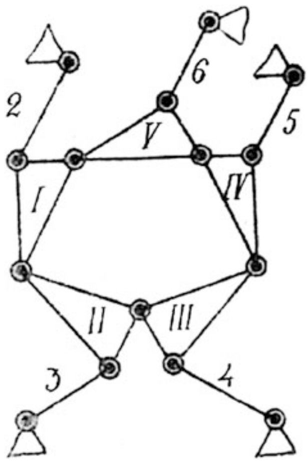


Fig. 9 A simple closed chain

Simple closed chains with expanded arms, as well as those containing them as overlays, are attributed by Assur to Class III. The resulting chains may be distinguished by the number of links of a simple closed chain with simple arms and by complexity of the arms' development. The number of extreme links of a simple closed chain with developed arms defines a chain *category*, and the number of rigid links with simple arms, a chain *order*.

To represent the structure of complex mechanisms graphically, Assur makes a schematic drawing of a structure, consisting of circles and connecting lines (Fig. 10). A circle designates an armless link, a strikethrough circle a single arm link, and two concentric circles a two-arm link. Lines designate the chains connecting the links. Near the line, he puts a figure specifying the number of chain links (when it is important). Sometimes, designations are complemented and changed. The arm coupling chains are designated by straight lines, one-arm links and their groups adjacent to armless links by curves. A dot line designates *locks*—a set of two three-joint links connected with a common joint. The links which are a

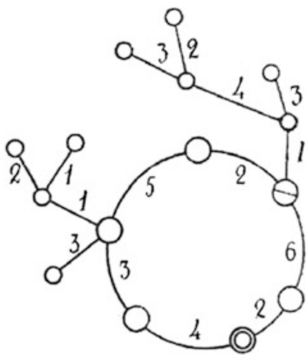


Fig. 10 Scheme of a class III chain of 6th category, 28th order

part of the lock are called lock links. When three curvilinear segments are linked to such a circle, they form a *nodal point*. In other words, a nodal point is an armless link to which three one-arm links are connected.

To study these formations, one has to set a possibility of traversing all the links once, returning to a starting link. For this purpose, assuming flexibility and extensibility of the connecting segments, we may deform the scheme without breaking the mutual arrangement of its components so that all the nodal points (armless links) are placed in a round formed by the segments connecting adjacent links.

The schematic drawing of the chains led Assur, as he writes, «to the formations treated in a not very popular section of geometry called *Geometria* or *Analysis situs*, a part scattered in separate journal papers, not having any systematic text-book in any languages till now». At present this field of mathematics is called topology. It is quite remarkable that Assur independently arrived at the statement of topological problems.

In Chapter 4, Assur converts Class III chains and gets the complex closed chains which cannot be attributed to Class III. If a complex closed multi-arm chain allows full traversal of all nodal points, then Assur attributes it to Class IV. The problem of structural analysis of mechanisms becomes topological and rather complicated at that. Assur writes: «All the chains investigated in this chapter we will attribute to Class IV. It does not include all the types in this class and the problem as a whole … the further we analyze, the more complex the issues in point become, the more complexities are piled up …». Listing the unresolved questions, Assur concludes: «These are the questions for which the answers may be given shortly, although it is possible that their solution is far from being simple».

All the chains which belong to the said four classes Assur includes in one big group, which he calls the first family. Assur addresses the further development of the chains in Chapter 5.

Assur builds the chains of higher families of links, which he calls the links of the second genus. A *link of the second genus* is an independent group of the groups connected between themselves by external coupling chains, provided that it is impossible to connect a portion of the existing groups into one, also allowing

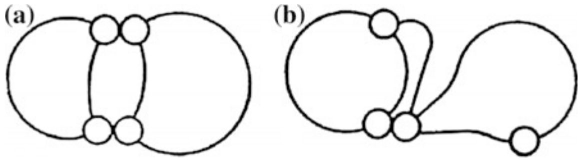


Fig. 11 A chain of the first (**a**) and second (**b**) family

traversal of all armless links. When such a chain forms a rigid, statically determinate joint with a frame and does not disintegrate into the elementary normal ones, it becomes one of the types of the chains of a higher family (Fig. 11).

The chains of the second family possess a great variety of forms in comparison with the chains of the first family. In the second family, the links of second genus can be connected not only with joints (as in the first family), but also with complex open chains.

The first class of the second family forms open chains consisting of 2, 3 and *n* links of the second genus. The second class is formed by the chains consisting of the links of the second genus and built in the manner of complex open chains. The third class consists of the chains formed by a closure of simple chains, differing in that there is only one traversal, and there is no third way between the two central links, apart from the two formed by traversal links.

In the case of a Class II chain of the second family, a replacement of such extreme chains with an arm will result in a complex closed chain not containing the latter, but will not eliminate all nodal links; the latter should allow traversal.

> If a complex closed chain, not having extreme chains, does not allow traversal of all nodal links, then the nodal links of the second genus break into groups, each of which allow such a traversal. This consideration points to the presence of chains of the third family formed by the links of the third genus where each link is formed from a closed chain of the second family. As it is for the second family, four classes are specified; in the third family, we specify four and, using a traversibility criterion, we come to the chains of the fourfold family whereof each link is formed from a closed chain of the third family, etc., indefinitely.

This is, in general, the classification of kinematic chains developed by Assur. It is investigated in detail for the first three classes of normal chains of the first family. The studies of Class IV chains are incomplete; there is no separation of the class into categories and orders. The study of chains of higher families was planned in general.

All existing mechanisms fall into a rather small group of structural formations and only occasionally get to the formations of other types. Assur demonstrated a possible rich range of mechanisms which can be derived by complicating their structure following a definite rule.

When a normal chain of any family and class is connected by joints with a frame, then a more complicated structure—a girder—is formed. Among the girders, one may find the instances of chains of very high classes. Assur thinks that this may have an application for the statics of constructions.

The second part of the treatise is dedicated to the design of a system of kinematic and static analysis of mechanisms, generalized enough to be applied to the studies of any mechanical structure. This problem had not been articulated prior to Assur.

In the introduction to the 2nd part of his study, Assur justifies the necessity of having a classification of mechanisms for conducting kinematic analysis. He gives the examples of when the generally specified methods of kinematic analysis appear suitable only for special cases, for example, for the Class II mechanisms with two-arm links. Assur writes: «Here, the 1st part of our work of classification should be a guideline, on the one hand, allowing us to split the mechanisms into families, classes, categories, orders, establishing certain features of various groups; on the other hand, these are precisely the structural differences which are accepted as the basis for the discrimination.» Setting forward the problem of definition of the speeds of points of a mechanism, Assur chooses the method of defining speeds and accelerations developed by Ch. Mohr (1835–1918). This method, in certain respects, was enhanced and supplemented by Assur.

Chapter 1 of the second part is devoted to the drawing of a picture of the speeds of points of a mechanism through graphical methods. First, a construction of a picture of speeds two-arm, three-arm and four-arm groups is presented. Special (singular) positions are specified, especially for the three arm group. Furthermore, Assur expands the obtained technique to the chains of the first class of all the orders.

After that, Assur consistently considers drawing of the picture of speeds of mechanisms of the second, third and the fourth classes of different types. In the latter case, the author notes the extreme complexity of the question. Nevertheless, he successfully solves this problem, though not completely; this speaks to the restricted possibilities of the graphical methods of research. In effect, all these are the variants of two methods—the method of singular points developed by Assur, and the method of special positions which he borrowed from Mohr, but further developed and complemented.

In this chapter, Assur considers statics of planar linkages. He studies the statics, pursuant to the two main principles: a principle of possible displacements (here he uses the technique of Mohr), and the principle of mutual polyhedrons of J. Maxwell (1831–1879). Assur writes:

> Before applying the great general principles, one has to try to divide the mechanism into basic elements for the first time specified in our work, into the normal multi-arm chains the mechanisms are composed of. Only after it has been found out does it become clear how to apply the specified general principles to the mechanism, and also to a rigid connection formed from an abutment and one or a series of stratifications of normal chains. It distinctly points to the organic relation existing between our classification … and the properties of mechanisms, in particular the methods of kinematic, static and also, in connection with what was laid out in the introduction, dynamic studies of mechanisms.

Thus, Assur finds the counterbalancing force by means of the theory of the auxiliary lever (later called the Zhukovsky lever). Geometrical interpretation of this method foresees the use of a picture of speeds considered in Chapter 1.

Further, Assur addresses a problem of definition of interacting forces between the links (constraint forces). He consistently considers the chains and mechanisms of the 1st, 2nd, 3rd and 4th classes of the types studied in Chapter 1. Apart from a few instances, Assur prefers the graphical methods almost every time. Often they appear to be very complex; they lose accuracy and clarity, although clarity is the basic advantage of graphical methods in comparison with analytical ones.

Assur perfectly understands the immensity of the problem. He writes:

> It may seem almost improbable that in the branch of science quite attended in the XX-th century, there was an area which was approached closely but which nevertheless remained unknown as a sealed book. Having found a key to this area in the quite simple domain of development of an arm, the author found himself confronted by an enormous problem. Like a person who has entered a virgin forest, he had to act in an absolutely autocratic and independent manner; he could not find any laid roads or footpaths here; they brought him only to the borderline of this domain. This area is rather broad though, and for its successful study in full one needs something more than the key idea of development of an arm, which opened this area to the eyes of the observer, allowing for the definition of its essence and making it possible to break it into the sections subject to study. The latter were many, an enormous number, the material for a lifetime's research. There are probably other, more convenient approaches to the separate sections, the keys to which have not been found yet. Perhaps it is destined that other generations will find them.

4 On the Circulation of the Treatise

Assur's «Research of planar linkages with lower pairs on the basis of their structure and classification» was published in limited circulation. The treatise turned out to be too complicated, and besides, the author had died, meaning Assur's ideas not only didn't receive much development, but were also completely forgotten for several years. Scholars mentioned Assur's classification in their work, but didn't use it to solve different tasks of analysis and synthesis of mechanisms. In fact, even in Assur's motherland of Russia, universities taught the structures of mechanisms according to F. Reuleaux. For the classification of mechanisms, different types of the R. Willis classifications were used. Mechanisms were calculated in an old manner: for every task, its own genuine way was found. Even those scholars who knew Assur's treatise well didn't use its ideas. N. I. Mertsalov, Assur's teacher, to whom Assur had shown his dissertation, considered Assur's method to be ineffective, both for the theory and for engineering practice. A. P. Malyshev (1879–1962) maintained that Assur's work was written in a complicated manner and that the developed methods were also too sophisticated. A. A. Ratsig (Assur's opponent at the defense of the thesis) and A. P. Ivanov (Assur's student, who studied applied mechanics) did mention Assur in their textbooks on applied mechanics (in 1930 and 1934 respectively), but didn't use any of his ideas. In 1925 in Leningrad the posthumous edition of a text-book of D. S. Zernov «Applied mechanics» was issued, edited by Ch. F. Ketov. In this book, Ketov, as editor, had confined himself to only one reference to Assur's treatise.

The status of Assur's ideas began to change, owing largely to I. I. Artobolevski (1905–1977), N. G. Bruevich (1896–1987) and V. V. Dobrovolsky (1880–1956). It should be mentioned that the three of them worked at the same department—the Department of Mechanics at the Air Force Academy in Moscow.

I. I. Artobolevski had read A. P. Malyshev's article from 1928, which had introduced him to the works of Assur. Artobolevski had found Assur's treatise with great difficulty, and that was a very rare exemplar. After he had acquainted himself with Assur's work, Artobolevski realized that Assur's theory opens up great possibilities for the development of a general theory of mechanisms. In the same year at the conference at the Moscow Textile Institute Artobolevski read a paper about Assur's work. Assur's structure and classification was enunciated by Artobolevski for the first time at the Moscow Institute of Chemical Machinery and then soon after at Moscow University.

The other scholar, N. G. Bruevich, was also one of the first to appraise the potential of Assur's ideas. In 1935 his work «Application of vector equations in the kinematics of planar mechanisms» was published. Using Assur's methods, Bruevich elaborated the method for solving the problems of kinematics using vector equations.

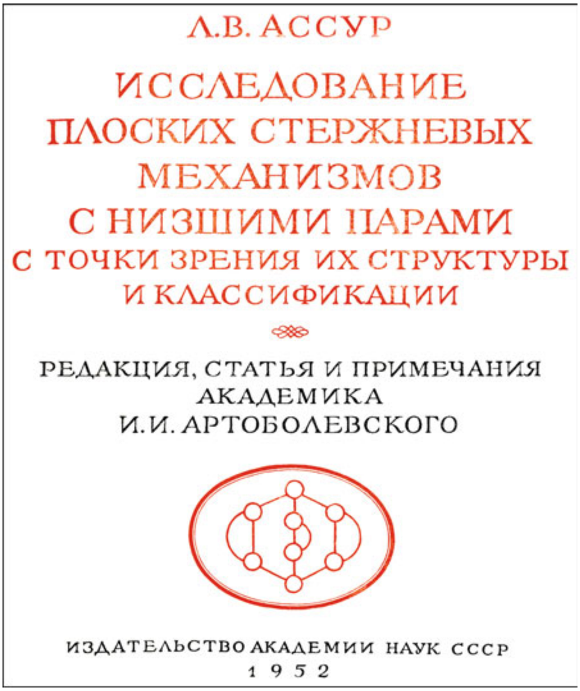
In 1936 V. V. Dobrovolsky, at the meeting of the theory of mechanisms team affiliated with the Technical Committee of the Academy of Sciences, presented a paper «Basic principles of the classification and structure of mechanisms», in which he set out Assur's main ideas.

In 1937 and 1938 on the basis of the lectures held at the Moscow Institute of Chemical Machinery and at Moscow University, Artobolevski had published a book, «Theory of machines and mechanisms». In this book, as well as in his lectures, Artobolevski described classifications and structures of mechanisms using Assur's ideas.

In 1938 the educational program for students «Theory of mechanisms and machines» with regard to Assur's study was elaborated and approved. This created a demand for the compilation of new text-books.

In 1939 the first text-book «Theory of mechanisms and machines», written in accordance with the new program, was issued. The authors of the text-book were Ch. F. Ketov (Assur presented him the copy of the treatise) and N. I. Kolchin (1894–1975). The first section of the text-book was dedicated to the analysis of the structure and classification of mechanisms according to Assur.

In 1940 the first edition of I. I. Artobolevski's text-book «Theory of mechanisms and machines» was issued. The author wrote about the classification and structure of mechanisms: «During the period from 1914 to 1918 an outstanding work by the Russian scholar Assur on the classification of planar mechanisms with a very profound analysis appeared. This work sets forth the classification of planar mechanisms, which is closely connected with the methods of kinematic and kinetostatic analyses of these mechanisms. The classification elaborated by Assur comprises almost all of the existing planar mechanisms in engineering. This treatise should be recognized as a work of exceptional value that has provided a wealth of material for a number of further studies by Russian researchers. The fact



Л.В. АССУР

ИССЛЕДОВАНИЕ
ПЛОСКИХ СТЕРЖНЕВЫХ
МЕХАНИЗМОВ
С НИЗШИМИ ПАРАМИ
С ТОЧКИ ЗРЕНИЯ ИХ СТРУКТУРЫ
И КЛАССИФИКАЦИИ

РЕДАКЦИЯ, СТАТЬЯ И ПРИМЕЧАНИЯ
АКАДЕМИКА
И.И. АРТОБОЛЕВСКОГО

ИЗДАТЕЛЬСТВО АКАДЕМИИ НАУК СССР
1952

Fig. 12 Title page of Assur's treatise's second edition (1952)

that the classification of Linen is used in only certain places abroad and occasionally in the USSR may be explained by the lack of awareness of Assur's works, as the classification of Linen may be fully inscribed in Assur's classification».

In 1952 the second edition of «Research of planar linkages with lower pairs on the basis of their structure and classification» was issued by the USSR Academy of Sciences printing house under the editorship of I. I. Artobolevski (within the series «Science classic scholars») (Fig. 12). The book comprised the title treatise, two additions written by Assur in 1915 and 1918, and the annex—a review by N.E. Zhukovsky about the treatise, an article by Artobolevski «L. V. Assur and his works on the theory of mechanisms», annotations and a list of scholarly works by Assur. The book had a fairly large circulation (2,500 copies) for a scientific monograph. Assur was acknowledged as a classic scholar of the theory of mechanisms.

This edition of the book had sparked a rising tide of interest in Assur's ideas. Assur's classification became an initial system of the structural classification for further studies within the Russian school of theory of mechanisms and machines. It was used in almost every textbook on the theory of mechanisms: S. N. Kozhevnikov («Theory of mechanisms and machines», first edition published in 1947, was translated into Polish, Czech, Hungarian and Chinese), N. I. Kolchin («Machine engineering» in five parts, first edition published in 1948–1957), Vl. A. Zinoviev («Theory of mechanisms and machines», first edition published in 1955, translated into English in 1963) and many others.

The works of Assur weren't translated into foreign languages, but his theory had become well known outside Russia. Foreign researchers started to use Assur's classification in their own works. At the same time, they made no references to the first or second editions of Assur's treatise. Recently, there had appeared some publications referring to Assur's classification as one that was commonly known, without any reference to the original source. This is a kind of an acknowledgement and recognition of the achievements of Assur in the field of the theory of mechanisms.

5 Modern Interpretation of Main Contributions to Mechanism Design

Actually, Assur's work has never been finished. It is known that Assur continued working on the classification, but his papers were lost. However, his ideas were taken over by other researchers.

In the 1930s I. I. Artobolevski developed a theory of three-dimensional mechanisms. In 1937 his monograph «The theory of three-dimensional mechanisms» was published. Artobolevski came to the conclusion that there was much in common in the structure of spherical and planar mechanisms. By analogy with Assur's groups, he developed a theory of multi-axial spatial groups. He noted the possibility of the reverse influence of classification of three-dimensional mechanisms on the classification of the planar ones.

In 1939 Artobolevski published a monograph «Structure, kinematics and kinetostatics of multi-link planar mechanisms» (Artobolevski and Dobrovolsky 1939). In this work, he ingeniously develops Assur's theory. Apart from the studies of the structures of mechanisms, the book contains a solution to the problem of definition of the groups' positions. The kinematics of mechanisms includes the questions of defining the accelerations, in addition to the speeds. The graphical methods applied and developed by Assur were then supplemented by an analytical method for vector equations. The developed graphical/analytical method appeared to be more clear, convenient and accurate than the graphical method. Assur's classification was expanded to the mechanisms which included translatory and higher kinematic pairs. The analysis of kinetostatics embraced the groups up to the third class of the higher orders.

Assur's principle of building a classification was used by V. V. Dobrovolsky. He stated his ideas in the works «The main principles of rational classification of mechanisms» and «The theory of mechanisms». Dobrovolsky (1953) suggested putting several layers of kinematic chains on an initial mechanism which can change the mechanism's degree of freedom. For such chains, he used the term «non-Assur chains» for the first time. Depending on whether the connected chain increases or reduces the degree of freedom, it is attributed to a group of positive or negative order. In this respect, the Assur chain not changing the degree of freedom of an initial mechanism belongs to the chains of zero order. The Assur groups, as they are kinematically and statically determinate, are of the highest spread. Dobrovolsky sees an expediency of introduction in non-Assur chains in that «they can join several mechanisms with independent movements into one, and thus, serve as a transmission medium between them». Dobrovolsky's work is also remarkable for his having tried to make a structural analysis of a mechanism not with one, but with several degrees of freedom.

I. I. Artobolevski also continued to develop Assur's ideas. In his work «Experience of the structural analysis of mechanisms» and in other works, he defined a structural group. *The Group* is a kinematic chain which, after its joining by extreme free pair elements to a frame, acquires zero degree of movability and which cannot be separated into independent kinematic chains of zero degree of movability. Assur assumed no difference between the notions of group and chain, and used both equally.

According to the classification of Artobolevski, the structural Assur groups are characterized by class and order. A group order corresponds to the number of elements of the kinematic pairs by which the group is connected to the links of previous groups and to the frame. A group class is defined by the number of kinematic pairs which include the links forming the highest contour of the group.

G. G. Baranov (1899–1968) in his study «Classification, structure, kinematics and kinetostatics of planar mechanisms with the pairs of the first kind» (published in 1952) offered another system of classification of the planar Assur groups. According to that work, a group class k equals one half of the number of its links, thus a two-link group (dyad) is the group of the first class, a four-link group is the group of the second class, and so on. All the groups of class k are divided into orders, as was suggested by I. I. Artobolevski.

I. I. Artobolevski's classification became the most widespread in Russia. It was not without its drawbacks, as noted by V. V. Dobrovolsky, G. G. Baranov, E. E. Peisach and others. The scientists mentioned that this classification did not fully characterize each separate group and did not embrace all possible groups of few links.

E. E. Peisach (1936–2008) offered an improved definition of an Assur group, more convenient for the structural analysis of mechanisms. On the basis of this definition, he offered a new classification of structural Assur groups. Its two basic structural criteria are the *class* and the *category*. Besides, there are four more additional structural categories—*the number of links, the number of kinematic couples, the order,* and *the number of changeable closed contours*. When the class and the group category are known, then all four additional structural criteria are defined univocally, i.e., they are dependent on two basic criteria. It is possible to present each mechanism in the form of a certain symbol code. Considering the symbol codes of the structures and casting out the repeated ones, it becomes possible to make electronic catalogues of the planar structural groups of various classes with rotational pairs. By means of the algorithm offered in the «Classification of planar groups of Assur» (2007) and the corresponding program, E. E. Peisach performed a structural synthesis of the Assur groups up to the sixth class inclusive, i.e., for $k = 1, 2, 3, 4, 5, 6$, and made an electronic catalogue of the Assur groups for $k = 2, 3, 4, 5$.

In 2000 the Springer publishing house published a book by a group of authors (M. Z. Kolovsky, A. N. Evgrafov, Yu. A. Semenov, A. V. Slousch), «Advanced Theory of Mechanisms and Machines». In this book, the following definition of a structural group is offered.

«A kinematic chain with given inputs is referred to as a *normal structural group of movability n* or simply a *structural group*, if the number of independent chain inputs n_c coincides with the number of degrees of movability w_c. A *simple* structural group is one that cannot be split into several structural groups with smaller numbers of links. A simple structural group may have zero degrees of movability (and, therefore, zero inputs as well), i.e., $n_c = w_c = 0$. Such a structural group is called an *Assur group*».

Such a structural group, as well as an Assur group, is kinematically and statically determinate, and an Assur group is a special case out of this group. Layering such groups (as well as an Assur group) on an initial mechanism or on a frame, it is possible to gain new, more complex mechanisms which will always be kinematically and statically determinate. Numerous mechanisms of modern cars, including spatial, multimotor, open-circuited ones, can be presented in the form of a chain of such structural groups. In the article «Program of the structural analysis of mechanisms» by Karlovskiy et al. (2005), a corresponding computer program is described. This program automatically separates Assur and non-Assur structural groups in a mechanism.

Assur's ideas came to the notice of foreign researchers thanks in a large part to I. I. Artobolevski. The notion of an «Assur group»became a recognized term. Many authors use the concept of an Assur group and Assur's ideas: Bouzakis et al. (2004, 2008), Calle et al. (2010, 2011), Ceccarelli (2004), Ceresole et al. (1996), Cheng (2005), Crossley and Seshachar (1971), Zhang and Xu (2011), Galletti (1979), Servatius et al. (2010a, 2010b), Shai (2010), Tereshin (2003, 2004), Dvornikov (2011), Ionesku (2003) and others.

In their article, Sun and Tang (2009) acknowledge the significant role of the methods of Assur groups in engineering planar mechanisms, and they also point out the moderate popularity of this method. Galletti and Giannotti (2009) present in their article an instrument for modeling the kinematics of planar groups in the system SIMULINK, which is based on the method of Assur groups, and for using it in teaching practice. Romaniak (2007) in his article offers the methodology of developing the Assur groups, dividing them into simple, complex and multiple ones. Calle et al. (2011) examine in their article the solution to the problem of kinematic analysis of Assur groups of class four (4). Wohlhart (2008) article is dedicated to the analysis of the positions of open Assur groups and the formation of planar open mechanisms. A short list of these and some other works of foreign researchers is given below in References.

To sum up, it can be said that Assur as a scholar was twice lucky. First, he discovered and developed a very viable and fruitful idea. Secondly, this idea wasn't forgotten after Assur's death, and was treated to further development by other researchers.

Acknowledgments The authors would like to thank the Fundamental Library at the St. Petersburg State Polytechnical University, the National Library in St. Petersburg, and also kindly thank Sergey Assur, Tatyana Raush and Nataliya Arefieva.

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Giuseppe Antonio Borgnis (1781–1863)

Marco Ceccarelli

Abstract Giuseppe Antonio Borgnis was among the first pupils of the newly-formed Ecole Polytechnique in Paris, after which he transferred his expertise to the University of Pavia in Italy where he enjoyed a long life of teaching activity. He contributed to the development of professional skills with the publication of a 9-volume handbook on machines that included his own classification and the first volume of technical terminology to be used in Europe in the 19th century.

1 Biographical Notes

Giuseppe Antonio Borgnis (Fig. 1) was born in Craveggia, Italy (Val Vegezzo in the province of Novara) on April 15, 1781 and died in Monza on August 16, 1863.

Throughout his life, Borgnis often returned to the town of his birth for his rest and holydays. The family was well off since the father Giovanni was a banker in Paris. Borgnis was well educated with special studies in mathematical disciplines, and although the revolution of the time affected the family, he was able to graduate as an engineer. He got a position as a naval engineer in Venice where he gained enough valuable expertise to write a book on machines in 1809. The expertise credited to him as a result of the publication of this first book led to his appointment in 1812 as a member of the Venice Academy. This also made it possible for him to go to Paris to attend courses at the Ecole Polytechnique. In Paris he deepened his expertise on machine design both in terms of theoretical studies and practical applications. His study of the views in Monge's approach allowed him to extend them to the point of proposing his own classification on mechanism variety for machine applications. Developing his ideas in more detail,

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Fig. 1 A portrait of Giuseppe Antonio Borgnis (1781–1863) (Borgnis's great-grand child Massimo Borgnis is thankfully acknowledged for the portrait and additional biographical notes)

he published ten books from 1818 up to 1823, handbooks on machine design and application that presented a practical implementation of his new classification.

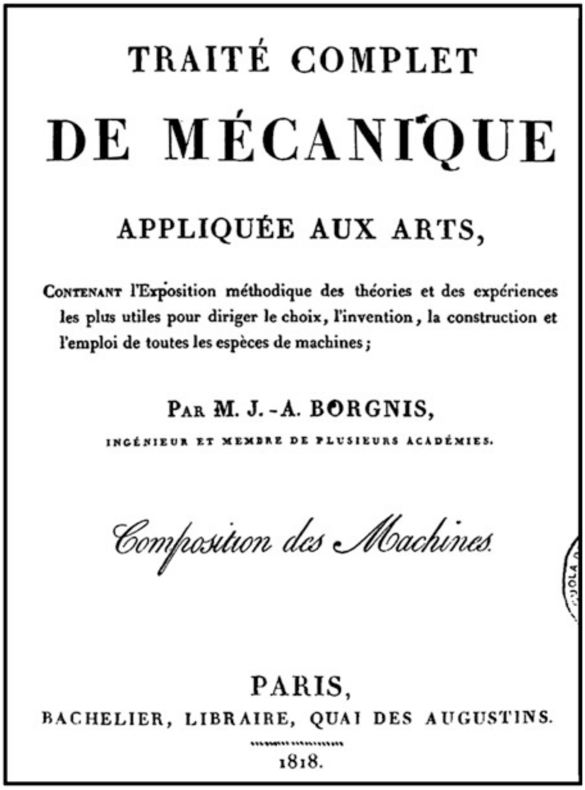
Once back in Italy in 1826, he was given a professorial position at the University of Pavia as a temporary teacher of Applied Mathematics. Then, in 1840 he was appointed full professor of Applied Mathematics and also gave lectures on Civil and Road Architecture. Because of his successful academic activities, Borgnis was elected Rector of the University of Pavia for the academic year 1842–1843, as reported in the historical records of Pavia University (1878). Because of his reputation, he was appointed as an active member of the Royal Lombard Institute of Science, Humanities and Arts, and as a member of the Royal Academy of Turin. He was also granted the honour of Knight of the Order of Saints Maurizio e Lazzaro by the Italian King Carlo Alberto.

He was a well reputed professor of Applied Mathematics and Civil Transportation Architecture, well established academic disciplines with applications in the area of engineering. Within the activity for those courses, he combined his interests and activities in theory and engineering designs, his influence spreading all over Italy during the first period of the Industrial Revolution, although he was based in the northeast state within the Austro-Hungarian Empire.

2 List of Main Works

Borgnis's Works can be grouped as follows.

- Handbook on Machines:
  1. "De la composition des machines" (450 pages, published in 1818) (Borgnis 1818a) (Fig. 2), which contains classifications and descriptions of mechanical devices in agreement with the approach proposed by Gaspard Monge but with an extension including a new machine classification. The treatise features drawings of 1,200 mechanical devices, which are also compared in term of figures and operational characteristics. The classification is summarized in Tables, which give a synopsis of available mechanisms at that time.
  2. "Du mouvement des fardeaux" (334 pages, published in 1818) (Borgnis 1818b), which contains a description of mechanical design and operational characteristics of the machines that can be used for transportation and the lifting of many different weights.
  3. "Des machines employées dans les constructions diverses" (336 pages, published in 1818) (Borgnis 1818c), which describes the design and operation of machines that are used for construction in the field of civil engineering, hydraulic engineering, naval engineering and military applications.
  4. "Des machines hydrauliques" (295 pages, published in 1819) (Borgnis 1819a), which contains an overview of machines that can be used in hydraulic systems. An in-depth study is reported for machines applied in agriculture and mining.
  5. "Des machines d'agriculture" (295 pages, published in 1819) (Borgnis 1819b), which contains descriptions of equipment and machines used in agriculture. Detailed studies are given of mechanisms that are used for harvesting machines, winding and drilling machines, and devices for production of oil and wine.
  6. "Des machines employèes dans diverses fabrications" (285 pages, published in 1819) (Borgnis 1819c), which contains the description of machines used in industrial plants for production of metal components, paper products, textile manufactures, and tannery products.
  7. "Des machines qui servent à confectioner les ètoffes" (335 pages, published in 1820) (Borgnis 1820a), which contains descriptions of procedures for the spinning of vegetal or animal material, comparative analyses of mechanical



TRAITÉ COMPLET

DE MÉCANIQUE

APPLIQUÉE AUX ARTS,

CONTENANT l'Exposition méthodique des théories et des expériences les plus utiles pour diriger le choix, l'invention, la construction et l'emploi de toutes les espèces de machines;

PAR M. J.-A. BORGNIS,

INGÉNIEUR ET MEMBRE DE PLUSIEURS ACADÉMIES.

Composition des Machines

PARIS,

BACHELIER, LIBRAIRE, QUAI DES AUGUSTINS.

1818.

Fig. 2 Title page of the first book of Borgnis's 9-volume handbook on machines containing his original machine classification

means for industrial spinning and equipment of different kinds of machines for different kinds of products in textile manufacturing.

8. "Des machines imitatives et des Machines théatrales" (285 pages, published in 1820) (Borgnis 1820b), which contains descriptions of mechanical devices that are used for any kind of transportation and movement, including devices mimicking animal motions and automata. The text includes an Appendix with interesting descriptions of old machines for theaters and how to adapt their use to current needs and other aims.
9. "Thèorie de la Mecanique usuelle" (359 page, published in 1821) (Borgnis 1821), which contains an introduction to the mechanics applied to practical industrial applications and refers to principles of Statics, Dynamics, and Hydraulics. Detailed descriptions and formulation are presented on primary mechanical transmissions.

• Terminology in a Technical Dictionary:

"Dictionnaire de mecanique appliquèe aux arts" (284 pages, published in 1823) (Borgnis 1823), which contains a list of technical terms with explanations to serve as the first terminology dictionary for standardizing terms in engineering. The machine description contains all bibliographic references and paternity indications of the machine conceptions.

- Other publications:
  "Studio delle machine" (in English: on the study of machines) (published in Venice in 1809) (Borgnis 1809), which is a treatise on the design of machines from his first professional experiences.
  1826: "Delle Macchine Idrauliche: I trattati" (in English: Treatises on hydraulic machines) (published in Bologna in 1826) (Borgnis 1826), which is a collection of treatises on hydraulic machines, such as those used for his academic teaching.
  1842: "Elementi di statica architettonica" (in English: Fundamentals on Statics in Architecture) (published in Milan in 1842) (Borgnis 1809), which is a textbook with his lecture notes on Statics for Architecture.

3 An Illustrated Survey of Borgnis's Handbook

Borgnis worked out the 9 volumes of his machine handbook (Borgnis 1818a, b, c, 1819a, b, c, 1820a, b and 1821) as a practical implementation of his classification of machines and mechanisms. He derived his classification from Monge's classification, which was published in the book (Lanz and Betancourt 1808), as discussed in (Lopez-Cajun et al. 2004; Ceccarelli 2004). Borgnis's criticism of Monge's classification was motivated by the fact that it was based only on motion possibility for input-output relationships. He completed the analysis of machine compositions by way of the view of practical engineering garnered through his professional experiences with a new classification structure. Thus, in his first book in 1818 on The Compositions of Machines (Borgnis 1818a) (Fig. 2), he introduced a classification as a function of the purposes of machines and mechanisms (when using a design of fully independent operation). The classification is organized in categories that are divided into classes; classes contain genres; genres group types with different mechanical designs; and types describe a variety of machines.

He classified the machines in six categories, namely Receivers (with 5 classes), Communicators (with 2 classes), Modifiers (with 6 classes), Frames (with 3 classes), Regulators (with 3 classes), and Operators (with 5 classes). Each category is organized into classes whose list is given in the Tables at the beginning of the book (Borgnis 1818a), as shown partially in Fig. 3 as an example of Borgnis's representation of the machine classification. Table 1 summarizes the structure of Borgnis's classification.

The Handbook concludes with an additional book (Borgnis 1823) focused on the terminology in a first attempt at a dictionary in the form of a very early standardization of technical terms.

In his handbook study of machines, Borgnis started from machines whose operation is based on human actions, with an early biomechanical approach. This analysis also presented him with the possibility of considering solutions with what we would now call biomimetics design. The survey is completed with the most

ORDRE PREMIER. — *RÉCEPTEURS.*

CLASSE PREMIÈRE. — RÉCEPTEURS ZOOLIQUES.

ESPÈCES.	VARIÉTÉS.	INDICATION DES Planch.	Figures.	Pages.
GENRE PREMIER. — *Récepteurs zooliques mus par des hommes.*				
1 A traction verticale du haut en bas.	1 Corde passée sur une poulie. . .	»	»	18
	2 Corde attachée à un levier rotatif.	1	1	21
	3 Double levier rotatif ou levier à bascule.	1	3	23
	4 Levier à tige inflexible. .	1	2	24
	5 Axe vertical de petites dimensions à rot. alter.	1	6	26
	6 Axe vertical de grande dimension à rot. alter.	2	5	28
	7 Cordes à nœuds de *Berthelot* .	3	7 et 8	29
2 A traction verticale du bas en haut.	1 *Té* ou tige verticale à barre horizontale.	1	5	30
	2 Levier rotatif.	1	4 et 10	31
3 A pression horiz. sans locom. par la force muscul. des bras.	Tige horizont. qu'un ou deux hommes tirent et poussent alternativement.	3	6	32
4 A pression horiz. par la force musculaire des jambes.	1 Plan horizontal flexible. . .	2	6	33
	2 Roue horizontale à rayons.	1	12	34
	3 Roue verticale à tasseaux.	1	15	36
	4 Axe à chaise mobile.	1	16	37
5 A traction ou pression horiz. locomotive. .	1 Homme tirant au moyen d'une corde ou d'une courroie posée en écharpe sur sa poitrine.	1	11	39
	2 Homme poussant une barre horizontale.	1	11	40
6 Manivelles.	1 Manivelle simple.	1	7	42
	2 Manivelle à tige mue par les pieds de l'homme.	1	8	44
	3 Maniv. à tige et à balancier vert. suspendu. .	1	9	45
	4 Maniv. à tige et à balancier vert. non suspendu	2	3	46
	5 Maniv. à tige et à balancier horizontal.	2	9	47
7 Treuils à leviers.	1 Treuils à leviers fixes. .		»	48
	2 Treuils à leviers mobiles.	»		49
8 Roues zooliques. .	1 Roue à chevilles.	1	17	50
	2 Roue à tambour.	1	18 et 19	52
	3 Roue à double force.	1	20	54
9 Échelle flexible. . . .	. . . .	2	2	57
10 Roues zooliques obliques ou horizontales	1 Roue zoolique oblique. .	1	13	68
	2 Roue zoolique horizontale.	1	14	69
11 Bascules. .	1 Bascule mue par un seul homme. .	2	4	70
	2 Bascule mue par deux hommes.	2	8	71
	3 Bascule à manivelle. .	2	7	72
	4 Bascule à arc de cercle. .	3	9 et 12	73
	5 Bascule à mouvement alternatif rectiligne.	3	4	74
	6 Bascule à double pression de M. *Desmandres*.	3	14	75
	7 Plateaux mobiles.	2	1	»
GENRE DEUXIÈME. — *Récepteurs zooliques mus par des animaux.*				
1 Manéges. .	1 Manivelle à manége. . . .	3	10	83
	2 Manége à flèches horizontales .	2	15	88
	3 Manége à flèches obliques.	2	15	89
2 Roues verticales.	1 Roue mue par des chevaux, en se servant de leurs jambes de derrière. . . .	2	10	90
	2 Roue mue par des bœufs ou buffles.	3	13	92
	3 Roue mue par des chevaux, en se servant de leurs jambes de devant.	2	12	93
	4 Roue mue par des chiens.	3	11	»
3 Roue oblique.	Roue mue par des bœufs	2	11	94
4 Plan incliné flexible. .		2	13	95
5 Plateaux mobiles.		2	16	97

Fig. 3 An example of Borgnis's representation of his machine classification in (Borgnis 1818a) (Fig. 2), referring to the category of Receivers

recent machines of the time, steam-powered machines. Each machine is described in a text with no formulation, which nevertheless can be derived, both in design characteristics and operational features, by referring to specific drawings that are collected in tables at the end of each book. A machine is described in detail in its mechanical composition with a drawing and text description indicating the main components with letters. A careful explanation of the operation is discussed in

Table 1 Structure of Borgnis's classification of machines and mechanisms

Category	1					2		3					
Class	1	2	3	4	5	1	2	1	2	3	4	5	6
Genre	2	8	3	4	2	4	4	3	2	2	2	2	1
Type	16	17	10	7	8	11	7	6	4	5	6	4	1
Machines	45	28	18	10	11	59	27	7	10	11	8	10	1

Category	4			5			6				
Class	1	2	3	1	2	3	1	2	3	4	5
Genre	3	2	3	3	3	3	4	5	3	2	5
Type	8	7	9	10	7	8	13	9	9	13	19
Machines	17	29	15	16	24	8	67	20	24	36	25

regard to the component's actions and aims by specifying both the mechanical function and the early thermodynamics behind it, when using steam power.

Specific machines are grouped into the 6 separate books of the collection, the first book giving an overview, and each subsequent book dealing with a specific field of application for a specific set of machines.

The last book of the handbook (Borgnis 1821) is devoted to the theoretical aspects of the mechanical functioning of machines by outlining basic principles of Mechanics for design and analysis purposes, even with specific formulation in the forms of the time that nevertheless would need interpretation for modern expressions.

Examples of Borgnis's presentation of machines are shown in Figs. 4, 5, 6, 7 and 8.

In particular, Fig. 4 shows an example from (Borgnis 1818a) displaying different levels of analysis that include both full designs, as in the system in Fig. 4a, and specific mechanisms, as in the collection in Fig. 4b. In this case, the size and complexity of the machines are also used by Borgnis to illustrate the success of his classification in considering machines of any size and complexity, when they have a well-defined operational capability. It is remarkable how Borgnis treats the last machines, like the locomotive in drawings 1 and 2 of Fig. 4a, with details and advanced graphical representation to show both the overall mechanical design and component coupling in mechanisms. Similarly remarkable are the synthetic drawings of mechanisms in the collection of Fig. 4b in which the kinematic functioning is clearly represented with early kinematic schemes.

The analysis approach in the machine classification of the book (Borgnis 1818a) is extended to the presentation of machines in the other books of the handbook, but with wider discussion towards a practical understanding of machines.

A first extension of the analysis is given in the first book (Borgnis 1818a) when dealing with full systems. An example of discussed Receivers is shown in Fig. 5, taken from Fig. 3 of Table 7 of (Borgnis 1818a). Table 7 also offers a kind of

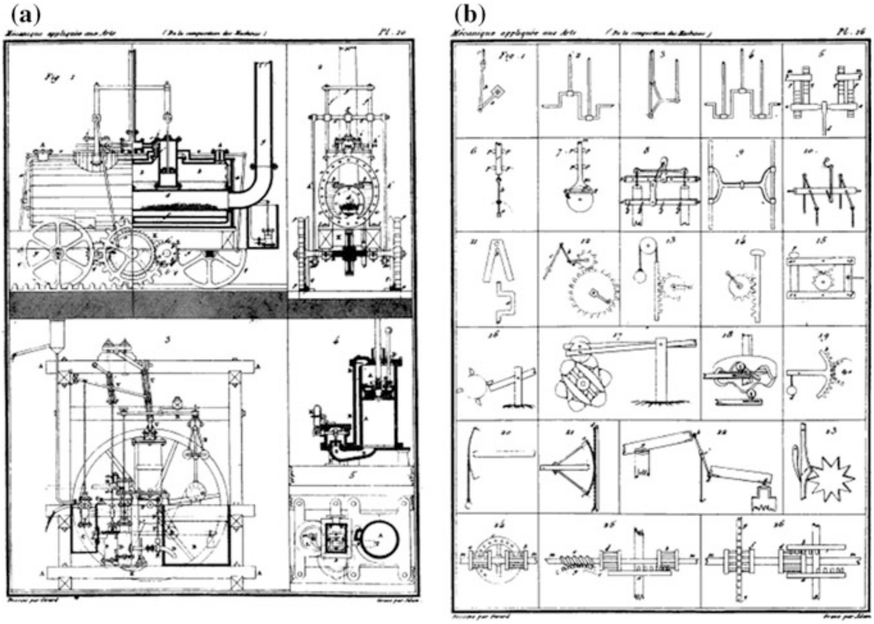


Fig. 4 Examples of Borgnis's study of machine composition from (Borgnis 1818a): **a** full machines in Pl 10; **b** mechanisms variety in Pl 2

overview of the evolution of the system by showing the solutions of Newcomenn and Watt, for which the corresponding text description gives dates and conception merits.

A full representation, even with partial side views, is shown in the example in Fig. 6, referring to an automatic saw machine. In the text, a description of the operation of each component marked with letters in the drawing is carefully described, with the additional aim of justifying the size. The case in Fig. 6 is an hydraulic actuated system from traditional machinery, but Borgnis extended the analysis by looking at solutions with steam engines and wind actuation.

In several cases, for machine analysis Borgnis gives additional comments on operational characteristics with numerical evaluations referring to a number of aspects, like cycle time, friction influence, power size as a function of the machine output, and material characteristics, both coming from calculations and well-established practices.

Besides standard machines of the time in several fields of applications, Borgnis also attaches the operational description to novel machine designs, such as the automata in the examples in Fig. 7 that are described as being useful beyond their standard use in the theater. In Fig. 7, an already traditional automaton, like the Vaucanson duck in drawings 1–3, is described along with its operation and a clear indication of the main mechanical parts for said operation.

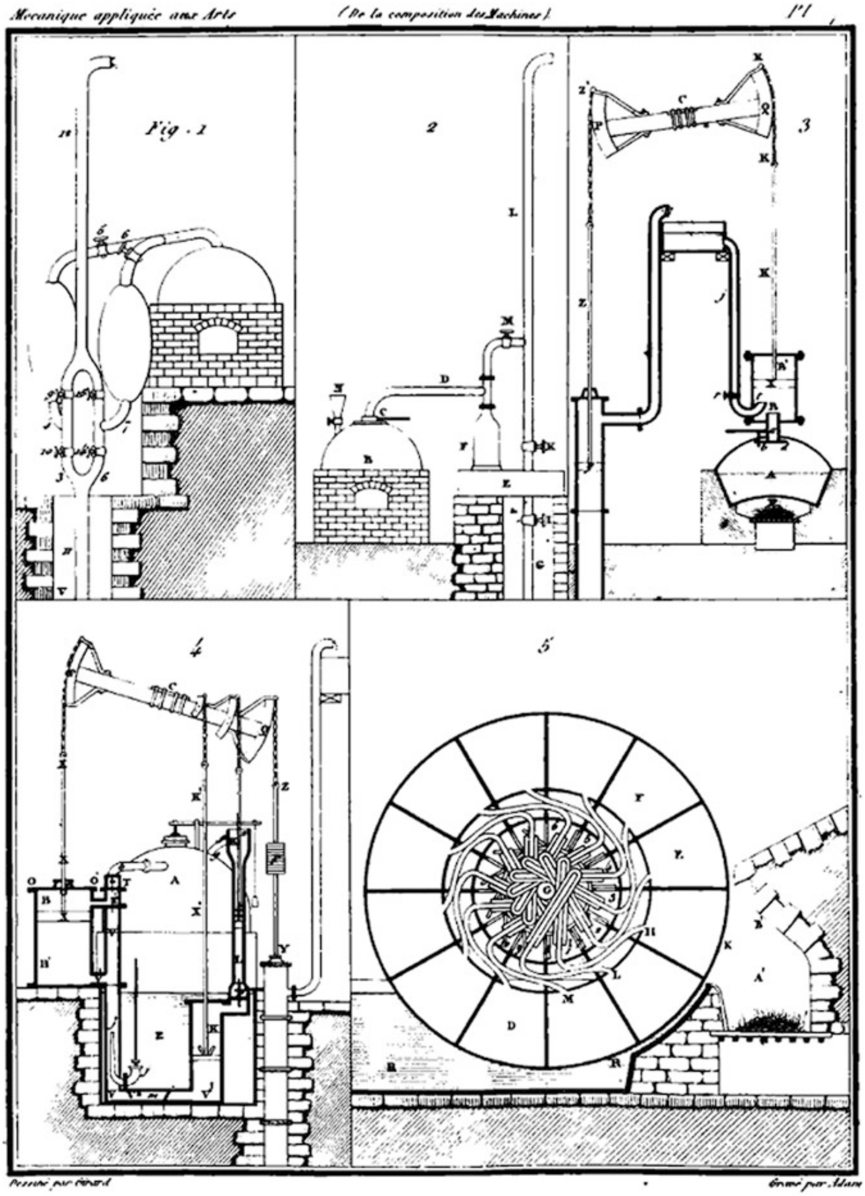


Fig. 5 Examples of Borgnis's study of current engine machines from Pl 7 in (Borgnis 1818a): Watt engine in Fig. 3 and Newcomenn engine in Fig. 4

In drawings 5 and 6 of Fig. 7, a mechanical android is presented with the main connections for articulating the body parts and a gear system centered as the power transmission system for giving motion to the links connected to the body parts.

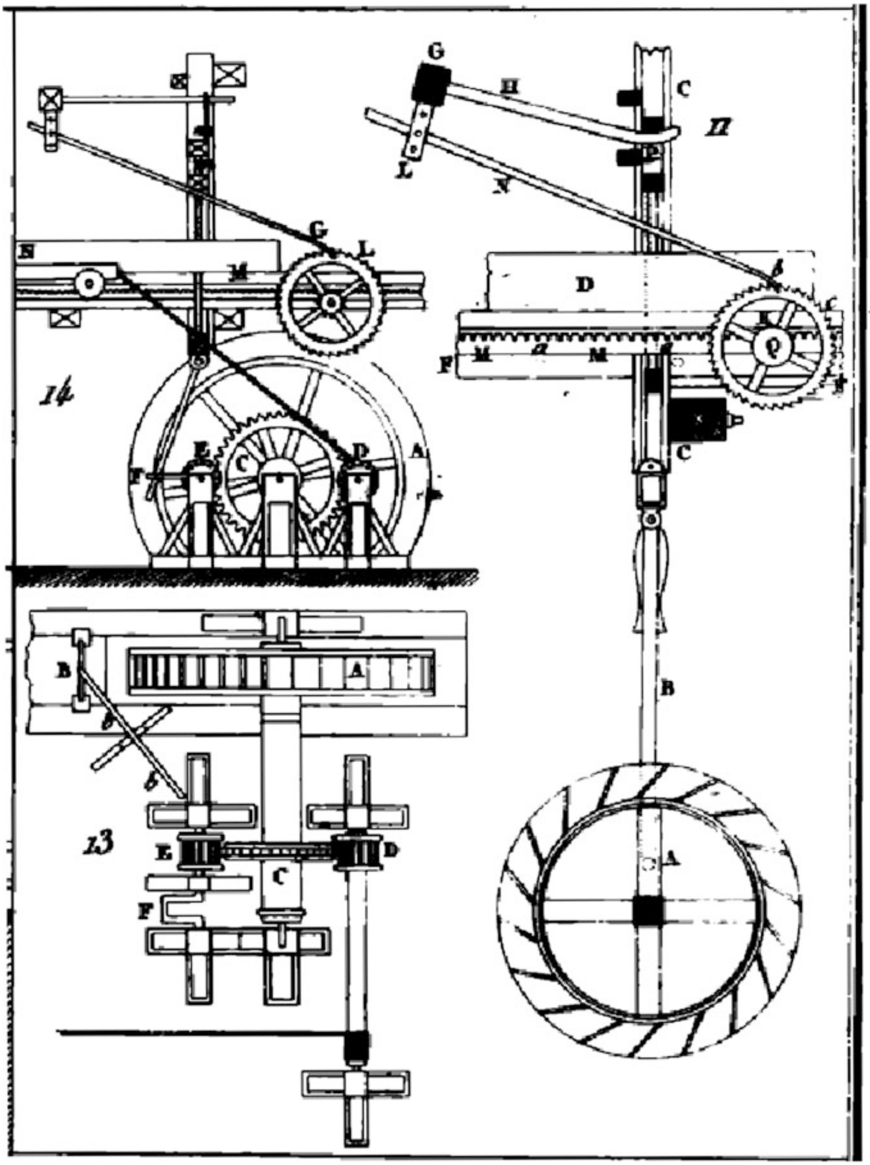


Fig. 6 Example of Borgnis's study of automatic machines in Pl 4 from (Borgnis 1818c): an hydraulic-powered sawing machine

In this case, although the mechanical design of the transmission system and link connections are clearly illustrated, the operation of the android is nevertheless not fully explained, since it looks a very last advanced solution.

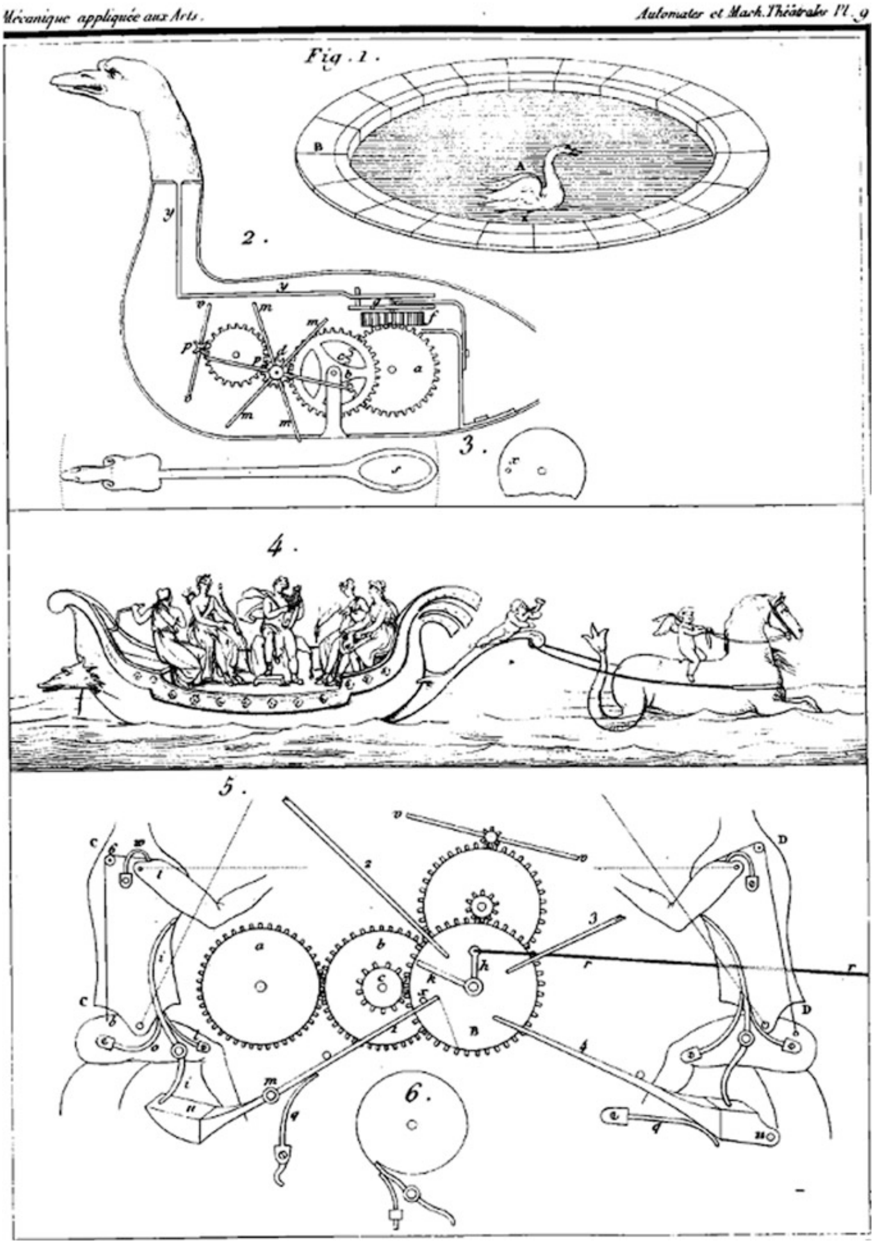


Fig. 7 Example of Borgnis's study of automata machines in Pl 9 from (Borgnis 1820b): the Vaucason duck in Figs. 1–3 and a geared android in Figs. 5 and 6

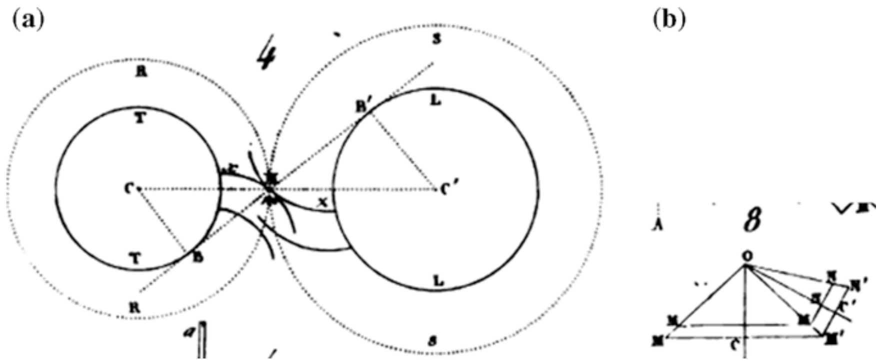


Fig. 8 Example of Borgnis's analytical study of mechanics of machines in Pl 7 from (Borgnis 1821): **a** Fig 8 for teeth profile in gears; **b** in Fig. 8 for conical gears

As for the above cases, Borgnis presents several different similar designs that can also be used for different applications. In the case of mechanical automata, some designs are also shown as prostheses, like, for example, for hands or full arms.

In all the books of the machine collections, machines are presented starting with human-powered machines up through traditional machines, from antiquity up to the then most recent ideas of steam powered solutions.

Figure 8 shows examples of analytical studies of mechanics both for operational characterization and design purposes as they are treated in the last book (Borgnis 1821) of the handbook. As for the examples in Fig. 8, mechanics are analyzed by referring to schemes with a very synthetic representation stressing the main parameters and constraints. The example in Fig. 8a refers to the study of profile generation of gear teeth with involutes profiled by looking at the geometrical construction and force transmission when in operation, likewise in the gear analysis of today. In Fig. 8b, an example of the application of conic gears is studied with a scheme that helps the description in the text to indicate the main parameters and operation constraints for efficient functioning.

In the book (Borgnis 1821), the mechanical analysis of each machine is completed with its formulation and numerical computations and form practices so as to give examples of practical characterizations. The notes are remarkable, with numerical considerations for practical efficient operations referring to material characteristics and friction effects.

The technical presentation of machines led Borgnis to the need to identify and collect a commonly accepted terminology for machinery as a natural complement for the handbook. This is the first volume on terminology that can be considered a milestone work in attempting a technical dictionary that today is well recognized as being necessary in all scientific areas, as stated in the several standards of the International Standard Organization (ISO). In the specific area of machine design, Borgnis identified a need that was only attached in 1990s with IFToMM activity leading to the last IFToMM collection of standardization and terminology in 2003 (IFTOMM 2003).

As Borgnis stated in the book's preface, the terminology collection is aimed towards summarizing the most widely used terms on machinery with a well-defined and accepted understanding. Examples are given in the following to show the synthetic characters but also the technical clarity of Borgnis's description of the terms in comparison with the corresponding IFToMM terminology.

'Machine' is described by Borgnis as a "general name that is used for several combinations of mechanical devices which are used frequently in Industry. Within the Statics, it is possible to distinguish the names of elementary machines of lever, pulley, inclined plane, screw, wedge and belt machine". In IFToMM, a machine is defined as a "Mechanical system that performs a specific task, such as the forming of material, and the transference and transformation of motion and force".

While in IFToMM, even the term 'mechanism' is specifically described, in Borgnis's terminology, it is not defined at all. But specific components are properly indicated; for example, a crank is described as "a link that rotates about an axis and at whose extremity is applied a force. There are cranks with simple, double, triple structure". In IFToMM, a crank is "a link able to rotate completely about a fixed axis".

Borgnis also specified terminology for machine operation within the definition of a term. Thus, for example, he defined a lifter as a combination of gears with a worm and a crank whose aim is to produce a large force through a small-sized device. Within brackets, he indicated the motion of weights as an additional characterization of the device. In general, Borgnis's definitions of terms are synthetic but additional indications are suggested to a reader to refer to other terms. In addition, specific hints are given to refer to literature on arguments of a wide variety of topics. For example, in specifying the term steam as also referring to steam machines, Borgnis added quite a long list of references on the topic, even mentioning past designers like Watt, Wolf, and Evans.

The terminology by Borgnis contains technical definitions and operational descriptions with theoretical background, including historical notes and indications of common applications.

4 On the Circulation of Borgnis's Handbook

The Borgnis classification was considered to be the next development of machine classification, as, for example, cited by Willis (1841) as a base for his improved views. The approach of analyzing machines and their mechanisms was also considered a reference for textbooks, as with the textbook by Carlo Giulio (1846) from the School of Engineering in Turin. Borgnis's work was well known in the 19th century, but was quickly forgotten even within Italian circles, as indicated, for example, by its omission as a reference for machine classification in the work by Francesco Masi (1883) from Bologna University.

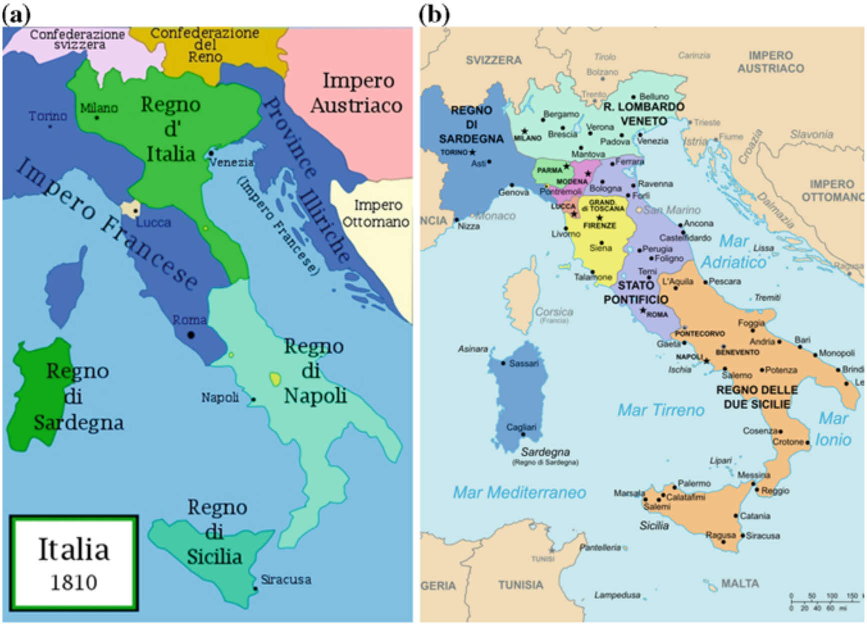


Fig. 9 Italian states in: **a** 1810; **b** 1840

Nevertheless, the great value of the Borgnis technical handbook, complete with its terminology dictionary, was its inspiration for further machine classifications (Ceccarelli 2004) in several books on machines even from the second half of the 19th century, although not always explicitly cited.

The circulation of Borgnis's handbook was limited, mainly confined to Italy, for at least two reasons, namely, the rapidly changing political situation and the reduced influence of Italian Universities at international levels.

Just after the Restoration, subsequent to Napoleon's defeat, the Italian political situation was characterized by the re-establishment of the several kingdoms under the influence of different European countries. The change and state fragmentation is summarized in Fig. 9. In Fig. 9a, the political situation is represented as referring to 1810 with the strong influence of France from the French Revolution all over the North and Center of Italy. This is also the reason for Borgnis's interest in going to Paris to enhance his machine expertise. In Fig. 9b, the restored situation is illustrated as referring to 1840 with several kingdoms and Northeastern Italy, which was soon included in the Austro-Hungarian Empire. But there were already considerable hopes for and actions towards a reunification of Italy at that time. This is mentioned to note that Italian society of that time, although fragmented into several kingdoms, had a very great impulse towards the possibility of a unified Italian kingdom, which actually was achieved over the next two decades through several wars and considerable participation of the population. In scientific terms, this led to a mixed result: over the following decades of the 19th century, these efforts towards reunification led to a loss of attention to the circulation of academic works among those kingdoms. Shortly after the reunification, governmental programs were instituted for a standardization of professional activities in academic circles that would consist of more than simply an extension of circulation of works, which, on the one hand, created a unified scientific community within Italy that had not previously existed. On the other hand, it made plans for international collaboration within academic circles even more problematic.

Nevertheless, Borgnis's handbook was held in esteem and used as a reference in professional activity, but was also an inspiration for teaching and research of the above-mentioned approach to machine analysis and machine classification, respectively.

Borgnis's book collection can be considered significant not only as an historical source of the machines of his time but also as an early modern approach to the study of the variety of machines for rational design and operation. A rediscovery of Borgnis's handbook collection deserves specific attention both in the analysis approach and its influence in machine developments for design and teaching in the 19th century, and even as an inspirational source for new solutions.

5 Conclusions

Giuseppe Antonio Borgnis is a figure in the History of MMS because he contributed to the clarification and expansion of machine classification with a modern approach towards practical applications with rigorous theoretical bases. His 9-volume handbook is significant from an historical viewpoint as a survey of machines at the beginning of the 19th century during the Industrial Revolutions and from a technical viewpoint for being one of the first modern handbooks on large machines, including an early standardization of terminology.

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Chun-Hung Chiang (1920–2008)

Hong-Sen Yan, Tyng Liu, Wen-Yeuan Chung, Shyi-Jen Tsai and Ching-Kuo Lin

Abstract Chun-Hung Chiang was a pioneer in the academic field of mechanism and machine design in Taiwan. His major research contribution was in the study of spherical mechanisms. While associated with numerical computing methods going back to the 1970s, he introduced body guidance, path generation, and function generation to the classical spherical mechanisms, and he developed concise research in regard to spherical mechanisms. Furthermore, he founded the committee/society of mechanism and machine theory in Taiwan and led the group to join IFToMM in 1983.

1 Biographical Notes

Chun-Hung Chiang (Fig. 1) was born on December 28, 1920 in Beijing, China. He grew up during a time of war, and through all the difficulty, he received a Bachelor's Degree in Aeronautical Engineering from the National Central

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Fig. 1 Chun-Hung Chiang (1920–2008)

University in Sichuan in 1943. He then joined the Third Aircraft Factory of the Chinese Aviation Commission (later the Chinese Air Force) as an airplane designer. In 1947, he was assigned to work in Taiwan. In 1948, he retired from the Air Force of the Republic of China (Taiwan) and became a Lecturer in the Department of Mechanical Engineering at National Taiwan University. In 1952, he was promoted to Associate Professor, but resigned 2 years later in 1954 so as to prepare himself to study in Europe and so that he could start to write a book "Mechanisms" (Chiang 1957) at the same time.

In 1957, he went to Germany and worked for Torpedo (a typewriter company) as a trainee for 6 months, and then for MSO Schleiftechnik GmbH as a design engineer for 4 years.

In 1961, he began a stint at the Swiss Federal Institute of Technology (Eidgenossische Technische Hochschule) as a teaching and research assistant. In 1963, he went to the University of Birmingham for a PhD study. He received his PhD from the Department of Mechanical Engineering in 1969, and later on was appointed as a Lecturer in the same department at the University of Birmingham.

In 1973, after drifting abroad for 16 years, he decided to go back to Taiwan, and began his academic career as a Professor in the Department of Mechanical

Engineering at National Taiwan University. In 1990, he retired with the honour of Emeritus Professor.

Professor Chiang started his research on kinematics of mechanisms in 1973 at the age of 53. From 1973 to 1990, he was the advisor of 8 M.S. students and (co-)author of 5 books, 26 journal papers (Mechanism and Machine Theory and ASME Transactions) and 11 other papers.

Professor Chun-Hung Chiang died on December 2, 2008 in Taipei at the age of 88.

2 Research Achievements on Spherical Mechanisms

Professor Chiang's book titled "Kinematics of Spherical Mechanisms" can be considered of great importance (Fig. 2; Chiang 1988, 1996, 2000a).

A spherical mechanism is a special case of spatial mechanism. The links of the spherical mechanism move on the spherical surface and the axes on which the links rotate coincide with the centre of the sphere. From 1950 to 1990, many papers were published on the theory of spherical mechanisms. Although there are quite a few similarities between spherical mechanisms and plane mechanisms, the mathematics is more complicated when analyzing and establishing spherical mechanisms.

Professor Chiang was highly interested in spherical mechanisms and therefore studied this topic quite intensively. He published several papers in the field of spherical mechanisms, especially on spherical four-bar linkages. One that is worth mentioning is the introduction of the pole and instantaneous motion of plane mechanisms into the synthesis of spherical mechanisms. Analytical solutions can be obtained at either finitely or infinitely separated positions, no matter whether for spherical body guidance, path generation, or functional generation.

Professor Chiang noticed that a great many researchers had published literature on spherical mechanisms but not a single book contained a collection of the theories regarding this topic thorough enough to qualify as a complete introduction. He started to collect and study literature on spherical mechanisms along with his own research in the early 1980s, and eventually authored the book "Kinematics of spherical mechanisms" in 1988, a book as thorough in its detail, including the texts and figures, as Professor Chiang himself had always been in his career as an educator. This book covers everything from the basics of spherical mechanisms to profound theories from a collection of around 200 sources, including a wide range of study fields, which indicates just how meticulous this gentleman was.

The book has been cited over and over again in hundreds of papers and even in patent documents. One may argue that this book is a classic for its analysis, design and application of spherical mechanisms.

Another important book by Professor Chiang is "Kinematics and Design of Planar Mechanisms" (Fig. 3; Chiang 1997, 2000b, 2002). The book covers the contents of Rudolf Beyer's work "Kinematische Getriebesynthese" (Beyer 1953),

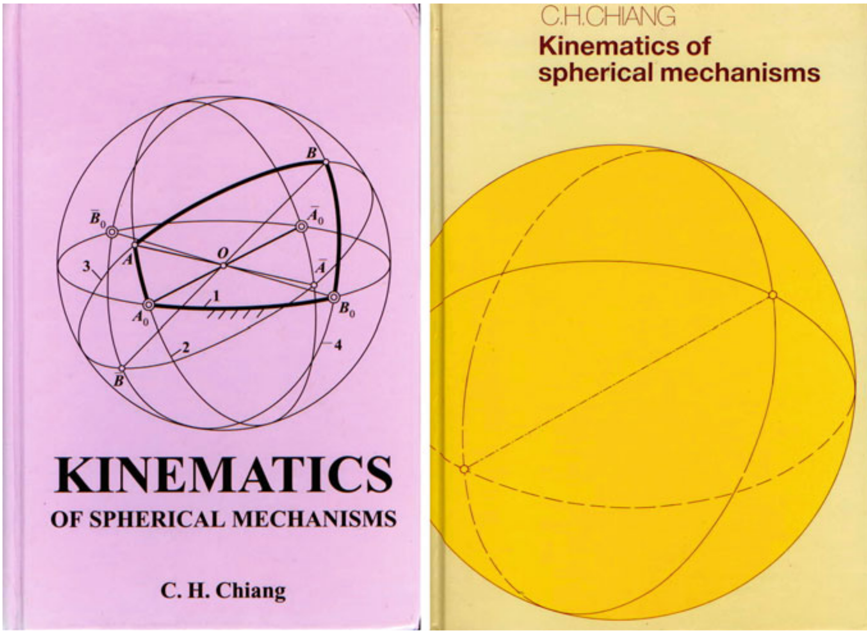

Fig. 2 Book covers of kinematics of spherical mechanisms (Chiang 1988, 2000a)

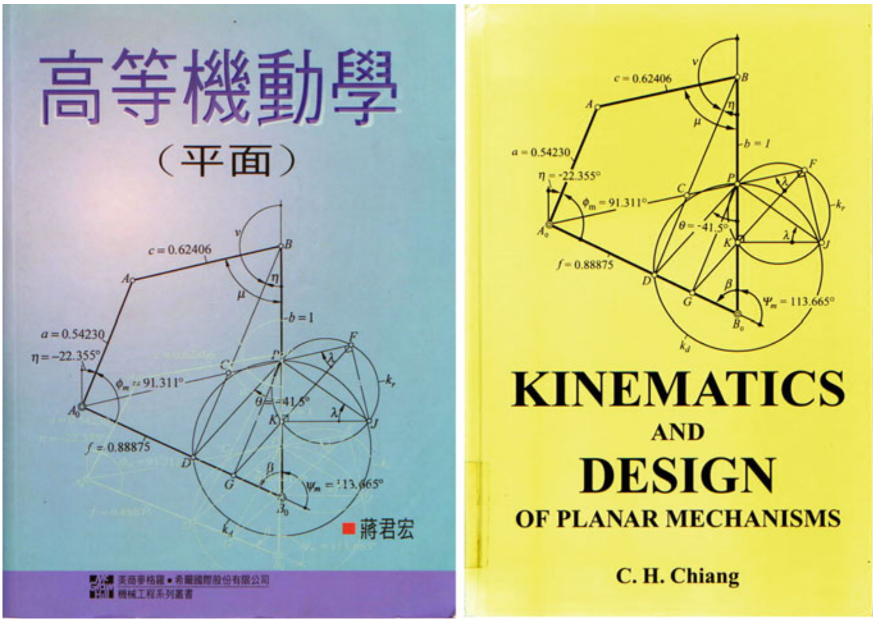

Fig. 3 Book covers of kinematics and design of planar mechanisms (Chiang 1997, 2000b)

adding material developed over the course of the 40 years since that book's publishing. It begins with the introduction of the concept of pole and theories derived, using the resulting analytical methods for analysis and synthesis of plane mechanisms, including body guidance, path generation, functional generation, and harmonic analysis. It stands as the most complete collection to date of information regarding kinematic synthesis of plane four-bar linkages.

3 Pioneer in Taiwan's IFToMM Society

Established in 1969, the International Federation for the Theory of Machines and Mechanisms (IFToMM, now the International Federation for the Promotion of Mechanism and Machine Science) is the largest international academic organization for mechanism and machine science. The IFToMM has a worldwide World Congress assembly every 4 years. Professor Chiang presented a paper (Chiang 1979) in the 5th IFToMM World Congress in Montreal, Canada in 1979, which made him the first Chinese scholar from Taiwan to attend an IFToMM activity.

In February 1983, Professor Chiang established the "Committee for Mechanism and Machine Theory" under the Chinese Society of Mechanical Engineering (CSME, Taipei) with himself as the committee Chairman and Professor Hong-Sen Yan as the Vice-Chairman. Then, he attended IFToMM's 6th World Congress held in New Delhi, India in December 1983, and successfully helped Taiwan (Chinese–Taipei) become an IFToMM member at that World Congress. As a result, there were, respectively, 2, 4, 16, and 19 delegates from Taiwan for the 1987 (Seville, Spain), 1991 (Prague, Czechoslovakia), 1995 (Milan, Italy), and 1999 (Oulu, Finland) IFToMM World Congresses.

Led by Professor Chiang, separate from the CSME (Taipei), the Chinese Society of Mechanism and Machine Theory (CSMMT, Taipei) had its first member assembly on March 24, 1990 at National Taiwan University (Taipei), with Professor C. H. Chiang as the first President and Professor H. S. Yan as the first Vice-President of the Society. In October 1990, CSMMT's first journal "Mechanism and Machine Design" was published, with Professor Chiang as the first editor-in-chief. In December 1998, the first National Conference on the Design of Mechanisms and Machines of the CSMMT was held at National Cheng Kung University (Tainan), hosted by Professor H. S. Yan, with 35 papers published in the Proceedings.

Professor Chiang retired in 1990 at the age of 70, but he never stopped contributing to Taiwan's IFToMM. In addition, he led a group of 18 researchers to work on and produce a collection of "Terminology of Mechanism and Machine Theory," which was published in 2000 by the National Institute for Compilation and Translation (Taipei, Taiwan; Chiang et al. 2000c). Even at his 80's, "Mechanical design" (Chiang 2009) was completed before his death and published in 2009.

4 Conclusion

Taiwan's academic activities in regard to mechanism and machine science/design would not have reached the scale and solid results that we know today if it were not for Professor Chiang's vision and efforts.

He was rigorous in research, solid in teaching and kind in advising young scholars. He received many awards, including the Distinguished Research Award of the National Science Council and the Academic Award of Sun Yat-Sen Academic and Cultural Foundation (Taipei).

For many years, we learned a lot from Professor Chun-Hung Chiang. If one were to ask what Professor Chiang was like, the answer would be, "He was quite a Professor!" The good professor may no longer be with us, but he will be respected and remembered forever.

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Konstantin Vasiljevich Frolov (1932–2007)

Olga Egorova

Abstract Konstantin Vasiljevich Frolov was a well-known scientist and one of the pioneers of vibration study, including its influence on machines and human beings. He received many high honors and awards in his Motherland and great recognition abroad. He devoted his life to the development and promotion of the Russian (Soviet) Engineering School, contributing to modern Mechanism and Machine Science through his work as engineer, scientist, and as the Director of the Institute for Machine Science named after A. A. Blagonravov of the Russian Academy of Sciences in Moscow.

1 Biographical Notes

Konstantin Vasiljevich Frolov (Fig. 1) was born on July, 22, 1932 in "Kirov City" (which, since 2004, includes the town of Kirov and 12 villages, comprising 40,000 people) of the Kaluga region (Russian Federation) into a family of office employees.

His mother, Frolova Alexandra Sergeevna, was a doctor who worked in X-ray-offices of military and municipal hospitals. His father, Frolov Vasily Ivanovich, was arrested in 1937 and became a political prisoner. Later, he was rehabilitated and left to live in Kazakhstan (USSR).

Konstantin Frolov was always open about the way his youth was affected by the terrifying period of World War II. Still, he was lucky and managed not only to survive but to obtain a good education.

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Fig. 1 Academician Konstantin Vasiljevich Frolov

From K. Frolov's personal childhood memoirs:

> …during those war-time years I collected shell splinters, German bombs and mine fragments, but not foreign stamps. Those splinters had freakish, but rather natural forms with a bright shine. They drew my attention to the phenomena of solid state physics, which at that time was very unclear to me, and already made me wonder what it was.

Konstantin Vasiljevich always spoke well of his first physics teachers, V. P. Prokonin and A. I. Morozov. It is interesting to note that Alexey Ivanovich Morozov (1928–2009) became known afterwards as an outstanding scientist, the founder of a completely new type of plasma jet motor, which was used successfully in the space industry.

As a young boy, Konstantin dreamed of being a military pilot, but life had very different opportunities and fortunes in mind for him. Thus, in 1956, Konstantin Vasiljevich Frolov graduated with honors from Bryansk University of Transport Machinery (Russia). As a student enlisted in the most prestigious specialty of "Turbine construction," he had already begun an active participation in the research work of professorial chairs that would motivate him to become a scientist in the future, and soon after graduation, young Frolov was directed «on a student distribution basis» to the Leningrad Metal Plant (Saint Petersburg today), one of the largest power engineering enterprises in the Soviet Union at that time. There, he began his activity in the design bureau for steam and gas turbines, later switching over to the laboratory “Vibration Study of Steam and Gas Turbines”.

In the late fifties, the Plant was visited by a group of famous Soviet scientists, Fedor Menasjevich Dementberg, Sergey Vladimirovich Serensen and Victor Olimpanovich Kononenko among them. They examined the work taking place at the laboratory, met the young researcher and had a private talk with him. As a result, in autumn 1958, Frolov entered a PhD programme at the Institute for Machine Science (IMASH RAS) in Moscow, and joined the Institute’s staff. Professor Victor Olimpanovich Kononenko was appointed to be his thesis tutor. From that time on, Frolov would be connected with the Institute in perpetuity (1958–2007).

Having started his scientific activity with research on the general problems of TMM, durability and reliability of machines, and the theory of oscillation, Frolov would concentrate thereafter on the development of vibration technology and vibration isolation of a human operator.

As an academician, Frolov proved that the main problems in engineering must be solved by greater reliance on brainpower rather than workforce. Material, financial and manpower resources in science are not boundless; this is why his special attention went towards making rational use of them. It was also at this time that he began promoting “human-free” technologies with broad use of robots.

2 Activity at the Institute for Machine Science

The Federal Budget-Funded Research Institute for Machine Science, named after Anatoly Arkadjevich Blagonravov of the Russian Academy of Sciences (IMASH RAS), is a respected institution, both in Russia and abroad, that solves fundamental research problems in the field of machine science and engineering (http://eng.imash.ru). Over the seven decades of its existence starting in 1938, IMASH RAS has been successfully performing its research activities alongside dealing with national problems, investing many of the developed results into national industries: machine-tool and automobile manufacturing, agricultural, metallurgical, petrochemical, aviation, space rocket, nuclear, defence and robotics engineering.

At IMASH RAS, Frolov began his research into the influence of energy source properties on the stationary and non-stationary vibration of mechanical systems. In 1962 he successfully defended his first thesis with the theme “Influence of energy source properties on vibration of autonomous systems”, in which the problem of the stability of various modes for a usual nonlinear, a parametrical, and a self-oscillatory system were studied, as well as showing the link (from a mathematics and physics point of view) between the nonlinear system parameters and the energy source characteristics.

Later, the updated results of his thesis were included in a book “Interaction of Nonlinear Oscillatory Systems with Energy Sources” (Frolov and Alifov 1985), translated into English and published in the USA (Frolov and Alifov 1990).

In parallel with his postgraduate study in 1960, Frolov attacked the problem of resonance states of solid bodies with nonlinear elastic links. As a result, the observed dependence of a resonance state on an energy source was shown and proved through mathematic methods, as well as some new objective laws reflecting the energy source influence on vibration of solid bodies being discovered and examined (Frolov 2007).

The young scientist’s success was noticed, and in 1964 Frolov was given the title of senior research assistant. Moreover, he was appointed to be the chief of a new vibration research laboratory, where he managed to combine his theoretical work, scientific publications and management duties. Thus, his engineering and managerial career began.

In October 1975, after the death of academician A. A. Blagonravov, Frolov (Fig. 2) took his place as Director of IMASH RAS. From that point on all the way up to his tragic death, he served as Head of the Institute. It is greatly to his credit that several new scientific fields were developed at IMASH, such as machinery and equipment vibroacoustics, power engineering objects strength, industrial robotics, biomechanics, rocket and space machinery and many others.

He was one of the first to intuit some of the most impressive breakthroughs in science. As he himself repeated, the objective law was clearly reflected in the birth of new directions at the junction between various fields of knowledge, such as biochemistry, biophysics, chemical physics, physical chemistry, molecular biology, and informatics. Modern directions applied the vast potential of the mathematical apparatus and computers; they required new specialists with a wide view of technology and science. Thus, Frolov attracted many young and ambitious researchers to the Institute.

While he was the Director, three new buildings were constructed, and during the second half of the 1980s, he organized a network of research institutes, establishing IMASH branches all over the Soviet Union, and became the General Director of the “United Institute for Machine Science”. That was done under the auspices of the USSR Academy of Sciences, to assimilate the IMASH wealth quickly and to link the established scientific schools and traditions, rather than to organize new independent research institutes. The main goals were to apply the results of basic research to the solution of engineering problems, to make generalizations on advanced accomplishments, and to forecast trends in the development of leading engineering branches.

In his own words, “the industries covered by the term ‘engineering’ play a special role in the modern economy affecting the people’s standard of living and a country’s defence capacity”. For accelerated development of the engineering industries, it is not enough to have an “arithmetical” increase in the output of all types of machinery, as the main task is to make more efficient use of machinery and cut down the time required to introduce the latest scientific-technological

Fig. 2 Konstantin Vasiljevich Frolov at IMASH RAS

achievements. That is why he put all his strength into providing the rapid expansion of the engineering industries and their radical overhaul.

In the 1970s, before Frolov was appointed Director of IMASH RAS, the problem of self-synchronization of oscillatory systems with two energy sources had been successfully solved by Frolov's scientific team, as well as the problems of the application of theoretical results for the design of new machines of vibrating principle of action.

The results of the extensive research and numerous experiments conducted in the late sixties by Frolov have received full reflection in a great number of scientific publications and were summarized in his thesis for a doctoral degree, "Vibration in Machines with Variable Parameters in Application to a Hydraulic Power Drive Dynamics". In 1970 Frolov was awarded a scientific doctorate in Engineering Sciences (Dr. Sc. Eng.).

The next step was a number of very interesting studies into human operator behaviour as a live link of an integrated biotechnical system, conducted with Frolov's personal participation in the vibration technics and technology laboratory, as well as in the biomechanics department of IMASH. These studies resulted in the idea of transition to the vibration field rearrangement, and as a result, allowed not only the exclusion of a harmful vibration influence on a human being, but on the contrary, raised the labour activity of a person with the help of vibrostimulation. The successful idea to turn the negative influence into a positive brought up a number of essentially new and courageous experiments on vibrostimulation and vibration therapy, in the field of bone fabric surgery in particular. The results were presented first as a lecture, "Dependence on Position of the Dynamic Characteristics of Human Operator Subjected to Vibration" (ASME 1970) and were later included in his publications (Frolov 2007).

Under Frolov's majestic talent for negotiation, the very interesting and unique collaboration between IMASH and the well-known USA aviation firms "Boeing" and "McDonnell Douglas" was established on a contractual basis. As a result, the whole complex of problems in the field of aviation and space technics was solved. For example, composite materials, which include polymers or metals reinforced with carbon, boron, silicate or even organic compound fibre, were used for the manufacturing of rocket tanks for fuel, the suppression of micro gravitational influences in space vehicles, and creation of comfortable conditions for the work of cosmonauts, and were also widely used in the "AN-24 Ruslan" aircraft (NATO reporting name: Condor)—a freight plane with the largest payload in the world. Machine elements made out of composite materials are of greater strength, longer durability and lower weight of 20–30 %, as compared to those elements made out of conventional materials. The most recent significant activity of the An-124 was in April 2011, when an aircraft was used to airlift a large Putzmeister concrete pump from Germany to Japan to help cool reactors damaged in the Fukushima nuclear accident and the An-225 was used to transport an even larger pump to Japan from the United States. (Unfortunately, there are no openly published works on the topic).

In accordance with Frolov's proposal, the experience accumulated by the aircraft and spacecraft industries in the sphere of reliability was adopted by all engineering industries. The principals of the approach to this vital problem were the following: the reliability of a new machine should be taken into consideration at the stage when work is conducted on the technical documentation and manufacturing process of a new product. Special test benches meeting the latest scientific requirements were carried out for simulating the conditions under which a new engineering product should be able to work: intensive heat and cold, high pressures, vacuum, high dust content, vibration, impact and torque.

IMASH RAS worked on a wide range of subjects. For example, it produced an industrial-type laser complex with a beam which was programmed to shift over the surface of a machine element. Advanced diagnostic systems were also developed. These systems were able to locate even the most minor trouble in the functioning of the most sophisticated equipment.

Frolov headed the investigation into the phenomenon of superductility that consists of the following: by adjusting the temperature and thereby decreasing the material's resistance to deformation, it is possible to control the formation of the crystalline structure in it. In this case, the force needed to stamp or to form the element will be several times less. Moreover, when an element is machined using this technique, it is characterised by minimal residual stress, if any at all. Thus, fatigue cracks will not appear and the service life of such an element will be several times longer. The research results were published in Russia and abroad as a book, "Vibroacoustic Diagnostics for Machines and Structures" (Frolov et al. 1991a).

Also under Frolov's direct control, a number of researches were carried out devoted to the study of destructive vibration influence connected with the load increase on mechanism links and machine components, which leads to stability loss, fatigue breakages, and desired motion law changes. Later, the results were published in "Thermal Stresses and Strength of Turbines: Calculation and Design" in USA (Frolov et al. 1991b). The above-mentioned problems of machine dynamics were solved with the help of classical methods of analytical mechanics, vibration nonlinear theory, theory of variable weight mechanics, elasticity theory, etc. On the other hand, the effect of vibration was used to develop pumps without frictional elements.

This very interesting experience was achieved with ultrasonic systems that play a special role in the wide range of vibration machines and devices. The ultimate strength of metals is nearly one hundred times greater than that of metals under ordinary conditions. Thus, some machines of even the best design use only a negligible amount of the potential strength of metals.

Frolov's main achievements at IMASH RAS, recognized all over the world, is that he founded the branch of biomechanics dealing with the effects of exposure to machine vibrations and formulated the scientific principles underlying the theory of systems used to protect human operators from such vibrations. The research results were published in "Applied Theory of Vibration Protection Systems" (Frolov and Furman 1980); in "Vibration Technology: Theory and Practice" (Frolov and Goncharevich 1991a, b); and in "Vibrations in Technics, Reference Book" (Frolov 1978–1981, 1995, 1999).

However, Frolov's activity at the Institute was always aimed towards practical application and to a teaching of both the solutions and the approach for the formation of clever professionals. Being the Head of the Institute, he directed the work of its departments and branches in Moscow and outside. He achieved everything through his work and talent. Thus, he contributed considerably to making IMASH RAS into one of the most famous and successful scientific institutes not only in Russia but all over the world.

From K. Frolov's personal memoirs:

> Here (IMASH RAS) I have found my way from being a post-graduate student to being an academician and the Director of the Institute. The Institute became my life, my daily care, my pleasure, and sometimes my pain, my disappointment… I am happy that for more than 30 years… I have headed this wonderful collective of remarkable people, outstanding scientists, and employees of the Institute for Machine Science of Russian Academy of Sciences.

3 Teaching Activity

For more than 45 years, Konstantin Vasiljevich Frolov combined his research with teaching, and is equally remarkable for his contribution to the education of young scientist and engineers. He was an excellent teacher, and his rich technical and scientific culture enabled him to offer interesting courses in the sphere of machine mechanics, machine parts, and dynamics. His lectures were always full of the latest information about achievements in international science and technology. He continued the Russian traditions and skilfully organized the educational process, promoting the introduction of modern methods of teaching.

From 1961–1976, he worked at the Moscow Technology Institute of Light Industry, and in 1973, he was elected their Department Chairman of "Theoretical Mechanics and Theory of Mechanisms and Machines". He wrote a number of lecture courses, methodical study guides, and a new set of laboratory operations manuals.

As the Chairman, he insisted that each professor-lecturer should engage in very active scientific researches together with the students. In recognition of his overwhelming activity, Frolov was conferred in 1971 with the academic status of Professor in the field of Mechanism and Machine Science.

In 1978 Konstantin Vasiljevich headed a Chair of "Theory of Mechanisms" (TM) at Bauman Moscow State Technical University (BMSTU) (Fig. 3), a position he maintained up to his death in 2007, as well as being a "Board of Studies" member and a "Dissertation Council" member of the University.

His textbook (Fig. 4) "Theory of Mechanisms and Mechanics of Machines", based on a new concept of teaching the "Theory of Mechanisms" course, has been published in four editions at BMSTU (http://bmstu.ru). Frolov was also the editor of the original manual for higher technical schools and colleges "Mechanics of industrial robots" (Frolov and Vorobiev 1988–1989), which was published in Moscow by Vicshaya Shkola. Even today, in the 21st century, it can be used as a handbook for designers and experts in the field of industrial robotics.

Frolov was one of the first to understand that no higher educational establishment or secondary technical school could give its graduates all the knowledge and skills needed to function efficiently at work. He voted for reform of the higher education system that could make the institutions of higher education more flexible in responding to the needs of scientific and technological progress. He promoted the solution to this problem as teaching future researchers and engineers from their first day at school how to work independently, when the thirst for new knowledge and desire for constant study should come naturally to a present-day specialist. This is a pivot of the developing concept of uninterrupted learning. His words that "everyone must study and study constantly" are as relevant as ever, perhaps even more so than in the last century.

Anyone who ever had dealings with Konstantin Vasiljevich Frolov recognized his unusual open mind. Endowed with a prodigious memory and remarkable working power, he fully engaged himself in guiding younger colleagues and subordinates, conducting doctoral theses, and lecturing at world famous technical universities. He appreciated not only the analytical and experimental skills, but also the organizational skills of his colleagues and students. He thought that such qualities as business knowledge and the ability to understand people were necessary for a modern science leader. He tried to push people with these talents and to move them up the career ladder. Not coincidentally, more than 25 of his former post-graduate students became doctors of science and professors. The author of

Fig. 3 Main building of Bauman Moscow State Technical University

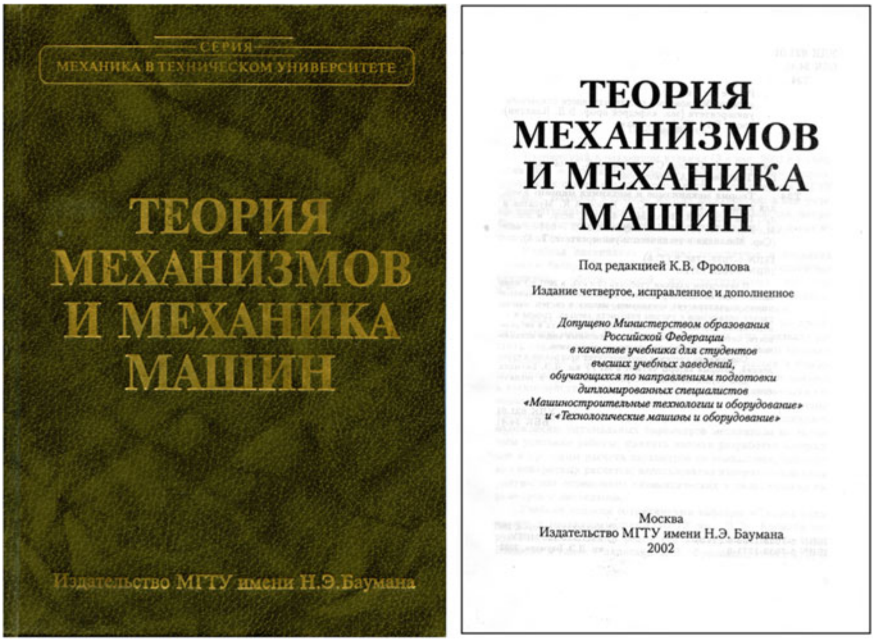

Fig. 4 "Theory of mechanisms and mechanics of machines" textbook (Frolov 2002)

this paper was also among those young students who under his tutelage managed to graduate from university, enter the post-graduate program and gain a degree of Doctor of Science.

4 List of Main Works

The list of scientific works by Konstantin Vasiljevich Frolov includes more than 500 titles. His series of works on machine dynamics were honoured with the Gold Stodola Medal.

The most interesting results of Frolov's research were published in fundamental monographs, textbooks and books:

"Applied Theory of Vibration Isolation Systems" (1980),
"Theory of vibration technics and technology" (Frolov and Goncharevich 1981),
"Scientific foundations of engineering progress" (1982),
"Membrane Vibration in a liquid" (Frolov and Antonov 1983),
"Methods of Machine Development and Modern Problems on Mechanical Engineering" (1984),
"Vibration is a friend or enemy?" (1984),
"Interaction of nonlinear oscillatory systems with power sources" (1985),
"Vibration Technology: Theory and Practice" (1991);
"Theory of Mechanisms and Mechanics of Machines" (2002)
"Selectas. Vibration Technics" (2007).

From 1978–1981, he participated in a six-volume scientific edition "Vibrations in Engineering," issued by the publishing house "Machinostroenie", Moscow, acting as scientific editor of two volumes of this edition (volume 1, 1978; volume 6, 1981).

His fundamental work "Science in the strategy development" (1991), based on the results of his many-sided creative activity, should also be mentioned, as well as the Encyclopedias "Machine-building" and "Security of Russia", for which he was the editor.

5 On the Circulation of Works

Many of Frolov's works were translated into foreign languages; some of them were reissued in Russia, especially his textbooks. For example, the textbook for technical universities "Theory of Mechanisms and Mechanics of Machines" (Fig. 4) has sustained four editions. It was issued in Moscow by BMSTU Publishing House and has continued to circulate among students and professors.

His works were successful during his life and continue to be so today, cited by modern authors and of great interest to the younger generation of researchers.

His main monographs "Applied Theory of Vibration Isolation Systems"; "Theory of Vibration Technics and Technology"; "Vibration Technology. Theory and Practice"; "Interaction of Nonlinear Oscillatory Systems with Energy

Sources"; "Thermal Stresses and Strength of Turbines: Calculation and Design" and others were translated into English and issued in the USA.

His book "The classification and peculiarities of oscillatory systems with limited excitation" (Frolov and Gluharev 1970) was translated into Slovak and issued in Bratislava.

Frolov actively participated in International Congresses and Conferences, giving lectures. For example, his report "Dependence on position of the dynamic characteristics of human operator subjected to vibration" (ASME, Frolov 1970) aroused much interest in scientists around the world, as well as his report during the VI World Congress on TMM.

The most successful of Frolov's works, in terms of circulation, are devoted to vibration studies. The processes and equipment which are based on vibrational and vibro-impulse influence by wave technologies are very popular among users of crushers, mixing devices, separators, pressing equipment, machines for surface treatment, finishing treatment machines, resonance equipment, vibration systems for WIG-ship movement, etc.

Frolov researched such systems with new properties, the main ones being the machine's dynamic circuit, frequency spectrum of its own vibrations and damping coefficient. Besides this, it is necessary to remember that modern vibrational, vibroimpact and other wave machines and devices may have considerable structural and technological variety, including drives with different operational principles in contrast to equipment of the usual type with rigid kinematic links and constant movement trajectory under any kind of loads. Based on the principles of vibration and wave methodologies, new planetary and biplanetary drives, chambers and special mixers were developed.

The technology of vibration crushing may play an important role in connection with the high frequency of oscillations of the crushing element, preliminary crushing of the products due to destruction of surface microcracks and defects in the inner structure of the particles. Crushing, in contrast to the usual process, is implemented in a more efficient way, namely by the stroke. Vibration crushers are also characterized by a range of technical and operational qualities. In the proposed systems, reduction of dynamic loads is provided, which makes it possible to decrease the installed capacity of the drive and construction sizes of elements. The crushing elements do not have a rigid kinematic connection, so the vibration influences do not transfer directly to the elements of drive and do not lead to breakages of the machines.

Under Frolov's direction, new transportation vehicles for passenger and cargo transfer (WIG-ships) were designed. They may carry up to eight passengers. They were certified and used as water transportation vehicles (lakes, rivers, coastlines and interisland ways) and land transportation vehicles (tundra, deserts) in Russia, Southeast Asia, South and North America and in Africa. WIG-ships do not require ports, aerodromes and roads. They consume less fuel and provide the opportunity for transfer over rough terrain. A WIG-ship is carried through the air by aerodynamic forces like traditional aircraft. The difference between their principles of movement is that a WIG-ship moves at the ground surface. This leads to the effect called “Wing-in-ground” (WIG), which refers to an aerodynamic air cushion.

However, the usage of the newest achievements in vibration, wave and vibroimpulse technologies makes it possible to create new highly efficient equipment for mixing polyfractional mediums and their compaction, and also makes it possible to create principally new devices.

Based on years of vibration studies, the six-volume monograph “Vibrations in technics” with Frolov as the editor (Frolov 1978–1981, 1995, 1999) is the first resource to cover this field comprehensively, starting from basic vibration theory and ultrasonics, from both fundamental and applied standpoints. Areas covered include vibrations in machines, buildings and other structures, vehicles, ships, and aircraft, as well as human response to vibration.

Almost every article provides a concise and authoritative introduction to a topic. The monograph includes essential facts, background information, and techniques for modeling, analysis, design, testing, and control of vibration. It is highlighted with numerous illustrations and is structured to provide easy access to required information.

6 Interpretation of the Main Contributions

Modern MMS widely applies achievements of all innovative sciences, from elementary particle physics and nanotechnology to genetics to the conquest of outer space to engineering, etc. The main contribution of academician Konstantin Vasiljevich Frolov to the development of theoretical, experimental and applied mechanics as a part of MMS is recognized by the scientists and specialists of many countries all over the world.

Frolov’s bibliography includes more than 500 published works (see the List of Main Works). Great interest among scientists and experts was caused by his monography “Methods of Machine Development and Problems of Mechanical Engineering” (Frolov 1984a, b), published in the context of the scientific series “Fundamentals of Machine Design”, initiated by Frolov. There is no doubt that this edition promotes considerable expansion of modern methods of machine design and helps designers, researchers, experts of mechanical, instrument and tool engineering, machine-building, etc.

It is necessary to note the Academician activity connected with the scientific literature edition, as Frolov was the editorial board chairman of the multivolume encyclopedia “Machine-Building”. 44 volumes have already been published to this day. The main aim of this edition is to promote essential improvement of quality of machines and efficiency of a machine-building complex in total. The encyclopedia shows almost all the highlights of the progressive methods and technologies of mechanical engineering and the best decisions in modern technics design and construction.

Contributing to national and international technical journals since 1977, Frolov was the editor-in-chief of the academic magazine "Engineering Science". Under his initiative, in 1990 the edition was transformed into a new magazine "Problems of Mechanical Engineering and Machine Reliability" (Fig. 5a) for the purpose of increasing the topic range and the information support level of fundamental and applied scientific researches.

Frolov was also an editor-in-chief of the international magazine "Mechanical Engineering and Automation Problems" (Fig. 5b), which received recognition among scientists and experts all over the world. Engineers and specialists from the USA, Finland, Hungary, Poland, Bulgaria, the Czech Republic, Slovakia and many other countries were presented by this magazine's editorial board.

Frolov regarded knowledge as a means of communicating with others. That is why the most important purpose of both international magazines was to inform about the most advanced research-and-production experience, new constructional materials, and high technologies, as well as to assist in multinational contacts between scientists all over the world.

Frolov also headed the editorial council of "Scientific and Technical Progress in Mechanical Engineering".

His meteoric career continued in 1976 when at the age of 44 Frolov was elected a corresponding member of the Academy of Sciences of the USSR (now RAS), moving up to full member in 1884. In 1985, he was made the academician-secretary of a new scientific branch, Machine-Building, Mechanics and Process Control Systems, and later, from 1985 to 1996, served as Vice-President of the Academy. Within seven years (1985–1992), he promoted the organization of perspective fundamental researches into and active participation of the Russian academic institutes in the solution to the most important applied problems of mechanics. He also worked out ways in which the results of scientific researches might be made economically effective.

Frolov made a great contribution as an editor and author, but he also established a new branch in science: biomechanics of the human being in work entailing the effects of vibration. He achieved well-earned international fame due to his inter-disciplinary studies in the field of mechanics, biomechanics, vibration, physics and ergonomics. Developed under his lead, the studies enabled the solution of a number of urgent problems dealing with operators of machinery and equipment creating an environment of vibration.

Another position that Frolov held was President of the International Fund "Znanie" (Knowledge), named after Sergey Ivanovich Vavilov (1891–1951), as well as being a member of many foreign academies and an active or honorary professor of leading national and foreign universities. He served as Academician of the All-Union Academy of Agricultural Sciences of the Soviet Union (VASKhNIL) from 1985 on, and was the Honorary President of the Academy of Engineering of Russia.

(a) (b)

Fig. 5 Academic magazines. **a** Problems of mechanical engineering and machine reliability. **b** Mechanical engineering and automation problems

He believed that accelerated social-economic progress should bring humankind to new frontiers. In the sphere of the spiritual life of society, this meant bringing the achievements of science and cultural values within the reach of the broadest masses of the population, and moulding a harmoniously developed personality.

Frolov was a great promoter of the most advanced technology and equipment, working hard at re-equipping and modernizing the technological enterprises of Russia. In this context, he saw the main tasks as being the more efficient use of machinery and qualitative renovations; cutting down the time required to put the latest scientific achievements into practice; and the establishment of intersecting scientific-technological complexes with the purpose of integrating science with production.

For the great services to his Motherland, academician Konstantin Vasiljevich Frolov was given the title of Hero of Socialist Labour, awarded two Lenin Prizes (Gold Star), and the State Prize. Among foreign prizes and awards, he received the Aurel Stodola Gold Medal of the Slovak Academy of Science, the "Silver Medal" of the Czech Academy of Science "For services to science and humanity", and the "Mikhail Pupin Gold Medal" in the former Yugoslavia.

Unfortunately, after a bout of serious illness, on November, 18th, 2007, Konstantin Vasiljevich Frolov passed away in Moscow at only 75 years old. Nevertheless, he had led the rich life of a man, a consummate professional, one who dedicated himself to Mechanism and Machine Science, and Applied Theory of Vibration Isolation Systems in particular. He was a very optimistic and goal-oriented person.

From K. Frolov's personal memoirs:

> The constant strong belief in good deeds and their fulfilment is the main source of optimism that always inspires me in finding the solutions to difficult problems.

6.1 Contribution to History of MMS

Frolov gave much of his attention to the History of Mechanism and Machine Science as well as to scientific heritage in general and the role of prominent domestic and foreign scientists in the formation of modern scientific knowledge. His book "Outstanding Soviet Scientists: Anatoly Arkadjevich Blagonravov", written in cooperation with Arseny Arkadjevich Parkhomenko and Mikhail Konstantinovich Uskov, was translated into English and enjoyed successful worldwide circulation. This detailed investigation shows the great contribution made by the Russian engineering school to the development of MMS. It is no small thing that, by his suggestion, the Institute for Machine Science (IMASH) is now named after A. A. Blagonravov.

Frolov supported the Workshop on the History of MMS (IFToMM) held in 2005 under his direction at BMSTU to recognize the significance of the Russian TMM developments.

Additionally, Frolov dedicated a number of interesting historical lectures and articles to outstanding scientists: Michail Vasiljevich Lomonosov, Ivan Ivanovich Artobolevski, Victor Olimpanovich Kononenko, Leonardo da Vinci and Isaac Newton in particular. His publication "Newton and Modern Mechanics" (Frolov 1988), devoted to the great English scientist, proves that mankind is obliged to Newton for ushering in a new epoch in natural sciences: physics, astronomy, mathematics, and engineering, on the basis of facts that for a period of more than 300 years after the initial publication of "Beginnings…" appeared only as insignificant amendments to Newton's theories.

With this publication, Frolov showed the important and instructive role of the History of Science and Technology. Firstly, we learn to appreciate what we possess today; secondly, the historical approach allows us to estimate the practical value of science; and lastly, the History of Science makes up for "short-sightedness" in estimates of discoveries already made and theories already developed. Newton's scientific activity represents one of the brightest and most decisive stages in the evolution of human thought. His works marked a quantum leap in a long history of quantitative accumulation of knowledge of Nature. His theories were a huge contribution to the development of science and all modern civilization.

6.2 Contributing to IFToMM

Frolov was a great promoter of MMS throughout the world and carried out a large part of his activities through IFToMM, as he understood the importance of international contacts for both Soviet (Russian) and world scientists. He was an active member and worked hard for IFToMM's prosperity until his death. He was elected an EC Member (1984–1991), established a new IFToMM Technical Committee "Human-Machine Systems" in 1983, took the position of its Chair from 1984–1989, and in 1999, he was awarded an Honorary Membership. Only two Russians were ever granted this title—K.V. Frolov and I.I. Artobolevski. He made certain that there was a big celebration for what would have been the 100th birthday of Ivan Ivanovich Artobolevski, the first President of IFToMM, inviting the members of the Executive Committee, Marco Ceccarelli (Fig. 6) and Ken Waldron, to Moscow.

Konstantin Vasiljevich gave many lectures at Congresses and Conferences and published his papers under the auspice of the Kluwer/Springer publishing house. Thus, in 1979, at the V Congress in Canada, he gave a lecture on "Modern problems of vibration researches of Man-Machine Systems"; in 1983, at the VI Congress in India, he gave the plenary report on the achievements and problems of modern MM Science; and in 1987, in Spain at the VII Congress he lectured with a conceptual report on the problems of mechanics in scientific and technical progress.

6.3 "Man-Machine-Environment" Systems

In the late '60s, Frolov was the first to formulate the main problems of vibration isolation of a complex system "Man-Machine-Environment", a new scientific field then. He showed that, as a result of technical and industrial progress, the speed and power of modern machines and other technological equipment increased greatly and created mostly negative external conditions for a human being that had not been investigated before. The result was that certain factors, previously insignificant for human life, took on enormous significance. The problem of the influence of harmful vibration loads has become acute.

As a result, the new and more serious problem appeared as to how to isolate a human operator from the influence produced by the special type of machines and equipment with a vibrating principle of action in the working process. Frolov's investigation proved that vibrations, acting on humans, can reduce their productivity and the quality of their labour. It was therefore quite important to study the influence of various factors in regard to the efficiency of an operator as a live link in the "Man-Machine-Environment" system, or as we call it now, the integrated biotechnical system. For the first time ever, Frolov proposed considering dynamic features of the body of a Human being as an oscillatory system. Under Frolov's

Fig. 6 Marco Ceccarelli and Konstantin Frolov in IMASH RAS

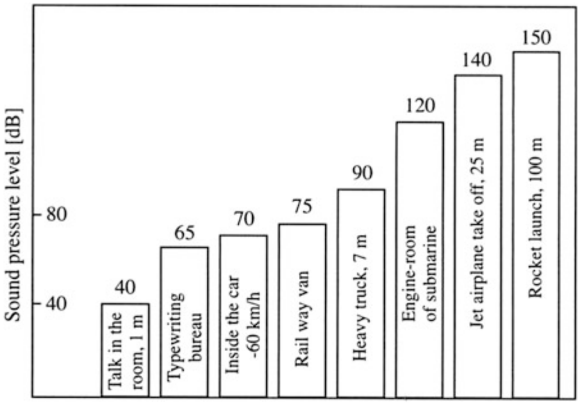

Fig. 7 Typical sound pressure levels (Frolov 2007)

direct participation, various dynamic models of the body of a human operator for various working positions under the influence of vibrations were developed and studied.

It is known that all kinds of vibration technology create vibrational and acoustic fields of varying intensity and over a wide sound spectrum. Typical sound pressure levels in dB are shown in Fig. 7 (Frolov 2007). A human being is mostly comfortable with a noise level below 40 dB, whereas noise levels of 80 dB and above are considered unacceptable.

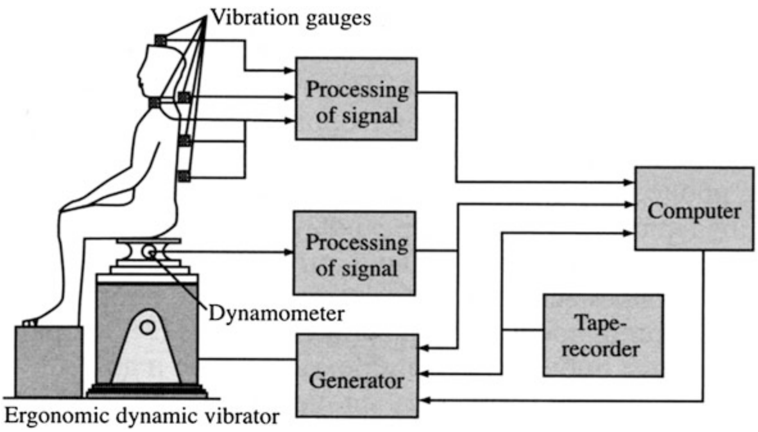

Fig. 8 Scheme of the unique vibration test stand (Frolov 2007)

To study the effect of vibration and noise on the functional and physiological features of a human operator, unique vibration test stands were created at IMASH under Frolov's direction (Fig. 8).

In Fig. 9, amplitude-frequency characteristics for different poses of a human operator are shown. Figure 10 illustrates the probability of mistakes by a human operator in the harmonic vibrational effect at 5 Hz (a), as well as the effects of vibration on various organs of a human operator (b).

Thus, Frolov became the founder of one of the most advanced scientific branches—Biomechanics of Man-Machine-Environment Systems. He carried out two Symposiums on "Man-Machine Systems", one in Udine (Italy) and one in Sukhumi (USSR).

Subsequent years proved the significance and applicability of his conclusions and achievements.

6.4 Contributing to Safety Programs

Konstantin Vasiljevich Frolov devoted a lot of his activity to the development and investigation of problems: resource and engineering safety of complex technical systems; theory and methods of the mechanics of catastrophes for engineering systems; theory of risks; the normative documentation on engineering safety, strength and resources of constructions. He was one of the ideological inspirations and a research supervisor for a popular multi-volume series of scientific books, "Security of Russia. Legal, Social-Economic and Science and Technology Problems", published by the International Humanitarian Foundation "Znanie" (Knowledge) under the support of the Security Council of Russia. More than 900 Russian experts and specialists have been invited to participate in those

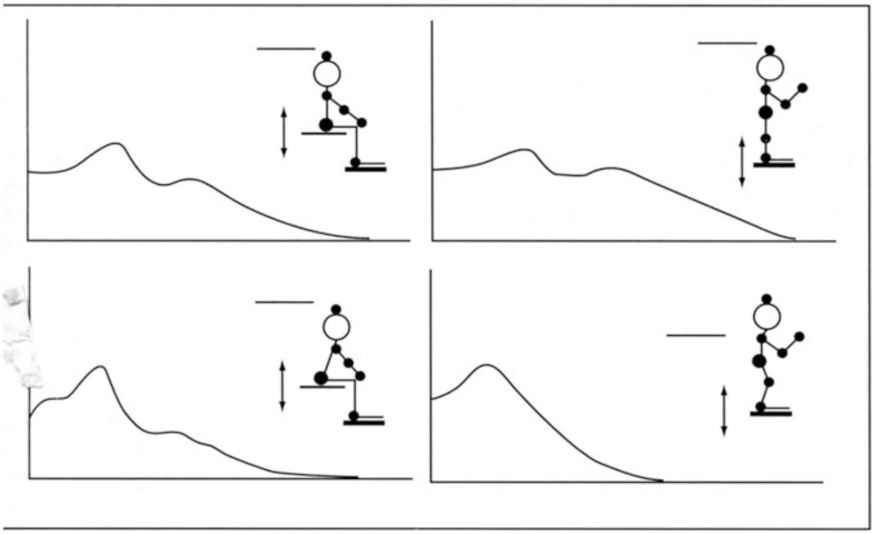

Fig. 9 Amplitude-frequency characteristics of a human operator (Frolov 2007)

publications. Actual achievements of Russian science and technology, up-to-date developments and international experience on different aspects of national security have been generalized in 35 published volumes, which are of inter-agency and inter-branch character correlating to the level and goals of an encyclopedia. To date, there are no analogues to such a publication dedicated to security and safety issues in the world; it remains unique.

Frolov gave very special attention to the problem of decreasing risk and maintaining the safety of complicated technical systems, human beings and environment in the occurrence of technogenic and natural calamities. Under his initiative, the nationwide scientific and technical "Safety" program was generated. Additionally, the International Safety Institute was created for the purpose of fostering cooperation in this matter all over the world.

It is necessary to bear in mind that the problem of multi-hazard risk assessment is complex and interdisciplinary. The solution requires analysis of technical, social, political, historical and cultural aspects and the problem of harmonization of national legislative frameworks in particular.

Frolov emphasized that the main goal was to reduce the vulnerability of critical infrastructures to catastrophes, developing protection systems, allocation of resources, and planning response and recovery operations after major catastrophes.

The realization of the "Safety" program came about owing to the assistance of the United Nations (UN) and close international cooperation with many countries: the USA, Japan, Great Britain, the Netherlands, France, the Peoples' Republic of China, South Korea, etc.

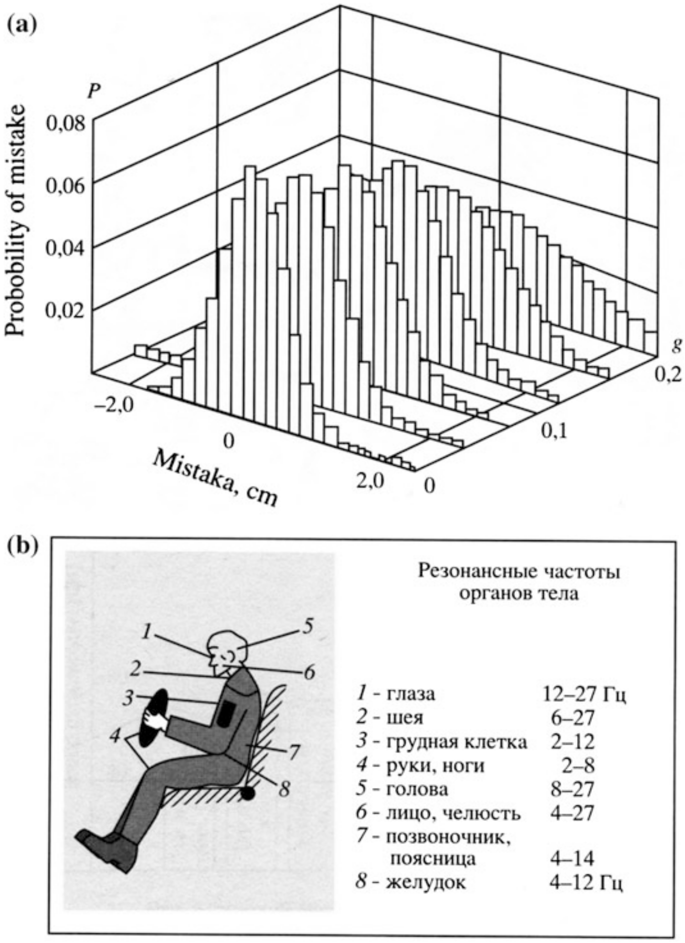

Fig. 10 **a** probability of mistakes of a human operator in the harmonic vibrational effect at 5 Hz. **b** Effects of vibration on various organs (Frolov 2007)

As a result, the creation of uniform international norms and requirements in the field of safety were developed.

In Frolov's own words:

> Today, there is an urgent need to develop an understanding of system behaviours and the vulnerabilities of interacting infrastructure networks in order to protect that infrastructure from naturally occurring hazards and man-made acts of terrorism. Infrastructure is the underlying foundation or basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions. The NATO-Russia Workshop focuses on the creation of a risk-informed analysis capability for modelling and predicting the behaviour of complex infrastructure networks; applying emerging technology to the problems of designing, constructing, monitoring, and operating critical infrastructure

> systems; and building an understanding of the social, economic, and environmental factors that affect, and are affected by, critical infrastructure. The problem posed by modern, complex infrastructure is that society has become completely dependent on the reliable functioning of these systems, yet, we do not fully understand the behaviour of these systems, which is subject to perturbations by natural hazards and malicious threats. Further, the characteristics of these hazards and threats are changing, driven both by global change and land use, and by changing political conditions. The disruption of the smooth functioning of civil infrastructure has important engineering and public policy implications, as well as social and environmental impacts.

It is obvious now, as Frolov predicted, that the importance of mechanical engineering's role in the solution of global problems of life support on the Earth in the 21st century be emphasized.

7 Concluding Remarks

Academician Konstantin Vasiljevich Frolov can be considered to be one of the great scientists of modern MMS. Through his extensive scientific activity, he approached numerous topics and contributed to the worldwide recognition of the Russian engineering school. His studies in the field of vibration, and complex systems of "Man-Machine-Environment", in particular, are fundamental and serve as a basis for the further development of MMS. As Director of IMASH and Vice-President of the Russian Academy of Sciences, Frolov made an enormous contribution to the development of theoretical, experimental, and applied investigations of machines. He was one of the founders of biomechanics in Russia, and the author and editor of many books, including the six-volume "Vibrations in technology" and the series "The foundations of machine design".

Frolov's main achievements in the field of vibro-pulsatile technics (percussive machines) can be identified in:

(a) Theory of periodic modes of movement of multi-mass systems of the above-mentioned type;
(b) Research into transitive modes, complicated periodic modes of movement of the simplest systems;
(c) Optimization results of systems with one and two degrees of freedom;
(d) Studies of synchronization phenomenon, including synchronization of unbalanced vibrators, etc.

His role in the development of mechanical engineering, applied theory of mechanic vibrations and vibration studies, biomechanics, Man-Machine-Environment Systems, vibration isolation and vibroacoustic diagnostics, nuclear reactor strength, and safety (natural and technogenic) problems is inestimable.

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Yeong-sil Jang (Unknown)

Moon-hyon Nam

Abstract Yeong-sil Jang (called Jang Yeong-sil in the Korean style, Unknown) was a Korean inventor and mechanical engineer who served as chief court engineer under King Sejong of the Joseon dynasty (AD 1392–1910). He made two Striking Clepsydras (*Jagyeong-nu*) in the course of equipping the Royal Observatory in AD 1432–38. He invented liquid-driven discrete ball-falling mechanisms and ball-driven discrete motion control mechanisms for operating dual-time-announcing devices, and applied these towards making the Striking Palace Clepsydra. He developed the mechanisms and employed them to make a functional astronomical clock, the Striking Heavenly Clepsydra, which worked in conjunction with a water-powered wheel drive. The clepsydra was a standard timekeeper capable of announcing twelve double-hours with a bell simultaneous with a visual display indicating the current time. Five night-watches and their twenty-five points could also be announced by way of a drum and gong without human involvement. The stories of his works are told in the *Annals of Sejong* issued in 1454 and are supplemented by accounts in the dynastic documents afterwards. His innovations on mechanism design led to subsequent astronomical clocks from the seventeenth century onwards in Korea. Not only did he assimilate the techniques of his Korean, Chinese and Islamic predecessors, but was also creative and innovative in the history of mechanism and machine design.

1 Biographical Notes

Partly due to the dynastic system, the major works and achievements of Yeong-sil Jang were recorded by official scholars of the royal court in the *Annals of Sejong*, called *Sejong Sillok*, the Veritable Records of the King Sejong. Among these, the

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Fig. 1 A painted portrait Yeong-sil Jang (*Courtesy* Scientist Yeong-sil Jang Memorial Society, Seoul, Korea)

stories of his invention and construction of the Striking Palace Clepsydra were written in the third article on the sixteenth day of the ninth lunar moon of the fifteenth year's and in the fourth article on the first day of the seventh lunar moon of the sixteenth year's (AD 1433 and 1434, respectively) *Annals of Sejong*. The Records of the Announcement of the Clepsydra Pavilion (*Borugak-gi*) on the Striking Palace Clepsydra and Yeong-sil Jang written by Don Kim (1385–1440) and Bin Kim (before 1445) in 1434 consisted of the memoirs written by Don Kim and inscriptions with a preface by Bin Kim (see Fig. 2). The two chroniclers had been collaborative members on Jang's research and development of astronomical instruments and clocks to equip the Royal Observatory from 1432 to 38. His inventions and innovations on mechanism design led to the construction of subsequent astronomical clocks from the seventeenth century onwards in Korea.

During Joseon, the biographies of the king as well as the minsterial-class (court Rank 2B or higher) were recorded in the dynastic annals, known literally as the *Sillok*. The annals covered important events that occurred during the reign of each king and brief entries were included on significant achievements by the ruler's subjects, including those of Yeong-sil Jang (Fig. 1). More than ten entries on him appeared in the *Annals of Sejong* during his twenty or more years of service to King Sejong. In addition to the official records, extant writings on him include the *Genealogy of the Asan Jang Clan* and documents on his works. Yeong-sil Jang was born to a high descent family around 1380's in Gaeseong, the capital of the Goryeo kingdom. According to the *Annals of Sejong* from 1433, his ancestor came from the Suzhou-Hangzhou area of Yuan China. His mother was an officially-sanctioned entertainer known as a *gisaeng* and he served in the Dongnae subcounty in Left Gyeongsang Province as a government slave during his youth. Dongnae was the closest area to Japan and the seat of a naval base.

According to the *Genealogy of the Asan Jang Clan*, the first settler (1st generation) at Asan, on the central west coast of the Korean peninsula across the Yellow Sea from mainland China, was a Chinese general named Jiang Xu, the Commander-in-Chief of the Imperial Army who was exiled from Northern Song at Kaifeng around 1120 after the war between the Song and the Jin Tatars. From that time on, his descendants lived at Asan and Gaeseong, serving the Goryeo government as higher officials, mostly in military posts. Sung Jang, of the 5th generation, served concurrently as a Director of the Astro-calendric Office (*Seoun-gwan*) and the Weaponry Office. Five of Yeong-sil's father's brothers (8th generation) all served as ministers in the government just before the fall of Goryeo, so they might have resisted the new Joseon regime. Four brothers survived by escaping from the capital to the countryside in Gyeongsang Province. Only Yeong-sil family remained in the capital; his father, Seong-hwi Jang, was executed and the social status of the remaining members was lowered, forcing his mother to be a *gisaeng*.

The above-mentioned records are confirmed by the *Annals of Sejong* of 1433. In this instance, we have definite information in the article on the hometown, family, personality, recruiting, and selection of Jang, as well as the invention of the Striking Palace Clepsydra and its elaborations, Yuan Emperor Shun Di's Palace Clepsydra (*Gong-lou*) of [1350] (History of Yuan 1976), and Jang's special promotion from the *Haeng-sajik* of court Rank 5A to 4A *Hogun* [a general] of the Five Commands (*Owi*) of the army:

> … [the King] said, "The ancestral hometown of the executive supervisor (*Haeng-sajik*) Jang Yeong-sil was the Suzhou-Hangzhou area of the great Yuan, and his mother was a *gisaeng*. He displayed greater skill than most ordinary men, so former King Taejong (r. 1400–18) recruited him, as did I. There were discussions about assigning him to a supervisor *Byeoljwa* (court Rank 5A) at the Bureau of Royal Attire (*Sangui-won*) during the years 1422–23… so I assigned him to a supervisor. Yeong-sil Jang has not only dextrous skills, but his personality is also excellent and he is smarter than any of the others,…, now he has created a Striking Palace Clepsydra, and though he followed my guidance during its construction, nobody could have made it except him. I heard that there was a Striking Palace Clepsydra during the reign of Shun Di [Togan Timur, r. 1333–67] of Yuan, but it probably would not work with the same accuracy of Yeong-sil's. In consideration of his reward for inventing such a distinguished instrument, which shall be transmitted through all ages, I am willing to select him to be a *Hogun.*"

As a government slave in Dongnae, Jang would have had to make and repair weapons, build warships, print books, and so on. However, the Joseon government treated the registered craftsman as government slaves, which were quite different from private slaves, although similar to agricultural slaves. They could be freed in some cases, their social status could be raised, and they were allowed to enter government service. Jang was a very talented and ingenious artisan, and it is said that the sub-county magistrate recommended him to King Taejong, who was looking for talented people. By law, his registration in the local government was transferred to the capital so that he could serve at the royal court. As mentioned above, he served as a court engineer under two kings from the early 1400s to 1442. After the enthronement of Sejong, he was freed from lowborn status and assigned as a supervisor at the Bureau of Royal Attire in 1423. In 1424, he was sent to Yanjing (now Beijing, China) for on-the-job training in astronomy with two royal astronomers. He was put in charge of handicrafts and engineering affairs at the royal court from 1434, and eventually promoted to a court Rank 3B *Dae-hogun* [a grand general of the Five Commands]. (*Annals of Sejong* 1438) In 1442, Jang oversaw the making of an open palanquin (sedan chair) for the king. The vehicle broke down during a royal procession, and Jang was punished along with his assistants. His appointment letter was revoked, and he was forced to resign his post. Jang's judgement was subsquently suspended by special royal decree. The dates of his birth and death are not known, and most of his later years are shrouded in mystery.

One of the famous official scholars from King Sejong's reign, Geo-jeong Seo (1420–88), mentioned Yeong-sil Jang and court musician Yeon Pak (1378–1458) in his *Essay at Writing Garden* (Seo 1487) as follows:

> When King Sejong creates Korean ritual music (*A-ak*), Yeon Pak achieves it,…. And when King Sejong creates Striking Clepsydras, no craftsmen were capable of realizing the will of the sovereign and his ideas, but only the *Hogun* Jang Yeong-sil received the commission and was able to fulfil the wisdom of the king, so the king gave him a most important position. All the people said that Yeong-sil Jang and Yeon Pak were born to meet the needs of the times, achieving King Sejong's astronomical and musical undertakings splendidly.

Yeong-sil Jang name is known all over Korea for his contributions to the invention of the Striking Clepsydras. Many Korean institutions have commemorated him through exhibitions in museums, science parks and family society, etc. The Asan Jang Society constructed an altar and tombstone to commemorate him at Asan where his first settler's tomb is located. He was inducted into the Korean Science and Technology Hall of Fame as representative of a proud historical people and he is celebrated in many science museums in Korea. (See websites at end of references.) The Bank of Korea printed an image of the 1536 Striking Palace Clepsydra (see Fig. 3) on the front of the ten-thousand Korean banknote from 1979 to 2007, commemorating its creators, King Sejong and Yeong-sil Jang. The Ministry of Culture of Korea chose Yeong-sil Jang as a "Cultural Figure" and decided that August of 1990 would be the "Month of Yeong-sil Jang", complete with lectures, seminars and a Special Exhibition of Antiquarian Clocks (Nam 2002). Several kinds of biography have been published about him, such as Jeong (1999), written specifically for children, Kim (2005), a novel aimed at laymen, and Nam (1995, 2002), a book recently published for the realms of academia.

2 List of Main Works

His works and achievements have been summarized as follows by bringing together dynastic records and all extant writings (Cheon 1974; Nam 2002):

- He was probably involved in the design and construction of a water-clock instigated by King Taejong and his crown prince (later King Sejong). (Rufus 1936)
- In 1424, upon his return to Seoul from Beijing, he made an improved Night-watch Clepsydra (*gyeongjeom-gi*) to replace the Night-Clepsydra (*gyeong-nu*) made in 1398. Around this time, Sejong commissioned Pak Yeon, the Supervisory Council Controller for Music and Dance, to improve the classical ritual music *A-ak*, and Jang developed native musical instruments with Pak. Pak also later developed armillary spheres with him.
- In 1432, he was assigned to participate in the Royal Observatory construction project, where he was put in charge of engineering and construction. He developed astronomical instruments and automatic water-clocks, and made improvements to metal moveable type and printing technology.
- In 1433, he invented the Striking Palace Clepsydra (*Jagyeok-gung-nu*) under the commission of the king.
- In 1434, the new clepsydra was put into service as the standard time-keeper for the kingdom. He also developed high strength copper-zinc and lead-tin alloys for casting the metal type of the Gap-in Year (*Gapinja*).
- In 1437, he learned metal refining techniques from a Chinese metallurgist and developed a new astronomical clock, the Striking Heavenly Clepsydra, following King Sejong's idea.
- In 1438, the new heavenly clock was installed in the Respectful Veneration Pavilion. Jang was promoted to the position of a *Dae-hogun* as a reward.
- In 1438, he was assigned as Special Supervisor for collecting copper, iron and soft iron produced in Gyeongsang Province.

In this article, only the first Striking Clepsydra invented in 1433 and employed as standard timekeeper from 1434 will be reviewed.

3 Review of Main Works on Mechanism Design

3.1 Preamble

A summary of the events surrounding Yeong-sil Jang's construction of the Striking Palace Clepsydra appears in Don Kim's memoirs of the *Annals of Sejong* (see Fig. 2) as follows:

"The king worried about potential errors and mistakes made by the time-announcing officials, so he commissioned *Hogun* Yeong-sil Jang to make wooden immortal figures to announce the time automatically, without human involvement. The construction of the time-announcing machinery was preceded by building of the three-pillar-wide pavilion, and a two-story box was built in the space between the eastern pillars. The three immortal figures were erected on the pedestal of the upper story as sounders, announcing double-hours by a bell, night-watches by a drum and the number of watch-points by a gong. Below the lower story, a horizontal wheel was set up with a line of 12 double-hour figures around the circumference. Each figure was carried on thick iron rods that allowed it to pop up and down bearing a time-tablet to announce one of twelve double-hours in sequence."

We also have descriptions of Jang's personality and position from Bin Kim's inscriptions of the *Annals of Sejong* (Fig. 2) as follows:

> Yeong-sil Jang was a government slave who served at Dongnae Sub-county [of Gyeongsang Province] and a man of ingenious character who regularly took charge of the engineering and crafts of the royal courts.

The new clepsydra was named the Clock of the Announcing Clepsydra Pavilion (*Boru-gang-nu*), or Announcing Clepsydra Pavilion (*Boru-gak*) or the Palace Clepsydra (*Geum-nu*), after its housing. Alternately, it was called the Clock of the Respectful Veneration Pavilion (*Heumgyeong-gang-nu*), or the Respectful Veneration Pavilion (*Heumgyeong-gak*) officially. [In modern times, it has been called "Striking *Ong-nu*" by Hong (1944, 1946), "*Ongnu*" by Jeon (1963, 1998), and "Jade Clepsydra" by Needham et al. (1986), respectively, although *Ong-nu* (jade clepsydra) is only a water-clock with a jade-outlet for supplying water to the driving water-wheel of the clepsydra]. Don Kim also recorded the story of the Striking Heavenly Clepsydra in *The Records of Royal Observatory* (*Ganui-dae-gi*) in the third article on the fifteenth day of the fourth lunar moon of the nineteenth year (1437) of King Sejong.

The Memoir of the Respectful Veneration Pavilion (*Heumgyeong-gak-gi*) in the third article on the seventh day of the first lunar moon of the twentieth year (1438) of King Sejong.

According to the *Annals of Sejong* (1438), it originated from an idea the king had, with Jang subsequently constructing its installations, resulting in a splendid heavenly clepsydra capable of displaying a revolving model sun, thirty-six time-announcing puppets, rural scenes of the four seasons and an inclining vessel (Nam 2002; Hahn et al. 2000) (see Fig. 4). In this instance, we have a description of the role of Yeong-sil Jang in the making of the heavenly clepsydra as follows:

> The *Respectful Veneration Pavilion* (*Heumgyeong-gak*) has been completed [on the seventh day of the first lunar moon of the twentieth year (1438) of King Sejong]. A *Daehogun* Yeong-sil Jang installed it, however, its scales and the exquisiteness of the systems came from the king's wisdom, and the pavilion is located at the vicinity of the King's Office in the *Gyeongbok-gung* palace. It was ordered by the king that Don Kim write a memoir ….

In this instance, Don Kim described the installations in more general terms and provided little information on the mechanisms of the instruments.

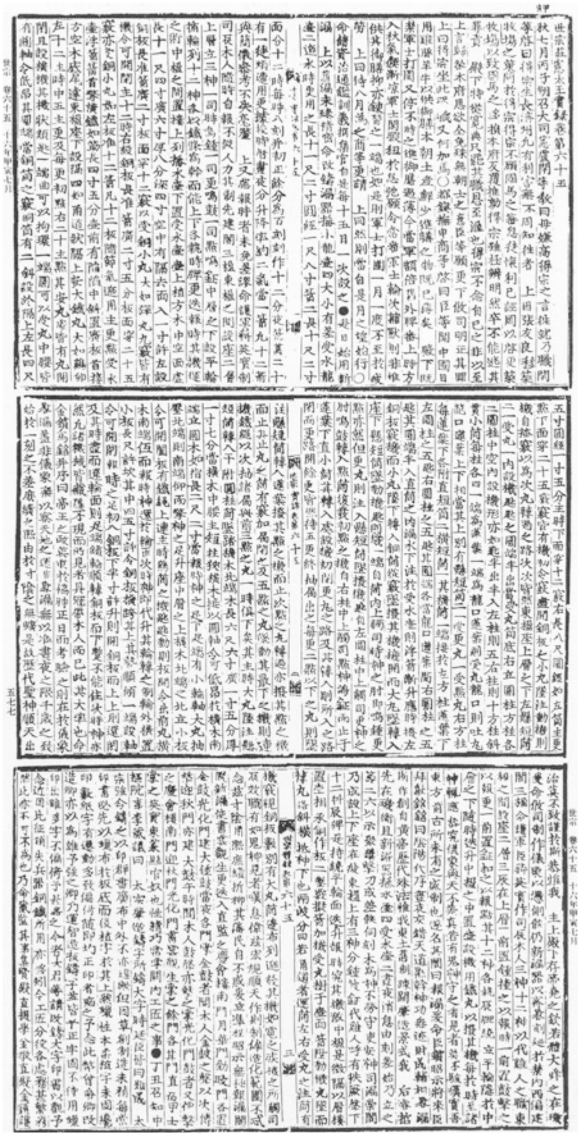

Fig. 2 The Records of the Announcement of the Clepsydra Pavilion (*Boru-gak-gi*) in Chap. 65 of the *Annals of Sejong*. In six pages of the records written in two thousand Chinese-Korean characters (from the filled circle ● on the upper-right page to the filled circle of the lower-left page), the memoirs are 1,260 characters, with the rest of the 740 characters being inscriptions with a preface. (Reprint from Nam 1995, p. 139)

3.2 Implementing the Mechanism and Machine Design from the Memoirs of the Announcing Clepsydra Pavilion

According to the memoirs, the overall configuration the Striking Palace Clepsydra consisted of three major parts: (1) an inflow-type water-clock system with dual-time measuring and dual-time small-balls releasing mechanisms to mark the beginning of each double-hour and each night-watch and its points, (2) a dual-time announcing system operated by dual-time large-balls at the beginning of each double-hour, and at each night-watch and its points, and (3) a transmission route connecting these two systems by providing funnels and guides for receiving dual-time small-balls. The systems comprised various devices, mechanisms and machines. To visualize Jang's work on the design of the mechanisms described in the memoirs, it is necessary to sketch the mechanisms of the instruments themselves, because there are no illustrations in the memoirs. In the memoirs, Don Kim provided detailed information of the installations, which we shall quote at length below.

The uniqueness of the clepsydra was its capability of announcing dual-times automatically with visible and audible signals: 12 double-hours (one double-hour (*si*) corresponds to two of today's hours), and 5 night-watches and their points (each watch (*gyeong*) was divided into 5 points (*joem*), resulting in 25 temporal subdivisions per night from dusk to dawn; each night-watch corresponds to about two hours today). Thus, the clepsydra was used as a standard timekeeper to announce the time of the curfew alert (*injeong*, "people at rest") in the evening, the removal of curfew (*paru*, "quit the clepsydra") at the dawn, and the midday drum (*ogo*, "quit morning services") following the sunset and sunrise in Hanyang, the capital city of the dynasty (now Seoul).

To harness the dual time-announcing machines, Jang made use of various sophisticated mechanisms. The function of the water-clock system is to measure dual-time and announce the beginnings of double-hours, the night watches and their points by releasing dual small-balls. The system consisted of a constant water-head regulation device, a float indicator-rod, and dual small-ball releasing wooden-casing, in conjunction with a rising float-indicator rod. The released small-balls were sent to the pre-processor of the dual-time announcing systems via falling small-ball reception devices and guides for travel. The small-balls do not have enough force to trigger the big time-announcing systems and need to be empowered, and thus, converted to large-balls. The released large-balls operate the double-hour machine, announcing the beginnings of each double-hour by striking a bell once and then displaying a corresponding time-tablet by changing the 12 double-hour puppets in sequence. The large-balls also operate the night-watch machine, announcing the 5 night watches and their 25 points by beating a drum and sounding a gong, i.e., dual-time-signals.

The memoirs tell the whole story of the design and construction of sophisticated mechanisms and machines by Yeong-sil Jang to implement the dual-time announcement. The following sections detail the essential mechanisms in the

Striking Palace Clepsydra with quotations from the memoirs. Each quotation will be followed by a brief introduction of each mechanism, and then discussion.

3.3 Liquid-Driven Discrete Ball-Falling Mechanism

To announce dual-times in a discrete fashion using ball-operated puppets, it may be necessary to generate a dual-time-signal marking each time-announcing instant in conjunction with dual time-measurement. Jang invented the falling dual time-ball method marking the beginning of each of the 12 double-hours, 5 night watches and their 25 points. Thus, the *falling dual time-ball mechanism* of the dual-timekeeping inflow-clepsydra system is essential for operating dual-time announcing machines. In this instance, we have detailed descriptions of the design of the water-driven falling-ball mechanism generating discrete time-signals in the memoir:

"The design of the [clepsydra] machinery is as follows: Between the central pillars, two different levels of decks were set up, with water-delivering vessels arrayed on the upper deck and water-receiving vessels on the lower deck. Above each water-receiving vessel, a plain rectangular open-front hollow wooden casing is erected, 11.4 c long (c stands for the Korean *Ju-cheok* employed in instrument-making, with 1 c being equivalent to 20.70 cm), 0.6 c wide, 0.08 c thick and 0.4 c deep, and a guide set up within about 0.1 c inwards from the front. A 0.2 c wide copper plate coinciding with the length of the indicator-rod is set up on the left-hand side of the wooden casing. Twelve holes are drilled into the surface of the plate to receive the small copper balls as big as a firelock-bullet. The holes all have devices which can be opened or closed, and these control the double-hours. A 0.25 c wide copper plate of the same length is set at the right-hand side of the wooden casing. Twenty-five holes are drilled into its surface to receive small copper balls, as with the left-hand side copper plate. To coincide with different night-watch graduations on the 12 indicator-rods, 12 copper plates are drilled and set with hole-devices for each wooden casing. These are used in rotation following the Fortnightly Periods and also used to control the night-watches and their points. An indicator-rod with a 0.45 c long chopstick-like iron latch on the top is floated in the water-receiving vessel."

To measure time, Jang designed an inflow-type measuring vessel and a float-indicator-rod which graduated all the dual-times simultaneously. He then came up with an idea of small-ball releasing mechanisms in conjunction with the rising indicator-rod in the time-measuring vessel. A mechanism to convert the rising water-level into the dislodging of the small-time-balls made it possible to measure analog-times and mark the discrete-time index simultaneously. This enabled substantial separation of the water-clock system, i.e., input terminal, from the time-announcing system, i.e., output terminal, resulting in a stable and effective time-announcing machine free from conventional complicated water-powered wheel mechanisms. To generate more accurate time-signals, small-balls were loaded onto the moving ball-holders.

3.4 Ball-Driven Discrete Motion Control Mechanisms

3.4.1 Small-Ball-to-Large-Ball Converting Mechanism

To operate the time-announcing machines, which require a larger amount of potential energy, it is necessary to amplify the incoming small-signal to a large-signal, i.e., convert incoming small-balls released from the water-clock system into a large cast iron ball. This is carried out through use of the *small-ball-to-large-ball converting mechanism* in the dual-time announcing system.

The detailed description in the memoir is as follows:

"Two copper tubes are made and installed sloping above a channel [parallel]. The left-hand tube, 4.5 c long and 1.5 c in diameter, controls 12 double-hours; 12 holes are drilled along its under-side. The right-hand tube, 8 c long and the same diameter as the former, controls the night watch and point; 25 holes are drilled along its under-side. The holes all have devices [capable of opening and closing], which are left open initially. When a small copper ball is dropped from the copper plate, [it falls into a funnel, travels through the sloping wide board, rolls into a tube], and then falls into the hole, operating the device so as to close the hole automatically. Thus, the device forms a path for the following ball to run past, and one after another until all the holes are closed."

"[Below two copper tubes,] there are four [parallel] channels forming alley-like grooves. On the three channels rest [37] large-iron-balls (i.e., large-ball) as big as hens' eggs: the 12 on the left-hand channel control the 12 double-hours [machine]; the 5 on the center control the 5 night watches and their first points [mechanisms]; and the 20 on the right-hand control the additional points [mechanisms]. At the ball-resting-places, large-ball-switches are installed. These are shaped like a spoon which is bent at one end to restrain the large-ball while the other end is rounded to receive a small-ball. The waist of each spoon is mounted on an axle to allow it to go up and down, and the rounded end of each spoon is aligned with a hole in the copper tube above."

The function of the copper tube mechanisms is to drop the small-balls on the rounded end of the mechanical spoons in turn. The hole devices employing trap doors operated by falling small-balls provide the routes for the subsequent incoming small-balls to travel to the next holes sequentially. This pattern of action repeats until all the openings are closed. To operate the double-hour and the night-watch machines, the large-balls resting on the ball-falling mechanisms should be released following the proper incoming of the dual small-balls. The incoming 12 and 25 small-balls are sequentially dropped into the 12 and 25 holes drilled underneath the tube. The 12 large-balls resting on the left-hand channel are released following the opening of the mechanical spoons activated by the 12 small-balls. In contrast to the double-hours, the falling 25 small-balls operate the 25 mechanical spoons sequentially; however, the released large-balls operate the night-watch and initial-point mechanisms once every 5 times.

Every 4 large-balls among each of the 5 large-ball sets operate watch-point mechanisms, i.e., the 2nd to 5th balls are used to announce the 2nd to 5th points of each night-watch. Thus, the 1st, 6th, 11th, 16th, and 21st large-balls operate the 1st, 2nd, 3rd, 4th and 5th night-watches and their initial-point-spoons, i.e., 5 for the night-watch and 5 for the initial-point, announcing the 1st, 2nd, 3rd, 4th and 5th night-watches and their 1st points. Five sets of 4 balls, i.e., 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, 15, 17, 18, 19, 20, 22, 23, 24, 25, operate only 20 watch-point-spoons. The announcement of the night-watches and their points took place as: 1st night-watch and 1st, 2nd, 3rd, 4th and 5th point, 2nd night-watch and 1st, 2nd, …, 5th night-watch and 1st point, …, 5th point, for a total of 5 night-watches in a night. Thus, the 1st, 6th, 11th, 16th, 21th large-balls rest in mid-channel and 5 sets of 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, 15, 17, 18, 19, 20 and 22, 23, 24, 25 large-balls rest on the right-hand channel.

3.4.2 Striking and Escaping Mechanisms for Audio-Visual Time-Signals

To announce double-hours audio-visually, with consecutive bell sounds and images, the bell-striking and time-tablet display mechanisms should be activated one by one with a large-ball, i.e., a single-stroke (input)/double-acting (output) spoon mechanism is needed. Again, from the memoirs:

"At left, below the upper-story pedestal on the eastern space box, there are two short tubes suspended [in tandem]: one to pass the large-balls and the other to house a mechanical spoon. The rounded end of the spoon sticks out halfway toward the bottom of the ball-passing tube."

"As the water flows into a water-receiving vessel, the indicator-rod inserted on top of the float upward gradually. Corresponding to the passage of the double-hours, the iron latch on top of the indicator-rod triggers a hole-device set in the left-hand copper plate, and a small-ball held in it falls outside the plate. It [falls into the funnel and finds its way along the sloping wide board], entering the 4.5 c long copper tube and running through it. It falls on the hole-device, [causing the device to move, and then falls into the rounded end of the mechanical spoon], releasing a large-ball. Thus, the large-ball falls into the short tube suspended below the pedestal and operates the mechanical spoon below it. The top of the device, [which is linked to the other end of the mechanical spoon], pops out from the accompanying short tube to touch off the elbow of the double-hour announcing puppet, causing it to sound the bell immediately."

"[Each of] the double-hour-control large-balls, [having operated the bell-sounding mechanism once], passes the suspended short tube, runs into the short tube attached to the round column, and falls, depressing the northern end of the horizontal wooden bar stuck in the bottom of the round column. The horizontal bar is 6.6 c long, 0.15 c wide and 0.17 c thick. The center of this bar pivots on a round axle upon two short pillars, so that this horizontal bar can go up and down. At its southern end stands a round stick as thick as a thumb and 2.2 c long, which engages below the foot of a double-hour announcing puppet bearing a time-tablet. There is a small iron wheel at the end of the puppet's foot. When a large-ball depresses the northern end of the horizontal bar, the southern end is raised and the foot of the puppet is held up to the position above the mid-story. North of the northern end of the horizontal bar stands a small board which opens and shuts. The upper part of the board is connected by an iron chain with the mechanical spoon, which is set within the suspended short tube controlling the double-hours. When the spoon is operated by a large-ball, the board opens and the preceding large-ball comes out. As the southern end of the horizontal bar drops, the [preceding double-hour announcing] puppet returns to the surface of the horizontal wheel, and the following puppet rises to replace it. The wheel-rotation system functions as follows: Outside the horizontal wheel, a small board about 1 c long with a cutaway about 0.4 or 0.5 c in the center is set, bridged horizontally by a smoothly inclined copper-plate which has a pivot at one end to allow it to open and close. The feet of the double-hour announcing puppet first protrude forward about 0.5 c below the copper plate. When it is raised, it opens the copper plate and the puppet remains raised, the copper plate then returning to the closed position. When its double-hour is elapsed, the puppet returns to the surface of the wheel, and the iron wheel at the end of the foot rolls smoothly downwards along the surface of the copper plate until it cannot go any further. The following double-hour announcing puppet goes up and down in the same way."

The first paragraph depicts the configuration of the first twin-output control mechanism, i.e., the spoon which is linked to the bell-striking and time-tablet-displaying mechanism. The second paragraph depicts the process from the injection of water into the water-receiving vessel to the bell sounding once. The third paragraph depicts how the image of the bell sound indicating the time is displayed. To do this, a sloping copper-plate and a horizontal-bar (lever) mechanism control the rotation of the horizontal carousel wheel, resulting in replacement of the time-tablet bearing puppets in order. This plate-lever-puppet sub-system constitutes the second control mechanism and works as a ball-driven unidirectional escapement.

In the memoirs, Don Kim described the configuration and functions of the ball-driven horizontal carousel wheel rotation system faithfully. When a large-ball depresses the northern end of the horizontal bar, the tip of the round stick raises and opens the copper-plate, while the puppet remains simultaneously raised, and the copper-plate returns to the closed position. When its double-hour is elapsed, the puppet returns to the surface of the wheel as follows: As the puppet drops vertically along the iron rods by virtue of its own weight, due to the protruded bottom of the small iron wheel, it encounters the inclined copper-plate blocking its path. The small wheel has nowhere to go, so it rolls down along the inclined copper-plate, which causes circumferential movement of the puppet and results in rotation of the horizontal wheel. The next puppet then comes into position to be lifted.

3.4.3 Switching and Resetting Mechanisms for Dual-Time-signals

To announce the 5 night-watches and their 25 points, it is necessary to design satisfying announcing regulations, i.e., counting the number of night-watches with their initial-points simultaneously, and rest of the points, i.e., the 2nd, 3rd, 4th and 5th points of each night-watch, consecutively. Again, we have a detailed description from the memoirs:

"On the right-hand [below the mid-story pedestal], 2 round columns and 2 square pillars have been erected. In the hollow interiors of the round columns, spoon-shaped devices are set: half out and half in. 5 spoons are in the left-hand column and 10 in the right-hand. Small slanting tubes penetrate each square pillar [from top to bottom]: 5 in the left-hand one and 4 in the right-hand. [The small tubes] are all set with a lotus-leaf at one end and a dragon mouth at the other. The lotus-leaf [openings] pass the large-balls through [the small tube] and the dragon mouths spew them out. A set of lotus-leaf and dragon mouth face upwards and downwards, respectively. Above [the round columns], 2 short tubes are suspended separately, one to receive the night-watch balls and one to receive the point balls. Under each lotus-leaf of the [left-hand] and right-hand square pillars, 2 [additional] straight short tubes and one [additional] horizontal tube are attached. One end of the horizontal tube is connected below [all] the lotus-leaves of the left-hand [and right-hand] square pillars. The rounded ends of the 5 spoons in the right-hand round column are located between the dragon mouths and the lotus-leaves [in the left-hand square pillars]. The rounded ends of each of the 5 spoons of [the left-hand round column and] the right-hand round column penetrate halfway into the [additional] straight [short] tubes."

"The [processes] for announcing the night-watches and their points are similar, but the [initial-] watch-ball runs into the short tube suspended [above the left-hand round column] to fall and operates the rounded end of the [uppermost initial-watch's] mechanical spoon, which, from within the top of the device [linked to the other end of the mechanical spoon], pops out from the left-hand round column and touches off the elbow of the night-watch announcing puppet, causing it to sound the drum [once]. It [then] runs into the slanting small tube to operate the [initial-watch's] initial-point mechanical spoon again, and the top of the device [linked to the other end of the mechanical spoon] pops out from within the right-hand round column, touching off the elbow of the watch-point announcing puppet to sound the gong [once]. Then, the [initial-watch] ball stops in the straight small short tube below the lotus-leaf. In the tube where the ball stops, a device is installed that initially blocks the [initial-] watch ball's [straight] route, [i.e., the straight short tube to guide the subsequent watches' mechanisms]. As soon as the [initial-] watch ball runs into the straight [short] tube, it depresses the one end of the device, so the entry of the slanting small tube, [which has passed the ball just before], is closed, and the blocked night-watch [straight] route is open. At the following night-watches, the operation is the same. When the fifth-watch ends, the crossbars are withdrawn and all the rest balls [depressing the devices in the straight short tube] come out. The point-ball of each night-watch from the second onwards falls into the suspended short tube [and operates the uppermost mechanical spoon set in the right-hand side of the right-hand round column to sound the gong once]. It then rolls into the lotus-leaf [set in the right-hand side of the right-hand square pillar] and operates the [second-] point mechanical spoon [under the straight short tube to sound the gong once again. From there, it rolls into the uppermost slanting small tube in the right-hand square pillar, is released from the mouth of the dragon, falls into the small short tube], and stops. [As soon as the ball runs into the straight short tube, it depresses the one end of the device so the entry to the slanting small tube, which has passed the ball just before, is closed, and the blocked straight short tube is open.] Thus, the next, i.e., the 3rd and 4th point-balls, fall [into the suspended short tube and operate the uppermost and 2nd mechanical spoons], followed by the 3rd and 4th mechanical spoons, and then pass through the [2nd and 3rd slanting small tubes] and stop, [the same as the 2nd point-ball]. The tubes where the balls stop have holes with crossbars closing them [initially]. When the 5th-point ball operates the 5th-point mechanical spoon, [rolling into the lowermost slanting small tube] and falling on the lowermost device, then an iron wire connected to it pulls out all the crossbars in turn, [so that this ball] and the [rest] of the preceding three points-balls [in the straight small tubes] all fall down at the same time …"

The mechanism described above in the first part of the second paragraph of the memoirs is a device which indicates a gradual opening of the passages employing on-off *switching mechanisms*, carrying functions of logic to implement counting night-watches with initial-point announcements.

The description in the second part of the second paragraph indicates how to count the rest of the points after the initial-point of each night-watch. The uppermost spoon set among the five point-spoons in the point mechanism acts like an incremental device, i.e., $N_{new} = N_{old} + 1$ in modern computing devices. After the announcement of the 5th point of each night-watch, the last ball operates the lowermost device in the point announcing mechanism, withdrawing 3 large-balls from the straight short tube of the point-mechanisms, and then *resets* the straight tubes to their initial states. Thus, the mechanism enables announcement of the 2nd to 5th points of the next night-watch starting from the first. This means that the point-mechanism should repeat another 4 identical cycles, i.e., the 2nd to 5th-points of the night-watches four more times. To do this, the 3 already used balls resting in the 3 straight tubes below the lotus-leaf should be released from the tubes to 4 ball sumps with the 5th-point ball. The *counting* of the point-mechanism is carried out by the *reset mechanism*. This kind of mechanism is employed in the night-watch and initial-point mechanisms to repeat another identical cycle for the next day by withdrawing 5 large-balls from the straight short tube; quoting the last sentence of the first part of the second paragraph, "When the fifth-watch ends, the crossbars are withdrawn and all the rest balls [depressing the devices in the straight short tube] come out".

3.5 The Term "Machine" in the Memoir

In the memoir quoted above, the term "*gi*" appeared, a noun meaning "device", "mechanism" or "system", also used as a demonstrative pronoun, e.g., "mechanical spoon" in that particular sentence, or a compound word, e.g., "mechanical spoon", "hole device". The term "machine", appearing in the last paragraph of the memoirs, depicts the external appearance of the clock simply as follows:

> All the *machines* are hidden so that they cannot be seen outside. This is the whole appearance of the new [Striking Palace Clepsydra].

Thus, the time-announcing system of the Striking Palace Clepsydra consisted of various machines, i.e., the small-ball-to-large-ball converting mechanism and the double-hour and night-watch machines, which are hidden in the box. Needham et al. (1986) translated the term "machine" as "mechanism". The term "machine" means elaborate or ingenious devices from ancient days in China (Zhang 2000). It first appears in the *Annals of Sejong* which was cited above in Korean history, however, the usage of the term was apparently popular among the scholars of King Sejong's court, including Yeong-sil Jang and his associates, owing to the construction of the Striking Palace Clepsydra. So, the Striking Palace Clepsydra can be defined as a hydro-mechanical clock which consisted of a dual-time falling-ball inflow-float clepsydra system and a dual-time-announcing system, of which the announcing system comprised the small-ball-to-large-ball converting mechanism and the double-hour and the night-watch machines.

4 On the Circulation of Works

The above-mentioned records in the *Annals of Sejong* are supplemented by accounts in official publications, such as *Comprehensive Study of Korean Civilization* (ECSKC) published in 1908. The Striking Clepsydras were a symbol of prestige of the Neo-Confucian state ideology and had been recreated several times after loss by fire and warfare, and also influenced the making of astronomical clocks in 1669. These were possible with the aid of reports made by Don Kim and his associates, as well as attending staff and clockmakers, on the creation of the Striking Clepsydras (ECSKC 1908). In 1536, King Jungjong (r.1506–44) ordered a duplication of Sejong's Striking Palace Clepsydra, as shown in Fig. 3, building a new Announcing Clepsydra Pavilion, assembling a Sejong's Sun-and-Star Time Determining Instrument, and constructing an observatory for the instrument in the *Changdeok-gung* palace, according to the *Annals of Jungjong* (1536).

Prince Gwanghae (r. 1609–22) ordered the rebuilding of the *Heumgyeong-gak*, and Sejong's Striking Heavenly Clepsydra was restored in a new location in the *Changdeok-gung* palace after the Japanese invasions of Korea (1592–98, the

Fig. 3 Relics from the Striking Palace Clepsydra copy made in 1536 after King Sejong's from 1434. The top three vessels are water-delivering and the two vessels on the ground are water-receiving. The relics were relocated to the *Deoksu-gung* palace in Seoul in 1938 (Photo by Nam 1995)

so-called Imjin War) according to the *Diary of Ganghaegun* (1616). *The Building Heumgyeong-gak Uigue* (*Uigue* is the state ceremonial and construction manuals for the king's perusal and/or storage at relevant government organizations) was compiled in 1614 and burned during the French invasion in 1866 (Nam 2012).

Prince Gwanghae also ordered the building of a new *Boru-gak* at a new location in *Changgyeong-gung* palace, and restored the Striking Palace Clepsydra (the 1536 copy) using major parts that had survived the damage during the wars. *The Repairing Boru-gak Uigue* was compiled in 1618 and also burned during the French invasion at Gangwha Island in 1866. From the late eighteenth century on, the 1536 duplicate-based clepsydra was used under the name of *Geum-nu*, the (Striking) Palace Clepsydra with striking puppets having been dismantled until the abolition of The Curfew-alert and Curfew-lift regulation in 1895. Relics of the clepsydra, three water-delivering and two water-receiving vessels with a float-indicator, were collected by the newly opened Imperial Household Museum and exhibited outdoors from 1908 until 1938, whereupon they were moved to the present *Deoksu-gung* palace (Fig. 3) and designated by the Korean govenment in 1985 as National Treasure Number 229, Striking Clepsydra of Announcing Pavilion Borugak (Nam 2012). Thus, the relic is a precious reference to make up for the brief descriptions of the clepsydra part of the Striking Palace Clepsydra in Don Kim's record. In the case of the Striking Heavenly Clepsydra, there remain no relics. Figure 4 shows an image of the Striking Heavenly Clepsydra.

Fig. 4 This image of the Striking Heavenly Clepsydra shows a model sun (*1*) revolving around the mountain and four jade female immortals (*2*) standing on the multi-colored cloud, each facing in one of the four cardinal directions, striking a golden bell with a wooden mallet to announce the double-hour. At the same time, the four guardian gods (Blue Dragon, Red Bird, White Tiger and Black Snake) (*3*) also face the cardinal directions. At the southern foot of the mountain are an hour-jack and three warriors (*4*) that strike the double-hours, night-watches and their points with respective instruments. On the ground are twelve gods of the Zodiac (*5*), occupying their respective positions, and behind them are holes. At the fifth double-hour, the Hour of the Dragon, the hole behind the Dragon opens, the Dragon double-hour immortal (*6*) comes out with a time-tablet, and the Dragon figure stands still. The process continues with other hours in succession. At the south of the mountain, an official figure (*7*) with a silver bottle pours water into an inclining vessel (*8*) that lies on its side when empty, stands upright when half full, and falls over again when full. Rural scenery sculpture (*9*) cited in the *Ode of Bin* depicts peasants working around the mountain in the four seasons (Nam 2002)

5 Modern Interpretation of Main Contributions

A modern interpretation of the memoir of Don Kim on Yeong-sil Jang's works on the design of mechanisms and machines cannot be identified directly. In summary, the mechanisms and machines that he designed can be interpreted in modern engineering terminology. To visualize these mechanisms and machines, illustrated diagrams have been made based on the translation of the original text because there are no drawings in the memoir at all, as mentioned above (Nam 1985, 1989a, b, 1990). Identification of the parts and components of the mechanisms and their interrelationships, as well as the creation of the physical representation of those systems, leads to an understanding of the structures and functions of the complex mechanisms and machines.

This approach is similar to so-called reverse engineering, which is the process of discovering the technological principles of a human made device, object or

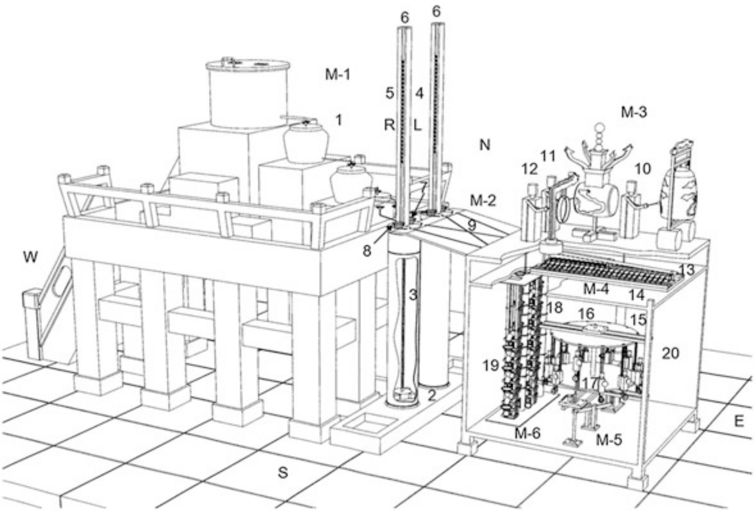

Fig. 5 Illustration of the Striking Palace Clepsydra with explanatory diagrams showing how to fabricate six modules into a time-announcing system (south elevation). M-1: *1* water-delivering vessels; *2* water-receiving vessels; *3* float-rod; *4* left-hand (L) copper-plate mechanisms; *5* right-hand (R) copper-plate mechanisms; *6* wooden casings. M-2: *7*, *8* funnels to receive falling small-ball; *9* small-ball guides. M-3: puppets *10*, *11*, and *12* stood in front of a bell, a drum and a gong, respectively, *20* striking machinery. M-4: *13* dual copper-tube mechanisms; *14* large-ball rest-releasing mechanisms. M-5: *15* bell-striking mechanism; *16* horizontal carousel wheel mechanism carrying the double-hour puppets, one of them *17* displays a time-tablet. M-6: *18* night-watch mechanism and their initial-point mechanism; *19* watch-point mechanism. E, W, S, and N: orientations (Adapted from Nam 2012)

system through analysis of its structure, function and operation (Chikofsky and Cross 1990), an approach that can be found in many other instances (Needham et al. 1986a, b). This approach proved to be very useful in making significant drawings through trial-and-error and was used to draw up a plan of reconstruction drawings (Nam 1998; Seo et al. 2000).

The illustrated diagrams and figures were made from the translation of the memoir so as to visualize the contents of the corresponding paragraphs (Nam 1998, 2012). Technical details can conveniently be considered by modular mechanisms and machines as follows: M-1 Dual-timekeeping inflow-clepsydra system with dual-time small-ball releasing mechanisms; M-2 Dual-time small-ball receiving funnels and small-ball guides; M-3 Dual-time announcing system; M-4 Dual-time small-ball-to-large-ball converter in a dual-time announcing system; M-5 Double-hour announcing machine; M-6 Night-watch announcing machine. M-x stands for module number to depict interdependent mechanisms and machines. The numbers 1, 2, and 3 are given for three main parts of the Striking Palace Clepsydra, and 4, 5 and 6 are major parts of the time-announcing system. Figure 5 shows the combination of the six modules.

Fig. 6 Reinstated replica of the Striking Palace Clepsydra (frontal view). The labels M-x are the same as in Fig. 5. The whole installation measures approximately 6 m in width, 2 m in depth, and 5.7 m in height. (Photo by Nam 2006)

To implement the designs as shown in Fig. 5, a project to reconstruct the Striking Palace Clepsydra was launched by the Cultural Heritage Administration (CHA) of Korea during the 2004–2005 commemoration of the opening of the National Palace Museum of Korea, which was supposed to be inaugurated in 2006. The construction of the replica was carried out from 2004–2005 under contract with Konkuk University, with which the author (M. Nam) has been affiliated. The reinstated replica worked very well and announced dual-times exactly. It was installed as a permanent exhibition for daily operation starting in November 2007, as shown in Fig. 6 (Nam et al. 2007). Modern interpretations of the mechanisms were carried out with the aid of sub-assemblies and re-created parts. The sub-titles of the mechanisms discussed above were extended so as to interpret them in a modern sense.

5.1 Liquid-Driven Discrete Time-Ball-Releasing Mechanisms: Analog to Digital Converter

It is a novel technique to install the vertical linear ball-channel mechanisms above the inflow-float vessels as Yeong-sil Jang did, and to tip the ball-holders to drop the balls loaded in them so as to dissect time into discrete intervals corresponding to each instance of time-announcement. It is comparable to the ball-channel in the

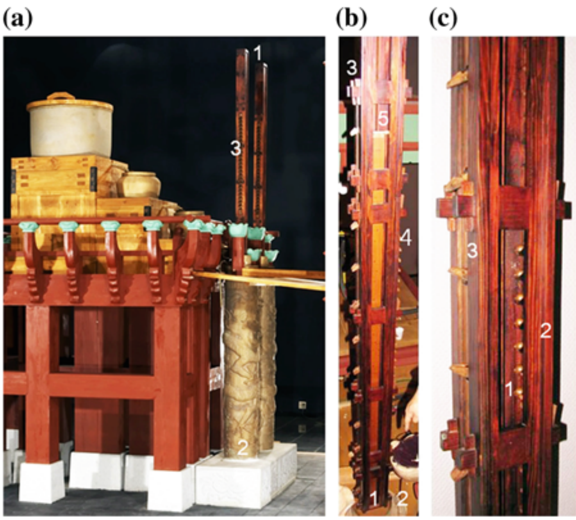

Fig. 7 A dual-timekeeping inflow-clepsydra with the dual-time ball-releasing mechanisms. **a** A wooden-casing (*1*) is erected above a water-receiving vessel (*2*), in which a pair of ball-channels (*3*) is housed on the opposite walls of the wooden-casing. Two water-receiving vessels with two wooden casings are used alternately for daily changeover, accordingly. **b** The wooden casing (*1*) is erected above a water-receiving vessel (*2*). The left-hand ball-channel (*3*) is for double-hours and the right one (*4*) is for night-watches. The floating indicator-rod (*5*) passes through both ball-channels. **c** Solid copper balls (*1*) are placed in the night-watch ball-holders of its ball-channel (*2*). Balls for the double-hours are on the double-hour ball-holders (*3*) (balls are not shown) (Photos by Nam 2006)

candle-clock of al-Jazari (1974), which drops 14 balls from a vertical channel partitioned into 14 chambers as the constant hour has elapsed in a day. The time is marked by counting the number of balls which have been released. Figure 7 shows the dual-timekeeping inflow-clepsydra system with dual-time small-ball releasing mechanisms M-1. Jang's direct linear mechanism can be evaluated as an innovation in the field of dissecting time employing rotary elements, such as anaphoric Arabic-water-clocks, Archimedes' clepsydra and 'The Water-Powered Armillary (Sphere) and (Celestial) Globe Tower' of Su Song and Han Gong-lian, which uses a steelyard clepsydra-escapement mechanism to count 'One-hundred-marks' (Li 1997; Needham et al. 1986; Su 1937). These methods were all operated like modern analog to digital converters (A/DC). Features of Jang's mechanism enabled substantial separation of the water-clock from the time-announcing system, resulting in stable and effective operations of the time-announcing systems, as mentioned-above. A liquid-driven falling-ball mechanism employing dual-timekeeping inflow-clepsydra was an unprecedented way of counting time in the history of clepsydra-making.

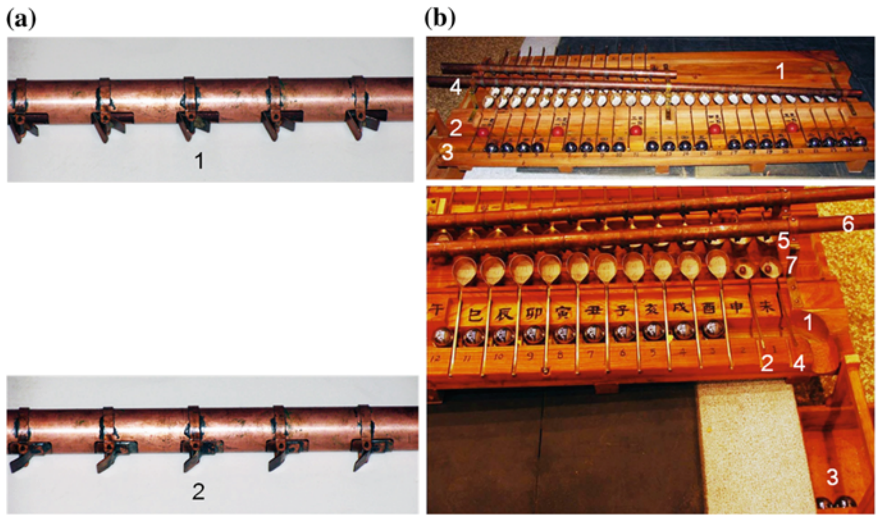

Fig. 8 The copper-tube mechanism and the large-ball release mechanisms. **a** The copper-tube mechanism. The holes in the tube in open (*1*) and closed (*2*) states. **b** An assembly of the copper tube mechanisms with dual large-ball-falling mechanisms. *Upper* Large-ball-releasing mechanisms (*1*) into which are loaded 5 balls (*red* in *color*, numbered 1, 6, 11, 16, and 21, from *left* to *right*) resting on the upper-channel (*2*) to operate the night-watches and their initial-point mechanisms, and 20 balls (*black* in *color*, numbered 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, 15, 17, 18, 19, 20, 22, 23, 24, 25, from *left* to *right*) resting on the lower-channel (*3*) to operate the watch-point mechanism below the night-watches' copper-tube mechanism (*4*). *Lower* The other side of the upper one, showing 12 large-balls for operating the 12 double-hours machine. The two ball-rest spaces (*2*) (numbers 1 and 2, Sheep and Monkey double-hours, respectively) in the double-hour large-ball channel (*1*) are vacant due to the two balls (*3*) having been released by the opening of the mechanical spoon levers (*4*) (numbers 1 and 2) by the falling of the two small-balls from two holes (*5*) (numbers 1 and 2) onto the double-hour copper tube mechanism (*6*) above. Two small-balls (*7*) will stay on the rounded end of the spoon until 12 double-hours have elapsed (Photos by Nam 2006)

5.2 Small-Ball-to-Large-Ball Converting Mechanisms: Mechanical Shift-Register and Amplifier

The small-ball-to-large-ball converter consisted of two copper-tube mechanisms for dropping the incoming small-balls on the mechanical spoon, which restrained the large-balls, and large-ball-rest-releasing mechanisms below the copper-tubes. The mechanical spoon, which is aligned with a hole in the copper tube above, acts like a lever restraining (closing) and releasing (opening) the large-ball by small-ball motion, thus the combination of copper-tube mechanism and the ball-releasing mechanism is a power converter, i.e., power amplifier. Figure 8 shows the principle of the creation of the ball-path in the copper tube mechanism and dual large-ball-release mechanisms M-4: (a) shows the copper tubes in an open state before the small-balls pass and closed after the passing and (b) shows an assembly of the copper tubes with dual large-ball-release mechanisms.

In terms of modern computer engineering, the copper-tube mechanisms are similar to the shift register. Delayed-action mechanisms postpone the opening or closing until a set period has elapsed. The ball-converting mechanism is the power supply of the time-announcing system.

5.3 Ball-Driven Discrete Motion Control Mechanisms: Double-Acting Spoon Mechanism and Unidirectional Escapement

The double-hour machine consisted of mechanisms for displaying the bell-striking and 12 double-hour puppets. A large-ball consecutively triggers the bell-striking mechanism once and touches off the carousel wheel mechanism to display the corresponding double-hour puppet in turn, replacing the formerly displayed puppet. The replacement of the puppets moving up and down is carried out by an escapement mechanism utilizing the puppet's own weight without requiring any gearing. Falling large-balls enable the time-announcing mechanisms to work in a discrete fashion and secure effective energy transmission and accurate time-announcement. Figure 9 shows the one stroke/double-acting spoon mechanism of the double-hour machine M-5: (a) double-hour machine (b) time-tablet puppet display mechanism (c) displayed time-tablet puppet and (d) depressed horizontal bar to display puppet.

Before the invention of a mechanical escapement which would allow a clock's movement to be controlled by an oscillating weight, a liquid-driven escapement was used in a washstand automaton by a Greek engineer, Philo of Byzantium (3rd century B.C.). In Song China (960–1279), Zhang Sixuan, Su Song (1020–1101) and Han Gonglian applied steelyard-clepsydra escapement mechanisms to count "One-hundred-intervals" in 'The Water-Powered Armillary (Sphere) and (Celestial) Globe Tower'. The ball-operated jackwork of the Elephant Clock of al-Jazari (1974) might have inspired King Sejong and Jang in the course of developing the time-tablet display mechanism in conjunction with bell-sounding mechanism (Romdhane and Zeghloul 2010). Needham et al. (1986) have argued that the elaborate time-annunciating mechanism using ball-operated jack-works was inspired by al-Jazari's 1206 clocks, which were not copied but instead adapted to fit the Korean time-keeping tradition by the eminent mechanical engineer Yeong-sil Jang and his supporters.

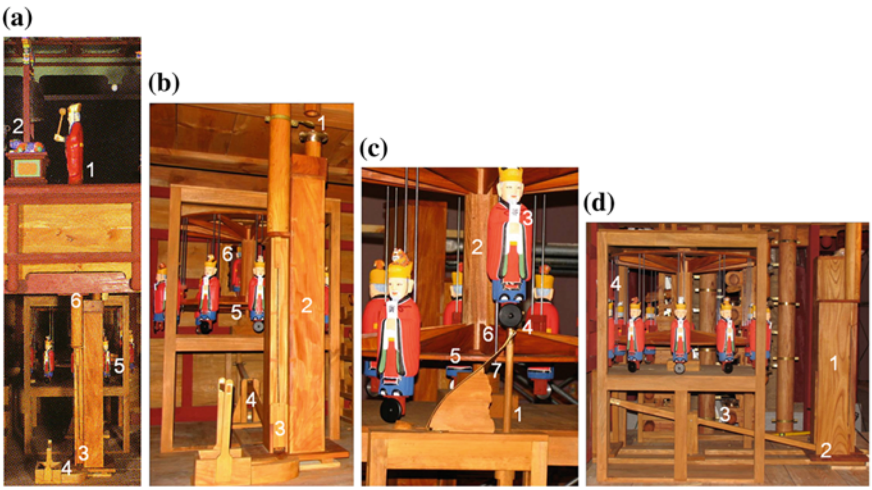

Fig. 9 Double-hour announcing machine. **a** Double-hour machine shown from the in- and outside at rear: the bell-striking puppet (*1*) and the bell (*2*) in front of it are placed on top of the machine; the horizontal carousel wheel (*5*) and bell-striking mechanisms (*6*) are shown at center. As the mechanical spoon (not shown here, see number *1* in **b**) is operated by a large-ball, the bell is rung and the small-board (*3*) is opened, allowing the preceding large-ball (*4*), which has depressed the horizontal bar during the former double-hour, to come out. **b** The time-tablet puppet display mechanism (back). Immediately after the large-ball operates the spoon (*1*), the depressed bar (*4*) is raised and the puppet which announced the preceding double-hour returns to the surface of the horizontal wheel (*5*), following which the small-board (*3*) is shut. The large-ball, which had operated the mechanical spoon just before, falls to the short tube below the spoon (*1*) and rolls into the tube (*2*), depressing the raised end of the horizontal bar (*4*) so that the lowered end of it is raised, resulting in the elevation of the next time-tablet puppet (*6*), which was waiting to be lifted. **c** The time-tablet puppet display mechanism (front). As the round stick (*1*) implanted vertically on the southern end of the horizontal bar raises the feet of the puppet (*2*) bearing the time-tablet (*3*) with the inclined copper-plate (*7*), so the puppet remains raised and supported by vertical iron rods (*6*), and the copper-plate returns to the closed position. When its double-hour is elapsed, the round stick is lowered and the small iron-wheel (*4*) rolls down, following the inclined copper-plate (*7*), and returns to the surface of the wheel (*5*) by gravity, as the wheel rotates 30 degrees clockwise concurrently. **d** Side view of the time-tablet display mechanism. The large-ball, which operates the mechanical spoon, falls into the route in the tube (*1*) and depresses the raised end (*2*) of the horizontal bar (*3*), causing a time-tablet puppet (*4*) to be lifted and remain raised until the next double-hour is announced by the bell (Photos by Nam 2006)

5.4 Ball-Leverage Switching and Resetting Mechanism: Advent of Quinary Digital Counter

Yeong-sil Jang designed an elaborate mechanism so that each night-watch and its first point could be announced with a large iron ball, i.e., one iron ball can trigger one gong-sounding spoon lever after it has triggered the proper number of drum-sounding spoon levers. To match the functions of the large-ball-releasing mechanism, the night-watch machine is made of various devices, mechanisms to satisfy

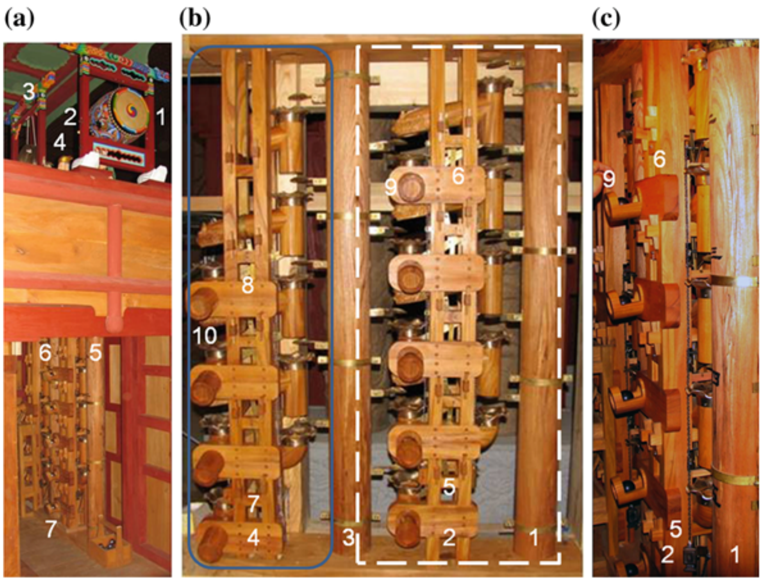

Fig. 10 M-6 machine for announcing night-watches and their points. **a** Night-watch announcing machine shown from the in- and out-side at rear: a drum (*1*), a drum-beating puppet (*2*, hidden behind the drum), a gong (*3*) and a gong-sounding puppet (*4*) are placed on the pedestal. The elbows of the puppets are linked to rods within the left- and right-hand round columns (*5*) and the control mechanism (*7*), respectively. **b** Enlarged view of the control mechanisms of the night-watch announcing machine. The control mechanisms for announcing the night-watches and their initial-points are in the dotted square, where the number 5 is the resetting mechanism, (*6*) is one of four switching mechanisms and (*9*) is one of 5 large-ball sumps. The watch-point announcing controller is in the round square block, where the resetting mechanism (*7*) is triggered at the end of each night-watch and the three balls which have depressed each end of three switches in the ball-rest are discharged through three inclined tubes (*10*), the states of the three switches then resuming for the next cycle. These resettings take place five times in a night. The uppermost spoon in the left-hand round-column (*3*) acts like the sort of incremental device which carries out $N_{new} = N_{old} + 1$ in a modern computer. **c** Oblique view of the control mechanisms indicating the resetting actions at the end of the night-watches. Similar actions take place at the end of each night-watch, i.e., the fifth point of each night-watch. The numbers are the same as in (**b**) (Photos by Nam 2006)

announcing regulations for 5 night-watches and their points. The counting controller with automatic resetting device in the watch-point-machine is similar to a modern digital 5-digit counter consisting of various automatic switches to close and open valves, change flow directions or reset. Design of the automatic switching and reset mechanisms enabled him to make a dual-time-signal announcing machine, and it deserves attention in the history of horology. Importantly, the night watch-point announcements by pre-programmed float-rods enabled the Striking Palace Clepsydra to operate as a programmable computer.

Figure 10 shows a re-created M-6 machine for announcing night-watches and their points. The night-watch machine consists of the announcing devices, which are placed on top of the machine, and their control mechanisms, which are below the two puppets in the box, as shown in Fig. 10a. The elbow of the drum-beating puppet is linked to a rod within the round column (5), and the elbow of the gong-sounding puppet is linked to a rod within the round column (7) of the control mechanism (6).

Details of the control mechanisms of the night-watch announcing machine are shown in Fig. 10b, consisting of a controller for the night-watches and their initial-points and a controller for announcing the watch-point. The round column (1), square pillar (2) and right-hand round column (3) (dotted square) constitute the night-watches and their initial-point announcing controller. The left-hand round column (3) and the square pillar (4) (square) constitute the watch-point announcing controller. The square pillar (2) acts as a quinary system digital counter so that the night-watch-charge puppet can beat its drum and the watch-point-charge puppet can sound its gong to announce the five night-watches with their initial-points. The switching and resetting mechanism in the square pillar (4) enabling the watch-point announcing mechanism acts as a quinary system digital counter so that the watch-point-charge puppet can sound its gong to announce the four points of each night-watch. The reset takes place through the lowermost device (5) resetting the states of the four switching mechanisms (6) of the square pillar (2) and similarly through the lowermost device (7) of the other square pillar (4) resetting the states of the three switching mechanisms (8) in regular sequence. Number 9 is one of 5 ball sumps, and (10) one of 4 inclined tubes for ball-discharge. The uppermost spoon in the point-mechanism acts like an incremental device of a modern computing machine. Figure 10c shows an oblique view of the control mechanisms indicating the actions of the resetting mechanism at the final stage of the announcing of 5 night-watches.

This clepsydra operated on a closed-loop system whereby it continued to work as long as balls were loaded into the small-ball-holders above the inflow-vessels and the rest into the large-ball-channels of the ball-releasing mechanisms. There is no precedent for the ball-driven logic device that emerged out of Jang's quinary digital counter. The Striking Palace Clepsydra run by the liquid-driven falling balls and the ball-driven discrete motion-controlling mechanisms deserves to be called the first hydro-mechanically engineered dual-time clock in the history of horology, and the reinstated replica served to reveal its structure, novelty and creativity, as well as the innovative genius of its inventor.

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Karl Hoecken (1874–1962)

Hanfried Kerle

Abstract After the death in 1922 of Wilhelm Hartmann, the direct successor of Franz Reuleaux in the "Lehrstuhl für Getriebelehre" (Chair of Kinematics) at the Technische Hochschule (TH) in Berlin-Charlottenburg, there was a succession of interim professors, until Hermann Alt from Dresden finally got the chair in 1939, again as full professor. Karl Hoecken belonged to this row of interims, serving from 1930 to 1934. Looking through Hoecken's estate, we find some new aspects of the famous kinematic model collection established by Reuleaux. This paper also takes up four publications by Hoecken on mechanisms, models and their kinematic equations, and thus, gives a historical overview of Hoecken's contribution to the field of kinematics at that time.

1 Biographical Notes

Because of the fact that the author never met Karl Hoecken personally and because the family name "Hoecken" is unknown now in Braunschweig, where the family members lived until the early '60s, it was difficult to trace exact data in the present day. Reliable sources were hidden in two big cardboard boxes that were handed over to the author by the supervisor of his own doctoral thesis, the late *Bekir Dizioğlu* (1920–2006). The boxes were mainly filled with copies of Hoecken's publications and patent papers, many photos and lists of mechanism models, and partly unpublished documents, charts and sketches.

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Karl Hoecken was born on May 31, 1874 in Berlin. In 1946, after the end of World War II, he moved to Braunschweig with his family, his wife Anna and their two sons, Hermann and Richard. He continued to live in Braunschweig until his death in 1962 at the age of 88.

Hoecken studied land surveying at the Landwirtschaftliche Hochschule (Agricultural College) in Bonn-Poppelsdorf, where he passed his engineering examination in 1896. In 1903, he continued his studies, now in mathematics and physics, at the University of Bonn. In 1906, he became assistant lecturer for geodetics at TH Darmstadt, and then transferred to the same position at TH Berlin in 1908. After a quarrel with his professor one year later, Hoecken changed again and got a leading technical position as an instrument maker at the company "Optische Anstalt C. P. Goerz AG" in Berlin-Friedenau until 1914. This year was also the beginning of World War I. From 1914 to 1918, Hoecken was employed in the field of military technical equipment in the "Reichswehrministerium" in Berlin. Also thereafter, until 1928, Hoecken worked as a teacher and consultant in different ministry departments and co-operating companies in Berlin, Danzig and Amsterdam.

Between 1922 and 1928, there was no real holder of the chair of kinematics at TH Berlin. When *Franz Reuleaux* (1829–1905) had to leave the TH in 1896, *Wilhelm Hartmann* (1853–1922), one of his scholars, became his successor in the chair and at the same time curator of Reuleaux's famous kinematic model collection, housed in the western part of the ground floor in the main building of the TH.

In 1930—at the age of 56—Karl Hoecken got his chance, becoming lecturer of kinematics and curator of the Reuleaux collection. He was active in the chair for only four years until 1934. Among Hoecken's papers, there is—among other things—a map of the collection rooms (Fig. 1).

The area of the collection comprised 205 m^2, including two rooms for the lecturer and one assistant. After Hoecken's retirement and the short interim of *Rudolf Franke* (1870–1962), the chair of kinematics was finally transferred to *Hermann Alt* (1889–1954) from TH Dresden. Alt became full professor again in 1939, i.e., 43 years after Reuleaux's forced retirement (Mauersberger 1988; Kerle 2011, 2012).

Hoecken tried a comeback as a civil employee and instructor in military departments of the then "Wehrmacht". The author found documents in the archive of the library of TU Braunschweig which prove that in 1946 Hoecken—now living in Braunschweig—applied for a lecturer position in kinematics, but his request was declined.

2 List of Main Works

Following Hoecken's educational and professional career chronologically, we can divide his main works, i.e., scientific papers and patents, into four categories (cf. Tables 1, 2):

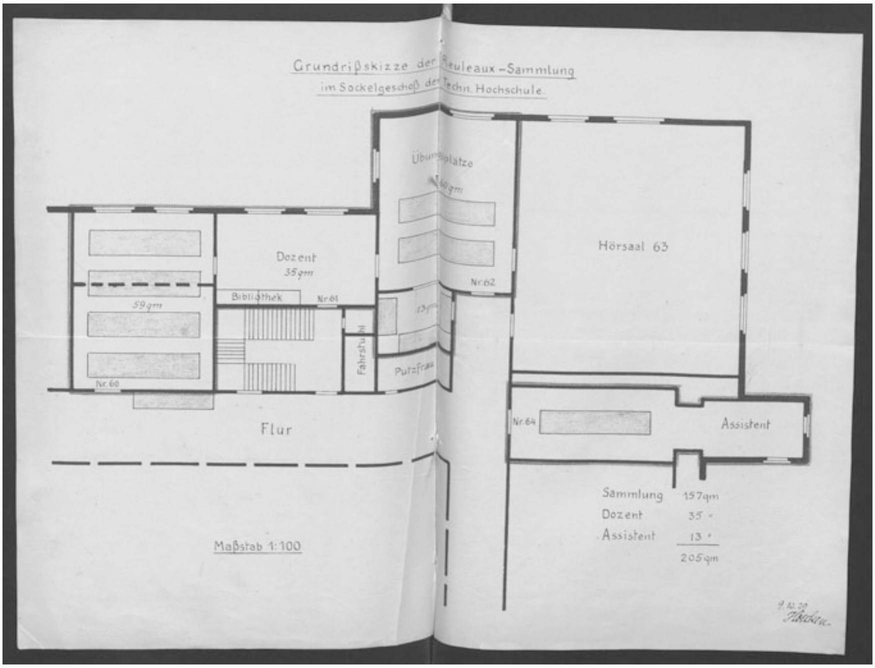


Fig. 1 Map showing the rooms of the Reuleaux collection in 1929

- Computing Mechanisms and Linkages (C1)
- Computing Machines (C2)
- Nomographics (Graphical Calculus) (N)
- Mechanism Theory or Kinematics (K).

The list of patents describes Hoecken's industrial period when he was working at "Optische Anstalt C. P. Goerz AG". The company was founded in 1886 by *Carl Paul Goerz* (1854–1923) and started off selling mathematical instruments. Soon, Goerz added photographic and astronomical devices to his sale supply. The company grew very fast and became famous for the development and manufacture of optical instruments for all purposes, including military. Eventually, Goerz had branch factories in New York, London, Paris, Vienna, St. Petersburg, Riga and Bratislava. In 1926, the Goerz company was merged with its biggest rival, the Zeiss Ikon AG company in Dresden and Jena (Zaun 2009).

Table 1 List of Hoecken's main scientific publications

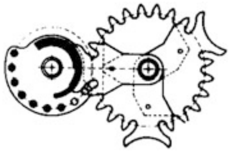
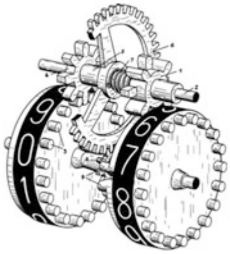
Year of publication	Category	Title of scientific publication
1909	C1	Neuer Rechenapparat zur Ermittlung der Produkte s · sin a und s · cos a (New calculating apparatus for determining the products s · sin a and s · cos a)
1911a	C1	Arithmetischer und trigonometrischer Universalrechenapparat nach Hamann (Arithmetical and trigonometrical universal calculating apparatus by Hamann)
1912	N	Über ein neues Instrument zur Ermittlung des Steuerwinkels und der resultierenden Geschwindigkeit bei Flugzeugen und über die Anwendung der Nomographie zur Lösung solcher Aufgaben (On a new instrument for determining the control angle and the resulting velocity of aeroplanes and on the application of nomographics for the solution of such tasks)
1913	C2	Die Rechenmaschinen von Pascal bis zur Gegenwart, unter besonderer Berücksichtigung der Multiplikationsmechanismen (The calculating machines from Pascal up to today with special consideration of multiplying mechanisms)
1916a	C1	Mechanismus zur automatischen Einstellung konjugierter Objekt- und Bildpunkte (Mechanism for automatic adjustment of conjugate object and image points)
1923/1924a	K	Berechnung der Räderstellung für Stirnräderwendegetriebe (Calculating the wheel positions of spur gears for positive as well as negative rotary direction of the output wheel)
1923/1924b	K	Zur Theorie der Wälzhebel und über einen daraus abgeleiteten Zahnrädermechanismus (On the theory of profile lever pairs and on a gear mechanism derived from it)
1930a	K	Das exzentrisch angetriebene Räderknie zur Vermittlung ungleichförmiger Drehung mit Rast und Rückwärtsgang (The eccentrically driven gear train for generating non-uniform rotation with dwell and reverse motion)
1930b	K	Sternradgetriebe (Star-wheel mechanisms) 
1930c	K	Die Erzeugung von Rasten durch Koppelgetriebe (Generating dwells with linkages)
1930d	N	Ermittlung zusammengehöriger Objekt- und Bildpunkte vermittels des Kardanproblems (Determination of matching object and image points by means of cardanic motion)
1933a	K	Rechnerische Ermittlung eines Konchoidenlenkers (Determining the links of a conchoidal linkage)
1933b	C1	Ellipsenzeichner (Ellipses drawing device)
1938	K	Verfahren zum Verzahnen unrunder Räder (Method of cutting non-circular gearwheels)

Table 2 List of Hoecken's main patents

Year of publication	Category	Title of patent
1911b	C2	Addiervorrichtung mit Zahlenschiebern (Adding apparatus with number sliders)
1914	C2	Rechenmaschine mit Tastatur und durch eine Schere betätigtem Zahnstangensystem zum Antrieb des Zählwerks (Calculating machine with keyboard and a rack-and-pinion system actuated by a scissors-type device for driving the counter)
1916c	C1/C2	Zehnerschaltvorrichtung mit einem Umlaufgetriebe (Tens carrying apparatus with a planetary gear mechanism) 
1916b	K	Schaltgetriebe zur Umwandlung einer ständigen Bewegung in eine absatzweise sich vollziehende (Mechanism for transforming uniform motion into intermittent motion)
1917b	C2	Zehnerschaltvorrichtung für Summierwerke (Tens carrying apparatus for adding machines)
1917c	K	Vorrichtung zur Übersetzung der Bewegung einer gleichförmig umlaufenden Welle ungleichförmig auf eine zweite (Apparatus for transforming uniform rotation of one shaft into non-uniform rotation of another shaft)
1919	C1	Ellipsenzeichner (Ellipses drawing device)
1921a	C2	Schaltwerke für Rechen- und Additionsmaschinen (Intermittent motion mechanisms for calculating and adding machines)

3 Review of Main Works on Mechanism Design

In the following, four examples of Hoecken's main works on mechanism design are presented:

- Ellipses drawing device ("ellipsograph")
- Six-link dwell linkage
- Conchoidal straight-line linkage
- Redtenbacher's gear train.

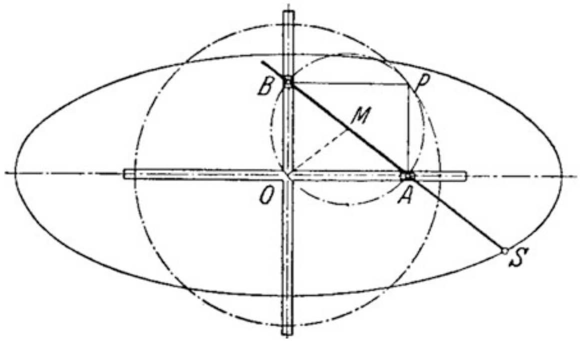


Fig. 2 Use of Cardanic movement generated by a double slider (*A* and *B*) to draw ellipses (*S*)

3.1 Ellipses Drawing Device ("ellipsograph")

In Hoecken's time, a mathematical instrument for generating exact ellipses in technical drawings was very much in demand with engineering designers. A parametrical description of an ellipse is given by the equations $x = a \cdot \cos \varphi$ and $y = b \cdot \sin \varphi$, with a and $b \neq a$ being the half axes of the ellipse. The best known mechanism for generating ellipses is a perpendicular double-slider, which may also be replaced by two circular centrodes (Cardan circles or circles of *Geronimo Cardano*, 1501–1576) rolling on each other, with radii AB and AB/2 respectively (Fig. 2). Each point on the straight line through points A and B—for example, point S—follows an ellipse with a = BS and b = AS (Hartmann 1891).

Hoecken created a special version of the double slider above, choosing a "pair-contraction" of the two pins in A and B, resulting in a perpendicular cross-slider with centre point P (drawing pencil) (Fig. 3) (Hoecken 1919).

The cross-slider is driven by a square frame that is coupled to and moved by two parallel-crank linkages of different lengths, thus giving adjustable half axes $a = O_1A_1$ and $b = O_2B_2$, and moving the point P on an ellipse in the xy-plane, i.e. $(x/a)^2 + (y/b)^2 = \cos^2\varphi + \sin^2\varphi = 1$. The square frame follows a circular-parallel path in the xy-plane without rotation (Hoecken 1919; Kaiser 1919). Figure 4 shows a prototype of Hoecken's "ellipsograph".

3.2 Six-Link Dwell Linkage

With dwell linkages having one degree of freedom, the output link temporarily comes to a standstill, while the input link moves continuously. The standstill or dwell position is characterized by zero values of the velocity and acceleration of the output link, related to the fixed link. In return positions, i.e., so-called "dead positions", the velocity of the output link is also zero, but not its acceleration. The dwells generated by linkages are normally only approximate ones, i.e., the zero

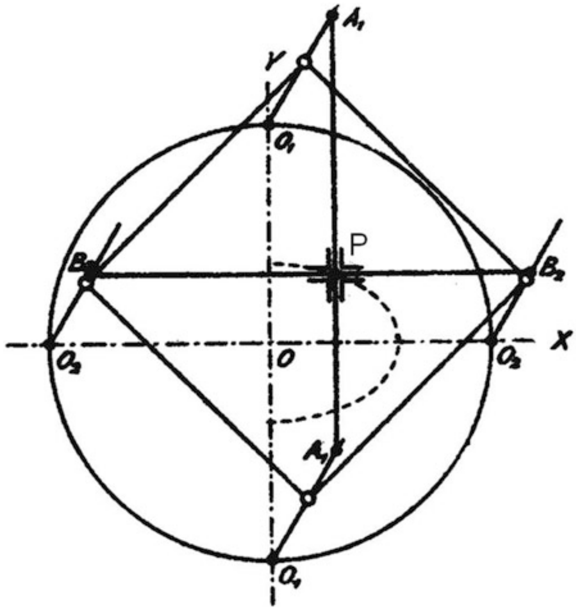


Fig. 3 “Pair-contraction” of A and B in P changes the double slider into a cross slider to draw ellipses

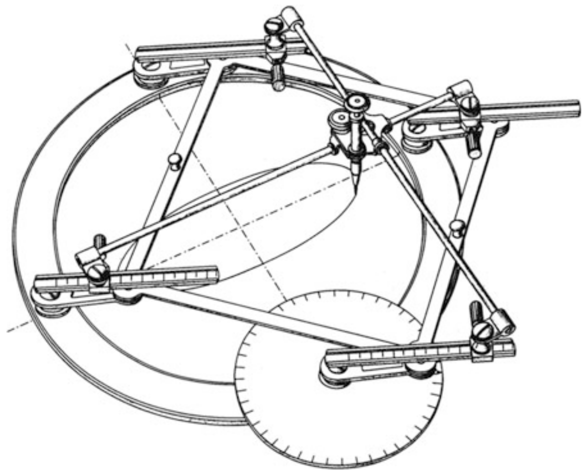


Fig. 4 Design details of Hoecken’s “ellipsograph”

values of velocity and acceleration of the output link mentioned above are reached only approximately or on an average (Alt 1932a, b; Meyer zur Capellen 1963).

The best known structures, or so-called “kinematic chains”, of dwell linkages have six links and are of the type “Watt” and “Stephenson” (Hain 1980). In Hoecken’s estate, there is a technical drawing showing a four-link crank-rocker with a two-bar coupled to it. The drawing “Rastgetriebe” from February 11, 1932 reveals details of the links, their dimensions and even a counterweight on the opposite end of the rocker for static balancing (Fig. 5).

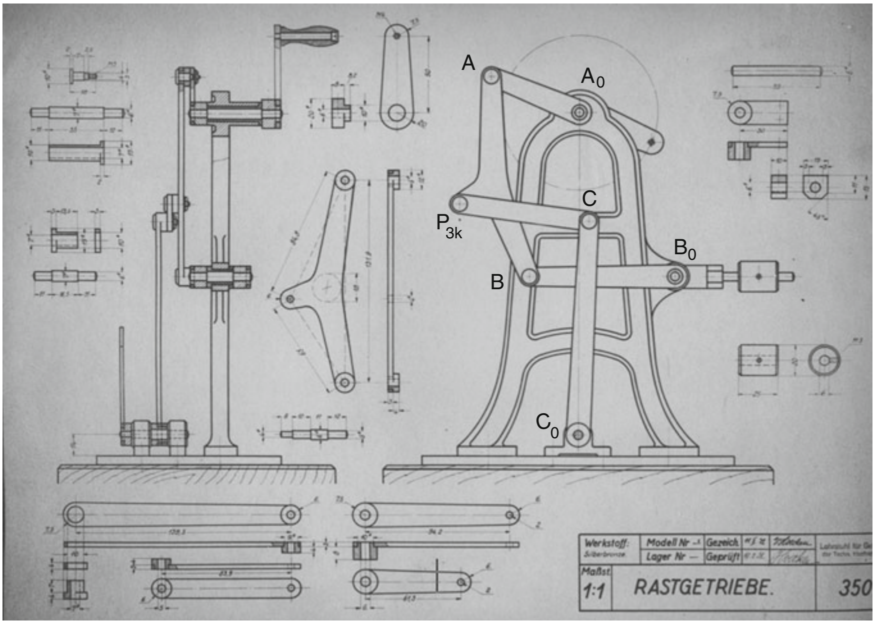


Fig. 5 Technical drawing of Hoecken's six-link dwell linkage showing details for its manufacture

The dimensions of Hoecken's six-link dwell linkage are as follows (dimensions in mm length units):

$n_0 = B_0C_0 \approx 124.0$	$A_0C_0 \approx 215.0$
$n_1 = A_0B_0 \approx 127.0$	$n_2 = A_0A = 61.3$
$n_3 = AB = 131.9$	$n_4 = B_0B = 94.2$
$n_5 = CP_{3k} = 83.9$	$n_6 = C_0C = 139.5$
$AP_{3k} = 84.8$	$\angle P_{3k}AB = 24.45°$

It is very interesting to discover that Hoecken put his linkage onto a typical Reuleaux frame and assigned it the model number 2201. There is also a paper by Hoecken on dwell linkages (Hoecken 1930c), but it does not describe his model as shown in Fig. 6.

By means of the commercial program "Mathcad 11," a kinematic analysis of Hoecken's six-link dwell linkage can now be performed to find out the accuracy of Hoecken's approach, the results of which are presented in Fig. 7.

The approximate dwell of output link 6 (C_0C, Fig. 5) is realized within the range $120° \leq \varphi \leq 180°$ of input link 2 (A_0A, Fig. 5). Within this range, the angle φ_6 of the output link only falls from 214° to 213°, the angular velocity of the output link shows an absolute maximum deviation from zero of 0.022 rad/s, and that of the angular acceleration amounts to 0.018 rad/s^2.

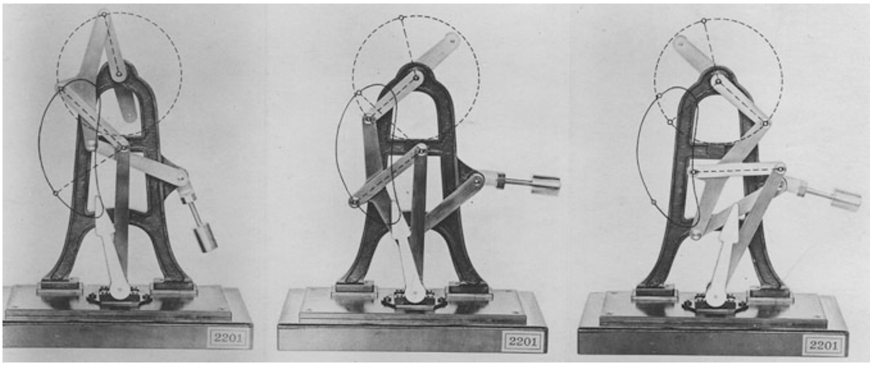


Fig. 6 Hoecken's six-link dwell linkage as a model mounted on a Reuleaux frame

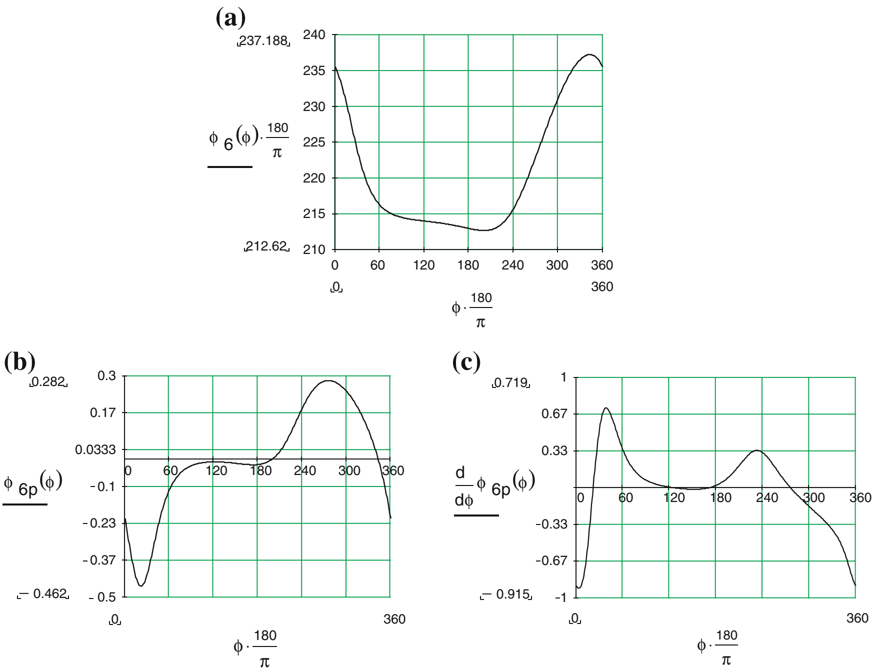


Fig. 7 Kinematic analysis of Hoecken's six-link dwell linkage: Angle (**a**), angular velocity (**b**), and angular acceleration (**c**) of output link 6 versus crank angle φ (input link 2)

3.3 Conchoidal Straight-Line Linkage

From the kinematic point of view, the conchoidal straight-line linkage is a four-link centric angle-slider linkage (Fig. 8a).

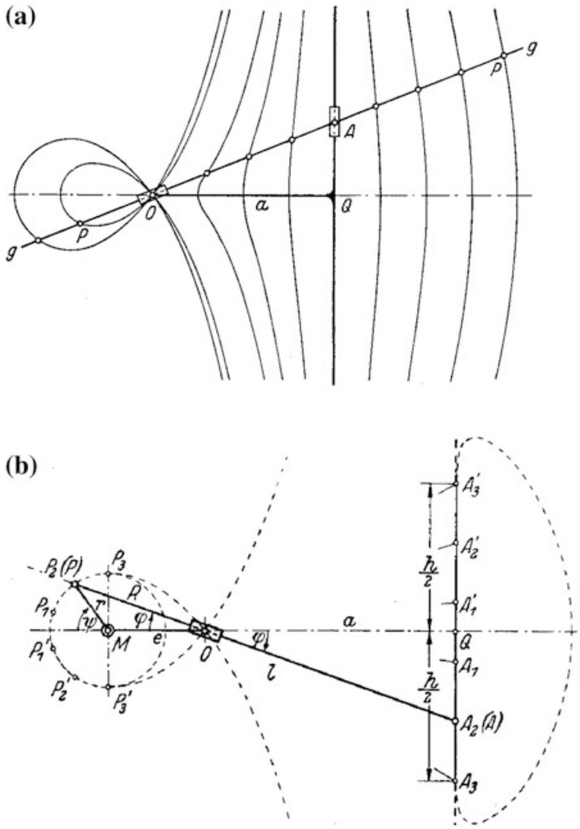


Fig. 8 Centric angle-slider with conchoidal coupler curves (**a**) and a centric inverted slider-crank (**b**) which approximately replaces (**a**)

The coupler link, shown as the straight line gg, constantly slides through the fixed sliding point O, whereas the movable sliding point A is led along the fixed straight line through Q having the distance a from O. The sliding direction of point A is perpendicular to the symmetry axis passing through O and Q, the latter also being the horizontal axis x of a rectangular coordinate system.

Every point P on coupler straight line gg follows a conchoidal curve. In case P is located on the opposite side of OA, the conchoidal curve contains a closed crunode. If this crunode is partly similar to a circle, it may be approximately replaced by a circle arc with centre point M on the x-axis and radius r (Fig. 8b). Thus, a centric inverted slider-crank linkage is found as a substitute mechanism, where the slider in A can be dropped, because its path partly consists of an approximately straight line, perpendicular to the x-axis (Hoecken 1933a).

Hoecken equates the polar equation of the crunode with that of a circle around M and takes into account that all coupler curves of the inverted slider-crank are symmetric related to the x-axis. He determines the dimensions of this substitute mechanism, which approximately leads coupler point A along a straight line

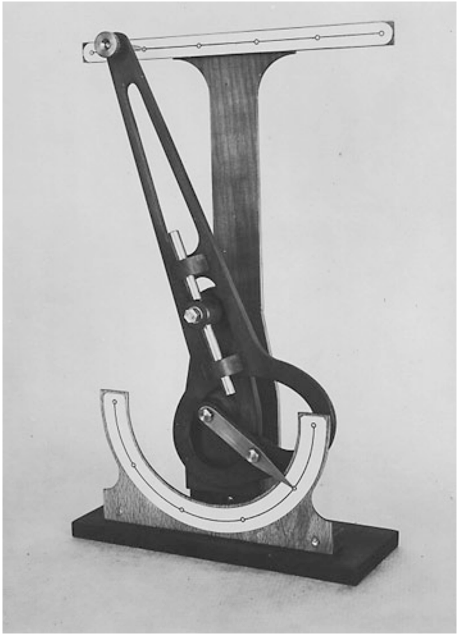


Fig. 9 Hoecken model of a conchoidal straight-line linkage

through six points in finite neighbouring order with a distance of h/5 between two points each. Taking a = OQ = 100 mm length units for given, Hoecken gets the following data: e = OM = 38.6378, $h = A_3A_3' = 120.7658$, l = AP = 161.9516 and r = MP = 23.3341. Hoecken writes that the maximal deviation of the coupler curve within $h = A_3A_3'$ from an exact straight line results in 0.0203. Moreover, Hoecken built a compact model in order to show the usefulness of his ideas and the validity of his calculations (Fig. 9).

One should keep in mind that the mathematical aids in Hoecken's time were limited and mainly consisted of tables of logarithmic and trigonometric functions. Slide rules were also in use, but not very efficient and/or precise. Solving Eq. (1), for example, namely

$$2el \cdot \cos^3\varphi - (l^2 + 2ae + e^2 - r^2) \cdot \cos^2\varphi + 2al \cdot \cos\varphi - a^2 = 0, \qquad (1)$$

to calculate e, l, r, where three different angles $\varphi = \angle AOQ$ are given above or below the x-axis (cf. Fig. 8b), requires multiple interpolation and iteration procedures to gain results with four digits after the decimal point.

By means of the commercial program "Mathcad 11," Hoecken's calculations can be verified and his statements confirmed (Fig. 10).

In Fig. 10, the input crank angle $\phi = 180° - \omega$ is introduced, instead of ω as in Fig. 8b. The deviation of only ±0.0203 mm from x_{ref} is valid between $122° \leq \phi \leq 238°$ crank angle.

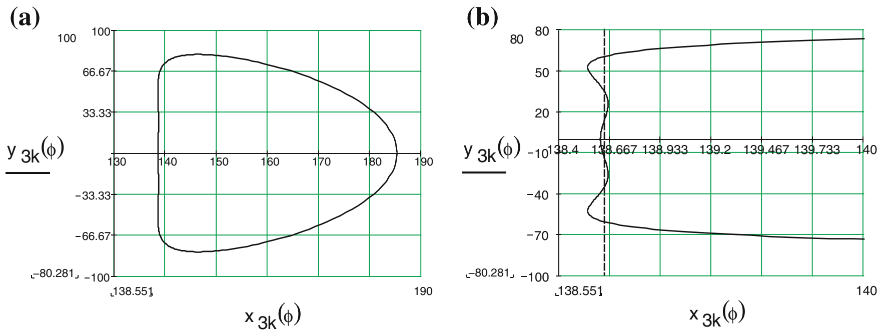


Fig. 10 Coupler curve of Hoecken's conchoidal straight-line linkage: **a** general view, **b** zoomed view around the reference vertical (broken) straight line $x_{3k} = x_{ref} = a + e$

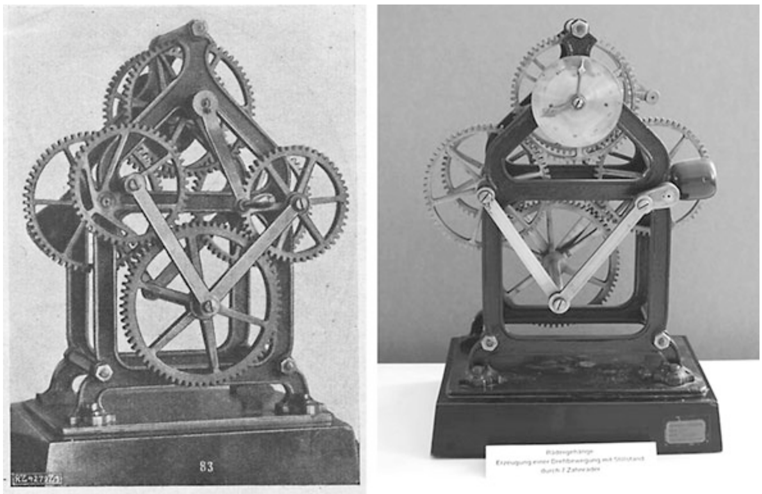


Fig. 11 Redtenbacher's gear train, back view (*left*) and front view (*right*)

3.4 Redtenbacher's Gear Train

In 1926, Hoecken visited TH Karlsruhe. He found, among other things, the model of a gear train with seven gearwheels. The model belonged to the Redtenbacher model collection in Karlsruhe, but nobody could explain to Hoecken the purpose of this model (Hoecken 1930a).

Figure 11 (left) shows the back of the Redtenbacher gear train with model number 83 in a photo taken by Hoecken himself. The author is happy about the fact that there is a second photo on the internet (Moon 2011), now revealing the front of the model (Fig. 11, right). This photo was taken in 2001 or 2002 by Francis C. Moon from Cornell University in Ithaca, NY (USA), during a visit to

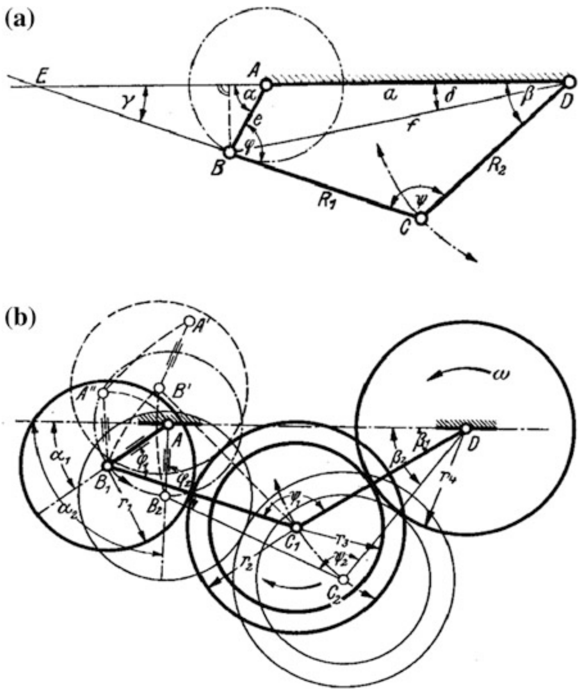


Fig. 12 Hoecken's sketch of Redtenbacher's gear train: Basic four-bar linkage (**a**), compound gear train (**b**)

TH Karlsruhe. It is not necessary to write about the significance of *Ferdinand Jakob Redtenbacher* (1809–1863) in the evolution of mechanical engineering as a science in Germany, because there is a detailed and excellent description of his lifework, cf. (Wauer et al. 2009, 2010).

Hoecken explains that three of the seven gearwheels are unnecessary for the mechanism to function correctly, but only serve to make the input rotary axis with the driving crank coincident with the output rotary axis ("returning" mechanism). Both axes have metal pointers in the form of arrows for demonstration, similar to those on a clock.

The base mechanism is that of a crank-rocker ABCD (Fig. 12a) with four two-by-two mating gearwheels with their centres in B, C and D (Fig. 12b). The gearwheel centred in B forms the input crank (eccentric wheel) and rotates around A (input angle α). Depending on the dimensions of the crank-rocker and the radii r_1 to r_4 of the gearwheels, it is possible to vary the output angle ω of gearwheel 4 related to the input angle α of crank or gearwheel 1, i.e., the transmission ratio can be partly positive, zero (standstill of gearwheel 4) or negative (the "pilgrim's step" motion of gearwheel 4), while crank 1 rotates continuously with constant angular velocity. The rotary motions of the gearwheels originate from the variable difference angles $\varphi(\alpha) = \angle ABC$, $\psi(\alpha) = \angle BCD$ and $\beta(\alpha) = \angle ADC$ between the adjacent bars of length e–R_1, R_1–R_2 and a–R_2.

Hoecken used his own extensive geometric-mathematical equations to calculate the output angle $\omega = \omega(\alpha, t)$ (time t) and output angular velocity $d\omega/dt = (d\omega/d\alpha)\cdot(d\alpha/dt)$ for given dimensions and given input quantities α and $d\alpha/dt \equiv 1$ rad/s of the gear train.

Hoecken's results are checked by using the commercial program "Mathcad 11" again. Given the dimensions $a = AD$, $e = AB$, $R_1 = BC$, $R_2 = CD$ of the crank-rocker and the radii r_1 to r_4 of the gearwheels, where $r_1 + r_2 = R_1$ and $r_3 + r_4 = R_2$ and setting $r_1/r_2 = \mu$ and $r_3/r_4 = \upsilon$, we first make use of a set of kinematic equations for four-bar linkages and calculate the angles φ, ψ and β. Then, we care for the wheel rotations and follow the equations

$$\omega_0 = \omega(\alpha = \alpha_0 = 0), \text{ etc. for } \varphi_0,\ \psi_0,\ \beta_0, \tag{2}$$

$$\omega_0 = (1 + \upsilon) \cdot \beta_0 + \upsilon \cdot (1 - \mu) \cdot (360^\circ - \varphi_0 + \alpha_0) = 0, \tag{3}$$

$$\omega(\alpha) = \omega_0 + \beta(\alpha) - \beta_0 - \upsilon \cdot [\psi(\alpha) - \psi_0] + \mu \cdot \upsilon \cdot [\varphi(\alpha) - \varphi_0]. \tag{4}$$

In order to demonstrate the effectiveness of these equations, we take Hoecken's example and set the lengths in mm of the four-bar links and the gearwheel radii as follows: $a = 50$, $e = 15$, $R_1 = R_2 = R = 35$. We distinguish between three cases concerning different gearwheel ratios, i.e., case I: $r_1 = 25$, $r_2 = 10$, $r_3 = 20$, $r_4 = 15$; case II: $r_1 = 20$, $r_2 = 15$, $r_3 = r_1 = 20$, $r_4 = r_2 = 15$; case III: $r_1 = 10$, $r_2 = r_3 = r = 25$, $r_4 = r_1 = 10$ (Hoecken made a slight mistake when he wrote $r_1 = r_4 = r = 25$). Case III is equivalent to the fact that there are only three instead of four gearwheels. The results are shown in Table 3.

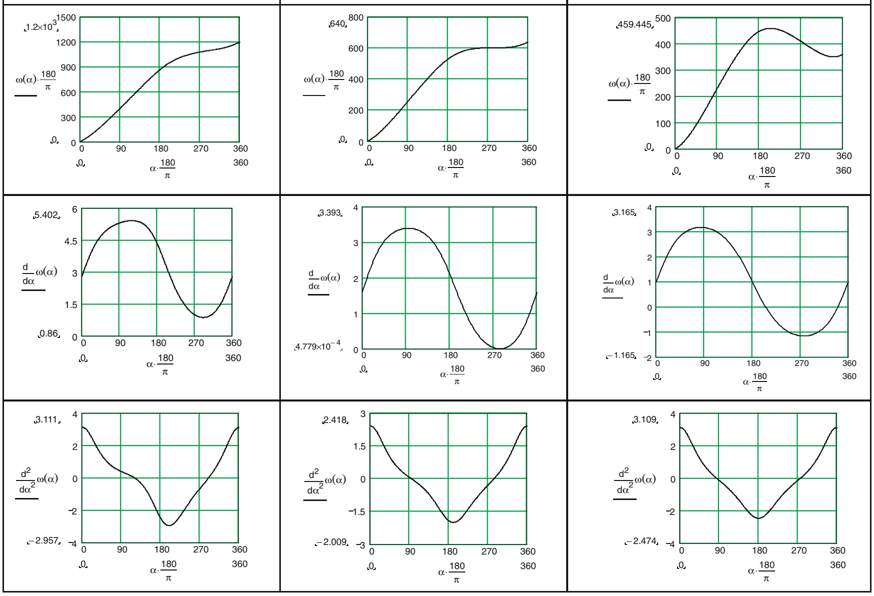
The columns represent the output angle $\omega = \omega(\alpha)$ and its derivatives $d\omega/d\alpha$ and $d^2\omega/d\alpha^2$. Because of the fact that the input angular velocity is constant and of unit value, the derivative functions $d\omega/d\alpha$ and $d^2\omega/d\alpha^2$ are equivalent to the angular velocity and angular acceleration with respect to the output of gearwheel 4.

Case I reveals a continuous positive ratio between the output angle ω and input angle α, the output angular velocity varying within the positive range without reaching zero; in case II, there is a standstill of the output gearwheel momentarily at point $\alpha = 285°$, a condition that Kurt Hain already named a "point dwell" position in coherence with a special six-bar linkage (Hain 1981); case III stands for a "pilgrim's step" motion of the output gearwheel in the range $205° \leq \alpha \leq 340°$, i.e., gearwheel 4 rotates partly in the opposite direction related to input gearwheel 1.

Some 17 years later and now living in Braunschweig at the age of 73, Hoecken again tackled the problem of finding the dimensions of a "pilgrim's step" geared four-bar linkage. Hoecken wanted to solve the complicated equations by means of nomographic charts. He typed all the pages and drew all the figures of a new publication, but he never published it. Hoecken's economic problems just after World War II were greater than his wish for publication. In Hoecken's estate, there is also a photo of a model of a four-bar with three gearwheels (Fig. 13).

Table 3 Output motion of gearwheel 4 versus input crank angle in Redtenbacher's gear train showing three different cases

Case I Positive ratio	**Case II** (Hain) "Point dwell"	**Case III** (Hoecken) "Pilgrim´s step"



Hoecken set the length R_1 of the coupler BC equal to the length R_2 of the rocker CD, the radius of input gearwheel 1 equal to the radius of output gearwheel 4 and the radius of gearwheel 2 equal to that of gearwheel 3, this latter condition again being equivalent with the earlier case III with only three instead of four gearwheels, i.e.,

$$R_1 = r_1 + r_2 = r_3 + r_4 = R_2 = R, \tag{5}$$

$$r_1 = r_4 = r, \quad r_2 = r_3 = R - r. \tag{6}$$

There is an input range of width $\alpha_2 - \alpha_1 = 2\delta$ of input gearwheel 1 or crank AB, where the output gearwheel 4 rotates in reverse direction to gearwheel 1, this output range being $\omega_2 - \omega_1 = \varepsilon$. For given r, $R = r + r_2$, and δ, Hoecken found the following solutions for the lengths a (fixed link) and e (crank, eccentricity) of the four-bar linkage ABCD:

$$(a/R)^2 = 1 + \left[\left(R^2 - r^2\right)/\left(R^2 + r^2 \cdot \tan^2\delta\right)\right]^{1/2}, \tag{7}$$

$$(e/R)^2 = 1 - \left[\left(R^2 - r^2\right)/\left(R^2 + r^2 \cdot \tan^2\delta\right)\right]^{1/2}, \tag{8}$$

$$\varepsilon/2 = \delta - (R/r) \cdot \arctan[(r/R) \cdot \tan\delta]. \quad (9)$$

One possible solution of a proper nomographic chart for solving Eqs. (7) and (8) is shown in Fig. 13 (below), consisting of three straight lines. After having chosen, for example, two arbitrary values of 2δ and a/R—or e/R, respectively—on the two corresponding straight lines on the left and right side, these two values define a straight line themselves which intersects the third straight line in the middle at the solution points r/R or r_1/R, respectively.

The nomographic chart in the figure additionally shows a broken line which represents the solution a/R = 1.387 or e/R = 0.28, respectively, for given values of $2\delta\ ° = 20$ and r/R = 0.38.

4 On Hoecken's Role as One of the Successors of Franz Reuleaux in Berlin

When Hoecken took over the leadership of the "Lehrstuhl für Getriebelehre" at TH Berlin in the summer term of 1930, he offered two lectures to his students, "Ausgewählte Kapitel aus der Getriebelehre" (Selected Chapters of Kinematics) and "Einleitung in die Nomographie" (Introduction to Nomographics). Two years later, Hoecken added a lecture about "Die mechanischen Rechenmaschinen" (Mechanical Calculating Machines). Hoecken's lectures were not obligatory for graduate students. This fact is astonishing only at first glance; it was a leftover consequence of the quarrels Reuleaux had had many years earlier with some of his colleagues at TH Berlin. Later on in 1896, Reuleaux had to leave TH Berlin involuntarily. Moreover, in 1902—three years before Reuleaux's death—lectures on kinematics were even removed from the obligatory curricula for mechanical engineering students (Mauersberger 1988; Moon 2003). It is also meaningful that Wilhelm Hartmann, Reuleaux's follower, did not get the position of a full professor in kinematics. Hoecken wanted to base his lectures on those of Hartmann, and consequently Hoecken's lectures on kinematics were strongly related to the ideas and works of Reuleaux. Among Hoecken's papers is an announcement advising his students to visit the famous Reuleaux kinematic collection in order to learn more about kinematics. Hoecken's activities at TH Berlin ended as the winter term of 1934 was still ongoing; clear reasons for this sudden end have not been found. Some of Hoecken's personal notes from that time indicate that the social democrat Hoecken was unpopular with the national socialists in Berlin. On the other hand, there are also contemporary documents which supply evidence that Hoecken never missed any chance to quarrel with his colleagues and the university administration in order to get a better position and more money. In addition, Hoecken was already 59 years old by that time.

The much more interesting point as far as the kinematics community is concerned is this: Immediately after his appointment as lecturer and curator of the Reuleaux collection, Hoecken took inventory of it. He made a primary list on a

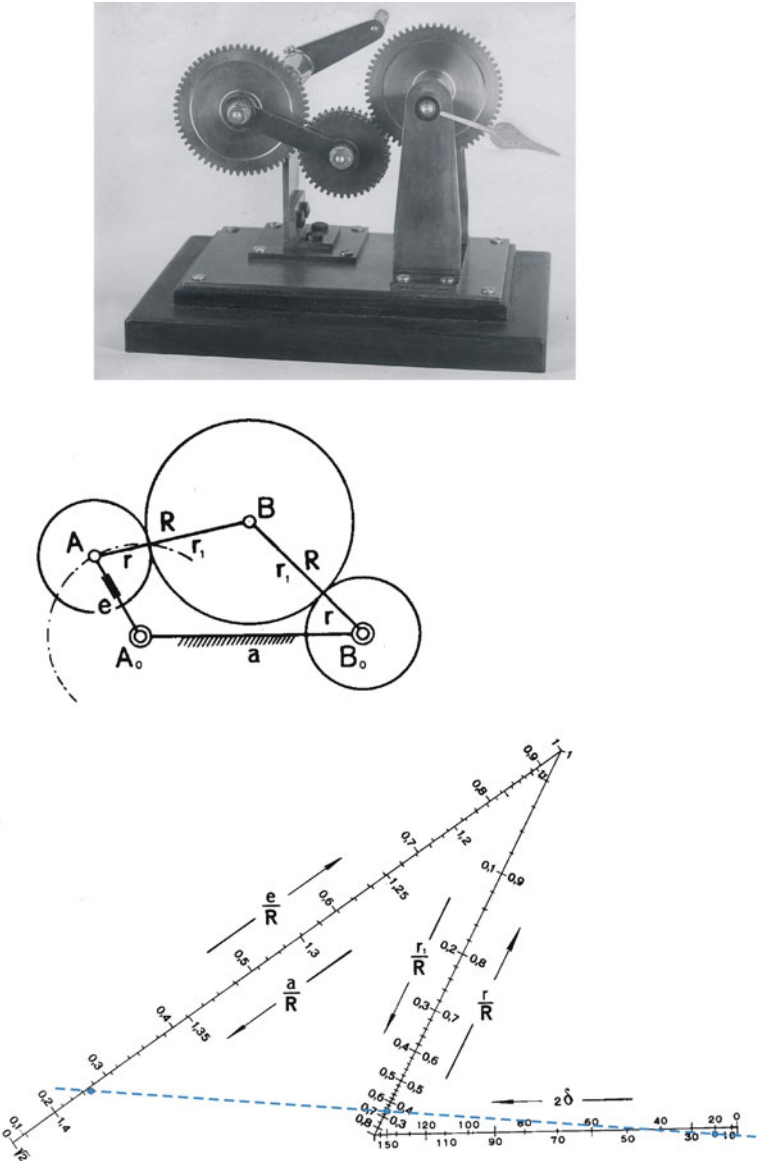


Fig. 13 Redtenbacher's gear train reduced to three gearwheels ($R_1 = R_2 = R$) and gearwheel radii $r_1 = r_4 = r$

typewriter of all 795 items in the collection, but not every item named on this list was a mechanism, a mechanism element or a machine model.

Hoecken found a new numbering system for the models in the collection, differing strongly from that which Reuleaux, his model maker *Gustav Voigt* and

Table 4 Hoecken mechanism models belonging to the Reuleaux collection

No.	Model name	No. in Hoecken's primary list
1	Keyboard with straight-line guide for computing machines	348
2	Double straight-line guide having opposite directions	347
3	Reversing mechanism with Oldham coupling	833
4	Flip ratchet mechanism	1764
5	Double rotating inverted slider-crank	1239
6	Drive of parallel shafts by means of a parallel linkage	2050
7	Seven-link spatial screw chain	2001
8	Spatial shaft coupling	
9	Spatial chain with 3 + 4 d.o.f.	
10	Spatial branched chain with 2 + 2 + 3 d.o.f.	
11	Angular straight-line guide	350
12	Star-wheel gear having internal gear meshing (driver bigger than star-wheel)	
13	Star-wheel gear having internal gear meshing (driver smaller than star-wheel)	
14	Kirsten propeller	
15	Device for cutting elliptical gearwheels	
16	Rolling pairs, one limited linearly	
17	Straight-line guide having opposite directions	
18	Spatial chain with 2 + 5 d.o.f.	
19	Eccentric conchoidal straight-line guide	
20	Intermittent mechanism having 120° intermittent angle	
21	Reversing mechanism with gearwheels	
22	Shifting mechanism	
23	Angular shaft coupling for constant rotary transmission	
24	Revolving mechanism	929/930
25	Cardanic gearwheels	349

his son *Otto Voigt* had introduced and used at the beginning (Voigt and Voigt 1907). On the occasion of the two industrial fairs in Leipzig in 1928 and 1929, there were also two mechanism model exhibitions to which German university institutes and industrial companies contributed. The models presented there were also compiled in two booklets (AWF and VDMA 1928, 1929) with new number stickers. Hartmann probably changed the numbering system of the model collection, perhaps because he wanted to merge the two lists "I. Verzeichnis" and "II. Verzeichnis" of the Voigt catalogue.

Hoecken wrote a second list on his typewriter that comprised 25 "genuine Hoecken models" (cf. Table 4). Hoecken pointed out that he himself had designed and manufactured all the models named on this second list. A closer inspection of this list reveals that 10 of the specified models were already part of the Reuleaux collection, while the other 15 models were new ones, and it seems that Hoecken added these 15 new models to the collection during the years of his leadership.

What's more, there is a third list by Hoecken, this one handwritten, which comprised items/models that

- were eliminated from the collection because they belonged to the group of auxiliary parts or were damaged,
- Hoecken himself had built, bought or got as gifts from industrial companies.

We also learn from this third list that Hoecken created a new group "20" of spatial mechanisms, consisting of 24 models. He assigned the name "Freiheitsgrade" (degrees of freedom, d.o.f.) to this group.

All the three of Hoecken's lists are combined below (cf. Table 5). This table presents the state of the art of the kinematic Reuleaux collection by the end of 1934.

Some additional remarks are necessary:

- First column: There are 22 different groups of models; the content of group 21 is unknown.
- In the second column, all the models of the Reuleaux collection in Berlin are given following Hoecken's primary list numbers. Genuine Hoecken models included are written in italics and put in parentheses. The Reuleaux models that were exhibited on the occasion of the two industrial fairs in Leipzig are given separately below a broken line. The photo numbers attached to these latter models and published in (AWF and VDMA 1928, 1929) are put in parentheses.
- The fourth column contains the group names or model types. The matching Reuleaux-Voigt models listed in (Voigt and Voigt 1907) and described by Moon (2007, 2011) are written in italics and put in parentheses.
- The list reveals a total of at least 772 models in the Reuleaux collection, including 21 Hoecken models, as well as 17 small models made of sheet metal, also contributed by Hoecken. In addition, there were 15 genuine Hoecken models that Hoecken mentioned, but had not had the time to assign numbers to (cf. Table 4).

Owing to the fact that the Reuleaux collection contained models that were not invented or designed by Reuleaux himself, the question sometimes arises as to how to identify genuine Reuleaux models, those "designed by Reuleaux". Neither the typical Reuleaux frame nor the stand of a model, as shown, for example, in Fig. 6, gives a secure answer. It makes sense to assume that the models at the beginning of the collection from 1870 were genuine Reuleaux models. But the best source for finding genuine Reuleaux models are the two lists in (Voigt and Voigt 1907). Here, some of the model names have supplements, such as "von Reuleaux" or "nach Reuleaux" or simply "Reuleaux". Hoecken also added these supplements to his primary list.

In addition to his lists, Hoecken made a row of photos of the models in the famous kinematic Reuleaux collection (cf. Figs. 14 and 15).

Table 5 List of models of the Reuleaux collection in Berlin in 1934

Group number	**Berlin model numbers** ***(incl. "Hoecken models")***	**AWF/VDMA model numbers R … (photo no.)**	**Number of models**	**Model types** ***(incl. "Reuleaux-Voigt models")***
0	001-009, 016-032, 040-043 *(041)*		30	Element pairs and four-link mechanisms *(A1-A3, B1, B2, C1-C4, C6, D1-D4, D14, H1, H; 91)*
1	101-106, 108, 109, 112, 114, 116, 117, 120-129, 132-135, 137-148, 152-156	148 (36), 155 (35)	43	Drawing auxiliary devices and mathematical instruments *(B3, B4, D10, D12; 119-122)*
2	201-203, 211-214, 221-224, 227		12	Simple machine tools *(87, 88, 118, 123)*
3	301-350 *(347-350)*	307 (196)	50	Straight-line guide mechanisms *(S1-S39)*
4	401-434	423 (284)	34	Parallel guide mechanisms *(T1-T14, U1, U2; 39-45)*
5	501-510, 512, 513, 516-526, 528-531, 534, 535, 539-554	528 (219), 535 (194), 550 (28)	45	Mechanisms with gearwheels and friction wheels *(C7-C9, Q1-Q8, W1-W6; 46-49, 52-54)*
6	601-629	608 (171), 609 (172), 614 (279), 615 (162), 618 (164), 622 (169), 623 (283), 626 (281/282)	29	Chamber wheel mechanisms *(F1-F6, I1-I9; 67-71)*
7	710-715, 726, 727, 731-733, 741-773, 781-788	765 (110), 768 (107)	52	Cycloidal rolling mechanisms *(R1-R7)*
8	801-836 *(833)*	809 (237), 815 (241), 824 (113), 832 (239)	36	Gear trains and reversing mechanisms *(G1-G7, M9, Y11, Y13, Y18; 60, 62, 63, 73-77, 84-86)*
9	901-931 *(929, 930)*		31	Reversing and shifting mechanisms with gearwheels, friction wheels and belts *(V14-V16, Y3, Y5-Y7, Y9, Y10, Y14-Y17, Y19, Y20)*
10	1001-1017		17	Reversing mechanisms with planetary gearwheels *(Y2; 56-59)*

(continued)

Table 5 (continued)

11	1101-1124, 1130 - - - - - - 1108 (181), 1109 (4), 1112 (12), 1118 (3), 1119 (20)	25	Four-bar linkages and coupling mechanisms *(D5, D7, D8; 72, 78, 79, 89, 90)*
12	1201-1239, 1241, 1242 *(1239)* - - - - - - 1230 (193), 1241 (175), 1242 (176)	41	Crank mechanisms *(C5, D6, D9, D11, D13, E1-E7, K2, K3)*
13	1301-1321, 1324, 1325, 1327 - - - - - - 1307 (225), 1312 (222), 1313 (161), 1319 (224)	24	Screw mechanisms *(M1-M8; 116)*
14	1401-1423	23	Belt mechanisms *(Y1, V1-V13; 80-83)*
15	1501-1503, 1507, 1509-1514, 1516, 1517, 1520, 1550-1562, 1564-1567, 1570-1572 *(1550)* - - - - - - 1513 (197)	33	Planetary gear trains and cycloidal rolling mechanisms *(O1-O5; 92-105)*
16	1601-1657, 1659-1666, 1668, 1671 *(1660)* - - - - - - 1603 (48), 1611 (52), 1613 (51), 1629 (50), 1644 (61)	67	Cam mechanisms with translating follower *(L1-L6; 1-38)*
17	1701-1757, 1760, 1763-1765, 1767-1783, 1785, 1786, 1788, 1789, 1792-1799 *(1764, 1776, 1792-1794)* - - - - - - 1721 (252), 1724 (140), 1726 (112), 1727 (145), 1737 (133), 1772 (134), 1779 (153), 1786 (37), 1789 (254)	90	Ratchet mechanisms *(N1-N3, N6-N13, N15-22, N24-N26, X1-X4, X6-X12; 50, 51, 64-66, 117)*
18	1800-1833 (17), 1837 *(1833 (17))* - - - - - - 1827 (243), 1829 (47), 1830 (151), 1831 (45)	34 (+17)	Jointed couplings and coupling mechanisms *(P1-P5, Z1-Z7; 55)*
19	1901-1913, 1915	14	Belt and rope trains *(61, 106-115)*
20	2000, 2001-2008, 2012, 2015, 2016, 2025-2027, 2030-2032, 2035, 2038-2040, 2050, 2051 *(2001, 2031, 2039, 2050)*	24	Mechanisms with more than one d.o.f. and spatial mechanisms
21			Unknown
22	2201 *(2201)*	1	Dwell mechanisms
Total	*(21 (+17))*	755 (+17)=**772**	

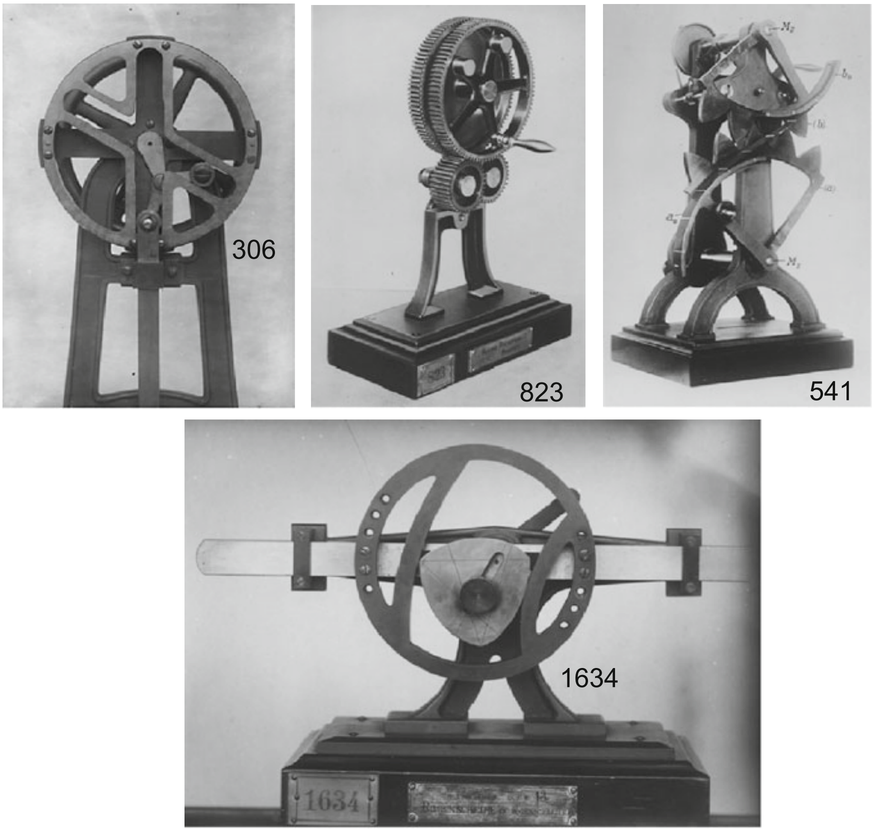


Fig. 14 Hoecken photos showing genuine Reuleaux models: oblique double slider ellipse and straight-line linkage 306 (*S04*), two coupled spur-gear sets for reversed motion 823 (*G07*), involute gear tooth profile 541 (*Q04*), positive return cam mechanism 1634 (*L06*)

The capture of Fig. 14 also contains the model numbers (in italics) that are used in the Voigt catalogue. The four genuine Reuleaux models shown have different stands. With two of them, namely no. 823 and no. 1634, there are brass labels affixed to the model stands—perhaps another distinguishing mark of a genuine Reuleaux model.

5 On the Circulation of Works

Hoecken published the results of his research activities at the end of an era which, in Germany and Europe, is called the mechanization period. His profound knowledge of mathematics and the practical experience he got as an employee in several industrial companies were ideal prerequisites for developing and presenting useful solutions for various mathematical and measuring instruments and mechanisms. In Hoecken's time, there were 3 existing German journals that were mainly esteemed by the German-speaking kinematic community:

1. Reuleaux-Mitteilungen—Archiv für Getriebetechnik
2. Zeitschrift für Instrumentenkunde
3. Zeitschrift des Vereins Deutscher Ingenieure (VDI).

Planned publications were evaluated carefully by acknowledged experts in the field of kinematics. Hoecken's most fruitful years were those during the period of his leadership of the "Lehrstuhl für Getriebelehre" at TH Berlin from 1930 to 1934. In 1926, on the occasion of a conference on mechanisms at TH Dresden, Hoecken was invited to speak about straight-line linkages in front of 25 famous kinematicians, including Hermann Alt, Ludwig Burmester, Martin Grübler, Karl Kutzbach and Rudolf Hundhausen (Hoecken 1926). Additionally, Hoecken's works on straight-line linkages, star-wheel gears, dwell linkages, and gearwheel linkage combinations were spread in, among others, the following specialized books: Beyer (1931, 1953), Jahr and Knechtel (1930) and Hain (1967).

Hoecken's creative urge in the field of kinematics decreased considerably when he left TH Berlin in 1934.

6 Modern Interpretation of Main Contributions to Mechanism Design

Hoecken lived and worked in a period when computers were based on mechanical elements, say, mechanisms and gears. They were taken as mechanical auxiliary devices, working slowly and able to calculate only through the use of the four fundamental operations of arithmetics. Trigonometric or logarithmic functions had to be replaced by proper numerical progressions. Hoecken's education and studies in the field of geodetics strongly helped him to overcome mathematical difficulties. His interest and practical talent for mathematical and optical instruments grew parallel to his employment in industrial companies. Following the list of his patents, we learn that Hoecken became an expert in mechanical calculating machines and computing mechanisms (Hoecken 1909, 1911a, 1913). Geodetics and his excellent knowledge of the mechanics of calculating machines formed the basis of Hoecken's access to kinematics. The combination of linkages with lower pairs (surface-contact) and gearwheels with higher pairs (curve-contact) attracted him especially. And indeed, the use of both types of mechanisms, i.e., geared linkages or linkages with profile links (cam type), makes kinematics more interesting and enlarges the spectrum of applications.

Graphical methods in kinematics (and statics) were familiar to Hoecken, but he did not use them. Instead, he preferred nomographical methods, i.e., the design of

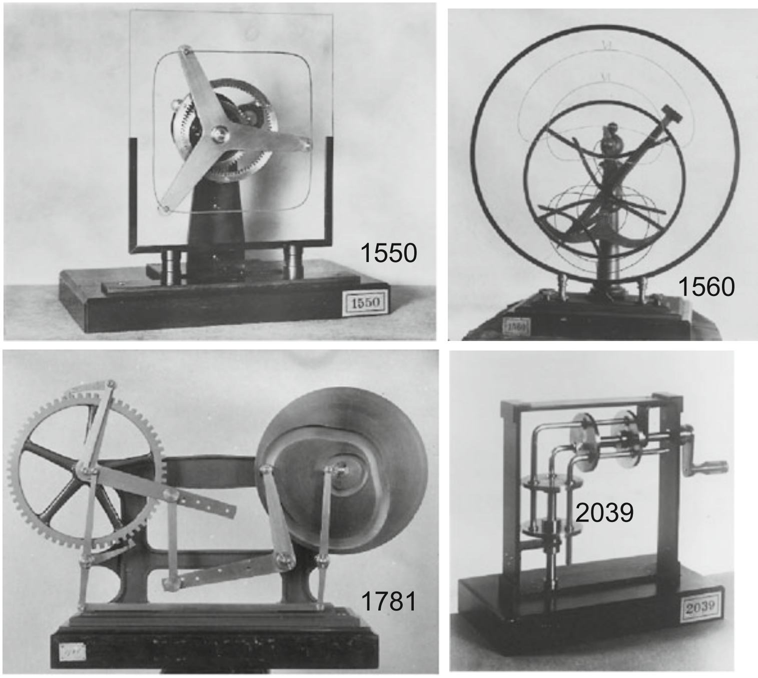


Fig. 15 Hoecken photos showing non-genuine Reuleaux models: hypocycloidal gearwheels for triple square tracing 1550 (Hoecken), four-bar linkage with replacing centrodes 1560 (Hartmann), ratchet mechanism with cam and gearwheel 1781 (Hundhausen) spatial rectangular shaft coupling 2039 (Hoecken)

charts or nomograms. Nomograms show mathematical equations in a graphical form, and thus, replace tedious numerical tables. Admittedly, nomograms are normally less precise than tables, but they have more clarity (Schwerdt 1924; Svoboda 1948). Perhaps Hoecken's masterpiece in regard to using nomograms in kinematics is his paper on star-wheel mechanisms (Hoecken 1930b) with a triple set of the main design angles for the star-wheel (output) and its driver (input). It must be pointed out that Hoecken's nomographical approach when evaluating analytical expressions in kinematics was also taken up later by Hermann Alt and Johannes Volmer in order to find the proper dimensions of four-bar linkages for given geometric conditions (Alt 1941; Volmer 1958).

Hoecken's paper on a conchoidal straight-line linkage (Hoecken 1933a) was part of some straight-line linkage ideas which Hoecken presented in the course of lectures and national conferences on kinematics. Some straight-line linkages with special dimensions still have the supplement "nach Hoecken (by Hoecken)" today, and—for example—Hoecken's fantastic "ellipsograph" (Hoecken 1933b) is even mentioned in a modern book of geometry (Glaeser 2005).

Acknowledgements The author wishes to thank Mr. Hans-Joachim Zerbst from the library of the Technische Universität Braunschweig, Mr. Wolfram Kändler from the Historisches Institut of the Justus-Liebig-Universität Gießen, and Mr. Sven Oehlsen from the archive of the Technische Universität Berlin for making inquiries and giving important hints. Moreover, the author is very much obliged to the staff of the "Geheimes Staatsarchiv – Preußischer Kulturbesitz" in Berlin-Dahlem—especially Mrs. Marie-Luise Adlung and Mr. Thomas Breitfeld—for giving support and access to many documents concerning Hoecken's activities at TH Berlin.

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Michael Spirov Konstantinov (1921–1991)

Penka J. Genova

Abstract Michael S. Konstantinov was one of the founding fathers of IFToMM and was relevant to the development of MMS through achievements in Mechanism Design and early Robotics between 1950 and 1990.

1 Biographical Notes

Prof. Michael Spirov Konstantinov (Fig. 1) was born on March 22, 1921 in Sofia and died in that same city on April, 8 1991.

His father was a successful and well-regarded lawyer in Sofia (he died in 1936) and his mother was descended from a rich family in the town of Veliko Tirnovo, where she graduated from a German-speaking school. After elementary school, Prof. Konstantinov studied for 2 years, also in a German-speaking school, in Sofia. His rich relatives on his mother's side, however, decided that he would receive a better education in the Sofia Military School (SMS) where the Bulgarian state would provide for him. He successfully graduated from the SMS, attending an aviation class in his last course of study. By the time of the communist coup d'etat in Bulgaria on September 9, 1944 and the invasion by Russian troops, he was a second lieutenant in the Bulgarian Army.

Konstantinov participated in the so-called Liberation War against Nazi Germany as the pilot of a Stuka bomber (from the German '**Stu**etz**ka**mpfflugzeug'), and he was awarded a military cross and a Soviet medal. It was then proposed that he should follow the Bulgarian military attaché to Paris on a diplomatic mission, since he had a command of French and German. However, he diplomatically declined that very tempting proposal and joined the Sofia School of Engineering in 1945 as a

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Fig. 1 A portrait of Prof. Michael Spirov Konstantinov

student in civil engineering. He later took up the newly-founded specialty of mechanical engineering and successfully graduated as a mechanical engineer in 1949. Konstantinov was very well paid as a pilot, and thus, was able to give financial help to his mother and sister, the latter of whom was a student in architecture at that time. He also managed to cover the mortgage of the house he inherited from his father by teaching private courses on Theoretical Mechanics. During this period, he supervised large groups of students and published textbooks on mechanics theory and related problems. These activities were the basic sources of his income.

As a graduate engineer, Konstantinov won a competition and became an assistant in "Hydraulic machines" at the newly-founded Mechanical-Electrical Institute, in the Department of "Hydraulic Machines," which was headed at the time by Prof. Vassil Gerov, a graduate of Ecole Polytechnique. Prof. Gerov and his only assistants, M. S. Konstantinov and P. Zlatarev, formed an interesting and amusing informal association, since together they represented the meeting of three scientific schools, namely, the French, the German and the Russian. Assistant Professor M. Konstantinov was very familiar with Russian and German studies on Machine Dynamics and Theory of Mechanisms through the works of Mertsalov, Chebishev, Assur, I.I. Artobolevskiy, S.N. Kozhevnikov, Burmester, Grubler, Kutzbach, Alt, Lichtenheld, and others. He established a close contact with Prof. Lichtenheld at the Technical University of Dresden in 1956 after being invited for 3 months to be a visiting researcher in the "Getriebelehre" department. The students in Mechanical Engineering had been taught a course on Machine Dynamics up to 1954. However, owing to a proposal by Konstantinov, a course on "Mechanisms and Machine Theory" (MMT) was subsequently included in the teaching program. His lectures were very attractive (I attended them as a student in the second course of graduates), and they are still remembered as legendary. The Bulgarian Publishing House "Technika" issued his lectures on "Mechanisms and Machine Theory" in 1959, and they are still of current interest because of their original ideas and fluent style. Their theoretical basis is solid and the book is popular in Bulgaria as the "Black" one (its cover is black). It has become a basic work not only for students but for researchers, too.

Prof. Konstantinov's habilitation was not a smooth process, since he was known to have graduated from the Czar's Military School, and that was not favoured by the "Democratic" regime in Sofia. This was not until 1962, when he became an Associate Professor thanks to his teaching practice and research. The disciplines "Machine Elements", "Mechanisms and Machine Theory" and "Lifting-Transport Machines" were united in a single department headed by Prof. G. Angelov, who studied and specialized in Germany before World War II. It was later divided into three departments, namely "Machine Elements", "Mechanisms and Machine Theory" and "Lifting-Transport Machines". Konstantinov was elected Head of the "Mechanisms and Machine Theory" Department and became a Full Professor in 1971. From 1973 to 1987, he headed the Central Laboratory of Manipulators and Robots at the Technical University of Sofia, he was Deputy Head of the Centre of Robotics beginning in 1978 (the year of its foundation), and he headed the School of Robotics for training and re-qualification of higher technical staff.

His main awards for scientific research and public activity are:

- Order "Cyril and Methodius" II-nd degree;
- Honorary medals of the Leningrad Polytechnic Institute, the University of Rostock, the Higher technical School "Otto von Guericke"—Magdeburg;
- "Doktor-Ingenieur ehrenhalber" of the Technical University—Dresden.

A survey of Konstantinov's biography was published in Patarinski (1993).

2 List of (Main) Works

Prof. Konstantinov's scientific research and results have been presented in more than 200 papers, reports, monographs, etc., that were published in Bulgaria and abroad, in the former USSR, the USA, Japan, the former DDR, England, Canada, Romania, Poland, the former Yugoslavia, Hungary, Italy, Austria, and other countries. A short selection is listed in the References as extracted from the MMT archives, like the most significant ones as Konstantinov and Markov (1980), Konstantinov and Djamdjiev (1979), Konstantinov (1967, 1973a, b, 1975, 1977, 1979), Konstantinov and Dshamdshiev (1975), Konstantinov et al. (1978), Patarinski et al. (1985), Satshi et al. (1978).

3 A Survey of Scientific Activity

Prof. Konstantinov carried out intense scientific activity in many fields of MMS. His works cover the following topics:

- Contour and centroid mechanisms with analogous memory;
- Theory of concentrated masses for the study of the inertial forces and dynamics of machines and robots (Prof. Konstantinov is the designer of the theory of point mass concentration in mechanisms and machines);
- Structural theory of mechanisms and machines;
- Criterial theory of the synthesis of grabbing mechanisms (grabbers) in robotics;
- Synthesis of centroid and band gearings with variable transfer function;
- Industrial robots with active control;
- Definitions and terminology in MMT and industrial robots (Prof. Konstantinov was the leading expert; the material was incorporated into standardization documents published in the official documents of the International Commission A at the IFToMM Federation);
- Kinematics, structure and dynamics of industrial robots (Prof. Konstantinov was the leading scientist; the topic was adopted as part of the National Program on Robotics).

The following activities were carried out:

- Reconstruction and modernization of manipulators for the rolling industry; reconstruction and modernization of manipulators for coiling of metal sheet rolls—Metallurgical Pant “Kremikovtsi”;
- Development of machines for protective coating of graphite electrodes for the electric arch furnaces in the metallurgical plant “Kremikovtsi” (patented in the USA, the former FRG, Japan and other countries). The technology brought significant revenue and was applied in the former FRG and Bulgaria.
- Development of elastic reduction gears (wave gearings), tooth gearings and friction gearings applied in instrument design and robot engineering; pin elastic reduction gears, type “Rota”, for the needs of the metallurgical plant “Kremikovtsi” (patented in the USA, the former FRG, England and other countries);
- Development of a multi-arm robot attending the operation of presses for hot pressing of tooth gears and other components—the technology requires multi-positional execution of successive operations;
- Development of a manipulator-automat for the fabrication of match boxes (approbated; its adoption proved to be economical, essentially increasing equipment productivity);
- Development of a manipulator for ferritic memory broaching—for the needs of the Electronic Memory Plant.

Monographs and textbooks authored by Prof. M. Konstantinov.

- A monograph-textbook for specialists in MMT; Author: M. S. Konstantinov, issued 1959.
- Five textbooks and lecture notes on MMT; collective works; Leading author: M. S. Konstantinov;
- A textbook "Dynamics of Multi-cylinder Motors";
- Lecture Notes in Machine Dynamics—German edition of the lectures delivered by Prof. M. Konstantinov in Rostock, the former DDR, in 1971.

Prof. M. Konstantinov delivered lectures and presented scientific reports in the former DDR, England, Italy, the former FRG, Romania, Japan, Canada, the former USSR, the USA, and other countries.

4 Prof. Konstnatinov's IFToMM Activity

Prof Konstantinov was very active and influential in the IFToMM from the early days of its foundation and first promotion.

The IFToMM is now a well-established federation in the field of MMS with a vision formed in its early days augmented towards the future. In the Appendix, a short account of the IFToMM's history is given as taken from the IFToMM webpage.

From 1961 to 1965, Konstantinov established contacts with scientists from Eastern and Western countries and colleagues from the USA and Australia. He proposed the idea of establishing an international organization of scientists in "Mechanisms and Machine Theory".

The first International Conference on MMT was held in 1965, and its organization lasted for almost 2 years. Scientists from 17 countries participated in the event, during which 54 reports were presented. The most important decision made by the forum was the foundation of an International Coordination Committee (ICC) whose tasks were to plan future international conferences and analyze the possibilities of founding an International Federation of the Theory of Mechanisms and Machines (IFToMM).

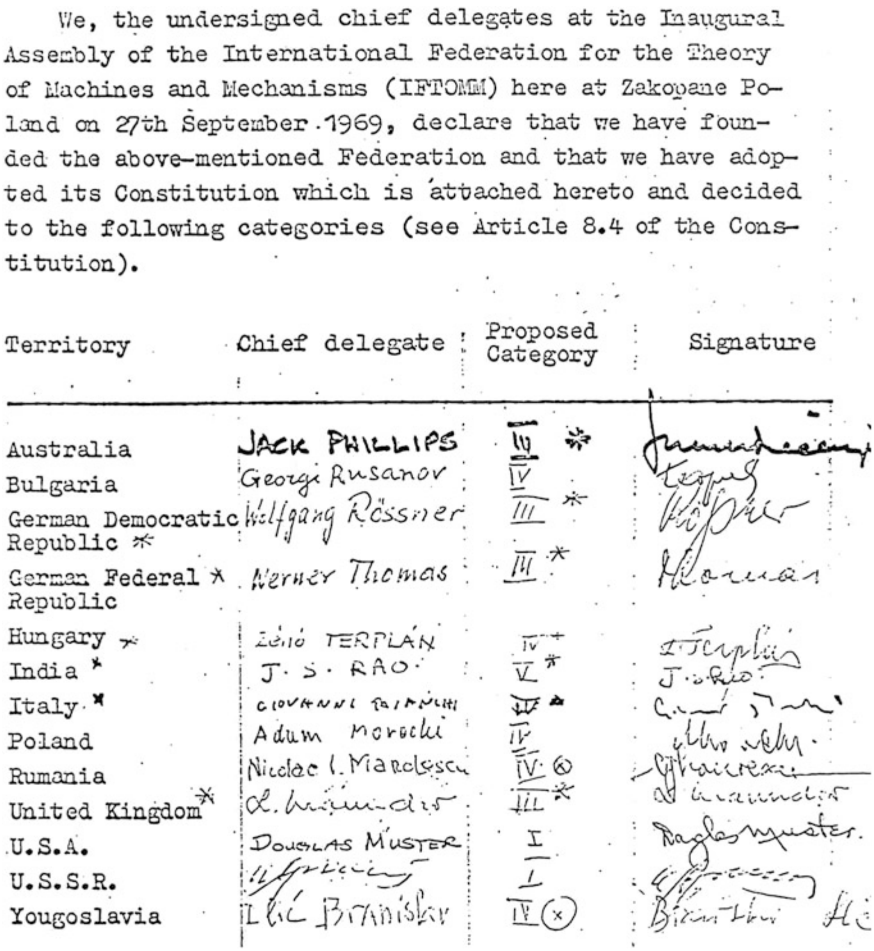
Two years later, professors Artobolevskiy, Konstantinov, Oderfeld, Meyer zur Capellen and Crossley met at the 4th Soviet Conference on MMT in Suhumi, Georgia (1967). They decided that the name of the federation would be the IFToMM, International Federation of the Theory of Mechanisms and Machines. In fact, this was the third session of the ICC, since the second one was held in the former DDR, but was not attended by scientists from the USA. The Suhumi forum took a stand on designing an IFToMM Constitution, and Prof. Crossley was entrusted with the preparation of the first version of that Constitution. He adopted for that purpose the statute of a number of other international organizations, such as those of crystallographers, geodesists, geographers etc.

An ICC meeting planned in Sofia in 1968 failed, since Western participants refused to attend due to the invasion of the former Czechoslovakia by Soviet troops. In their correspondence, Profs. Konstantinov and Crossley prepared a version of the Constitution to be adopted by the ICC before the Constituent Assembly planned for the Congress in Zakopane in September 1969.

Thus, an ICC meeting was held in Varna (June 1969) preceding the Constituent Conference. Versions of the constitution by Prof. Oderfeld (Poland) and Prof. Bessonov (USSR) were also discussed. Profs. Crossley and Konstantinov prepared a final version in just one night, and the Constitution was officially approved and published in 1979 in the MMT journal within the IFToMM NEWSSHEET rubric. The Preamble noted Bulgarian merit in founding the IFToMM, as well as that of the first 20 country-members. Noteworthy were the following operative commissions: A—Commission for Standardization and Terminology, B—Training Commission, C—Commission for Relations with Industry, D—Conference Commission, E—Commission for MMT History, and F—Publication Commission. The foundation of four Technical Committees was also agreed upon, namely for Robots and Manipulators, Rotor Dynamics, Tooth Gearings and Lever Mechanisms. All these activities contributed to the design of a strict and effective organization, setting a prerequisite for further integration with other international organizations.

The IFToMM was founded on September 27, 1969 during the Conference in Zakopane, Poland (Figs. 2 and 5). The first Assembly elected Acad. Artobolevskiy (former USSR) as President of the Federation, Prof. Crossley (USA) as Vice-President, Assoc. Prof. M. Konstantinov (Bulgaria) as General Secretary, Dr. Thomas (former FRG) as Treasurer and Prof. Oderfeld (Poland), Prof. Belgaumkar (India) and Prof. Hunt (Australia) as members of the Executive Council (EC). It was decided that the MMT journal, whose Editor-in-Chief was Prof. Crossley, would become the official IFToMM journal (Figs. 3 and 4).

Over the following years, IFToMM activity was mostly concentrated in Sofia, since it lay within the competence of the General Secretary. There was real euphoria, since the Organization united MMT scientists and erased boundaries between East and West. It reached its climax during the congress in Dubrovnik in the former Yugoslavia, September 1971. The Chairman and Chief Organizer was Prof. Pantelich, and Prof. Crossley wrote that he was a man of strong imagination and limitless energy. 198 reports were presented and later published in 8 volumes. The General Assembly decided that the "Journal of Mechanisms" would be renamed "Mechanisms and Machine Theory". The representatives from the former DDR and FRG were especially pleased with the results of the congress and the atmosphere overall was extremely friendly (a fact to which I can attest, having been there). A number of photos were taken of the familiar/friendly atmosphere, some showing the slightly tipsy participants singing. One picture shows Profs. Pantelich and Philips embracing each other, Prof. Volmer appears in his pyjamas, Prof. Boegelsack conducts the show, Prof. Roth begs us not to be so noisy, Prof. Konstaninov carries a camera, and I can be seen eating bananas (those photos were not published in the previous material and are in the family archives of each



We, the undersigned chief delegates at the Inaugural Assembly of the International Federation for the Theory of Machines and Mechanisms (IFTOMM) here at Zakopane Poland on 27th September.1969, declare that we have founded the above-mentioned Federation and that we have adopted its Constitution which is attached hereto and decided to the following categories (see Article 8.4 of the Constitution).

Territory	Chief delegate	Proposed Category	Signature
Australia	JACK PHILLIPS	IV *	
Bulgaria	Georgi Rusanov	IV	
German Democratic Republic *	Wolfgang Rössner	III *	
German Federal * Republic	Werner Thomas	III *	
Hungary *	Zeno TERPLÁN	IV *	
India *	J. S. RAO	V *	
Italy *	GIOVANNI BIANCHI	IV *	
Poland	Adam Morecki	IV	
Rumania	Nicolae I. Manolescu	IV ⊗	
United Kingdom *	[illegible]	III *	
U.S.A.	DOUGLAS MUSTER	I	
U.S.S.R.	[illegible]	I	
Yougoslavia	Ilić Branislav	IV ⊗	

Fig. 2 The signed foundation act of IFToMM (Courtesy of IFToMM Archives)

participant). This is all indicative of the 'family character' of the IFToMM that was established naturally from the organization's beginnings. Some of those photos and others from later events are shown in Figs. 6, 7, 8, 9.

The 4th meeting of the EC was held in 1972 in Udine. Before the expiration of Prof. Konstantinov's 4-year mandate, the Bulgarian delegation proposed that Assoc. Prof. Emil Stanchev be appointed as General Secretary. The reasons for that appointment were political. However, regardless of the mandate's expiration and the regrettable politics, Prof. Konstantinov remained a member of the EC at the insistence of all ICC members. Although disappointed, he not only participated in Federation activity, but also unselfishly aided Assoc. Prof. Stanchev in his work. Their cordial and sincere friendship lasted until Assoc. Prof. Stanchev's death.

Fig. 3 Participants at the conference in Zakopane in 1969 (Courtesy of IFToMM Archives)

What counted for Prof. Konstantinov was that the General Secretariat stayed in Bulgaria-Varna. Unfortunately, this did not last long.

Although incomplete, one can get a good idea of the Federation's activity, examining, for instance, the agenda and problems discussed at the annual meeting of the EC held April 12–14, 1973 in Split in the former Yugoslavia. New members of the EC were elected: Assoc. Prof. Stanchev—General Secretary, Prof. J. Bianchi (Italy), Prof. Maunder (England), Prof. Pantelich (the former Yugoslavia) and Prof. Philips (Australia). Prof. Oderfeld and Prof. Philips missed the meeting, while Prof. Konstantinov, a former General Secretary and Chairman of Commission B, and Prof. Bessonov and Prof Kobrinski (Russia), chairmen of Commission D dealing with conference organization and the Organizing Committee of ROMANSY 73, all attended. The agenda covered 8 items: (1) Report on the activity of the Organizing Committee of ROMANSY—reported by Prof. Kobrinski; (2) information about the preparation of the 4th World Congress on MMT planned for 1975 in Newcastle upon Tyne, UK, submitted by Prof. Maunder; (3) report on the activity of the General Secretary—reported by Assoc. Prof. Stanchev; (4) Preliminary report on the statute of IFToMM—reported by Prof. Konstantinov; (5) report on the Federation activity in 1975—reported by Prof. Konstantinov; (6) report on the financial activity—reported by Dr. Thomas; (7) report on the newly elected members of IFToMM—reported by Assoc. Prof. Stanchev; (8) discussion of some organizational problems. The debate and decisions pursuant to Item 1 outlined the possibility of starting a collaboration between ROMANSY and the IFToMM. During the meeting, it was

Fig. 4 Prof. Crossley speaking at the Constituent Assembly at the conference in Zakopane in 1969 (Courtesy of IFToMM Archives)

Fig. 5 Prof. Konstantinov conversing with Acad Artobolevski during a coffee break at the Zakopane conference in 1969

Fig. 6 Prof. Konstantinov and Prof. Rovetta (Italy) at the IFToMM Int. Symposium on Progress in TMM-Robotics at Varna from October 7–9, 1985

Fig. 7 Prof. Konstantinov and Prof. Manolescu (Romania) at an IFToMM conference

decided that: the preparation of world congresses should begin no later than 2 years prior to the start of the events, and each congress should approve the host of the next one; periods of carrying out national conferences and congresses should not coincide; The National Committees should select papers submitted for presentation; a statute of the Federation should be prepared and presented to the EC in 1974 for discussion; the budget of the General Assembly for 1973 should be 2,700 US dollars, and for 1974, 3,000 US dollars; Prof. Crossley, in his capacity as Editor-in-Chief of the MMT journal, should regularly publish information on EC activities; and finally, the Meeting highly apprised the activity of the former General Secretary and expressed special thanks to him for his good work in founding and consolidating the Federation. A Committee, including Prof. Crossley, Prof. Konstantinov, Prof. Oderfeld, Prof. Bessonov and others, was elected to prepare the constitution. The General Secretary announced the enlistment of new members—Cuba, Canada, the Netherlands, Israel and Belgium. The EC recommended that he become aware of the organizational experience of CISM and IUTAM and explore the ground for

Fig. 8 Prof. Konstantinov revising IFToMM documents with Prof. Jack Philips

Fig. 9 Prof. Konstantinov at a meal with Prof. Justo Nieto (Spain) and Jacques Hervè (France)

establishing relations with Japan, Zambia, Sierra Leone, France, Finland, Norway, Egypt and Sweden.

Prof. Konstantinov headed the Central Laboratory for Manipulators and Robots at the Higher Institute of Electrical and Mechanical Engineering, Sofia. He organized five International Summer Schools in Robotics (PRACTRO), which are still held every 2 years.

The climax of Bulgarian IFToMM activity was the organization and implementation of the First International IFToMM symposium on teaching MMT (CEMeMaT), January 27–30, 1975, in Pamporovo, Bulgaria. World-famous scientists delivered reports—Prof. Philips, Prof. Roessner, Prof. Roweta, Prof. Dicioglu, Prof. Oderfeld, Prof. Moretzki, Prof. Manolescu, Prof. Gavrilenko, Prof. Seireg, Prof. Luck, Prof. Bogdan, Prof. Duditsa, Prof. Bradt, Prof. Volmer, Prof. Wicker, Prof. Pesen and many others. A number of reports discussed the teaching of MMT in the former USSR, the USA, Italy, Poland, the former Czechoslovakia, Romania, Australia, etc. Prof. Konstantinov organized the CEMeMaTRO conference in Blagoevgrad, on September 22, 1982, which proceeded in Gabrovo under the name PRACTRO. The importance of these forums in teaching MMT and Robotics was highly appreciated. The International Symposium "Progress in the TMM—Robotics" was held in Varna, from October 7–9, 1985. It was attended by a number of scientists from Europe, America, Australia and Asia.

Up until Prof. Konstantinov's death, Bulgaria continued to participate in the international activities of the IFToMM. The national organization BulToMM still functions, and two conferences are organized annually under its auspices—one in Varna in September and one in Sliven in June.

The following photos from the archive of the Konstantinov family show Konstantinov in meetings with leaders and figures of the IFToMM during the period of the organization's initial growth, and clearly demonstrate a strong, friendly atmosphere of collaboration.

5 Conclusions

Professor M. S. Konstantinov is considered one the promoters and founders of the IFToMM who engaged in significant activity and had tremendous influence over the early establishment of a highly regarded IFToMM community. He achieved a worldwide reputation in MMS for his significant works in research, design, and the teaching of several topics of modern MMS, resulting in pioneering results towards modern solutions that are still of current interest.

A.1 6 Appendix—A Short Account of History of IFToMM

IFToMM was founded in 1969 and today is active as a third generation of IFToMMists, who can be named as those working within the IFToMM community. Knowing the History of IFToMM and how we arrived at today's modus operandi can give a greater awareness of community identity and significance.

IFToMM was founded as the International Federation for the Theory of Mechanisms and Machines in Zakopane, Poland on September 29, 1969 during the Second World Congress on TMM (Theory of Mechanisms and Machines). The main promoters of the IFToMM World Federation were Academician Ivan I. Artobolevski (USSR) and Prof. Erskine F. R. Crossley (USA), whose principal aim was to bypass the obstacles of the time of the Cold War in developing international collaboration in TMM science for the benefit of the world society. IFToMM started as a family of TMM scientists among whom we may identify the IFToMM founding fathers, who signed or contributed to the foundation act with the initial 13 Member Organizations, in the persons: Academician Ivan I. Artobolevski (USSR), Prof. Erskine F. R. Crossley (USA), Prof. Michael S. Konstantinov (Bulgaria), Dr. Werner Thomas (GFR), Prof. B. M. Belgaumkar (India), Prof. Kenneth H. Hunt (Australia), Prof. J. Oderfeld (Poland), Prof. Jack Phillips (Australia), Prof. George Rusanov (Bulgaria), Prof. Wolfgang Rössner (GDR), Prof. Zènò Terplàn (Hungary), Prof. Jammi S. Rao (India), Prof. Giovanni Bianchi (Italy), Prof. Adam Morecki (Poland), Nicolae I. Manolescu (Rumania), Leonard Maunder (UK), Douglas Muster (USA), Ilic Branisky (Yugoslavia).

The foundation of IFToMM was the result of an intense activity for stimulating and promoting international collaboration, more than had been done previously, and the process started in the late 1950s', as documented by several letters that are stored in the IFToMM Archive.

A first World Congress was held in 1965 in Varna, Bulgaria during which the foundation of IFToMM was planned as later it was agreed during the Second World Congress on TMM in Zakopane, Poland. The Congress series was immediately recognized as the IFToMM World Congress and today in 2007 we are celebrating the 12th event with a participation of 48 Member Organizations.

The IFToMM community has grown continually over time and the TMM has evolved to encompass large engineering science, including even new disciplines. This led in the year 2000 to an update of the name of the IFToMM Federation as IFToMM International Federation for the Promotion of Mechanism and Machine Science and a change of the name of TMM to MMS (Mechanism and Machine Science), in order to emphasize the modernity and broader mission of the IFToMM community.

IFToMM activity has grown in many aspects, as for example concerning the number of member organizations (from the 13 founder members to the current 48 members), the size and scale of conference events (with many other conferences, even on specific topics, at national and international levels, in addition to the MMS World Congress), and the number and focus of technical committees working on specific discipline areas of MMS (currently 13, with 2 more just established).

The IFToMM community evolved in character from that of a family of a few beginners and founders into a scientific worldwide community through the following generations:

- 1950s–1979 First generation: founding fathers and their friendly colleagues up to the 4-th IFToMM World Congress in Newcastle-upon-Tyne in 1975 with Prof Maunder as Congress Chair
- 1980–1995 Second Generation: students and people educated by founding fathers and their friendly colleagues; up to the 9-th World Congress in Milan in 1995 with Prof Rovetta as Congress Chair
- 1996-today Third Generation: educated people in the frame of IFToMM and within IFToMM activity with 48 organizations as IFToMM members.

IFToMM officers (who are the Chairs of IFToMM Member Organizations, the Chairs of Permanent Commissions and Technical Committees, and the members of the Executive Council) have contributed and still contribute as leaders to the mission of IFToMM, which is stated in the 1-st article of the Constitution as 'The mission of IFToMM is the promotion of Mechanism and Machine Science'. A complete list of IFToMM officers over time is available in the Proceedings of the Second International Symposium on History of Machines and Mechanisms HMM2004 that has been published by Kluwer.

In particular, Presidents and Secretaries General have had significant roles in guiding the growth and success of IFToMM. Their personalities are also representative of the IFToMM community in terms of reputation and visibility worldwide. The Presidents were Ivan I. Artobolevskii (USSR), Leonard Maunder (United Kingdom), Bernard Roth (USA), Giovanni Bianchi (Italy), Adam Morecki (Poland), Jorge Angeles (Canada), Kenneth J. Waldron (USA). The Secretaries General were M. S. Konstantinov (Bulgaria), Emil Stanchev (Bulgaria), Adam Morecki (Poland), Adam Morecki (Poland), Elizabeth Filemon (Hungary), L. Pust (CSSR), Tatu Leinonen (Finland).

More information on IFToMM and its activity can be found in the website: http://www.iftomm.org.

Details of the History of IFToMM can be found in the first Chapter of Proceedings of the First International Symposium on History of Machines and Mechanisms HMM2000 (published by Kluwer) in which all the Past IFToMM Presidents have outlined their historical perspective of IFToMM in contributed papers with references.

Marco Ceccarelli, IFToMM Secretary General (2004–2007)

Last Updated (Sunday, 26 June 2011 08:58)

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Francisc Viliam Kovács (1929–2009)

Erwin-Christian Lovasz, Corneliu Rădulescu, Valentin Ciupe, Corina Gruescu and Inocenţiu Maniu

Abstract Francisc Viliam Kovács was an innovator in mechanism science and a pioneer in Romanian robotics. His contributions cover a wide theoretical and applicative area. Furthermore, he was a talented manager, who founded the robotics section within the higher education at the University "Politehnica" of Timişoara. He wrote original books and developed new laboratories. His outstanding academic personality facilitated the launching of numerous scientific collaborations worldwide.

1 Biographical Notes

Francisc Viliam Kovács (Fig. 1) was born on November 26, 1929 in Timişoara, Romania. Beginning in infancy, he proved to have a remarkable intellectual capacity.

He attended courses at the Piarist Private High School in Timişoara between 1940 and 1948. He was a prize winner in his class through all his years of

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Fig. 1 Francisc Viliam Kovács Prof. Dr. Eng. mult. Dr. hc (1929–2009)

attendance and the first graduate after the final exam in the summer session of 1948.

In the fall of 1948, he attended the Mechanical Engineering Faculty of the Polytechnic Institute of Timişoara. He became a student leader, in recognition of his organizing and creative skills. He took courses on mechanical sciences, energetic engineering and rolling stock. He passed the final exam in February 1953, obtaining a degree in mechanical engineering.

A republican scholarship rewarded the remarkable professional qualities proven by F. V. Kovács during his university years.

After graduation, the Machine Elements and Mechanisms Department employed him as assistant professor starting on October 1, 1952. He was promoted to lecturer on October 1, 1953, when he was appointed to deliver the course on Theory of Mechanisms.

In February 1963, he won the competition for the title of university professor in the same discipline. In December 1970, he was elected head of the Machine Elements and Mechanisms Department in Timişoara. He held this position until his retirement in 1995, with a break from 1976 until 1984. During this period, he was Dean of the Mechanical Engineering Faculty.

At the beginning of his university activity, he was involved in the study of geometry and the reliability of gears, as well as the correlation between those two. His work in this field was rewarded with the 1966 Prize of the Education Ministry.

In the early ‘60s, he started working in mechanism synthesis, a domain in which he prepared his PhD thesis, entitled *Contributions to the elaboration of a unitary method for mechanism synthesis*. The thesis was presented in September 1969 at “Traian Vuia” Politechnic Institute of Timisoara. This work introduced the original concept of connection, a true foundation brick for designing any mechanism, and an idea further developed in numerous papers. Among others, the dissertation, entitled *Use of the notion «connection» in the theory of mechanisms and robotics*, was prepared on the occasion of the awarding of the scientific title of Dr. hc at the University of Craiova to Kovács.

Starting in 1980, Kovács lectured on robotics, therefore becoming one of the trailblazers in teaching this modern scientific domain in Romania.

During a career of almost 45 years in higher education and scientific research, Kovács proved to be a hard worker, a creative designer and a bold innovator.

Kovács was the founder of the higher technical education in robotics at the “Polytehnica” University of Timisoara and other universities in the country (Kovács 1987, 1997; Kovács et al. 1987, 1993). Beginning in the ‘80s, he started teaching an optional course in robotics at the Mechanical Engineering Faculty of Timisoara. Later, he initiated the specialization of graduates in robotics by delivering post-university courses in robotics, first at Timisoara, and then in Arad and Oradea. In 1990, the Industrial Robots specialization in the Romanian language was founded at the Mechanical Engineering Faculty of Timisoara. A similar specialization began later (1992) in the German language. Many former and still active lectures of these specializations are courses that were written and delivered by F. V. Kovács. He also held courses in robotics at the University of Oradea, “Aurel Vlaicu” University of Arad and “Eftimie Murgu” University of Reşita after 1995.

He published 16 treatises and 20 books at renowned publishing houses for students’ use. Two hundred and sixty nine of his scientific articles were printed in journals and conference proceedings in Romania and abroad. He registered 22 inventions and innovations and participated in 63 research commissions and grants, the majority of them as head of research staff (Kovács and Cojocaru 1982; Kovács et al. 1994, 1999, 2000; Kovács and Radulescu 1992, 1994).

Starting in 1990, the first issue of *Robotica and Management Journal* appeared, under the initiative and coordination of F. V. Kovács and I. Vela—professor at “Eftimie Murgu” University of Reşiţa (Kovács et al. 2002; Radulescu and Maniu 2009).

Francisc Viliam Kovács passed away on April 29, 2009.

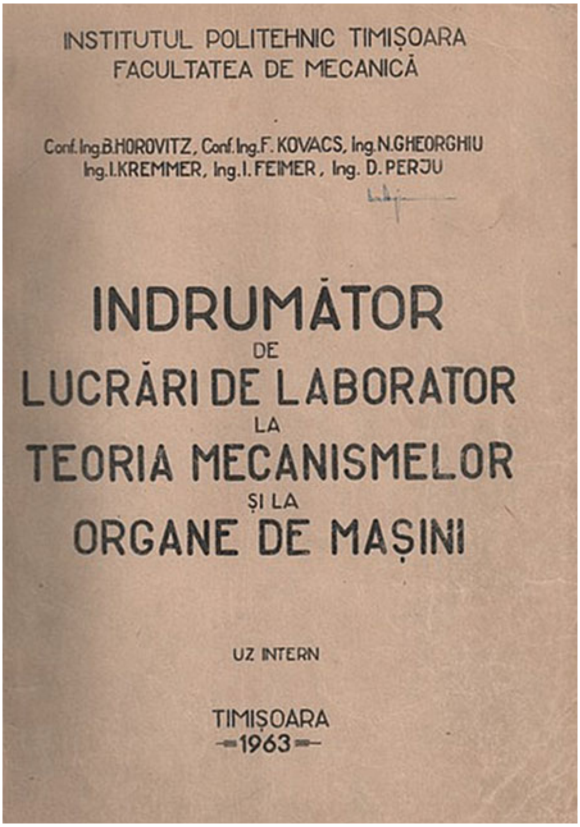


Fig. 2 Laboratory work Guide (1963)

2 List and Short Survey of His Works and Achievements

The achievements of F. V. Kovács cover a wide area of interest in mechanism science and robotics.

Chronologically speaking, his first significant contribution to the development of mechanism science in Romania was the collaboration as co-author for the first original *Laboratory Work Guide*, conceived and written at the University "Politehnica" of Timişoara in 1963 (Horowitz et al. 1963) (Fig. 2).

One of his theoretical contributions refers to the concept of connection, first defined and discussed in his PhD thesis, *Contributii la elaborarea unei metode unitare de sinteza a mecanismelor* (*Contribution to the elaboration of a unitary method for mechanism synthesis*), (Kovács 1969).

The concept was further developed in books, courses and articles, such as *Metode noi in sinteza mecanismelor* (*New methods in mechanism synthesis*), (Kovács et al. 1976)—Fig. 3, *Sinteza mecanismelor* (*Synthesis of the mechanisms*), (Kovács and Perju 1977), *Analiza mecanismelor* (*Analysis of mechanisms*),

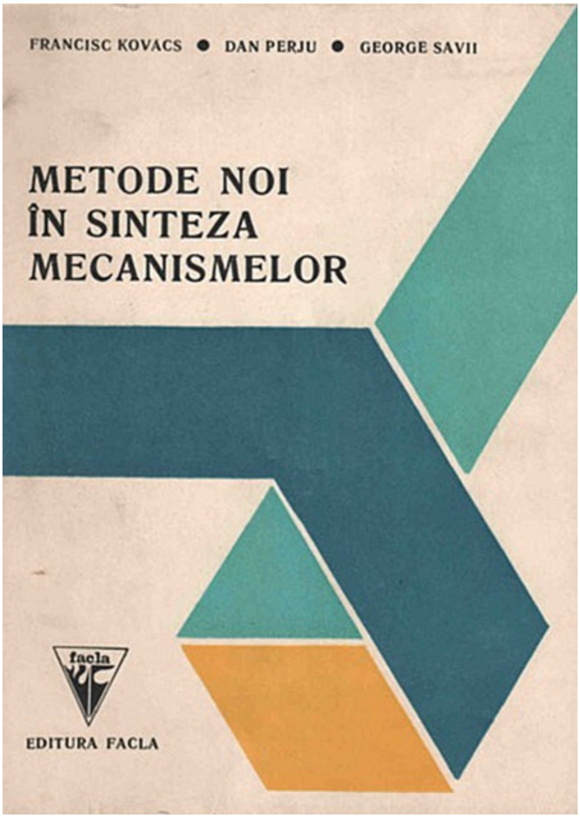


Fig. 3 New methods in mechanism synthesis (1976)

(Kovács et al. 1978), *Mecanisme* (*Mechanisms*), (Kovács et al. 1992), *Using the Concept "Connection" for Structural Analysis/Synthesis of Parallel Topology Robots*, (Kovács 1997a).

Another important theoretical contribution, named *The PeSiR Method* by its author, represents a mathematical model of a flexible manufacturing system. The model develops the geometric, kinematic and dynamic calculus of the system.

The PeSiR method was communicated at different scientific conferences in articles, such as *Robot's Guiding Devices. New Geometrical Model*, (Kovács 1996a), *Un nou model geometric al dispozitivului de ghidare al roboţilor* (*A new geometrical model of the guiding mechanism of robots*), (Kovács 1996b), *Noţiunea "Perechi de Sisteme de Referinţă"* (*PeSiR*) *şi unele utilizări în domenii de ştiinţe tehnice* (*The concept of "reference system pairs"* (*PeSiR*) *and some applications in the technical science fields*), (Kovács 2001), *Structural and Kinematical Modelling of Mechanical Systems of Mobile Robots using the concept "Pairs of Reference Systems"*(*PRS*), (Kovács 2001) and others.

The third field to which F. V. Kovács contributed substantially is robotics. As a hardworking pioneer, he published a long series of books, courses, handbooks and

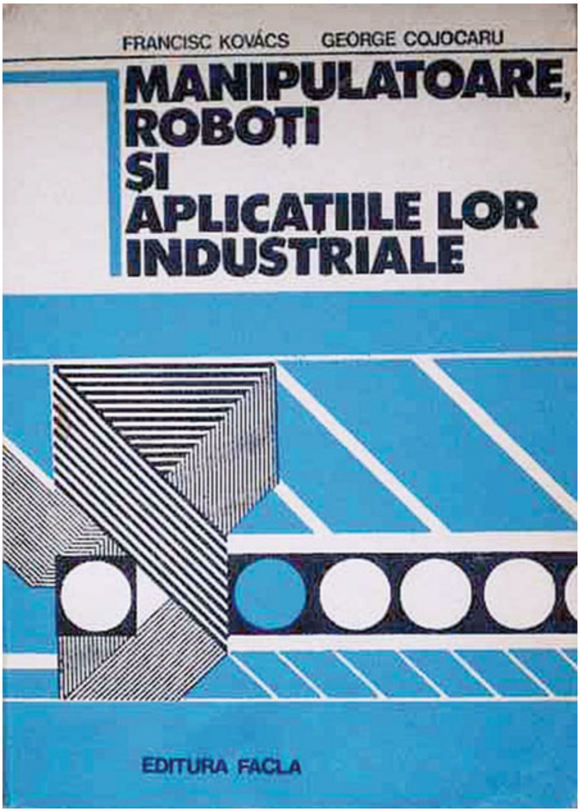


Fig. 4 Manipulators, robots and their industrial applications (1982)

articles. The most important titles are: *Manipulatoare, roboti si aplicatiile lor industriale* (*Manipulators, robots and their industrial applications*), (Kovács and Cojocaru 1982) (Fig. 4), *Robotul industrial REMT*-2 (*Industrial Robot REMT*-2), (Kovács et al. 1982), *Robot industrial REMT*-2*S* (*Industrial Robot REMT 2S*), (Kovács et al. 1986), *Trecut, prezent şi perspective în cercetările de robotică în Timişoara* (*Past, present and future in the robotic research in Timisoara*), (Kovács 1987), *Contributions to Research, Construction and Industrial Applications of Robots*, (Kovács et al. 1987), *Roboţi industriali* (*Industrial Robots*), vols. 1 and 2, (Radulescu 1992) (Fig. 5), 15 *Years of Robotics Research at the Timisoara Technical University*, (Kovács et al. 1993), *Flexible Manufacturing Line as part of "Robotized Flexible Manufacturing Systems" Laboratory of "Politehnica" University of Timisoara*, (Kovács and Radulescu 1994), Sisteme de fabricatie flexibilă robotizată (Robotized Flexible Manufacturing Systems), vols. 1 and 2, (Kovács et al. 1994), *On the Social Impact of Robotics in Romania*, (Kovács 1995), *The "Robotic Family"*, (Kovács 1997), *Fabrica viitorului* (*The plant of the future*), (Kovács et al. 1999) (Fig. 6), *Introducere în robotică* (*Introduction to Robotics*), (Kovács et al. 2000)—(Fig. 7), *Activity of the multidisciplinary robotic team in*

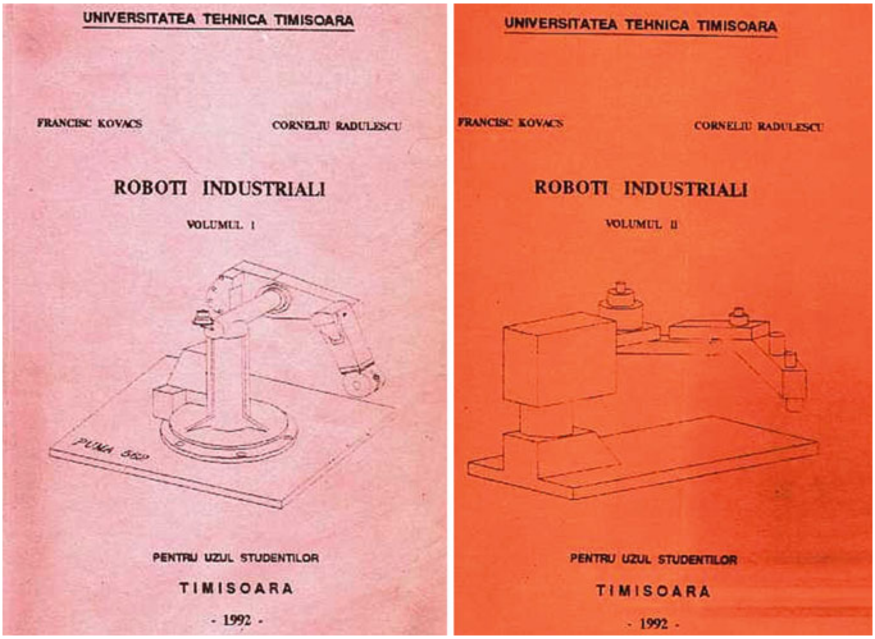


Fig. 5 Industrial robots, volume1 and 2 (1992)

Timisoara, (Kovács et al. 2002), Sisteme de fabricaţie flexibilă (Flexible Manufacturing Systems), (Kovács et al. 1999) (Fig. 8a) and *Roboţi de servicii* (*Service Robots*), (Kovács et al. 2001) (Fig. 8b).

During the ‘80s, Kovács founded and led the Robotics Multidisciplinary Team, which developed intense activity for conceiving and designing a large number of manipulators and industrial robots, as requested by the industrial applications of certain companies all over the country.

The activity of the robotics community, led by Kovács, resulted in several significant achievements, such as:

- the first Romanian industrial robot, REMT-1, included in the first Romanian flexible manufacturing cell, designed for machining the shafts of electric engines (in 1982, rewarded with the “Traian Vuia” prize of the Romanian Academy).
- 12 other types of robots, two of which received the gold medal at TIB (Bucharest International Technical Fair, 1987 and 1988).
- 7 robotized flexible manufacturing systems.

Kovács’ scientific and academic activity was honoured through numerous prizes, distinctions, titles and diplomas, awarded by institutions in his country and abroad.

Figure 9 shows the Diploma of Doctor Honoris Causa of the “Eftimie Murgu” University of Resita—October 2006 (Fig. 9a), the Excellence Diploma in Robotics

Fig. 6 The plant of the future (1999)

Development (Fig. 9b) and the "Traian Vuia" Prize of the Romanian Academy—1982 (Fig. 9c).

Kovács was an honorary member of many national and international scientific professional organizations and societies, such as the International Federation of Robotics, the International Federation for the Theory of Machines and Mechanisms, the Public Corporation of the Hungarian Science Academy, etc. He was also a member of the scientific committees of several scientific journals in the country and abroad.

3 Discussion of Contributions

3.1 The Concept of Connection

In order to generalize the kinematic groups by Assur (1952), which used only joints with one degree of freedom, F. V. Kovács introduced the concept of connection. The connection, in his view, means all the restrictions occurring in the

Fig. 7 Introduction to robotics (2002)

relative movement between the elements in order to provide constraint of motion of the mechanism.

The kinematic/geometric connection is defined as an open kinematic chain, which is interposed between 2 elements with known or imposed relative movement.

The connections are classified by their number of degrees of freedom (DOF), the number of elements and the kinematic pairs. They are divided into 3 types: connection type A, B and C (Fig. 10).

At planar mechanisms, a connection of type A is just a kinematic pair which can be class V or IV (number of restrictions in relative movement), according to Artobolevsky's classification, and are denoted $K_A(-2)$ and $K_A(-1)$, respectively, where the brackets represent the degree of freedom of the kinematic chain (L_k).

A connection of type B contains one element and two kinematic pairs. If both are class V, the connection has DOF = −1 and is denoted as $K_B(-1)$. For the connection with one kinematic pair class V and the other one class IV, DOF = 0 and the connection is denoted as $K_B(0)$.

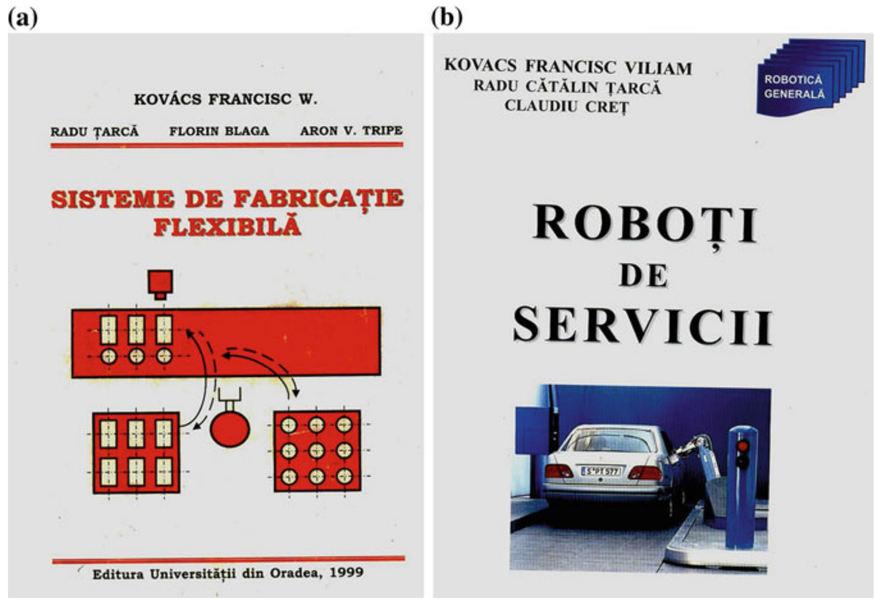


Fig. 8 Flexible manufacturing systems (1999) (**a**). Service robots (2001) (**b**)

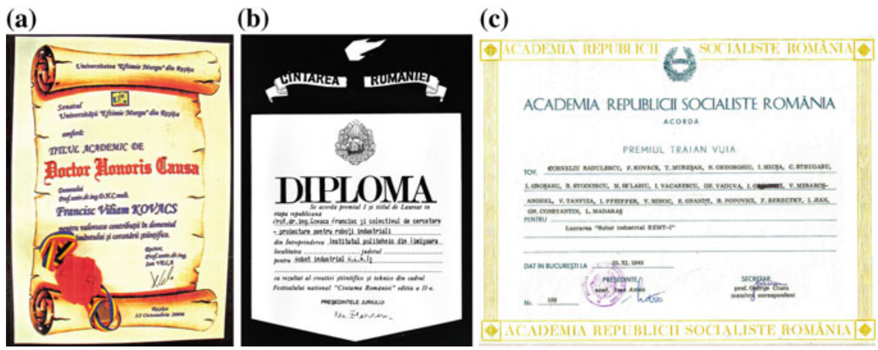


Fig. 9 Awards given to F. V. Kovács for his scientific and academic activity

A connection of type C may have any number of elements and kinematic pairs. The Assur groups (kinematic/structural groups according to Artobolevsky's classification) represent a particular case of the connection type C, denoted as $K_C(0)$. The degree of freedom of the connection's kinematic chain results from the relationship:

$$L_k = 3 \cdot n_k - 2 \cdot c_{5k} - c_{4k}, \tag{1}$$

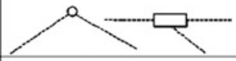
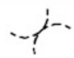
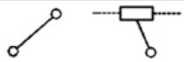
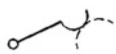
Type of connetion	Number of elements	Kinematic pairs		Kinematic scheme of the connection	DOF L_k	Notation
		Nr.	Class			
A	$n_k = 0$	1	$c_{5k}=1$		-2	$K_A(-2)$
			$c_{4k}=1$		-1	$K_A(-1)$
B	$n_k = 1$	2	$c_{5k}=2$		-1	$K_B(-1)$
			$c_{5k}=1$ $c_{4k}=1$		0	$K_B(0)$
C	$n_k = 2$	3	$c_{5k}=3$		0	$K_C(0)$
	any				L_k	$K_C(L_k)$

Fig. 10 Classification of connections by F. V. Kovács

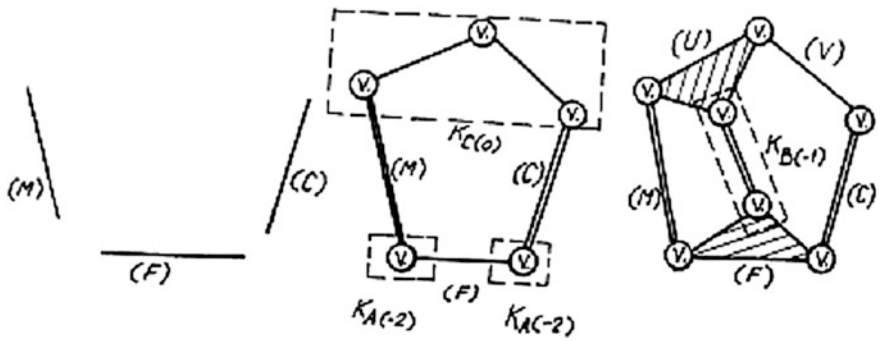


Fig. 11 Unitary method for mechanism synthesis based on the concept of connection

where n_k is the number of the connection's elements, c_{5k} is the number of the connection's kinematic pairs of class V, and c_{4k} is the number of the connections kinematic pairs of class IV.

Kovács developed a unitary method for mechanism synthesis in his PhD thesis (Kovács 1969) based on the concept of connections (Fig. 11) and published it in his books (Kovács et al. 1976, 1978, 1992; Kovács and Perju 1977).

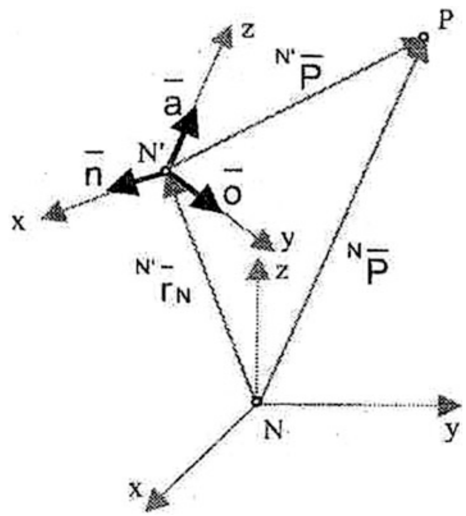


Fig. 12 Pair of reference systems

3.2 The PeSiR Method

Starting in 2000, Kovács introduced the theory of the "Pairs of Reference Systems" (PeSiR), a mathematical modelling of mechanical systems, of technological systems based on relative movements, and even of some economical systems (Kovács 1995, 1996a, b, 2001a, b).

The original concept "Pairs of Reference Systems" enables the unified mathematical modelling of technical phenomena involving relative motion of bodies. The definition of the concept allowed suggestions regarding applications in the Theory of Mechanisms, Robotics, Technology and Error Computation.

The PeSiR concept proposes a description of the relative position—orientation (situation) of the reference systems N and N' (Fig. 12) by a "situation matrix", ${}^{N}S_{N'}$:

$$ {}^{N}S_{N'} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ r_x & n_x & o_x & a_x \\ r_y & n_y & o_y & a_y \\ r_z & n_z & o_z & a_z \end{bmatrix} = \left[e_{ij}\right], \tag{2} $$

where e_{ij} is one element of a 4 × 4 matrix, situated in column j and on line i; n_x, o_x, a_x etc.—elements of the 3 × 3 orientation matrix (projections of the unit vectors in system N' on the axes of the system N) and

$$ {}^{N}\underline{r}_{N'} = \left[r_x \quad r_y \quad r_z \quad 1 \right]^T, \tag{3} $$

is the 1 × 4 position matrix of the origin N' in respect to N.

The relative orientation of the systems N and N' may also be expressed by means of an "orientation vector", ${}^{N}\underline{O}_{N'}$:

$$ {}^{N}\underline{O}_{N'} = \bar{n} + \bar{o} + \bar{a} \tag{4} $$

or a 1 × 3 "orientation matrix":

$$ {}^{N}\underline{O}_{N'} = \left[{}^{N}O_{rx} \quad {}^{N}O_{ry} \quad {}^{N}O_{rz} \right]^{T}. \tag{5} $$

Considering relationships (4) and (5), the position—orientation of the relative systems N and N' may be described by 1 × 6 matrix:

$$ {}^{N}\underline{S}^{V}{}_{N'} = [\, r_x \quad r_y \quad r_z \quad O_{rx} \quad O_{ry} \quad O_{rz} \,]^{T}. \tag{6} $$

The transition (transformation) from system N' to system N occurs through 3 finite translations—q_1, q_2, q_3—along the axes of the system N and 3 finite rotations—q_4, q_5, q_6—around the same axes. Mathematically, the transition is a product of translation—rotation operators:

$$ \begin{aligned} {}^{N}\underline{T}_{N'} = {} & (\mathrm{Trans}\,x, q_1)(\mathrm{Trans}\,y, q_2)(\mathrm{Trans}\,z, q_3) \\ & (\mathrm{Rot}\,x, q_4)(\mathrm{Rot}\,y, q_5)(\mathrm{Rot}\,z, q_6) \end{aligned} \tag{7} $$

or a 4 × 4 "transfer matrix":

$$ {}^{N}\underline{T}_{N'} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ q_1 & c_5c_6 & s_4s_5c_6 - c_4s_6 & c_4s_5c_6 + s_4s_6 \\ q_2 & c_5s_6 & s_4s_5s_6 + c_4c_6 & c_4s_5s_6 - s_4c_6 \\ q_3 & -s_5 & s_4c_5 & c_4c_5 \end{bmatrix}, \tag{8} $$

where

$$ s_4 = \sin q_4,\ c_4 = \cos q_4 \text{ etc.} \tag{9} $$

or a 1 × 6 matrix:

$$ {}^{N}T^{V}_{N'} = [\, q_1 \quad q_2 \quad q_3 \quad q_4 \quad q_5 \quad q_6 \,]^{T}. \tag{10} $$

Notice: The parameters q_i are time dependent:

$$ q_i = q_i(t). \tag{11} $$

The position—orientation of system N' in respect to N requires an expression of the transfer matrix from system N' to N:

$$ {}^{N}\underline{S}_{N'} = {}^{N}\underline{T}_{N'}. \tag{12} $$

The above expressions allow for establishment of the position vector, velocity vector and acceleration vector of a point P within a body bonded to system N', as follows:

$$ {}^{N}\underline{p} = {}^{N}\underline{T}_{N'}{}^{N'}\underline{p}, \tag{13} $$

$$ {}^{N}\dot{\underline{p}} = {}^{N}\dot{\underline{T}}_{N'}{}^{N'}\underline{p} + {}^{N}\underline{T}_{N'}{}^{N'}\dot{\underline{p}}, \tag{14} $$

$$ {}^{N}\ddot{\underline{p}} = {}^{N}\ddot{\underline{T}}_{N'}{}^{N}\underline{p} + 2{}^{N'}\dot{\underline{T}}_{N}{}^{N}\dot{\underline{p}} + {}^{N}\underline{T}_{N'}{}^{N'}\ddot{\underline{p}}, \tag{15} $$

where ${}^{N'}\dot{\underline{T}}_{N'}$ and ${}^{N}\ddot{\underline{T}}_{N'}$ are the velocity matrix and the acceleration matrix of the transfer from N' to N.

The mathematical models related to dimensions and relative displacements of reference systems are called "models of degree 0". The models relative to kinematics (velocities and accelerations) are called "models of degree 1" and those related to dynamics are referred to as "models of degree 2".

Within the PeSiR concept, ${}^{N'}\underline{T}_{N}$, ${}^{N'}\dot{\underline{T}}_{N'}$ and ${}^{N}\ddot{\underline{T}}_{N'}$ are models of degree 0, 1 and 2.

3.3 Simplified Dynamic Model of Robots' Guiding Device

F. V. Kovács proposed an original method for calculating the driving force and torque. The simplified dynamic model decouples the robot axes. This model treats each axis separately and ignores the mutual influences of the guiding device axes. Each axis, each module, and each driving joint is treated as a separate and isolated mechanical system consisting of a driving motor, a mechanical transmission and a consumer (Fig. 13).

The calculus is performed for the driving joint "i, i + 1" and considers the mobile elements "i + 1…n". The kinematic chain, including the final gripper and the manipulated object, is assumed to cover the most unfavourable position, where the reduced moment M_{red} is maximum.

The reference line for reduced values of parameters is the electric, pneumatic or hydraulic engine axis.

3.4 Calculus of the Reduced Resistant Moment/Force for the Driving Rotation/Translation Joint "i, i + 1"

The driving engine must develop an amount of power that exceeds the reduced power (due to gravitation, friction, inertia and technologic forces). Thus:

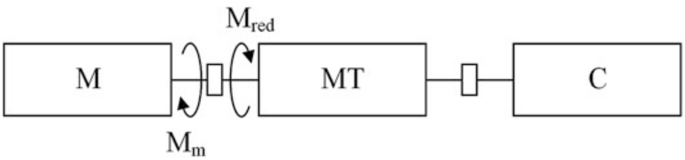


Fig. 13 Modelling of one single axis of the robot (*M* driving motor, *MT* mechanical transmission, *C* consumer, M_m driving torque, M_{red} reduced resistant torque)

$$\textit{rotation}: \begin{array}{l} P_m > P_{red} \quad \omega_m \cdot M_m > \omega_m \cdot M_{red} \quad \forall \quad \omega_m \neq 0 \quad \Rightarrow \\ M_m > M_{red} \\ M_{red} = M_{red\,g} + M_{red\ fr} + M_{red\,in} + M_{red\,tehn} \end{array}, \tag{16}$$

$$\textit{translation}: \begin{array}{l} P_m > P_{red} \quad V_m \cdot F_m > V_m \cdot F_{red} \quad \forall \quad V_m \neq 0 \quad \Rightarrow \\ F_m > F_{red} \\ F_{red} = F_{red\,g} + F_{red\ fr} + F_{red\ in} + F_{red\,tehn} \end{array}, \tag{17}$$

where M_m/F_m is the rotary motor moment/linear driving force; ω_m/V_m—driving angular velocity/linear speed; $M_{red\ g}/F_{red\ g}$—the reduced moment/force of gravitation forces; $M_{red\ fr}/F_{red\ fr}$—reduced moment/force of friction forces; $M_{red\ in}/F_{red\ in}$—reduced moment/force of inertia forces; $M_{red\ tehn}/F_{red\ tehn}$—reduced moment/force of technological forces, which are meaningful in case the robot carries a tool.

The reduced moment/force of gravitational forces acting upon the elements of the kinematic chain "i + 1…n" comes out from the balance of powers consumed in the system by the gravitational forces:

$$\textit{rotation}: P_{red\ g} = M_{red\ g} \cdot \omega_m = \sum_{j=i+1}^{n} G_j \cdot V_{Cj} \cdot \cos\alpha_j, \tag{18}$$

$$M_{red\ g} = \frac{1}{\omega_m} \sum_{j=i+1}^{n} G_j \cdot V_{Cj} \cdot \cos\alpha_j, \tag{19}$$

$$\textit{translation}: P_{red\ g} = F_{red\ g} \cdot V_m = \sum_{j=i+1}^{n} G_j \cdot V_{Cj} \cdot \cos\alpha_j, \tag{20}$$

$$F_{red\ g} = \frac{1}{V_m} \sum_{j=i+1}^{n} G_j \cdot V_{Cj} \cdot c, \tag{21}$$

where G_j is the weight of the element j; V_{Cj} the speed of element j mass centre; and α_j the pressure angle (Fig. 14).

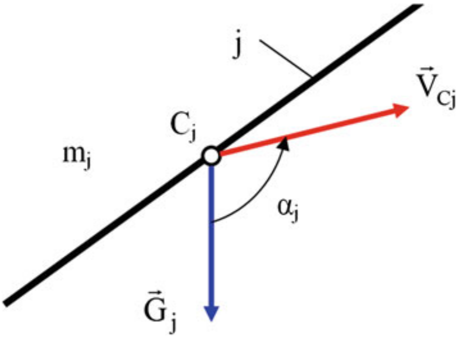


Fig. 14 Scheme for calculus of $M_{red\ g}$ and $F_{red\ g}$

The reduced moment/force of friction forces results from the condition of compensating the power wasted in the system due to friction forces acting in the joints of the kinematic chain "i + 1…n":

$$\mathit{rotation} : P_{red\ fr} = M_{red\ fr} \cdot \omega_m = \sum_{j=i+1}^{m} F_{fr_j} \cdot V_j + \sum_{k=m+1}^{n} M_{fr_k} \cdot \omega_k, \tag{22}$$

$$M_{red\ fr} \frac{1}{\omega_{m1}} \left(\sum_{j=i+1}^{m} F_{fr_j} \cdot V_j + \sum_{k=m+1}^{n} M_{fr_k} \cdot \omega_k \right). \tag{23}$$

$$\mathit{translation} : P_{red\ fr} = F_{red\ fr} \cdot V_m = \sum_{j=i+1}^{m} F_{fr_j} \cdot V_j + \sum_{k=m+1}^{n} M_{fr_k} \cdot \omega_k, \tag{24}$$

$$F_{red\ fr} = \frac{1}{V_m} \left(\sum_{j=i+1}^{m} F_{fr_j} \cdot V_j + \sum_{k=m+1}^{n} M_{fr_k} \cdot \omega_k \right), \tag{25}$$

where M_{fr_k}/F_{fr_j} is the friction moment/force in the joint k/j; ω_k the angular velocity of the element k; and V_j the linear speed of the element j.

The reduced moment of inertial forces for the kinematic chain "i + 1…n" results from the relationship:

$$\mathit{rotation} : M_{red\ in} = J_{red} \cdot \varepsilon_m, \tag{26}$$

$$J_{red} = \frac{2 \sum_{j=i+1}^{n} E_{Cj}}{\omega_m^2}, \tag{27}$$

$$\mathit{translation} : F_{red\ in} = m_{red} \cdot a_m, \tag{28}$$

$$m_{red} = \frac{2 \sum\limits_{j=i+1}^{n} E_{Cj}}{V_m^2},$$

$$\sum_{j=i+1}^{n} E_{Cj} = \sum_{j=i+1}^{m} \frac{1}{2} m_j \cdot V_{Cj}^2 + \sum_{k=m+1}^{n} \frac{1}{2} J_{Ck} \cdot \omega_k^2, \tag{29}$$

where J_{red}/m_{red} is the reduced inertial moment/mass (calculated from the condition that the kinetic energy gained by the entire system balances the kinetic energy provided by the driving shaft):

$$\sum_{j=i+1}^{n} E_{Cj} = \sum_{j=i+1}^{m} \frac{1}{2} m_j \cdot V_{Cj}^2 + \sum_{k=m+1}^{n} \frac{1}{2} J_{Ck} \cdot \omega_k^2, \tag{30}$$

where m_j is the mass of element j, concentrated in the mass centre C_j, which slides with the speed V_{Cj}; and J_{Ck} the inertial moment of element k, which rotates with the angular speed ω_k. Therefore:

$$J_{red} = \frac{1}{\omega_m^2} \left(\sum_{j=i+1}^{m} m_j \cdot V_{Cj}^2 + \sum_{k=m+1}^{n} J_{Ck} \cdot \omega_k^2 \right). \tag{31}$$

and

$$m_{red} = \frac{1}{V_m^2} \left(\sum_{j=i+1}^{m} m_j \cdot V_{Cj}^2 + \sum_{k=m+1}^{n} J_{Ck} \cdot \omega_k^2 \right). \tag{32}$$

The angular acceleration ε_m of the driving shaft for a trapezoidal distribution of the angular speed ω_m (Fig. 15) is given by the relationship:

$$\varepsilon_m = \frac{\omega_m}{kT}, \tag{33}$$

where $k < 1$ is the weight of t_{acc} and t_{fr}, within the total time, T, or:

$$t_{acc} = t_{fr} = kT. \tag{34}$$

The duration T of a cycle can be expressed as:

$$T = \frac{\Psi_j}{(1 - 2k) \cdot \omega_{k\ reg}}. \tag{35}$$

where Ψ_j is the angular pathway of the rotating element j; and $\omega_{k\ reg}$ the regime angular velocity.

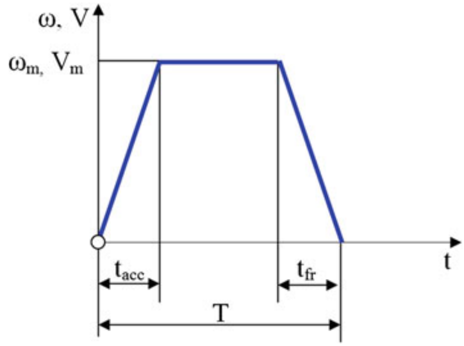


Fig. 15 Variation of the angular speed for a trapezoidal distribution

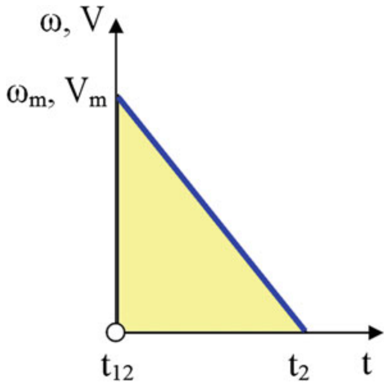


Fig. 16 Variation of the angular speed during the braking time

The linear acceleration of the driving shaft a_m, for a trapezoidal shape of linear speed variation, V_m (Fig. 15), results from the relationship:

$$a_m = \frac{V_m}{kT}, \tag{36}$$

$$T = \frac{h_j}{(1 - 2k) \cdot V_{j\,reg}}, \tag{37}$$

where h is the linear stroke of the sliding element.

3.5 Calculus of the Braking Moment/Force

For a driving joint "i, i + 1" powered by a rotary engine, it is necessary to pose the condition that during the braking time, the angular speed decreases to zero (point t_2 in Fig. 16). The kinetic energy corresponding to the moment of braking start, t_{12} is:

$$\textit{rotation} : E_C = \frac{1}{2} J_{red} \cdot \omega_m^2 \tag{38}$$

$$\text{or } E_C = \int_{t_{12}}^{t_2} M_{red} \cdot d\varphi = M_{red} \int_{t_{12}}^{t_2} d\varphi, \tag{39}$$

$$\textit{translation} : E_C = \frac{1}{2} m_{red} \cdot V_m^2, \tag{40}$$

$$\text{or } E_C = \int_{t_{12}}^{t_2} F_{red} \cdot ds = F_{red} \int_{t_{12}}^{t_2} ds, \tag{41}$$

where

$$\textit{moment} : M_{red} = M_{red\,g} + M_{red\,fr} + M_{red\,tehn} + M_{fr\,red}, \tag{42}$$

$$d\varphi = \omega_m dt, \tag{43}$$

$$\int_{t_{12}}^{t_2} d\varphi = \int_{t_{12}}^{t_2} \omega_m \, dt = \frac{1}{2} \omega_m (t_2 - t_{12}) = \frac{1}{2} \omega_m \cdot k \cdot T, \tag{44}$$

$$E_C = \frac{1}{2} M_{red} \cdot \omega_m \cdot k \cdot T, \tag{45}$$

$$M_{red} = \frac{2E_C}{\omega_m \cdot k \cdot T}. \tag{46}$$

$$M_{fr\,red} = M_{red} - M_{red\,g} - M_{red\,fr} - M_{red\,tehn}, \tag{47}$$

$$M_{fr\,red} = \frac{2E_C}{\omega_m \cdot k \cdot T} - M_{red\,g} - M_{red\,fr} - M_{red\,tehn}, \tag{48}$$

$$\textit{force} : F_{red} = F_{red\,g} + F_{red\,fr} + F_{red} + F_{fr\,red}, \tag{49}$$

$$ds = V_m dt, \tag{50}$$

$$\int_{t_{12}}^{t_2} ds = \int_{t_{12}}^{t_2} V_m dt = \frac{1}{2} V_m (t_2 - t_{12}) = \frac{1}{2} V_m \cdot k \cdot T, \tag{51}$$

$$E_C = \frac{1}{2} F_{red} \cdot V_m \cdot k \cdot T, \tag{52}$$

$$F_{red} = \frac{2E_C}{V_m \cdot k \cdot T}, \tag{53}$$

$$F_{fr\ red} = F_{red} - F_{red\ g} - F_{red\ fr} - F_{red\ tehn}, \tag{54}$$

$$F_{fr\ red} = \frac{2E_C}{V_m \cdot k \cdot T} - F_{red\ g} - F_{red\ fr} - F_{red\ tehn}. \tag{55}$$

The choice for a certain brake depends on the value of the necessary braking force or moment. For a driving joint connected to a rotary/linear electrical engine, these parameters are:

$$M_{fr} = M_{fr\ red} \frac{\omega_m}{\omega_{fr}}, \quad F_{fr} = M_{fr\,red} \frac{\omega_m}{V_{fr}} \tag{56}$$

$$M_{fr} = F_{fr\ red} \frac{V_m}{\omega_{fr}}, \quad F_{fr} = F_{fr\ red} \frac{V_m}{V_{fr}} \tag{57}$$

4 Modern Interpretation, Scientific and Technical Legacy of Achievements

4.1 The Concept of Connection

The connection, as introduced by F. V. Kovács, can be of a geometric/kinematic type if the imposed restrictions result from geometry or of a dynamic type if the restrictions occur due a certain system of forces acting on the mechanism in its movement.

The concept of connection was developed in 1973 by M. Crudu in his PhD thesis (Crudu 1973), considering the dynamical connections. W. Rehwald used, in his mechanism theory (Rehwald 1972) and in the self-developed program for analysis of the planar mechanisms KOSIM, a similar concept called “elementary groups”, which also considered the kinematic chains with kinematic pairs of class IV or with DOF = 2. The concept of connection has been presented in many books on the mechanism theory, edited at the “Polytehnica” University of Timisoara (Perju 1990), but was also proposed for use in robotics (Kovács 1997).

4.2 Simplified Dynamic Model of Robots’ Guiding Device

Beside the mathematical model of manipulation within a flexible manufacturing cell, the geometric models of positioning the manipulated object, and the kinematic and kinetostatic model of the guiding device, the dynamic model develops the concept of generalized force as a direct cause of motion.

In this regard, the motion equations of the robots develop based on the driving force and torque, respectively. Dynamics of robots study structures comprising open kinematic chains with conditions regarding guidance of robots along given trajectories and generalized coordinate, speed and acceleration. The aim of the calculus is learning the driving torque M_m or the driving force F_m. The literature offers three important dynamic models, namely: *Lagrange—Euler, Newton—Euler* and *Apple.*

Lagrange—Euler Model. The motion equations are second-degree non-linear differential equations, specific to the case in which there is a mutual influence between the guiding device axes of the robot (coupled movements). Usually, a simplified version of these equations is applied. The guidance dynamics and friction forces are neglected. The dynamic model Lagrange—Euler is operational if the following parameters are known: generalized coordinate, generalized speed, generalized acceleration, position vector of weight centres, axial and centrifugal inertia moments, and static moments.

Newton—Euler Model. This model considers each element of the guiding device as a rigid solid body. Knowing the mass centre and the inertial tensor of the element, the mass distribution is completely described. Movement of the element acceleration is needed. The required inertial force depends on the mass and acceleration. Newton's law for translational motion and Euler's equation for rotation link the inertial force, the mass and the acceleration. The dynamic Newton—Euler model allows for learning the driving inertial force and moment for the mass centre of each element. The input parameters are the position of the mass centre, its linear speed, the inertial tensor of the element, the angular velocity and acceleration.

Apple Model. Apple's equations describe the dynamics of non-holonomic systems. The model applies in case there is a mutual influence between the axes of a robot's guiding device (systems of coupled rigid bodies). Apple's equations reduce the dynamic model to expressing the energy of acceleration in relation to the generalized coordinate of each particle, the mass of particles, the result of active forces acting on a particle, with the condition that the result of the reactive forces under given constraints is zero. Therefore, the problem of the dynamic model reduces to the expression of the acceleration energy depending on the generalized coordinates. Applying Apple's equations for a robot, it is sufficient to compute the acceleration energy of an element (rigid body) and then to sum it for all the elements of the kinematic chain in order to learn the acceleration energy function.

As shown, dynamic methods require laborious calculation, in many cases impossible to complete within the initial phase of designing a robot, when, at best, manipulated mass, some geometrical parameters and kinematic parameters are known. The basics of the method aiming to calculate the dimensions of the driving motors of the robot's guiding were published in the first course on Robotics in Romania (Radulescu 1992). The design method proposed by F. V. Kovács was first applied in the calculus of the industrial robot REMT-1.

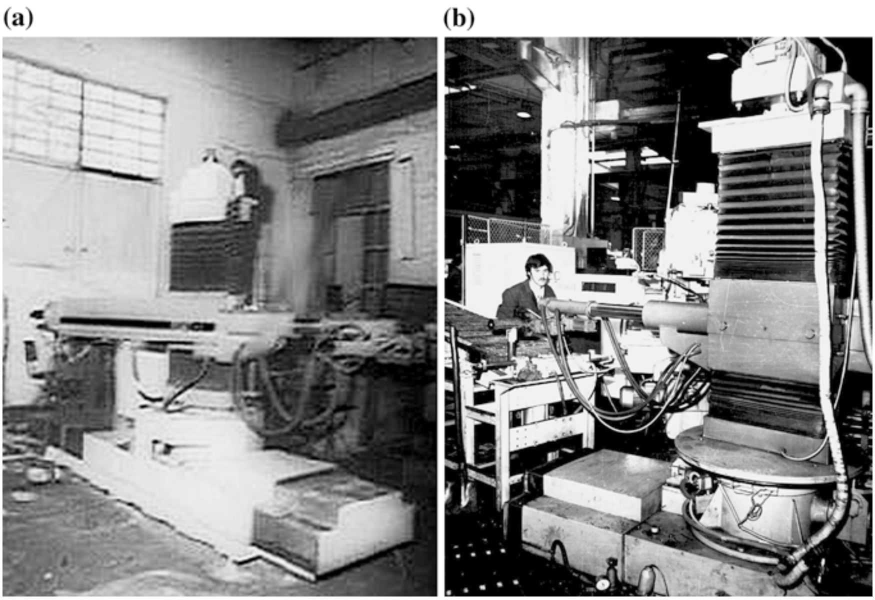


Fig. 17 REMT-1 in the first Romanian flexible manufacturing cell (Feb 8, 1982). **a** Design of REMT-1. **b** REMT-1 into the manufacturing cell

4.3 The First Romanian Flexible Manufacturing Cell

The first real problem solved by the Robotics Multidisciplinary Team was in relation to the study, research, design and manufacture of the electrically powered industrial robot REMT-1, in collaboration with the Electromotor Factory in Timisoara (Fig. 17a, b). The design of this first robot was developed under the coordination of N. S. Gheorghiu (Gheorghiu et al. 1980).

The main characteristics of REMT-1 are as follows:

- mechanical system structure $T \perp R \parallel T \perp T \parallel R$ (Fig. 18)
- electric actuation
- control system : ECAROM 800, adapted for robot control
- payload: 63 daN
- work space: parallelepiped + cylinder
- v_{max}: 0.2 m/s
- ϖ_{max}: 0.5 rad/s
- rotational encoders: TIRO 100.

On February 8, 1982, at the Electromotor factory in Timisoara, a flexible manufacturing cell used for the machining of 12 typo-dimensions of shafts for the rotors of the middle series of electrical motors began to operate, a cell that used the robot REMT-1.

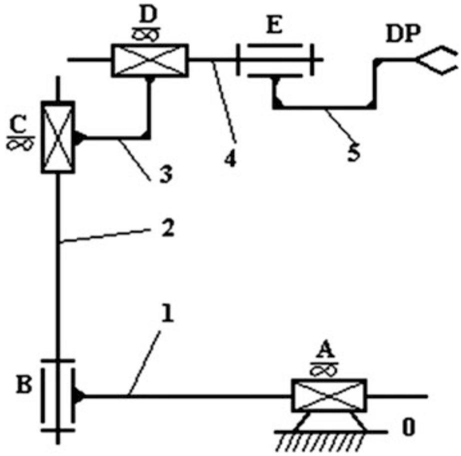


Fig. 18 Kinematic schema of REMT-1

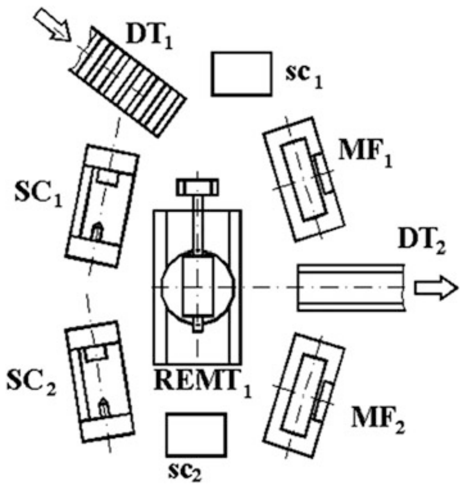


Fig. 19 Layout of the manufacturing cell

Figure 18 presents the layout of the manufacturing cell, and in Fig. 19a–c, there are several pictures of the machining manufacturing cell for the shaft family, using the robot REMT-1.

The components of the manufacturing cell for stepped shafts are:

- copying lathes SC1, SC2 2 pcs
- automated milling machines MF1, MF2 2 pcs
- transfer device for parts DT1 1 pcs
- gutter type transfer device for finished parts DT2 1 pcs.

Inside the cell, the industrial robot REMT-1 would grip the part presented as a laminate bar from the stepper gravitational transfer device, shown in Fig. 20a, and transfer it to one of the two numerically controlled copying lathes.

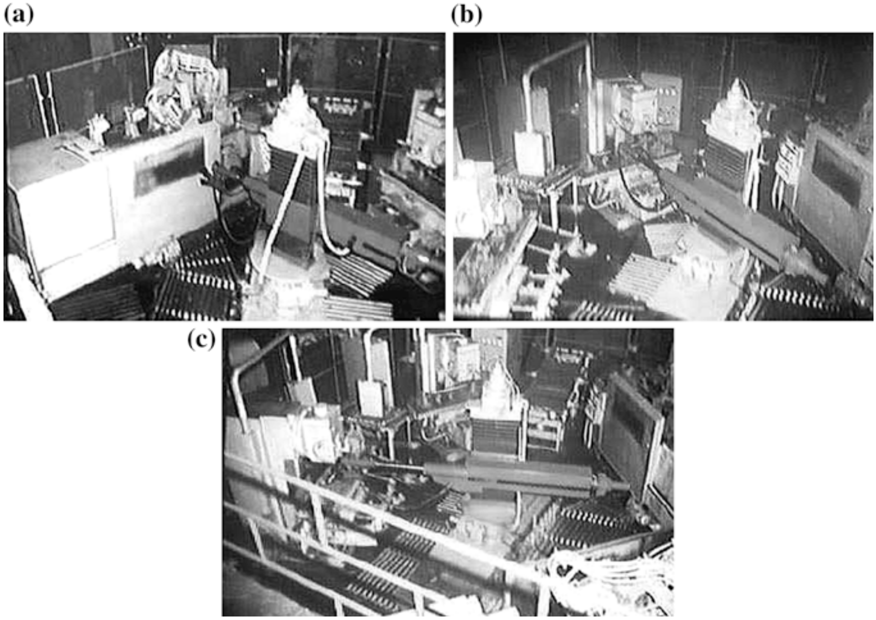


Fig. 20 Manufacturing cell for machining the shafts. **a** robot REMT-1, feeding a part to the copying lathe; **b** robot REMT-1, feeding a machined shaft to the first milling machine; **c** robot REMT-1, transferring a finished shaft to the cell evacuation device

When the lathe finished machining the stepped shaft, the industrial robot REMT-1 would grip the part from the lathe and transfer it to one of the two available milling machines, which shaped the keyway in an automated cycle (Fig. 20b).

Once the milling operation ended, the finished shaft was transferred to the evacuation device (Fig. 20c) and placed between the two milling machines.

By approaching the construction of manipulators and robots in a modular structure, five variants of robots in the REMT family (Kovács et al. 1982, 1986) were conceived and manufactured from 1982 to 1988, in collaboration with the Electromotor factory in Timisoara.

The success of REMT-1 has spurred interest in developing new robotic systems. By the end of the '80s, the following units had been designed, manufactured and deployed in industries:

- the robots REMT-2, REMT-2S, REMT-5 electrically actuated (within the Electromotor Timişoara factory)
- the family of electrically actuated minirobots MRE 12.5 and MAE 100 (within the Electrotimiş Timişoara factory)
- the family of pneumatic robots MRP 12.5 and MAP 100 (within the Electrotimiş Timişoara factory)

- the hydraulically actuated robot RH 1 KN (within the Electrotimiş Timişoara factory)
- the electrically actuated micro—robot Micro R 2.5 (within the Electrotimiş Timişoara factory)
- the pneumatic robot RP 1 (within the IAEM Timişoara factory)
- the robot RIE 50 electrically actuated (within the UNIO Satu-Mare factory)
- the family of synchronic manipulators MS 500, MS 200 and MS 1000 (hydraulically actuated) and the portal robot ROPOS 50 electrically actuated (within the IMMUM Baia-Mare factory).

5 Conclusion

Francisc Viliam Kovács contributed to the development of Romanian engineering in the fields of mechanisms and robotics. This development included several milestones:

- contributions to fundamental and applicative knowledge in both mechanism science and robotics
- foundation of specialized higher education in Industrial robots in the Romanian language in 1990 and in the German language in 1992
- prodigious publishing activity for the spread of knowledge of mechanisms and robots
- collaboration in the development of new laboratories in robotics
- first PhD advisor in the field of robotics in Romania, in the early '80s
- exceptional organizing and leadership of a large group of researchers, with remarkable practical achievements in robotics
- initiation of bilateral or multilateral research programmes with universities from Europe.

Kovács was not only a great scientist, but also an exceptional scholar. He was an expert connoisseur of history and literature.

Throughout his entire life, Kovács was a strong personality. The new generation of scientists, researchers and students have benefitted from his scientific legacy.

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Jan Oderfeld (1908–2010)

Teresa Zielinska

Abstract Jan Oderfeld contributed greatly to the field of machines and mechanism science, especially with his achievements in the development of aircraft jet engines, classification of machines and mechanisms, and introduction of optimization methods in mechanical design. He promoted engineering study and was one of the founding fathers of the IFToMM—the International Federation for Promotion of Mechanism and Machine Science. He was the innovator of significant improvements in complex machinery, as well as an excellent teacher to many generations of mechanical engineers. By developing and improving jet engines, he significantly contributed to the progress of aeronautical engineering.

1 Biographical Notes

Jan Oderfeld (Fig. 1) was born in an average-sized town in Poland, Częstochowa, on February 19, 1908. In 1924, he completed his secondary education, and in 1930, he graduated from the Warsaw University of Technology, Faculty of Mechanical Engineering.

Early in his studies, he showed an interest in solving industrial problems; afterwards, he got a job in the well-known machine-production plant “Pioneer” in Warsaw, Poland. After concluding his military service, he created a team of engineers who undertook the very challenging task of constructing a turbine jet engine. In 1931, they managed to construct two prototypes of the engine, both of which underwent successful tests (Bernardzikiewicz et al. 1933) (Fig. 2).

A brief look at the history of jet engines helps to shed light on the pioneering achievements of Jan Oderfeld.

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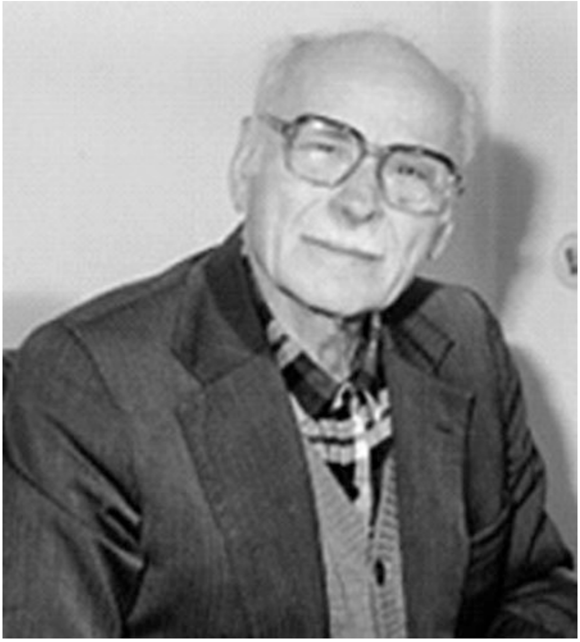

Fig. 1 Professor Jan Oderfeld (1908–2010)

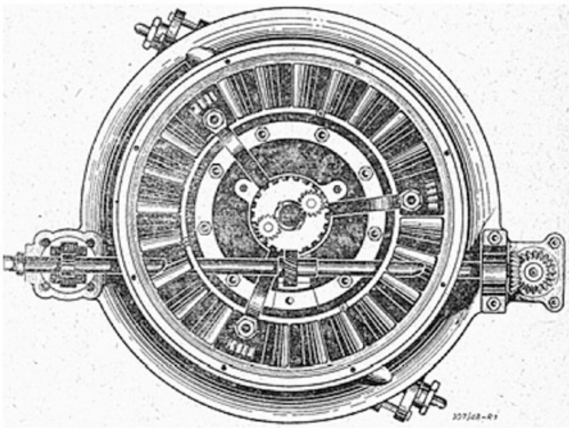

Fig. 2 First Polish jet engine developed by Jan Oderfeld and co-workers. Copy of drawing extracted from his paper

The first patent for a gas turbine used to power an aircraft was filed in 1921 by Maxime Guillaume (France). In 1930, in England, Frank Whittle submitted a patent for a two-stage axial compressor feeding a single-sided centrifugal compressor (granted in 1932). Whittle's first working engine appeared in April 1937. In 1935, Hans von Ohain, being unaware of the English designs, started work on a similar design in Germany, and his first centrifugal engine was successfully launched by September 1937. As can be seen from the two prototypes they

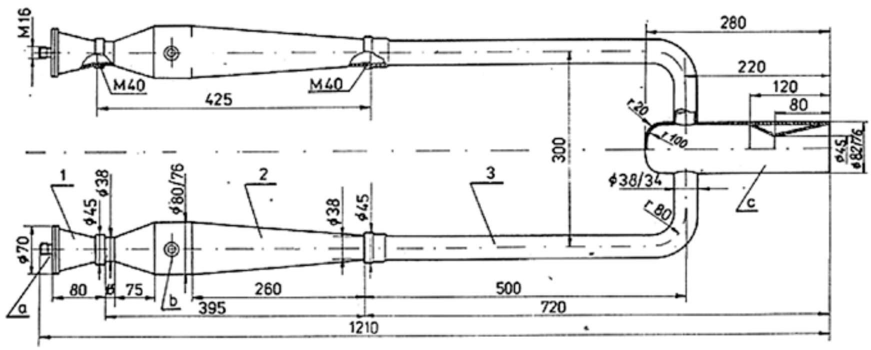

Fig. 3 Pulsejet engine (1933)—design drawing from Jan Oderfeld's publication

managed to deliver in the period of one year, 1931 (Foa 1960), Jan Oderfeld's team took the leading position in the global race for a good jet engine.

Development of pulsating combustion began around the 17th century. Christiaan Huygens, a well-known mathematician, designed a pulsating engine powered by gun powder (Foa 1960). In a pulsejet engine, air is admitted through movable vanes that are closed by the pressure resulting from each intermittent explosion of the fuel in the combustion chamber, thus causing a pulsating thrust. At the beginning of the 20th century, the Esnault-Peltrie push-pull combustion engine was patented. This engine used pulsed combustion to drive a turbine, and from this turbine, work was to be extracted. In 1909, Gorges Marconnet designed the first valveless pulsejet.

In 1932, on the premises of the Experimental Workshop of the Public Engineering Production Plant "Ursus" near Warsaw, Oderfeld's team constructed a pulsejet engine applicable for unmanned aerial vehicles (Fig. 3). Unfortunately, the pioneering work of the young Polish engineer came to a stop in 1933 due to a lack of funds. A model of that jet engine can be seen at the Museum of Technology in Warsaw.

From 1932 to the beginning of World War II, Jan Oderfeld worked in the Engine Production Plant "Skoda" P. Z. L. in Warsaw, first as a production engineer, and then, from 1936, as the head of the design team (Fig. 4). He contributed actively to the design and supervised the testing of the Foka (Seal) aircraft piston engine, which was applied to the Wilk (Wolf) aircraft in 1938.

Together with his team, he constructed a gas turbine for the aircraft piston engine Cirrus (Oderfeld 1937a, b) (Fig. 5). The turbine passed its tests successfully in 1938. From 1937 to 1939, he was also engaged in individual engineering activity, converting a carburetor aircraft engine into an injection one, which in those days was a novel invention.

In 1937, he started teaching by delivering lectures on aircraft engines at the Air-Force Officers' Cadet School in Warsaw (Oderfeld 1938a, b). During World War II, roughly seventy of his former students fought in the Battle of Britain, many of whom were killed.

PAŃSTWOWE ZAKŁADY LOTNICZE
w Warszawie
WYTWÓRNIA SILNIKÓW
Legitymacja Nr. 194/5
P. inż. Oderfeld
nazwisko i imię Jan
jest zatrudniony w naszej Wytwórni w charakterze:
kierownika grupy konstruk.
Okęcie, dn. 1 lipca 1937 r.
Ważna na rok wystawienia
Ważność legitymacji przedłuża się na rok:
1938 | 1939 | 19 | 19
pieczęć i podpis

Fig. 4 Jan Oderfeld's identity card, issued by the engine production plant

During the war, Jan Oderfeld worked in Skierniewice (a small town near Warsaw), running a cooperative machine-workshop called Rolnik (Farmer) (Fig. 6). Under his efficient supervision, a small repair shop with a small number of workers developed into a large production plant manufacturing agricultural machinery.

Immediately after the war, in the academic year 1945/1946, engineer Jan Oderfeld began to work for the Engineering High School. Holding the position of a temporary professor, he lectured on engineering mechanics, aircraft engine design, and statistical quality inspection methods. At the same time, he took a position at the Polish Committee for Standardisation (PKN), where he contributed to the restoration and completion of the standardisation activities. He initiated statistical quality inspection, which led to its successful implementation in both the industry and the army. In the PKN, at first, he was the Head of the Standards Editing Department, and finally, in 1948, he was appointed to the position of General Executive Officer, holding this post until 1951. The research which he conducted in co-operation with Professor Hugo Steinhaus, a famous mathematician, was of crucial importance for standardisation and production inspection.

Oderfeld pursued his activities in many different fields, cooperating with a variety of scientific and industrial centres. In 1949, he joined the Warsaw University of Technology, where at first he took the position of a temporary professor. In 1955, he was nominated to be an associate professor, and in 1961, he became a full professor. Between the years 1949 and 1955, he headed the Division for

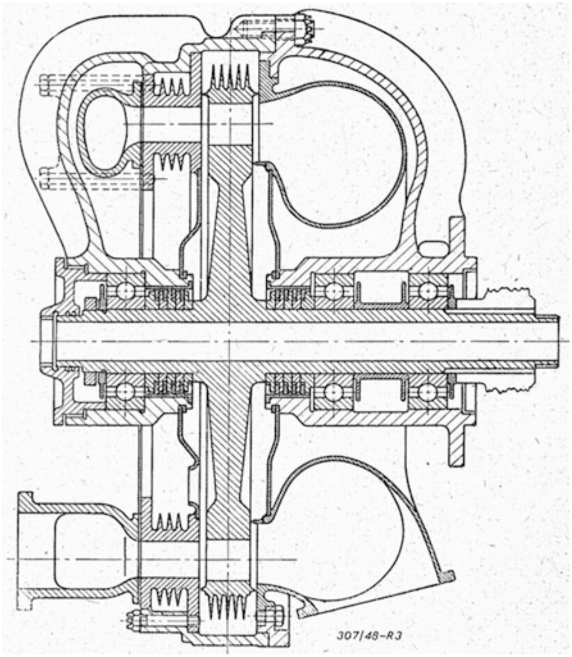

Fig. 5 Gas turbine for an aircraft engine—design drawing from Jan Oderfeld's publication

Fig. 6 Rolnik (farmer machine-workshop) where Jan Oderfeld worked during World War II

Fig. 7 Jan Oderfeld receiving his Doctor Honoris Causa diploma from the rector of Warsaw University of Technology—February 2008

Aircraft Engines, and from 1955 until his retirement in 1978, he headed the Division for Theory of Machines and Mechanisms (at present: the Division for Theory of Machines and Robots at the Faculty of Power and Aeronautical Engineering, WUT). This was the first university level educational unit addressing the theory of machines and mechanisms, which was a step towards the creation of the IFToMM. Soon after founding the Division, Oderfeld initiated a teaching course on the Theory of Machines and Mechanisms (TMM) and published the first textbooks on this subject in Poland. During the years 1964–1966, he served as a Dean at the Faculty of Power and Aeronautical Engineering of the Warsaw University of Technology. It was the result of his recommendation that the teaching programs at all mechanical faculties at WUT were modified in order to include fundamentals of control engineering, dynamical metrology and fundamentals of experiment planning. He also promoted numerical methods in both teaching and research. In February of 2008, at the age of 100, the Warsaw University of Technology conferred upon Professor Jan Oderfeld the title of Doctor Honoris Causa (Honorary Doctor) (Fig. 7). This very prestigious recognition is reserved for persons with truly exceptional achievements.

Jan Oderfeld passed away in Warsaw on March 17, 2010.

2 List of Main Works

1. Que peut-on attendr du turbocompreseur (J. Oderfeld, J. Sachs). Les Ailes 1937, Dec., 7–8.
2. Book: Aircraft Engines—Cooling Systems 1938 (111 pages, in Polish)
3. Book: Aircraft Engines—Cam Systems 1938 (240 pages, in Polish)
4. On the Dual Aspect of Sampling. Colloquim Mathematicum 1950, 2, 89–97
5. On Mechanism Classification, Archives of Machines Building, IV 1957, 367–374 (in Polish)
6. Book: Outlines of Machines and Mechanisms Theory, PWN 1959 (200 pages, in Polish)
7. Book: Introduction to Mechanical Machines Theory, WNT 1962a (300 pages, in Polish)
8. On Optimum Synthesis of Machines. General Lecture, IVth World Congress on the Theory of Machines and Mechanisms, Newcastle, 1975.

3 Review of Main Works on Mechanism Design

Among many papers published by Jan Oderfeld, it is worthwhile to note those on the so-called principle of duality, which created a basis for his Ph.D. Thesis on *Statistical set of products classified according to the alternative.* In 1951, this thesis was successfully defended at the Wrocław University of Technology (his supervisor was Professor Hugo Steinhaus). This work initiated his significant contribution to standardization, which is very important for the proper design and exploitation of machines and mechanism systems.

In cooperation with Professor Zdzisław Rytel, Oderfeld developed the Classification Frame for Standards, later replaced with the International Classification for Standards (ICS). During the years 1951–1974, he focused his activities on mathematics applied to machine engineering. He led the Group of Statistical Quality Inspection at the Mathematical Institute (now, the Industrial Application Department at the Institute of Mathematics of the Polish Academy of Sciences). His research covered a broad scope of mathematical methods applied to machine-building, rubber and military industries, as well as to medicine, biology and pharmacology. Moreover, from 1951 to 1954, he delivered lectures on statistical quality inspection at the Central School of Planning and Statistics (presently known as the Warsaw School of Economics).

Beginning with his first paper published in 1933, Oderfeld announced over 200 works in a broad scope of fields (over forty of them were published after his retirement), including 15 books and textbooks. His magnificent scientific achievements were supported by deep expert knowledge gained through practice. In general, his activities can be divided into three areas spaced through time with overlapping periods.

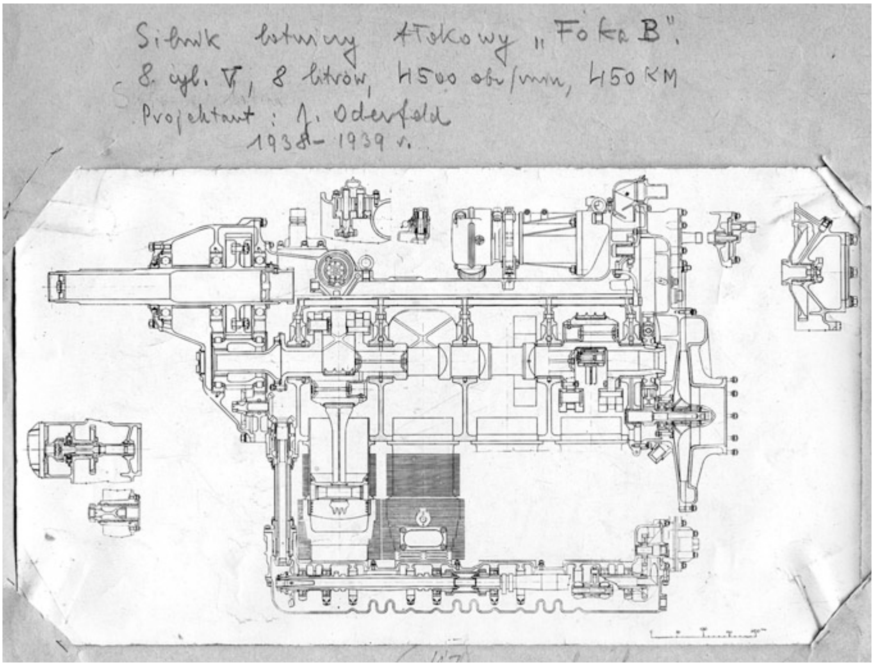

Fig. 8 Eight-cylinder aircraft piston engine Foka (*Seal*)—design drawing by Jan Oderfeld

The first period lasted over 30 years and covered the field of **aircraft engines** (Oderfeld 1937a, b, 1938a, b). The Professor was among those who constructed the first Polish jet engines (Fig. 8). He also dealt with piston engines. After World War II, he co-operated with the well-known Polish aircraft engine designer Wiktor Narkiewicz, dealing with gear system design (including cams) and optimal balance of crankshafts. He also investigated the combustion engines applied to Polish aircraft.

The second period of activity, which also lasted over 30 years, was devoted to **applied mathematics,** mainly in the fields of standardisation and quality inspection (Oderfeld 1950, 1954a, b). Oderfeld struggled for standardisation of units. He always emphasised that, from the engineering point of view, mathematics cannot be limited to the relations between dimensionless numbers. Oderfeld was far-sighted, and thus, long before the International Classification for Standards (ISO) was introduced, he encouraged his co-workers to use [kg], [m], and [s] units. Between the years 1946 and 1960, he defended this point of view against some local opponents, also indulging in international activities devoted to ISO development, which supported the world-wide implementation of an SI system of units.

In the third period, lasting over 50 years, the Professor dealt with the **theory of machines and mechanisms**, in its broad meaning, including metrology, control engineering, robotics and biomechanics. This was always the main focus of his activities. The research that he conducted on engine balancing and timing gear design starting in the pre-war period should be mentioned here. Later on, Oderfeld used this experience to develop the theory of machines and mechanisms, focusing on mechanism classification, kinematical analysis and development of design solutions for increasing the precision of mechanisms (Oderfeld 1957, 1959, 1962a, b, 1987). He analysed dynamical similarities, developed fundamentals of experimental testing in mechanics and contributed to optimisation methods for the purpose of machine design. His first works in this area appeared in 1954 and were devoted to economic factors that must be considered during machine design analysis (Oderfeld 1954a, b). Later on, Professor Oderfeld established his research school in this field, focusing on application of linear and non-linear programming methods for optimal design of machines and mechanisms (Oderfeld 1954a, b, 1962c) (Fig. 9). Many algorithms and methods which he developed were included in the design practice of complex machines and mechanisms, e.g., the optimisation methods employed in the design process of many well-known Polish jib cranes (Oderfeld 1975, 1976).

Together with Wiktor Narkiewicz, he patented an original design for magnetic drum memory. This should be mentioned as one of his most significant achievements. The design was implemented on a large scale. Subsequently, those memories were used in standard computers produced in Eastern Europe for many years.

4 On the Recognition and Circulation of Works

During his long professional career, Jan Oderfeld was involved in intense activities for different national and international scientific and technical organisations; he was a member of the Committee of Machine Design of the Polish Academy of Sciences, worked for groups and committees of the Polish Federation of Engineering Associations, and engaged in activities for the International Standard Organisation, as well as being a member of the Warsaw Scientific Society.

In 1969, while serving as the President of the Polish Committee for Theory of Machines and Mechanisms, he chaired the organising and scientific committee of the 2nd World Congress on Theory of Machines and Mechanisms in Zakopane, Poland. During the Congress, representatives of 16 countries **founded the International Federation for the Theory of Machines and Mechanisms (IFToMM)** (at present: the International Federation for the Promotion of Mechanism and Machine Science) (Fig. 10). Oderfeld was one of the founding fathers of this organisation, along with the following well-known scientists and researchers:

Academician Ivan Artobolevski (the former USSR)
Prof. Erskine F. R. Crossley (the USA)
Prof. Michael S. Konstantinov (Bulgaria)
Dr. Werner Thomas (the former FRG)
Prof. B. M. Belgaumkar
Prof. Kenneth H. Hunt (Australia)


general lecture

J. ODERFELD

SEPTEMBER 8-13 1975

Fourth World Congress ON THE THEORY OF MACHINES AND MECHANISMS

NEWCASTLE UPON TYNE · ENGLAND

ON OPTIMUM SYNTHESIS OF MACHINES

J. ODERFELD
Institute of Applied Mechanics, Technical University of Warsaw, Poland

SYNOPSIS In Sections 1 and 2 basic notions are introduced and relations between optimum synthesis and design explained. In Section 3 it is shown that the main problems in optimum synthesis are related to the following points: kind of information requested, kind of information available, number of objective functions, form of the objective function and of the constraints. Section 4 is a short review of the recent research in synthesis of machines.

Fig. 9 Title page of 4th World Congress on the theory of machines and mechanisms with the general lecture by Jan Oderfeld

Prof. J. Oderfeld (Poland)
Prof. Jack Phillips (Australia)
Prof. George Rusanov (Bulgaria)
Prof. Wolfgang Rössner (the former DDR)
Prof. Zènò Terplàn (Hungary)
Prof. Jammi S. Rao (India)
Prof.Giovanni Bianchi (Italy)
Prof. Adam Morecki (Poland)
Nicolae I. Manolescu (Romania)

Fig. 10 Photograph taken during the announcement of the IFToMM foundation act (*1* Ivan Ivanovich Artobolevski, *2* Adam Morecki, *5* Nicolae I. Manolescu, *6* Erskine F. Crossley, *7* Giovanni Bianchi, *8* Aron E.Kobrinskii, *9* Werner Thomas, *10* Jan Oderfeld)

Leonard Maunder (the UK)
Douglas Muster (the USA)
Ilic Branisky (the former Yugoslavia).

Oderfeld actively supported the development of the IFToMM and was one of its Executive Council members from the years 1969–1975. The Professor was a tutor for many Polish scientists who have performed numerous prestigious duties within authorities, committees and working groups of the Federation. The Polish School of TMM, established by Oderfeld, is highly appreciated. Up until his death, the Professor maintained a close co-operation with both the Polish Committee of TMM (being its Honorary President) and with the IFToMM. He followed IFToMM achievements and anniversaries, and being in good health, he participated in many IFToMM-supported events, even in his old age (Fig. 11).

In 1953, Jan Oderfeld was among those who established the Journal entitled “Applicationes Mathematicae”. From the years 1954–1991, he was a member of the Editorial Board of the scientific journal “Archives of Machine Design”. Among his accomplishments is his over thirty years of activity within the framework of the ongoing series of Technical Knowledge Contests for secondary school pupils, very popular in Poland. He was one of the founders and organisers of those contests.

Fig. 11 Jan Oderfeld (in the *middle*) attending the 16th CISM-IFToMM symposium on robot design, dynamics, and control 2006

5 Modern Interpretation of Main Contributions

Jan Oderfeld's achievements in the fields of science and education, as well as his organizational activities, have brought him many national and international awards. Among other honors, it must be emphasised that, during the 9th International Congress of the IFToMM in Milan 1995, the ranks of Honorary Member of the Federation and Honorary Member of the Editorial Board of the Journal of Mechanism and Machine Theory affliated with IFToMM were conferred upon him.

The recognition of Jan Oderfeld's contribution cannot be separated from the history of the IFToMM. Nowadays, the IFToMM is widely and well-recognised within 47 member countries. Many successful conferences have been initiated by IFToMM members. In 1969, the IFToMM was established with a mission to initiate and facilitate international collaboration between Eastern and Western countries, and it currently focuses on the support and enhancement of international collaboration and the exchange of research results in the field of Theory of Machines and Mechanisms.

The following three statements constitute the motto which Jan Oderfeld always emphasized and recommended:

- theory cannot be separated from engineering practice; they both should be combined, forming proper engineering art,
- each experimental result needs its error estimation,
- no detail should be neglected by a good engineer.

The above constitutes the best summary of his views and concludes his contributions to high quality engineering.

Acknowledgements The author wishes to thank Professor K. Kedzior, who made available the historical materials and provided the manuscript of the laudation speech given at Professor Jan Oderfeld's Doctor Honoris Causa award ceremony. These materials significantly aided in the work on this article.

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Leonid Smirnov (1877–1954)

Alexander Golovin and Denis Sashchenko

Abstract One of the leading scientific and pedagogical schools of Bauman University in the first half of the 20th century was the school of Applied Mechanics—Professor Leonid Smirnov's TMM. A number of well-known scientists who subsequently founded their own scientific and pedagogical schools came from it. This article describes the evolution of the teaching course in applied mechanics—the TMM of Professor L. Smirnov—in the 1st half of the 20th century. The main focus of his work was given to the comprehensive application of a graphic method of setting parameters for calculating machines.

1 Introduction

Professor Leonid Smirnov's activity covered the period of the 1st half of the 20th century.

The tenor of the Russian educational system changed over the course of the first half of the 20th century, changes that can be divided into three periods: before the Great October Revolution (before 1917), the '20s, and the '30s. Prior to 1917, universities only admitted people with good schooling. Accordingly, the courses were built considering this factor. This is particularly noticeable in the courses of

A. Golovin, passed away on 4 December 2014.

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Profs. Joukovsky (1898, 1921) and Mertsalov (1914, 1916). However, the Revolution made education accessible to workers and peasants deprived of this possibility before 1917. Unfortunately, the schooling of this population was inadequate. To prepare them for their studies in higher educational institutions, so-called "Workers' Faculties"—known as "Rabfak" in the vernacular of the time—were organized for adults whose experience came only from life and the field. Accordingly, the level of education received in the "Workers' Faculties" was lower than that received in the Gymnasium and Real college before the Revolution. In 20 years, a great number of the students were graduates of "Workers' Faculties" (see Footnote 2). This required a lower academic level of courses and only tests instead of exams to gain entry (Golovin 2004; Golovin and Tarabarin 2008). In the 30 years hence, young people who had graduated from normal high schools with a level of knowledge comparable to the one given in pre-Revolutionary schools (see Footnote 3) entered the country's universities. This required another adjustment in training courses, including the course of "Applied Mechanics".

2 Biographical Notes[1]

Leonid Smirnov (Fig. 1a, b) was born on August 26, 1877 to the family of a merchant of the 2nd guild.[2] In 1897, he graduated from "*Real uchilische*"[3] (Real college) and entered the Mechanical Department at the Imperial Moscow Technical School (IMTU, later the Moscow Higher Technical School, and now the Moscow State Technical University), from which he graduated in 1903 with the rank of mechanical engineer. During his period of study at IMTU, Smirnov had researched the dynamic crank-rocker mechanism, the results of which were published in the "Bulletin of the Polytechnic Society" (Bulletin of the Russian Polytechnic Society 1903).

On January 1, 1904, Smirnov was sent to Germany as a representative of his school to prepare for teaching and research activities. Smirnov attended lectures at the Dresden Polytechnic, and worked both in the laboratory of Professor Mollier and at the Institute of Physics. There, he conducted extensive experimental investigations. In addition, he carried out experiments on a Mollier trial-conducted steam engine whose results are processed by a heat chart. In 1905, Smirnov moved to Stuttgart and joined the local Polytechnic, where he lectured on turbine control and worked in the laboratory of engineering Ph.D. Bach. In the autumn of 1905,

[1] Private dossier of Professor Smirnov.

[2] Merchants of the 2nd guild had the right to trade in retail sales at the place of entry, maintenance of factories and handicraft establishments, and supply contracts in the amount of 15 thousand rubles.

[3] Real college-secondary educational institution in which the essential role for subjects was of natural and scientific focus.

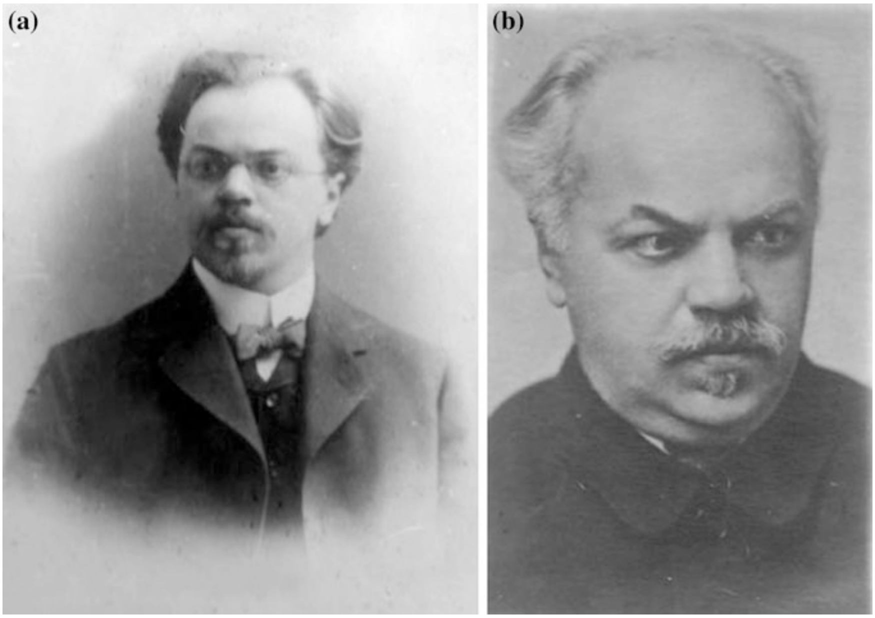


Fig. 1 L. Smirnov: **a** graduating student, **b** head of department in 1949

Smirnov moved to the University of Göttingen, where he attended lectures by a number of professors, including Prandtl on hydraulics and aerodynamics, Klein on projective geometry, Hilbert on mechanics and Voigt on elasticity. Under the direction of Prandtl, Smirnov worked on the definition of specific heat brine below 0 °C, which was relevant to the theory of refrigeration equipment, and participated in a number of experiments with thermal machines.

In autumn of 1906, Smirnov returned to Moscow. According to the results of his report, the Education Committee IMTU, on September 22, 1906, recommended him as a desirable candidate for a teaching position in the course of Applied Mechanics (theoretical machine-building) with the rights of public service, to handle the maintenance of group classes and graphic works. In addition, he was asked to organize the School Laboratory of the Steam Engine.

In 1919, Smirnov was chosen as a professor for the department of "Theory of Mechanisms and Machines" by the All-Union competition, and in 1927, he was appointed to a professorship in the Department of "Steam Engines". In 1934, he was awarded the honorary degree of Doctor of Technical Sciences.

From 1924 to 1940, Smirnov headed the Department of "Applied Mechanics" at the Moscow Electromechanical Institute of Transport Engineers. In 1929, Professor N. Mertsalov left Bauman University. Smirnov became the head of the "Applied Mechanics" department for TMM from 1943 up to 1948, thereafter remaining its supervisor until his death in 1953.

According to a tradition established at Moscow University (Artobolevsky 2005) in the time of N. Zhukovsky, a course in the theory of mechanisms and machines was always offered. Zhukovsky himself read fragments of the course, in particular, the dynamics of machines and control theory. After Zhukovsky, this course was read by Mertsalov, Smirnov, Timakov (also a professor at Bauman University), and then I. Artobolevsky.

Virtually all of Smirnov's active life was associated with Bauman University. He was a disciple of N. Zhukovsky in the field of mechanics. To a large extent, he was also a disciple of N. Mertsalov, although their approaches to problems of TMM were different. Mertsalov's lectures on kinematics and dynamics of mechanisms were on the same level as lectures for Moscow University students. According to the memoirs of Artobolevsky (2005), who attended Mertsalov's lectures in the '20s and introduced Artobolevsky to Smirnov, Mertsalov's lectures were quite difficult, assuming both a sufficient knowledge of geometry and that the listeners were able to form very clear opinions on their own. Students of the '20s had a lot of trouble understanding him. Smirnov, being fond of geometric constructions, used the scale and gave a strict sequence of transformations. In fact, with his lectures, information lists and more methodical instructions for graphic works, quite a wide range of engineering problems could be solved step by step (step one, step two, step three, etc.). Presentation of the material in lectures was accompanied by demonstrations of the model mechanisms, not only those created by his predecessors, but also those designed by him.

3 A List of Main Works by Leonid Smirnov

In our opinion, among the publications edited by Professor L. Smirnov, the **engineering design** *development* of devices and models and the modern translations of technical literature, comprise his **fundamental** works.

Key publications

1. Smirnov, L., Kinematics of Mechanisms and Machines, Moscow, State Publishing House, 1926, 186 pp. (in Russian)
2. Smirnov, L., Kinetics of Mechanisms and Machines, Moscow, State Publishing House, 1926, 206 pp. (in Russian)
3. Theory of the working process in the steam engine piston/Tutorial—M. Mashgiz, 1951. (in Russian)
4. Reference lists of Applied Mechanics/40 sheets, 6 editions 1922–1936. (in Russian)

Publications edited by Prof. L. Smirnov

5. Reference lists of Applied Mechanics/40 sheets, 6 editions 1922–1936. (in Russian) Methodical Text-books for Carrying-out Graphical Works in Applied Mechanics/Smirnov L. (Ed): Moscow, 1940a (in Russian)

The development of devices and models

6. Harmonizer—the device's system for adding harmonic curves in the Fourier/ Works of MMMI Release 2 (in Russian)

Translations

In the field of technical measurements, balancing of inertial forces in multi-machines, the theory of the regulators, the theory of friction.

4 A Review of Main Works

Analyzing the list of Smirnov's main works, his engineering and pedagogical orientation becomes immediately apparent.

Most of the graphic-analytical methods that he developed for solving engineering problems were based on the methods of mechanics and mathematics, but allowed the amount of calculations to be minimized using strict algorithmic geometric transformations.

In 1926, two books by L. Smirnov, "Kinematics of Mechanisms and Machines" and "Kinetics of Mechanisms and Machines" (Smirnov 1926a, b), were published. According to Smirnov, they reflected his seventeen years of teaching experience. The size of the book was limited by the contract with the publisher. This prompted the author to restrict the contents to what he viewed as the most necessary and important material.

In both books, the author introduced so-called scale in all of the formulas and graphical representations, beginning on the very first pages.

Currently, the presence of modern computing alleviates the consternation felt among students caused by complex geometric transformations, making the associated scale unnecessary. However, back then, these techniques allowed one to solve problems on the sole basis of geometric transformations and elementary calculated proportions. Honestly, the study of this material could be useful only if one was familiar with the foundations of theoretical mechanics.

"The entire treatment was carried out only for the planar case, since the study of movement taking place in three-dimensional space is not available for elementary exposition".

These works were developed in the coming years and served as the basis for the course of TMM, completed with the creation of the "Information lists on Applied Mechanics" (Smirnov 1940a) and "Methodical Text-books for Carrying-out Graphical Works in Applied Mechanics" (Smirnov 1940b).

In the preface to "Kinematics …", the author wrote that he maintained the position of Ampere, who considered only the modification of kinematics geometry.

The end result of material study was the opportunity to gain knowledge of velocity and acceleration, as well as the trajectories of individual points and the center of curvature of the trajectories in the most common mechanisms in engineering.

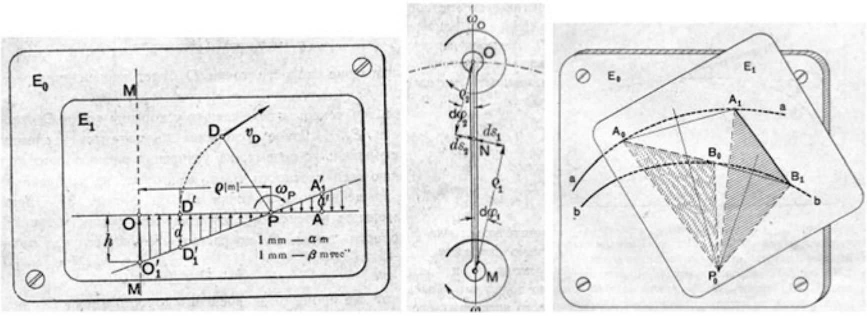


Fig. 2 Cases of plane motion from book "kinematics of mechanisms and machines"

The author also noted in the preface that the proposed work presented the main methods for motion investigation of separate parts of mechanisms and machines, as well as of more complex combinations of these parts.

4.1 Kinematics of Mechanisms and Machines (Smirnov 1926)

Chapters 1–3 review graphical methods for the simplest cases of a point and a body (the way, the speed and acceleration of a body in rectilinear motion, curvilinear translational motion, rotation of the body about a fixed axis).

In the examples, graphical integration and differentiation of functions of the form are considered.

$$s^2 = 2p(c - v),\ \frac{s^2}{a^2} + \frac{v^2}{b^2} = 1.$$

The graphical method for integrating the equations of the form is shown as

$$t = \int \frac{ds}{v(s)},\ v_0 = 0.$$

In Chapters 4–8, 3 cases of plane motion (Fig. 2) are treated.

In Chapters 7 and 8, the methods of accelerated plan construction, the definition of the center of acceleration, and the definition of the Carioles' acceleration are reviewed.

Chapter 9 describes the "transfer of movement from one plane to the other direct contact," which is the basis of the links theory (Fig. 3).

Attention is paid to the knowledge of the curvature radius of the trajectories described by the point of contact in relative motion.

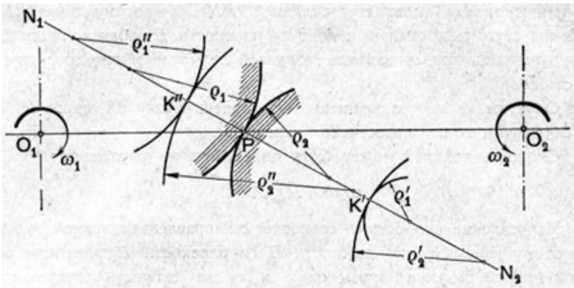


Fig. 3 Scheme of external gearing

Prof. Hartmann's book "Die Maschinengetriebe, Band 1" is then explained in the context of the poloid construction methods.

Chapter 10 considers kinematics linkage (method for speed and acceleration).

Examples of some of these include the experienced engine of Prof. Junkers (Fig. 4), the Wolseley motor system, and Stephenson's rocket.

4.1.1 Kinetics of Mechanisms and Machines (Smirnov 1926)

In the preface, the author emphasized that the name of the book considers the dynamics of machines, but by giving it the name "Kinetics …", Smirnov underlined that the amount of kinetic energy is the result of external forces (considering a positional system alone).

The book consists of 10 chapters. Chapter 4 (moment of inertia, its theoretical and empirical definitions), 7 (Transfer or enforcement powers), and 9 (the kinetic energy of the kinematic chain) are complementary, and are used for the preparation of material for the study of motion on the basis of experimental data, or set parameters.

Chapters 1–3 discuss the most common types of motion studied in theoretical mechanics: straight, curved (which is the result of two rectilinear motions), and rotation around a fixed axis.

As in "Kinematics …," explanations are based on graphic techniques and methods.

The device circuit diagrams shown in Fig. 5 allow the listener (or reader) to engage in thought experiments, or, in fact, simulation of the forces of curvilinear translational motion (Chapter 2) and rotational motion about a fixed axis (Chapter 3).

At the end of Chapter 3, the basics of balancing rotors are given.

Details of balancing rotors are covered in Chapter 5, and would also be presented in the illustrations to "Methodical Text-books …." (Smirnov 1940b).

Methods for determination of mass and moment of inertia of a body of arbitrary shape from the selected axis are presented in Chapter 4.

The principle of the approximate theoretical method of determining the moment of inertia of the body can be seen in Fig. 6.

As a result of formal geometric transformations of mass and moment of inertia, proportional segments in the elementary computed scale are represented.

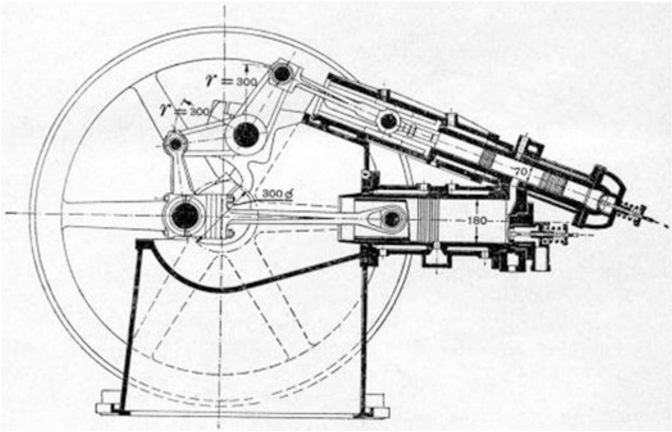


Fig. 4 Example of kinematics linkage of the experienced engine of Prof. Junkers

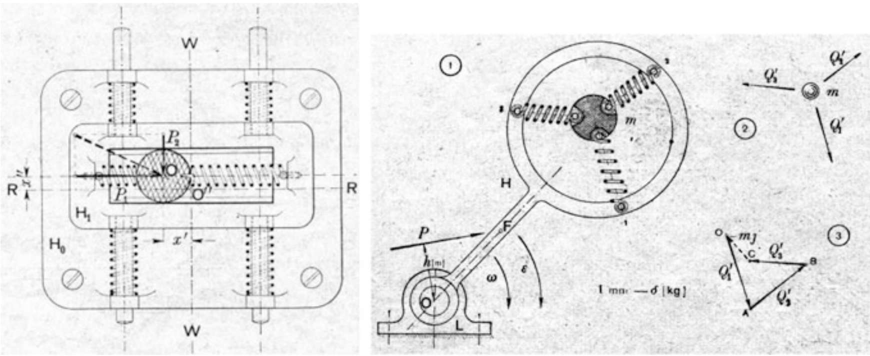


Fig. 5 Device circuit diagrams

Additionally, we present an experimental method for determining the moment of inertia—study of the oscillations of a physical pendulum.

Chapter 6 discusses the problem of rotation of a given moment of inertia under the action of given forces:

- movement to a constant force (acceleration to achieve a given speed),
- movement in the event of a given constant engine power,
- dispersal of a given relationship between the angular velocity and acceleration time,
- movement in the case where a change in engine power during acceleration can be controlled by the driver (see "Reference Sheets …" ≪and "Methodical Text-books …").

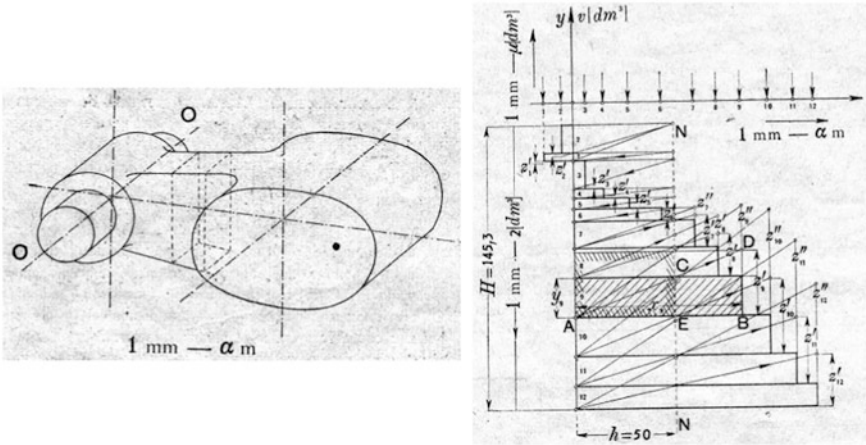


Fig. 6 Determination of the moment of inertia of the rod

Chapter 7 describes the method of reduction of forces and moments.

As a practical problem, we consider the problem of determining the parameters of a pneumatic cylinder power riveting machine (see "Reference Sheets …" and "Methodical Text-books …").

Chapter 8 deals with particular issues of friction in the joints and guides based on Coulomb's law, marking change in terms of the friction coefficient with increasing pressure and containing the graphical method for determining the friction in this case.

Figure 7 illustrates a graphical method for determining the work of friction with variable magnitudes of the coefficient of friction. Based on the method of force reduction, consider the problem of determining the loss of friction in the linkage.

Chapter 9 describes the method for determining the reduced moment of inertia and kinetic energy of the kinematic chain in the case of constant speed link or point reduction.

In Chapter 10, the problem of determining the law of motion for a given level of bringing the reduced moment of inertia, work and driving forces of resistance, as well as certain initial velocity, is decided. The solution is based Vittenbauer's method.

4.1.2 Reference Lists of Applied Mechanics

Currently, these sheets are a rarity.

We have found only 40 sheets (out of 18 issues), collected from the archives of the authors, libraries of Bauman university and the RSL (the Russian State Library). In fact, the reference lists were Smirnov's lecture notes. To work on them, he contracted a number of his students—the staff of "Applied Mechanics,"

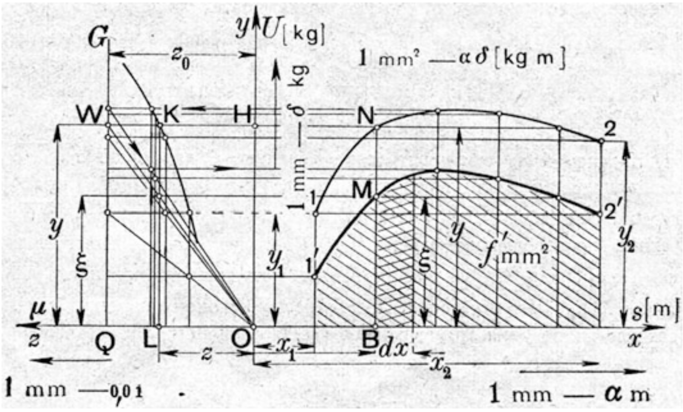


Fig. 7 Determination of the work of friction

G. Baranov, L. Reshetov, and B. Shitikov. Much of the material is beyond the scope of (Smirnov 1926).

It comprises an introduction and scope (developed by G. Baranov) and designation (worked on by the development team of the department).

Linkages

- Rectilinear motion. The method of graphical differentiation and integration (development, L. Smirnov). This theme is performed in graphical work No. 4 (Smirnov 1940b).
- The rotary movement, the triangle of velocities (development, L. Smirnov)
- Polygon speeds for multilink hinge mechanisms (development, L. Smirnov)—this material is missing.
- Kinematics of linkages, including the determination of the radius of curvature of any point of the curve crank (development, L. Smirnov).
- The complex motion of the system (development, G. Baranov)—this material is missing. The material includes general provisions, the kinematic chain for speed, streamlined for speed, the definition of normal acceleration, the Coriolis acceleration, accelerated plan, and simple plan accelerations.
- Theorem Grashof (development, L. Reshetov).
- Coupling (joint) Cardan (Hooke) (development, L. Reshetov).
- Investigation of the rocker mechanism Valskharta (Geisinger). (development, B. Shitikov)—this material is missing.

Determination of the moment of inertia (development, G. Baranov)—This material is missing.

This material includes general provisions, the analytical determination, the period of oscillation of the pendulum, and an experimental determination of that period.

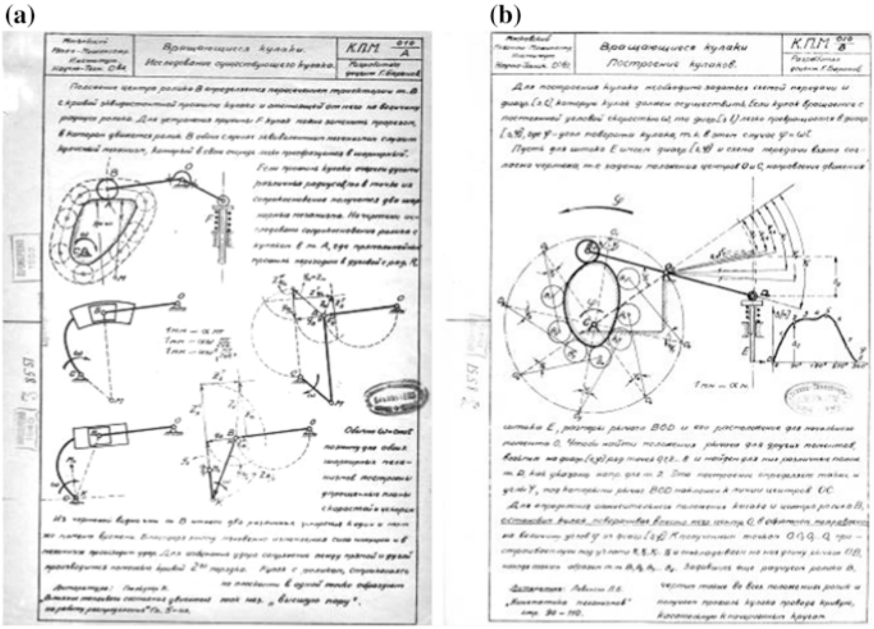


Fig. 8 Reference lists of a study: **a** existing cam, **b** construction of fists

Study of the wedge mechanisms (development, B. Shitikov)—This material consists of a double wedge [graphical work No. 7 (Smirnov 1940b)] and its application, worm gear, ring spring.

Rotating cams (development, G. Baranov)—This material includes the study of the existing cam (Fig. 8a) and the construction of a cam (Fig. 8b). The kinematic study of cam mechanisms by Hartmann is performed in graphical work No. 6 (Smirnov 1940b).

Gears (development, L. Reshetov)—This material consists of general properties (Fig. 9a), involute shape of gear tooth, the minimum number of wheel teeth with involute engagement (Fig. 9b), manufacturing of gears [graphical work No. 2 (Smirnov 1940b)], helical and chevron tooth's, worm gear and spiral gear (Fig. 9c).

Friction questions (development, L. Smirnov)—This material includes the basic provisions of the theory of friction of solids with insufficient lubrication, friction's second job as progressively moving and rotating parts of the machine, and the definition of friction—this material is missing, except for the above definition of friction forces.

The forces on the system (development, G. Baranov)—This material is missing. The material includes general provisions, the definition of an unknown force, the definition of forces in the mechanism, the friction in the mechanism, the movement of the system, and the calculation of the flywheel for a belt drive.

Dynamics of mechanisms (development, L. Smirnov)—This material includes the definition of the external forces needed to accelerate the four-crank kinematic chain; the four-crank inertial drive train, definition of "kinetic energy" and

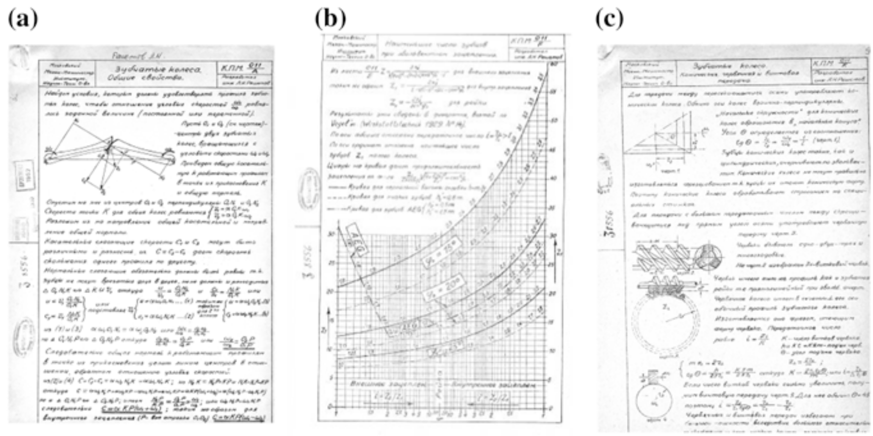


Fig. 9 Reference lists of a study: **a** the material consists of introduction of general properties, **b** illustration for involute shape of gear tooth, the minimum number of wheel tooth's with involute engagement, **c** discussion of manufacturing of gears (see graphical work in No. 2 of (Smirnov 1940b)), helical and chevron tooth's, worm gear and spiral gear

"effective mass" for the four-link kinematic chain, definition of force necessary to change the kinetic energy machines, the method for calculating the "moment of inertia" of the flywheel, and the movement of the flywheel under the applied forces. This material is reinforced in graphical work No. 7 (Smirnov 1940b).

Balancing of rotating masses (development, B. Shitikov)—This material is reinforced in graphical work No. 8 (Smirnov 1940b).

4.1.3 Methodical Text-Books for Carrying Out Graphical Works in Applied Mechanics (Smirnov 1940b)

Work on "Methodical Text-books…" was completed in 1940. The methodological guidelines were prepared with the assistance of Prof. N. Vzorov, who, according to the memoirs of contemporaries, was a brilliant lecturer.

The model sheets (shown in Figs. 10, 11, 12, 13, 14, 15, 16 and 17) were prepared under the direction of Vzorov, and performed by A. Savelova, who was head of the TMM Department from 1949 to 1951. In this study, we used a reference to "Kinematics of …", "The Kinetics of …", "Reference Lists …", as well as the Soviet and foreign transfers (the U.S., Germany), publication years 1931–1935. The authors' scruples should be noted. For example, references to work No. 5 were accompanied by a note about the use of unpublished methods proposed by L. Reshetov. In the 1st edition, eight graphic works were prepared that actually covered close to the entire course of TMM. In Minut (1973), the method of construction shows poloidnyh curves for non-circular gears for a given law of change ratio. However, we have found the indications and model sheets for it.

Work number 1. The study of the absorbing device for automatic coupling system "Peerless" (Fig. 10).

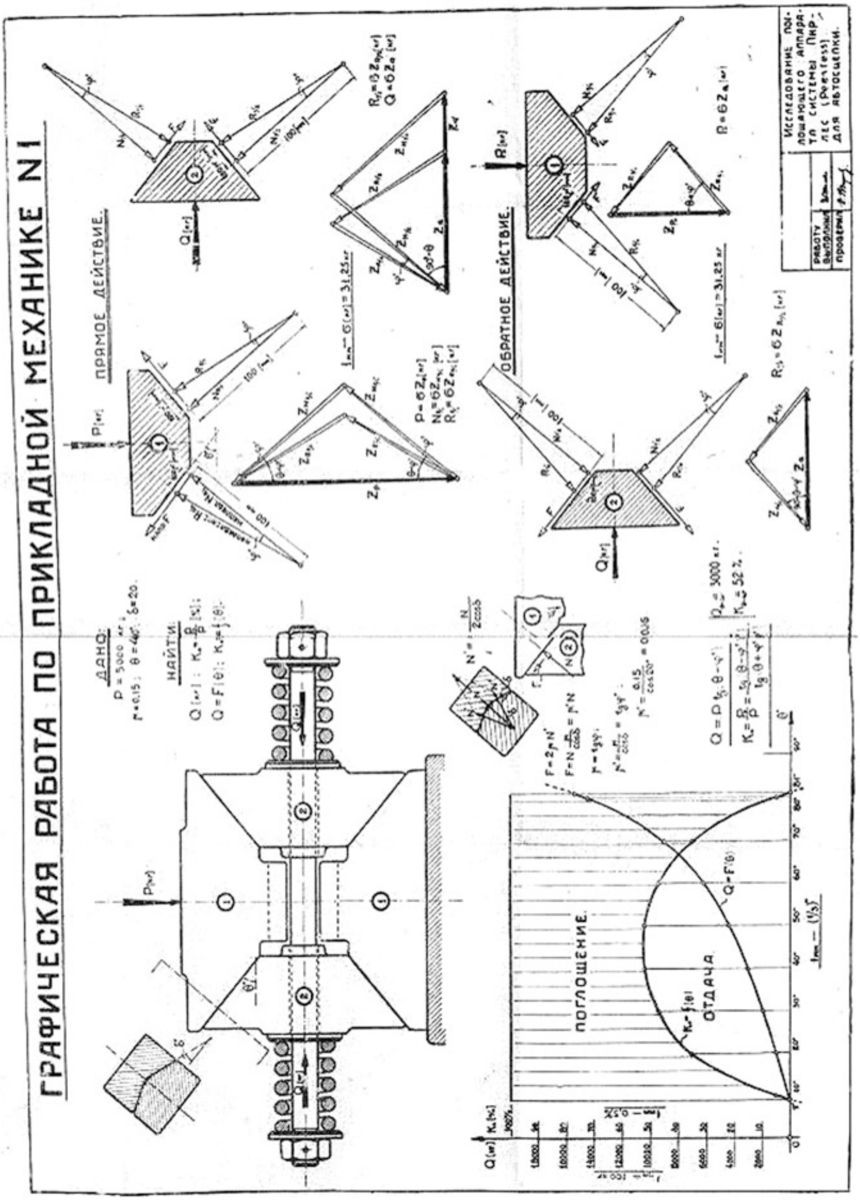


Fig. 10 Graphic work on “absorbing devices for automatic couplers”

Purpose of the device: to maximize energy absorption by the sliding friction that occurs on the sides of the wedges. This work is based on the theme "Clean and its application" (author, B. Shitikov). Design scheme hitch—4 trapezoidal wedge pins and 2 springs.

Work number 2. Involute meshing spur gears with straight teeth (Fig. 11).

This work is based on research by Reshetov (1935). Assigned work: to build corrugated mesh wheels on DJN-870 and Buckingham, as well as a normal engagement with the pinion gear.

Work number 3. The study of planetary gears with cylindrical wheels (Fig. 12).

The basis of this work comes from graphic techniques developed by Prof. Smirnov (1926). Some techniques were recorded lectures by Smirnov that were published by his first post-graduate student Baranov in (1932) and entered into the latest edition of the reference sheets. In particular, the issues of friction, wear and efficiency were addressed. In this study, we investigated the kinematics and forces in the planetary gear.

Work number 4. Kinematic study of linear motion (graphical integration and differentiation, Fig. 13).

The basis of this work comes from graphic techniques developed by Smirnov and Baranov (1932) and set out in the relevant data sheet.

Work number 5. A kinematic study of the mechanism of the "Ju" (Fig. 14).

The study of the method of triangle velocity and acceleration of plans, including the study of the kinematic crank point, set out in the relevant data sheet.

Work number 6. Kinematic study of the cam by Hartmann (Baranov 1932) (Fig. 15).

The purpose of this work was to construct graphs of displacement, velocity and acceleration of the ram for a given cam profile. The study is based on an approximation of the profile sections, circular arcs or line segments and the transition to the replacement of the relevant parts of the equivalent of a four-cam mechanism. The construction of the kinematic characteristics of the graphic was made through methods of integration and differentiation (Work number 4).

Work number 7. Determination of the moment of inertia of the flywheel (Fig. 16).

For a single-cylinder steam engine, double action, driving a dynamo, DC is used to determine the moment of inertia of the flywheel for a given coefficient of inequality.

The problem of the dynamics of the mechanisms described in and the data sheet: "The forces of inertia of the four-rod drive train," "Determination of the external forces needed to accelerate the four-crank kinematic chain", definition of "kinetic energy" and "effective mass" for the four-drive train, "Determination of the forces necessary to change the kinetic energy of the machine", the method of calculating the "moment of inertia" flywheel, "flywheel movement under the applied forces."

Work number 8. Balancing of rotating masses (Fig. 17).

We solve the problems of static and dynamic balancing of rotors based on the material presented in Smirnov (1926) and the data sheet [author, B. Shitikov].

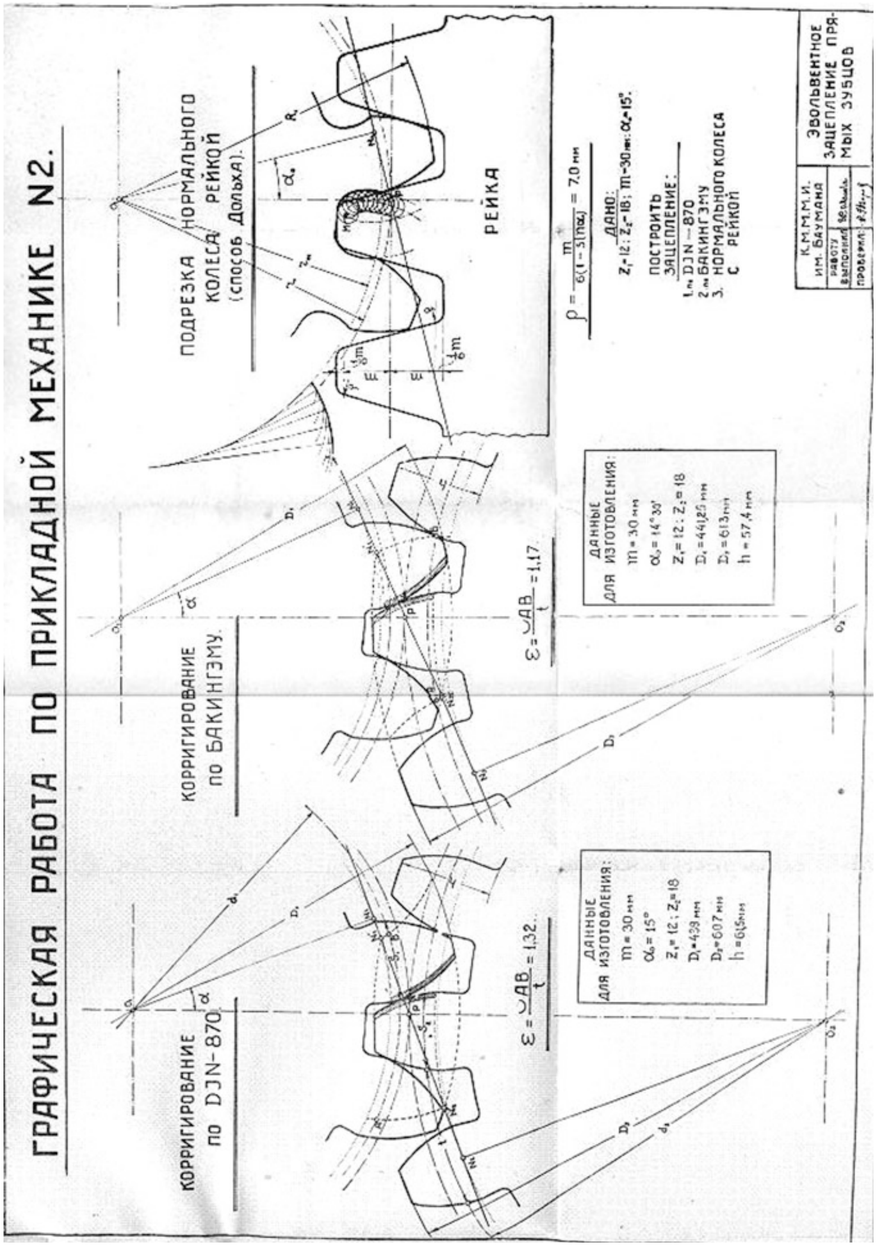


Fig. 11 Graphic work on “involute meshing spur gears”

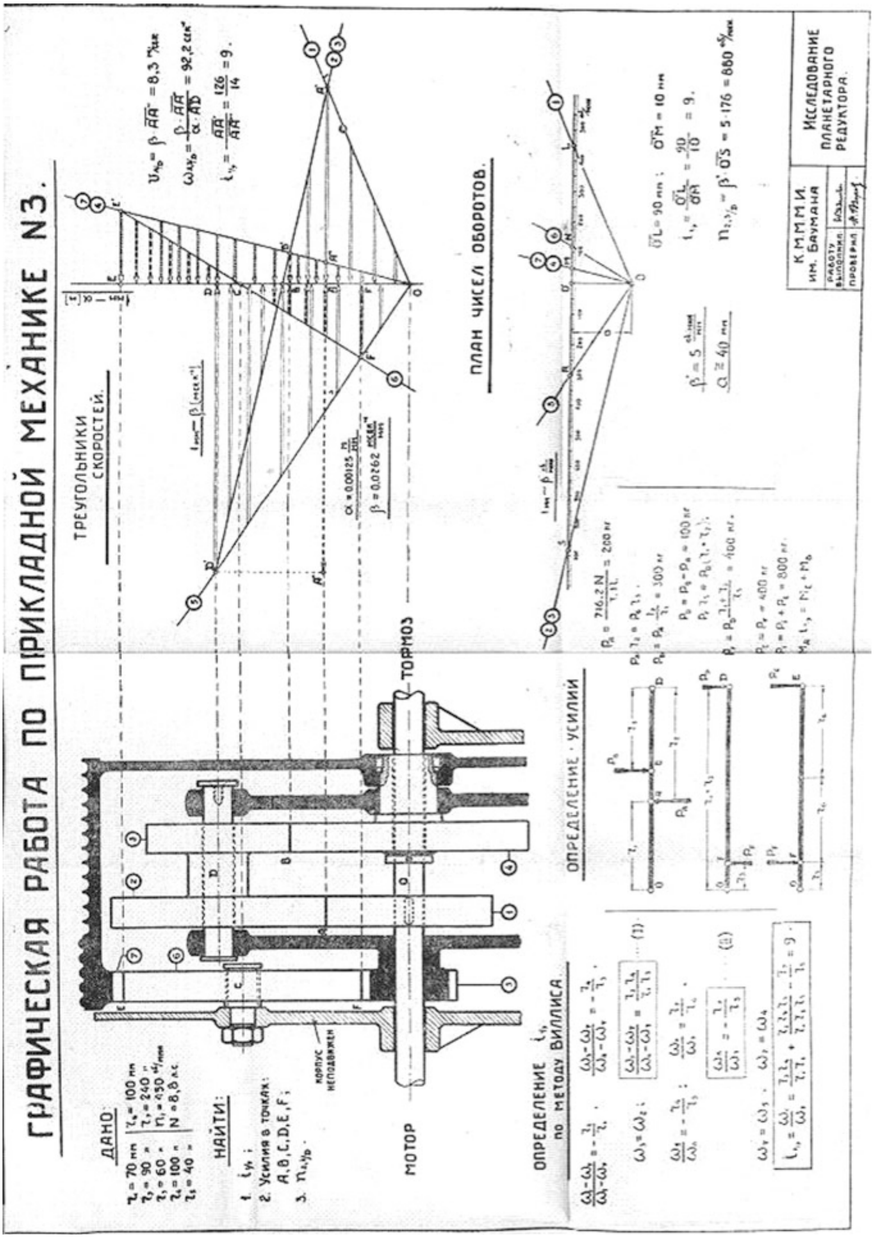


Fig. 12 Graphic work on “the study of a planetary gearbox”

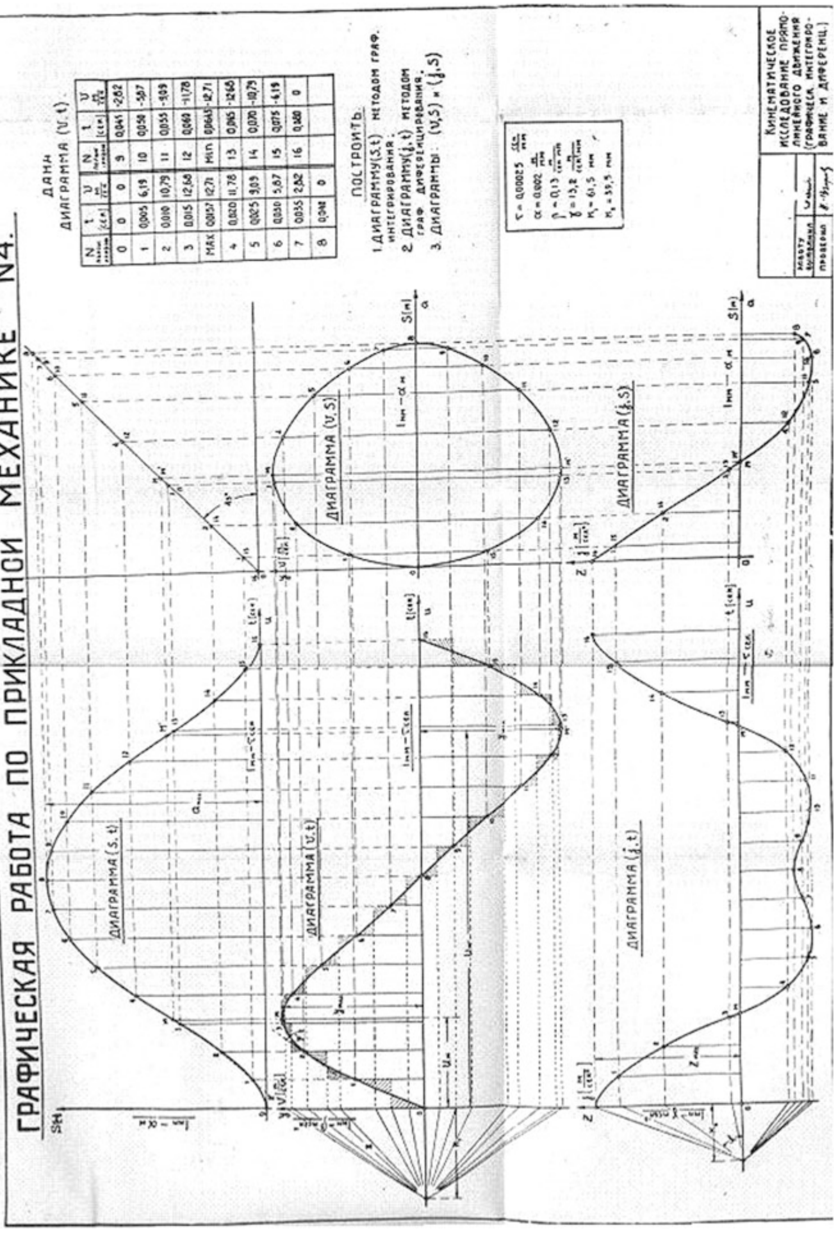


Fig. 13 Graphic work on “graphical integration and differentiation”

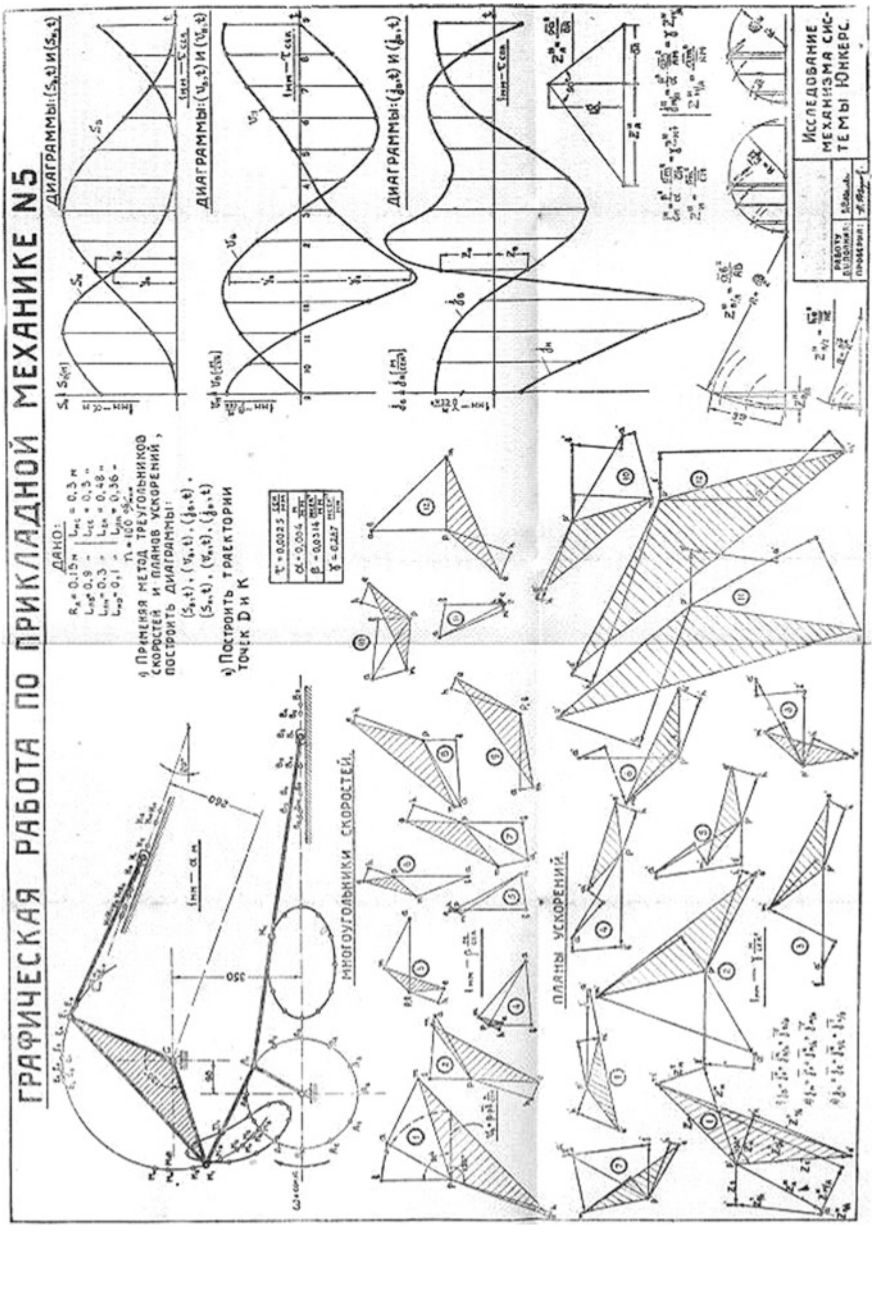


Fig. 14 Graphic work on “the kinematic study of the mechanism of the Junkers system”

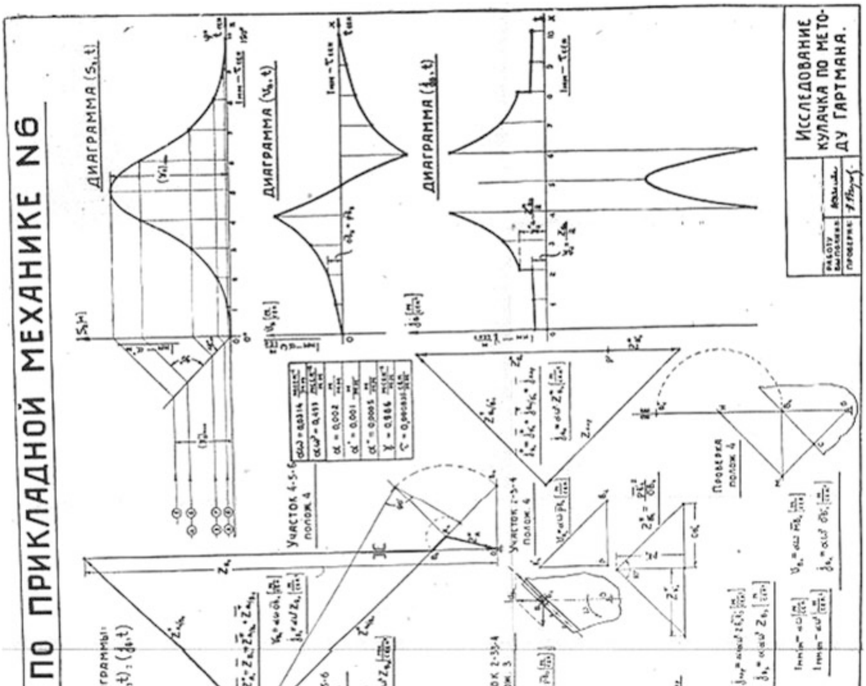


Fig. 15 Graphic work on "kinematic study by Hartman's method"

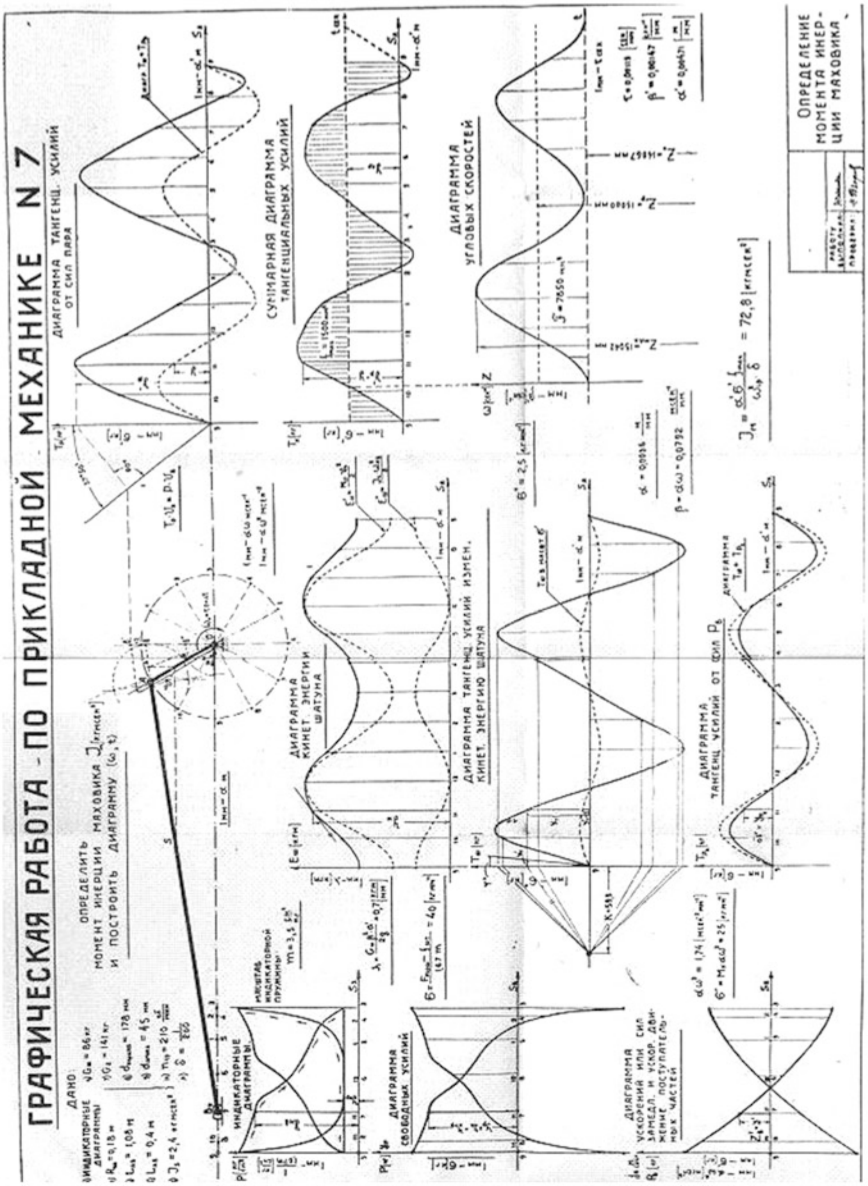


Fig. 16 Graphic work on "determination of the moment of inertia of the flywheel"

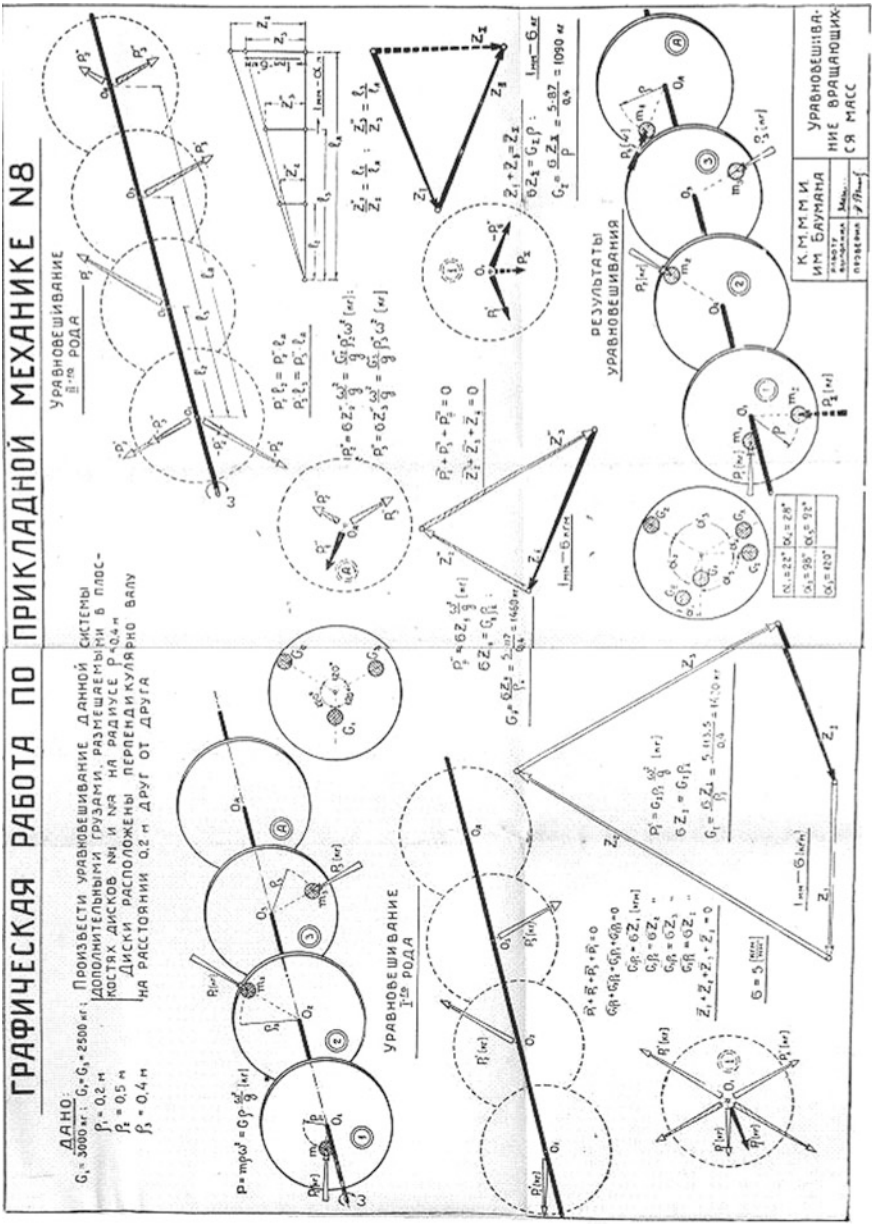


Fig. 17 Graphic work on the theme “balancing of rotating masses”

4.1.4 Theory of the Working Process in the Piston Steam Engine (Smirnov 1951)

This book has been accepted as a textbook for university engineering (engineering higher educational institutions).

The title page of the book is shown in Fig. 18.

The book consists of nine chapters, covering all aspects of the calculation and design of reciprocating steam engines, and is infused with the sum total experience of Professor L. Smirnov—the creator of the laboratory of steam engines at Bauman.

Chapter 1

This chapter considers workflow steam and methods for determining its parameters.

As an example, we are given the double expansion steam engine with one crank, installed in the laboratory of steam engines at Bauman (Fig. 19).

Chapter 2

This chapter explains the graphical methods for calculating the double expansion steam engine.

Questions of construction of a two-stage machine-D chart with one or two cranks are considered, as well as the association indicator diagrams of machine multistage expansion.

Chapter 3

This chapter addresses the problems associated with the efficiency steam engine.

A comparative assessment of existing machines and their efficiency is made, given the method of designing the machine so as to produce less vapor.

Chapter 4

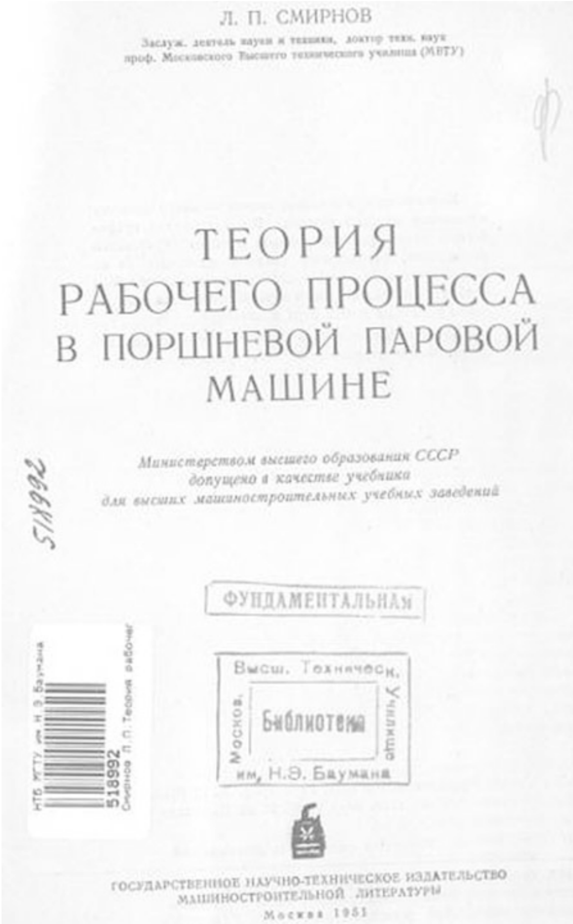
This chapter addresses the problems of designing vapor channels.

Chapters 5, 6

This chapter addresses the questions of spool charts, including spools with additional steam channels and rods of finite length. The disassembled design features a slide steam distribution system design.

Chapter 7

This chapter addresses the influence of the regulatory process on the basic parameters of spool steam distribution.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ТЕОРИЯ
РАБОЧЕГО ПРОЦЕССА
В ПОРШНЕВОЙ ПАРОВОЙ
МАШИНЕ

Министерством высшего образования СССР
допущено в качестве учебника
для высших машиностроительных учебных заведений

ГОСУДАРСТВЕННОЕ НАУЧНО-ТЕХНИЧЕСКОЕ ИЗДАТЕЛЬСТВО
МАШИНОСТРОИТЕЛЬНОЙ ЛИТЕРАТУРЫ
Москва 1951

Fig. 18 Title page of theory of the working process in the piston steam engine by L. Smirnov, published in 1951

Chapter 8

A study of the working process in the cylinder steam engine with a heat chart. An example of such a transformation is shown in Fig. 20.

Chapter 9

This chapter addresses the problems of the periodic motion of the heat flux in the wall of the steam cylinder.

The Development of Devices and Models

Out of a series of original devices developed by Professor Smirnov, one can distinguish the device for adding harmonic curves into a Fourier series—the "Harmonizer". There are approximate formulas for determining the coefficients of

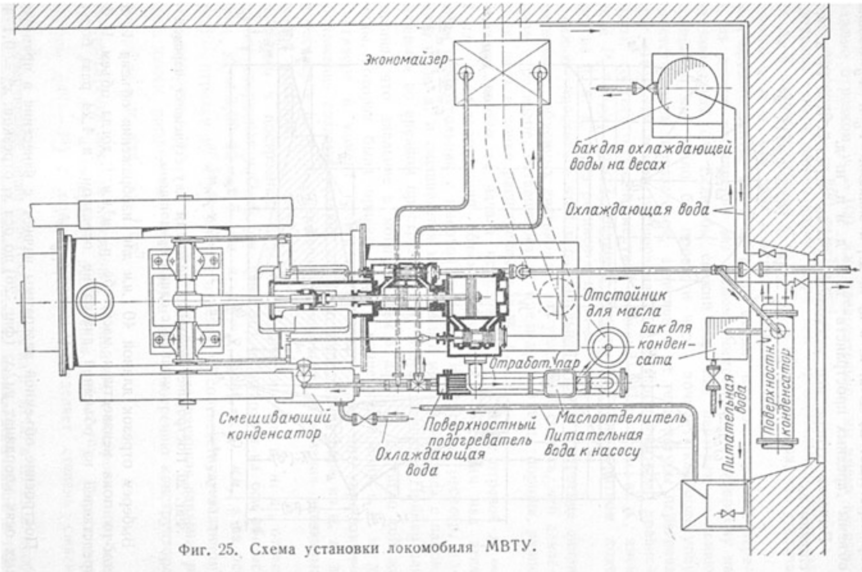

Fig. 19 Installation scheme of MHTS N. A. Bauman locomobile

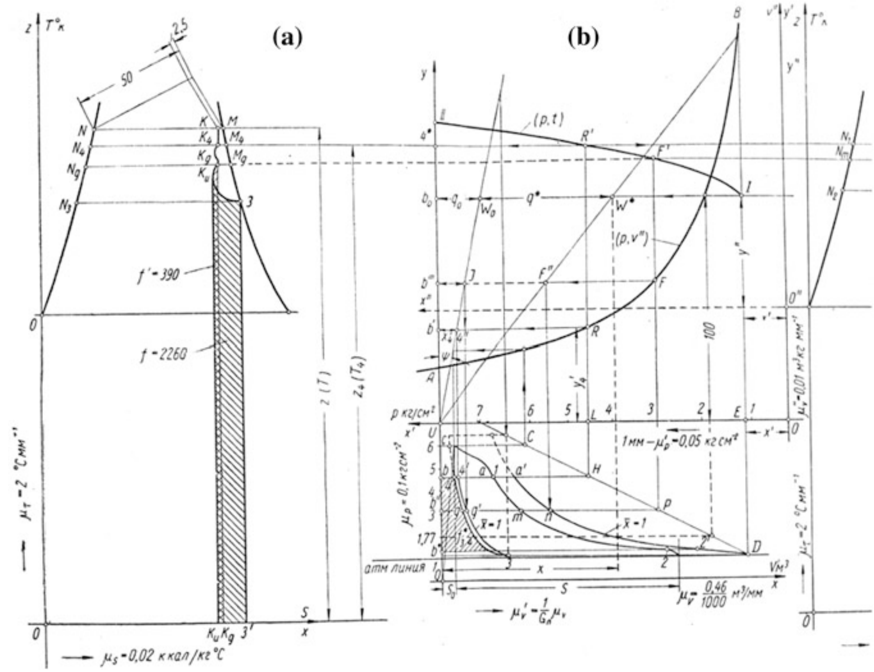

Fig. 20 Scheme of transferring the indicator diagram for a heat chart

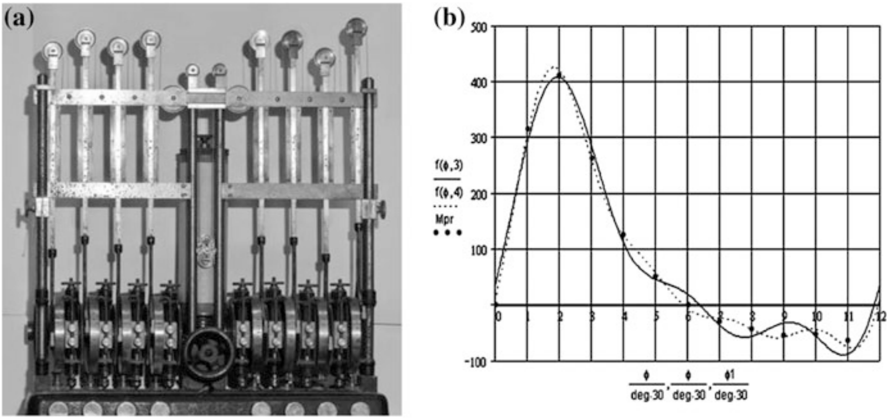

Fig. 21 Harmonizer of L. Smirnov, **a** general view, **b** approximation *curve*

the 6 pairs of sine and cosine functions of nature, formulas he worked upon with L. Smirnov, with sufficient accuracy to allow them to approximate 4–3 harmonics. A general view of the device is shown in Fig. 21a. Figure 21b shows the results of approximations for 3 and 4 harmonic standard features from the reduced moment of the compressor.

5 Scientific and Pedagogical School

Professor Smirnov's research interests were closely related to his teaching work and involved almost all subjects of TMM. This, as shown above, is reflected in the topics of reference lists and graphic-analytical work. The main areas of his school were:

- The teeth;
- Gears, including planetary;
- Balancing mechanisms;
- Development of the graphic-analytical methods of research;
- The evolution of mechanisms.

His disciples, who created their own scientific schools, were later known as esteemed scientists in their own right: L. Reshetov, B. Shitikov, G. Baranov, V. Gavrilenko, and G. Petrov.

5.1 School of Professor Leonid Reshetov

In 1932, engineer L. Reshetov of the exhibition committee-Union Exhibition gear-cutting case, suggested to the author, as the head of the department, that he consider the links and organize a correction of the existing systems. On the advice

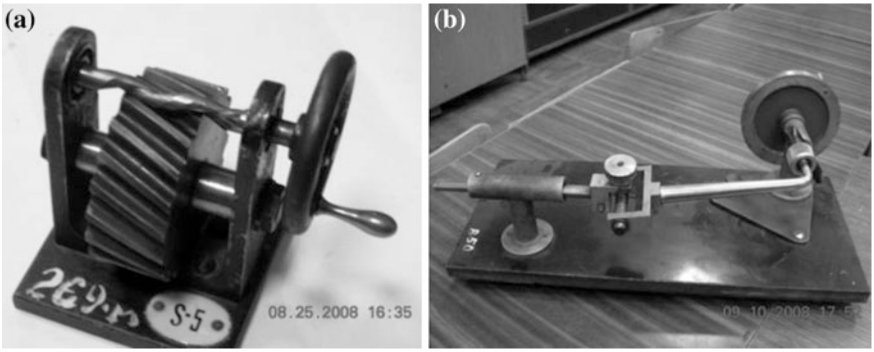

Fig. 22 Models of L. Reshetov: **a** single-tooth gear, **b** mechanisms without redundant links

of his professor, L. Smirnov, the author followed this path of independent research. The study was completed by the opening of the exhibition, and the theory presented in the spring of 1932 in the course of Applied Mechanics, delivered by him in MMMI on the specialty "Metal" (Reshetov 1935). Implementation of the link, due to the lack of equipment, did not occur until early 1934. This direction is decorated with a model of the single-tooth gear (Fig. 22a). The model exists in a single copy and is stored in the collection of the mechanisms Department TMM at Bauman University. This work apparently served as a source for Gavrilenko to create the geometric theory of involute gears.

The next study focused on the cam mechanism. A significant portion of the design issues of his research was occupied by mechanisms without redundant links. An example of such a mechanism is shown in Fig. 22b. He developed the original model of kinematic pairs, including paradoxical pairs with zero mobility.

L. Reshetov developed personally and in collaboration with his students a collection of more than 200 models of mechanisms: a model of kinematic pairs, Maltese mechanisms, gears, current collectors, etc. (Golovin and Tarabarin 2008). A considerable portion of them were of his own invention. Reshetov's share in the collection was about 30 %.

5.2 School of Professor Boris Shitikov

Engineer B. Shitikov was introduced to the work of balancing mechanisms by Prof. Smirnov.

After World War II, in which he participated and was awarded a number of medals for bravery, B. Shitikov was sent to the Agricultural Institute of Kazan. This appointment formed the basis for the development of an industrial plant for rotor balancing. Under his leadership, the original gearing (Fig. 23a) and a series of mechanisms based on Bennett's mechanisms (Fig. 23b, c) (Golovin and

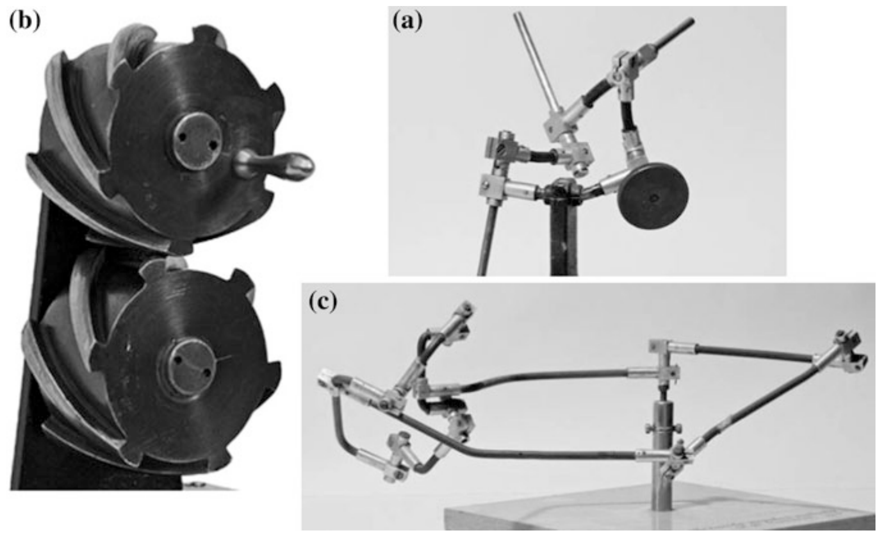

Fig. 23 Models, created by B. Shitikov and his scientific school: **a** gearing with external teeth and internal gearing, **b**, **c** mechanisms based on Bennett mechanism

Tarabarin 2008) were created. It should be emphasized that these studies have found a number of practical applications. For this, it was necessary to create a number of devices for the treatment of the structure.

5.3 School of Professor Vladimir Gavrilenko

In the late '30s, V. Gavrilenko continued working on the systematization methods for calculating gearing begun by L. Reshetov. The result was the creation of the geometric theory of involute gears. This paper was the basis for a number of studies. His student N. Skvortsova designed an internal gear transmission with the difference between the wheel and the gear being one tooth (Fig. 24a), the first of its kind in the world. Also, a systematic study of harmonic drive was begun for the first time in the country by his student Yuri Semin (Fig. 24b). Based on the development of these schools, laboratory gear and wave mechanisms and laboratory balances were established.

A school of balancing mechanisms and a corresponding laboratory were established at Bauman University as a result of the work of Professor Georgi Petrov and Associate Professor Alexandra Savelova.

A course in TMM, which included lectures, exercises, calculations, and graphical and laboratory work, had been created by the end of the '40s. We can assume that it was the perfect course, based on the graphic-analytical methods. With the advent of computer technology, the methods and techniques of this

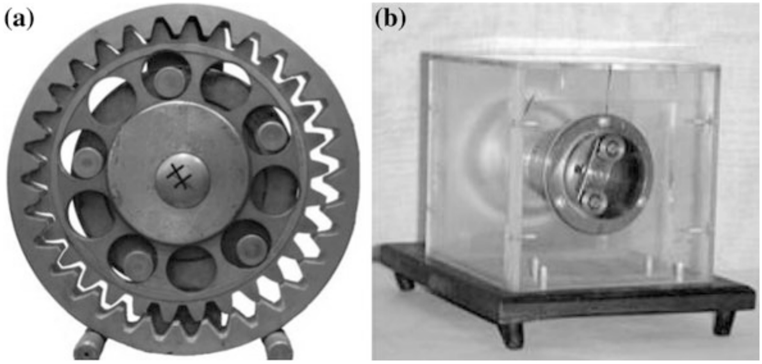

Fig. 24 Models, created by V. Gavrilenko and his scientific school: **a** gear transmission to the difference between the wheel and the gear in one tooth, **b** harmonic drive

course have become obsolete. Here, we may recall Poincare's observation that when science is perfected, it is often useless. However, for the time, the course was fully consistent with the contemporary requirements and allowed for the solution of practical engineering problems.

6 Modern Interpretation of Main Contributions

On the basis of Professor Smirnov's courses from 1950–1960, 5 issues of lectures (Lukichev and Savlova 1968; Skvortsova et al. 1956, 1959; Reshetov 1962) were prepared, including issue assignments for course design and a complex of laboratory work.

The basis of the course project formed "***Graphical Works in Applied Mechanics***…" (Smirnov 1940b). The course project consisted of the design assignment mechanisms of a car and included settlement and explanatory note 4 sheets A1 with schemes, formalism and the results of calculations covering at least 6 of the course topics (Bauman 1962).

Standard content of a course project.

List 1

Elementary linkage synthesis and synthesis of dynamic positioning system with $\boldsymbol{W} = 1$ (the definition of the moment of inertia of the flywheel and the law of motion-level reduction for steady motion). The calculations were based on the works of "kinematic study of the mechanism of the Junker engine" and "Determination of the moment of inertia of the flywheel". It should be noted that this list considered the 1st approximation of the solution of an autonomous system (Golovin et al. 2001).

Sheet 2

Certain reactions in the kinematic pairs with the inertial force units without friction. The calculations were based on the materials' data sheet 1.

Sheet 3

Design of machinery and gear engagement. Selection of the number of teeth of the planetary mechanism with $\boldsymbol{W} = 1$. The calculations were based on the construction and the works "Involute gearing of spur gears with straight teeth" and "Study of the planetary gear with cylindrical wheels".

Sheet 4

The construction of the cam profile for a given law of motion pusher and allowable pressure angle.

Calculation and construction based on the works of "kinematic study of linear motion (graphical integration and differentiation)" and "kinematic study cam".

A laboratory practice was initiated through the efforts of a student of Professor L. Smirnov, lecturer Alexandra Savelova. Savelova headed the Department from 1949 to 1951 after Smirnov's departure. The structure of the workshop included the following lab work.

Work number 1. Structural analysis of plane linkages. Materials used—refer to the schemes.

The unit works on the dynamics of the machine consisted of three papers using materials from books by Prof. A. Gromberg, "Testing machines and work in production, Vol. 1" and "Technical measurements when testing machines and controlling them in production Vol. 5" (translated from German, ed. L. Smirnov).

Work number 3. Construction of the mechanical characteristics of the fan.

Work number 4. Research into gearbox efficiency.

Work number 5. Deciphering the indicator diagram of reciprocating compressors.

Work number 6. "Rotor balancing".

Materials used (Smirnov 1940a, b), "Balancing of rotating masses".

The unit works on the gear wheels and gears consisted of two works based on the materials (Smirnov 1940a, b), "Gears" and "Involute gears of spur gears".

Work number 7. Gear cutting.

Work number 8. Decoding gear parameters.

There were 5 issues of the course lectures, published on the basis of a course of lectures by L. Smirnov (Lukichev and Savlova 1968; Skvortsova et al. 1956, 1959; Reshetov 1962), "Sheet for …" "Guidelines …" (Smirnov 1940b), lectures recorded by his students (Smirnov 1940b) in 1973 were converted into a textbook, edited by his disciple Gavrilenko (1973). As with the example set by L. Smirnov, great attention was paid to graphical methods and geometric transformations and scale. Much attention was paid to the section "Gears", set out on the basis of "Geometrical Theory of Involute Gearings" by Gavrilenko.

7 Conclusions

In the first half of the 20th century, the theory of mechanisms and machines as a scientific discipline reached the pinnacle of its development. At the same time, a new generation of students came along, so it was necessary to completely redesign the learning process towards providing training to a large number of specialist engineers in a country in dire need of people with such skills. Therefore, in the teaching of this discipline, the attention to the properties of the mechanisms was minimized. Therefore, simple and effective methods for calculation and design of mechanisms and machines, developed by Professor L. Smirnov, were modern, relevant, and state-of-the-art technology at the time.

TMM's contribution to the development of Smirnov's teaching methods has been somewhat overestimated—based on his ideas and works, many lectures were formed, laboratory classes created, and base course designs established.

The scientific and educational activity of Prof. L. Smirnov was the catalyst for the development of ideas that formed the basis of the establishment of five academic schools—G. Baranov's, L. Reshetov's, V. Gavrilenko's, B. Shitikov's and G.Petrov's.

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Kurt Rauh (1897–1952)

Burkhard Corves

Abstract Kurt Rauh was a scientist who with his practically oriented approach not only in mechanism theory but also in machine design, patent theory and agricultural engineering started a new research and teaching era of the above subjects at RWTH Aachen University.

1 Bibliographical Notes

1.1 Education and First Professional Experience in Saxony

Kurt Rauh was born in the town of Plauen, Saxony, Germany in 1897 as son of the Secondary School teacher Karl Rauh. So some teaching genes might have been involved in leading Kurt Rauh to finally become a university teacher (Fig. 1).

In the late 19th century the town of Plauen was a textile manufacturing center, specializing in lace manufacturing as well as curtains, white embroidery, garment products, muslin and gauze. Together with other manufacturing companies, Plauen was an industrial 'boomtown' in the western part of Saxony. Including textile manufacturing, Meyer's Encyclopedia (Meyer 1908) lists a large variety of different industrial activities such as cotton, wool and specialty spinning mills, dying mills, embroidery factories with more than 2,000 embroidery machines, doubling mills, tanneries, drive belt factories, machine factories, cement stone factories, breweries, a piano factory and a strong box factory. Possibly the last factory was needed in order to keep all the money generated by the different businesses in a

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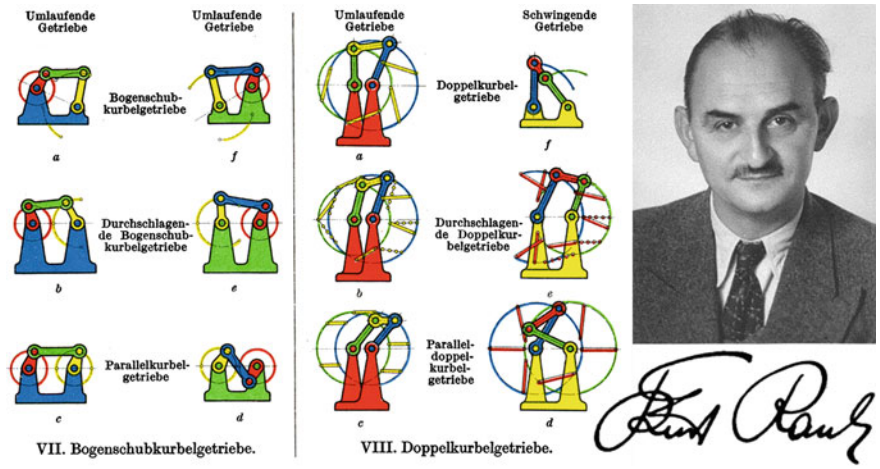


Fig. 1 Kurt Rauh (1897–1952)

safe place. The variety of the different industries is quite striking and possibly influenced Kurt Rauh in his later decision to become an engineer with particular emphasis on production machinery and processes.

During his pre-academic education, Kurt Rauh went to the "*Bürgerschule*", where also his father taught, and later on to the "*Realgymnasium*". The first was a typical Prussian Secondary School in urban areas that did not prepare its students for a classical university curriculum, but educated them for practical professions in the commercial and industrial area. The "*Realgymnasium*"—in contrast to a traditional humanistic "*Gymnasium*" based on classical philology with ancient Greek and Latin—focused on natural sciences and modern languages, but nevertheless prepared its pupils for university studies.

In May 1916 Kurt Rauh received his school diploma with the last school year due to WWI being reduced to less than two months. His high-school graduation certificate certified good performances and that he was "*entirely satisfactory in conduct*". In addition his diploma mentions "*He declares on his departure the intention of becoming a technician*". So obviously while still being at school, he had already decided to opt for an additional technical education.

His school diploma might have opened up the chance to directly start studies at the university, but due to WWI he had to join the army to fight for his country in Flanders and Russia for the next two years, which earned him medals for bravery and let him reach the rank of a Sergeant. After having attended preparatory courses in machine drawing at the vocational school in his hometown Plauen, he started his studies at the then "Technische Hochschule Dresden" (TH Dresden) now Technical University of Dresden in January 1919. As explained in detail by (Mauersberger 2005), TH Dresden was one of the leading institutions in the field of mechanism theory since the late 19th century. Therefore, it is probably no coincidence that Kurt Rauh in January 1919 enrolled as a student of mechanical engineering at TH

Dresden. It can well be assumed, that during his studies in Dresden, Kurt Rauh also got in contact with the mechanism collection described by Mauersberger (1997). Already in 1920 he had earned his "Vordiplom" (intermediate examination for a diploma) and just after a little bit more than another year he finished as "Diplom-Ingenieur" (graduate engineer) in November 1921. Immediately after finishing his diploma he started working as a design engineer for mechanical handling devices in the company "Mühlenbauanstalt und Maschinenfabrik vorm. Gebrüder Seck" (*mill manufacturer and machine company, formerly brothers Seck*) in Dresden-Zschachwitz. According to Starke (2005) the city of Dresden already at the end of the 19th century was among the leading locations of the food and beverage industry in Germany, and the company which Kurt Rauh joined as a design engineer was well esteemed and established. After having been converted to a shareholder company in 1886 its machinery became almost the standard in German breweries.

But in spring 1922 it seems he was already lured back into academia, starting a new job as scientific assistant at the "Institut für Maschinentechnologie" (institute for machine technology) of Prof. Rudolf Hundhausen again at TH Dresden. Hundhausen had studied Technical Mechanics and Mechanical Engineering in Berlin and Munich and worked between 1890 and 1892 as assistant lecturer for Kinematics and Machine Elements in Berlin. It can well be assumed that during this time he had contact with Franz Reuleaux, one of the leading kinematicians in Germany at that time (Braune and Corves 2012). Some proof of this assumption is the existence of a mechanism model identified by Kerle (2012) as a "false" Reuleaux model, which was designed in the Reuleaux model style by Hundhausen and as such documented by the then curator of the Reuleaux model exhibition in Berlin, Karl Hoecken (Fig. 2).

Hundhausen was director of the machine technology institute in Dresden since 1906 and a promoter of a large exhibition of then up-to-date machinery as described in Mauersberger (2007). Figure 3 shows the 1908 inauguration of the educational machine exhibition hall on the grounds of TH Dresden during the 49th General meeting of the VDI, the German Engineers Association.

But also Kurt Rauh's post graduate engagement at TH Dresden did not last long. Nevertheless it is interesting to take a glance at the testimonial written by Hundhausen who said of Kurt Rauh that "*already as a student he devoted himself with special preference and with great skill to the treatment of constrained motion and the utilization of scientific-kinematic knowledge to solve present practical problems of fabrication technology; already in his diploma thesis he solved a given task with exquisite success*".

In November 1922 he moved to Leipzig, Saxony again as a design engineer within the company "*Buch- und Kartonagenmaschinen O. Hoppe & Co*". This company, specializing in book and cardboard machines, is today part of ITW, a Fortune 200 global diversified industrial manufacturer of value-added consumables and specialty equipment with related services. In fact O. Hoppe & Co. in 1922 manufactured the first glued staple strips in accordance with a 1913 patent.

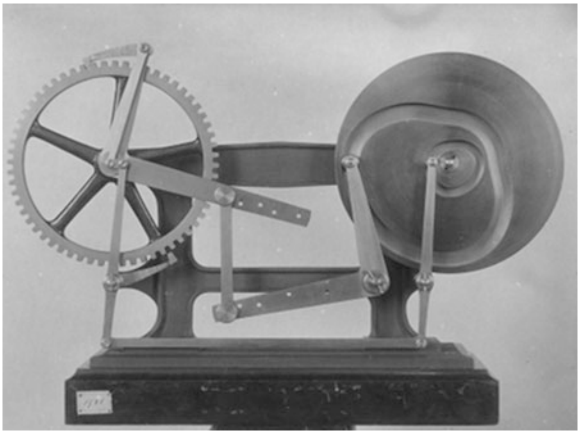


Fig. 2 Feeder mechanism designed by Hundhausen in the Reuleaux model style

Fig. 3 Inauguration of the educational machine exhibition hall on the grounds of TH Dresden during the 49th General meeting of the VDI, the German Engineers Association

1.2 From the River Elbe to the River Rhine

Again this engagement did not last long and on April 1st, 1923 Kurt Rauh moved to the west of the Weimar Republic to Bonn, where he started as the "*Leiter des Neuheiten- und Konstruktionsbüros und der Versuchsabteilung der Firma*

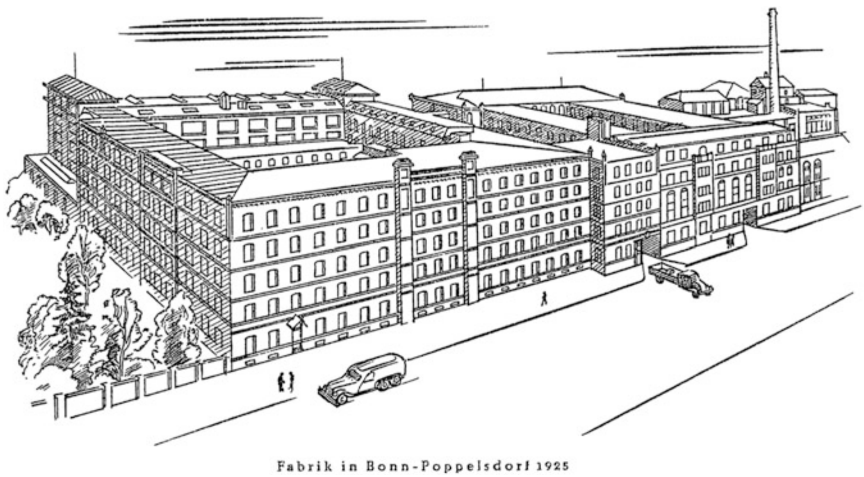


Fig. 4 F. Soennecken company in Bonn-Poppelsdorf in 1925 according to Ettighofer (1950)

F. Soennecken Bonn, dazu seit 1924 Leiter des Patentbüros und seit Sommer 1925 Assistent des Betriebsdirektors derselben Firma" (*head of innovation and design offices and experimental department of the company F. Soennecken, Bonn, and then, since 1924 director of the patent office, and since summer 1925 assistant of the operating director of the same company*). The German quotation is directly from his CV that accompanied his later dissertation (Rauh 1927a).

The company F. Soennecken, which was founded by Friedrich Soennecken 1875 in Remscheid later moved to Bonn, see Fig. 4, and became a large and well established Company dealing with all kind of office equipment from writing pens to punchers, copying machines and office furniture. It is interesting, that after having worked in different companies as a design engineer, in Bonn he directly started as the head of the innovation and design offices including the experimental department. Only a year later he also took over the responsibility of the patent office. Although the author could not find any direct evidence of a Soennecken patent that was explicitly connected to Kurt Rauh's name, Fig. 5 shows a British Soennecken patent of a puncher dated about the time Kurt Rauh was in charge of patent issues within the F. Soennecken Company.

It will be shown that dealing with patents for Kurt Rauh did not just mean writing and filing patent applications, but also thinking about the process of invention; in fact he was very much interested in a process that today is well known as the "innovation process".

Therefore patent issues kept Kurt Rauh interested even after he quit his job with F. Soennecken Company in 1926 in order to pursue a job as scientific assistant and later as scientific chief assistant at the "Landwirtschaftliche Hochschule Bonn-Poppelsdorf" (Higher Agricultural College in Bonn-Poppelsdorf), see Fig. 6. According to Hagemann (1924) the higher agricultural colleges had the task "*of scientific research in agriculture and to serve with their related*

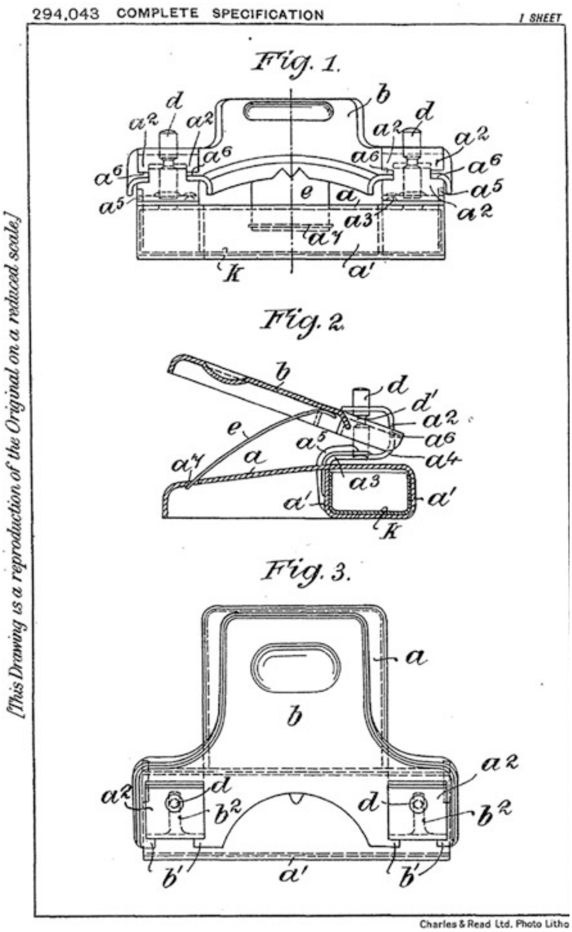


Fig. 5 Figures from GB 294,043: Improvements in or relating to punches for piercing paper and the like

primary and auxiliary sciences, to educate agricultural teachers and especially to train practical farmers to improve their general scientific technical knowledge as the basis for advantageous operations in agriculture". They should also give university students "*the opportunity to familiarize themselves with agricultural sciences and the relevant auxiliary sciences to the extent as it is desirable for their work in later working life*".

Within the Higher Agricultural College in Bonn-Poppelsdorf Kurt Rauh joined the "*Institut für Landmaschinenlehre und Physik*", the Institute of Agricultural Machinery and Physics directed by Karl Vormfelde, "*Professor der Ingenieur-wissenschaften*". According to Hagemann (1924), taking into account the growing importance of machine equipment for practical farming, "*the institute was equipped with all the tools to introduce students to the art of proper machinery for agriculture. There were constantly new machine designs tested which were on loan*

Fig. 6 Higher agricultural college in bonn-poppelsdorf (Hagemann 1924)

by the manufacturers for this purpose and which were also demonstrated to the students. Furthermore in its own workshop new appliances and the like could be produced". Obviously Rauh (1927b, 1934) demonstrate that statement.

At that time the Agricultural College in Bonn, which was founded in 1847 and only in 1934 became part of the Rheinische Friedrich-Wilhelms University in Bonn, did not have permission to promote candidates with the "Dr.-Ing"-title which is why Kurt Rauh submitted his dissertation (Rauh 1927a) to the former Technische Hochschule Hannover (TH Hannover), today Leibniz University Hannover where he received his Dr.-Ing.-title on July 12th, 1927. Comparing this date with the above mentioned dates of his professional career, it seems obvious that although he quit his first academic position at TH Dresden he never quit academia, at least in his mind. Otherwise it seems to have taken a very short time of just about one year to prepare his doctoral thesis (Corves 2012).

During Kurt Rauh's appointment at the Agricultural College in Bonn, which lasted until 1934, and after having finished his PhD thesis, he also worked on issues regarding agricultural machinery. In fact a list of his scientific publications dating from 1934 shows a lot of publications in journals dedicated to agricultural engineering: "Technik in der Landwirtschaft" (*Technology in Agriculture*), "Fortschritte der Landwirtschaft" (*Progress in Agriculture*), "Landmaschine" (*Agricultural Machine*), "DLG Mitteilungen" (*Releases of the German Agricultural Society*) "Deutscher Weinbau" (*German Winegrowers*) are the titles of journals where he placed his publications. These publications covered topics such as the examination of a 22-hp Gross-Bulldog Tractor from Heinrich Lanz Company, Mannheim, which is now part of the John Deere Company (Rauh 1927b).

Other topics were the current state of development of high-performance winnowers used for grain sorting in milling operations and surveys on machinery and equipment for viticulture (Rauh 1934) including specialties such as a deployable vineyard cable car.

Apart from these purely technical papers based on tests and examinations of all kind of different agricultural machinery, Kurt Rauh also obviously visited agricultural exhibitions and shows in Germany and abroad. The national exhibitions covered local shows such as the provincial traveling exhibition in Trier in 1927, the viticulture teaching exhibition in Koblenz in 1928, but also larger events such as the Exhibition of the German Agricultural Society in Hannover in 1931 and the Anniversary Agricultural Exhibition in Essen 1933.

Additionally he also visited international shows, such as the Royal Show in Newport, U.K. in 1927 and, very frequently, the Paris agricultural machinery exhibition in 1927, 1928, 1929, 1931, 1932 and 1933. In fact it appears that he established some ties to French colleagues already in those years, even though there is yet no direct evidence. Nevertheless the author of this paper found a notice in the personal files on Kurt Rauh, kept in the archives of RWTH Aachen University, indicating that in 1948, thus only very shortly after WWII, which found again the "archenemies" fighting against each other, Kurt Rauh was appointed technical correspondent of the French technical centre of agricultural machines ("*Centre Technique du Machinismes Agricole*").

But also publications in mechanism theory are listed especially about coupler curves and dwell mechanisms that can be derived from them (Rauh 1932, 1933a, b).

1.3 Kurt Rauh's First Contact with RWTH Aachen University

A letter written by the Institute Director of the Agricultural College in Bonn, Prof. Dr.-Ing. Karl Vormfelde, dated April 17th, 1928 to the Prussian Minister for Agriculture, Domains and Forestry in Berlin, marks the re-beginning of mechanism theory by a dedicated lecturer in persona Kurt Rauh at RWTH Aachen University. In fact as shown in (Braune and Corves 2012) mechanism theory was a known topic there right from the start in 1870 with some evidence that Franz Reuleaux, who was also frequently involved during the planning and development phase prior to the inauguration of what is now RWTH Aachen University, had some influence on the structure and curriculum of the new university. As a member of a commission advising on the above issues he also influenced the subjects to be taught (Gast 1921). Nevertheless as shown by Braune and Corves (2012) the interest in mechanism theory around the following turn of the century faded away to just become an appendix of the subject "Machine Elements". Therefore the above-mentioned letter marks a new application- oriented start of mechanism theory at RWTH Aachen University with the words:

> In order that agricultural engineering gets a firm footing also at RWTH Aachen University which is in the interest of German agriculture, I have caused my assistant, Dr.-Ing. Rauh to habilitate in Aachen with the topic "Kinematics and Agricultural Engineering". RWTH Aachen University will agree and I would therefore respectfully want to ask to approve to the habilitation of Dr.-Ing. Rauh in such a way that he will hold for 1 day each week during the winter term a 2 or 3 h lecture in Aachen. The work of the Agricultural Machinery Institute in Bonn-Poppelsdorf will not be negatively influenced by this habilitation. The scientific work and progress of Dr. Rauh will ensure an honourable success.

"*At the request of the Faculty of Mechanical Engineering*" the Prussian Minister for Science, Arts and Education gave "*a teaching assignment for mechanism theory to Kurt Rauh with effect from the start of the winter term 1929/1930*". So only shortly after finishing his dissertation and receiving the doctoral degree as Dr.-Ing., KURT RAUH had received the habilitation at RWTH Aachen University as well as the position in 1928 of a private lecturer while still keeping his position as Chief-Assistant at the Agricultural Machinery Institute in Bonn-Poppelsdorf until 1934. During this period of dual appointments, he worked on his first textbook on mechanism theory (Rauh 1931).

1.4 Development of Mechanism Science at RWTH Aachen University Under KURT RAUH

During his assignment with the F. Soennecken Company in Bonn, KURT RAUH also acted as director of the patent office. Actually the testimonial that he received from the owner of F. Soennecken Company stated:

> He handled and ran the pleadings and negotiations in patent cases required in dealings with the Patent Office and the Courts before these offices articulate and successfully. Mr. Rauh has a brilliant intelligence, a great general interest and is perfectly trustworthy.

Obviously his interest in patent issues remained alive even after he left the company in order to pursue his academic career. This can be proven by the fact that, besides his lectures and courses in mechanism theory, he also gave lectures regarding patent administration, which additionally were broadcast through the West German Radio (WDR) in 1932 with a printed version issued in 1935 (Rauh 1935a). The title of the broadcast sounded somewhat striking "*I register my own invention myself*" and was announced as being based on lectures on patent administration at RWTH Aachen University, "*grouped into five radio lectures*". Even after WWII he continued with lectures about patent administration (Rauh 1947) which were based on the former paper but broadened the scope so that the new paper contained an additional part B which carried the heading "*What does the engineer have to know about the patent process*?" This part gave explanations about patent issues such as infringement, preliminary injunction, infringement claims, patent expertise, patent trials and not to be forgotten: "*How to fix the fees for patent expertise*?"

Fig. 7 Exhibition hall of the 1929 mechanism show at Leipzig Technical Fair

From the historical perspective it is interesting to take a closer look at the second page of (Rauh 1935a) with references to other publications. These references appear under the heading "*Veröffentlichungen aus dem Institut für Getriebelehre der Technischen Hochschule Aachen*" (*Publications of the Institute for Mechanism Theory at RWTH Aachen University*). This means that already in 1935 there existed an Institute for Mechanism Theory. This assumption is confirmed by the fact that, according to the personnel records of RWTH Aachen University, KURT RAUH was appointed a full-time lecturer as of December 1st, 1934. Additionally in 1934 a memorandum on the "*Introduction of mechanism science at the technical teaching institutions as a compulsory subject*" was issued by the "Ausschuß für Wirtschaftliche Fertigung (AWF)" (*Committee on economic manufacturing*). This committee was established already during WWI on February 23rd, 1918 in order to help in the rationalization of operational production of all industries (DMG-Lib 2013). After WWI this institution was reorganized under the umbrella of the VDI, the Association of German Engineers. Its interest in mechanism science can also be seen from the fact that in 1928 and 1929 the AWF in collaboration with the VDMA (German Engineering Federation) organized a Mechanism Show alongside the Leipzig Technical Fair, Fig. 7.

The models shown during the exhibition have been described in brief in two volumes (AWF 1928, 1929). The foreword quite clearly describes the aim of these exhibitions:

> Despite the importance of mechanisms for the proper operation of machinery, equipment, etc. for any industry, the science of mechanisms and kinematics at our technical institutes

Fig. 8 Mechanism working sheets issued by the Committee on Economic Manufacturing (AWF 1928)

> faded into the background. The undersigned committee has therefore launched a special working group for mechanism presentations, which has the task to give mechanism teaching again its standing in the teaching curriculum as reflected by its importance in practical engineering, but especially also to provide practically useful documents for direct and immediate use in technical enterprises and plants.

Among the "*practically useful documents*", specific mechanism working sheets were presented, Fig. 8, that can be seen as forerunners of the mechanism descriptions presented in Corves et al. (2006).

The above mentioned memorandum from 1934 is a direct result of trying to better promote mechanism science as a major teaching subject at German technical universities. It starts with the words "*To have some knowledge of mechanism theory for the designer and production engineer is imperative, since mechanisms are present in all kind of machines, be it packaging machines, textile machines,* *glass processing machines, construction machines, forming machines, power machines, bakery machines, machine tools* etc".

According to the memorandum, the basics of mechanism science should be taught in compulsory courses, with the aim of providing the future engineer with the ability to design and calculate with complicated machinery. This memorandum was taken as the basis of a decree of the Prussian Minister for Science, Arts and Education requesting the introduction of a compulsory course in mechanism science for every mechanical engineering student. As a reaction of RWTH Aachen University, Kurt Rauh's two hours per week lecture "*Basics of Mechanism Science*" was declared a compulsory course for all Mechanical Engineering students in their fourth semester. An additional lecture "*Higher Mechanism Science*" was introduced as an elective course for students who had already finished their pre-Diploma after their second year. Thus between 1934 and 1939, Kurt Rauh had a full-time position as adjunct professor at RWTH Aachen University but without tenure. Only in summer 1939 was he appointed adjunct professor with tenure while maintaining the teaching license for mechanism theory.

Shortly before receiving the above-mentioned tenure, Kurt Rauh in February 1939 had issued a "*Report on scientific activities*" describing the focus of the scientific activities at his institute. His idea of mechanism theory is not that it was simply a special part of mathematics and mechanics but, in his own words "*mechanism teaching in Aachen is the centerpiece of creative and constructive conception and education of mechanism design engineers"*. In his report he also mentions a series on practical mechanism science, which was edited by him and printed by VDI-Verlag. The first issue of this series is dedicated to guidance mechanisms (Rauh 1935b), the second to Cardan and coupler motion (Rauh 1938) According to Kurt Rauh the latter greatly improved coupler curve theory, allowing the designer to switch from tedious trial-and error methods to well-aimed design. He also cites another colleague: "*lt is certain that this work of Prof. Rauh and his collaborators will give a strong impulse to the development of improved mechanisms*".

Very shortly he also mentions that between 1935 and 1937 he had worked for the "Reichs-Luftfahrt-Ministerium" (*Imperial German Ministry of Aviation*). He does not go into any details, but the report also mentions that, in the winter terms 37/38 and 38/39, additional courses in higher mechanism science have been taught especially for aviators.

Due to the start of WWII in September 1939, he was ordered to the "Heereswaffenamt" (*Army Weapons Office*) as Sergeant, the same rank as after WWI. In 1940 he was appointed Air-force Staff Engineer "*for the duration of the war*". This appointment ended when he became incarcerated in a POW camp of the Allied Forces, from which he was not released until August 1945.

1.5 Kurt Rauh's Post War Activities

Even though the official personnel record of RWTH Aachen University lists January 1st, 1946 as Kurt Rauh's first day back in office, there exists a hand-written letter from him dated November 8th, 1945 with the title of "Chair of Mechanism Theory", in which he requested an increase in the scope of the program to include to agricultural machinery. This request was postponed by the Faculty of Mechanical Engineering with the argument that as yet not all members of the faculty had been fully approved and thus the faculty board did not want to take any such decision. Already in February 1946 Kurt Rauh was again suspended from office, because he had to run through the "denazification-process" of the British Military Government in Germany. With the corresponding "Einreihungsbescheid" (notice of classification) within the British control area, he could not be fully active again at RWTH Aachen University until November 1st, 1946.

In the 1949 yearbook of RWTH Aachen University a short report of Kurt Rauh (Rauh 1949a) can be found concerning the "Dozentur für Getriebelehre, Maschinenaufbaulehre und Patentlehre" (*Lectureship in mechanism science, machine design theory and patent science*). Obviously the scope of Kurt Rauh's lectureship now also included patent science and machine design theory. The latter subject is explained in the same report as the theory of machine design and construction "*ohne notwendiges Vorbild*" meaning without necessary model, i.e. machine design from scratch. Furthermore he reports that, even though the rooms and teaching material were completely destroyed during the war, already new research activities had started as could be seen from two new dissertations and six published papers. Furthermore he stated that in the few years following WWII the number of students who had been educated in his subjects was larger than in the 12 years prior to WWII, which shows increased teaching activities not only in mechanism science but also in machine design and patent science. Additionally Kurt Rauh reports about activities to incorporate agricultural engineering within his scope, probably with the idea to build upon his expertise in this field. In fact as a push or result of his efforts to establish agricultural engineering in 1949 he publishes a book "*Entwicklungslinien im Landmaschinenbau*" (*Design lines in agricultural engineering*) (Rauh 1949b).

In 1951 Kurt Rauh embarks on a research and study journey organized through the ERP (European Recovery Program) for a roundtrip through the United States (Corves 2012). The ERP, better known under the name of the "Marshall-Plan" after the then U.S. Secretary of State George C. Marshall who proposed this plan, was aimed at helping the countries of Europe that had been destroyed by the war (Britannica 2013): The U.S.-sponsored program was designed to rehabilitate the economies of 17 western and southern European countries in order to create stable conditions in which democratic institutions could survive. Kurt Rauh kept a four volume diary about his journey (Rauh 1951). In the 1952 Annals of RWTH Aachen University an additional report of Kurt Rauh on his ERP roundtrip, issued posthumously, can be found (Rauh 1952). There he does not simply give a description of his research and study trip but also the reasons for the necessity of this trip and the positive results for himself and for his thinking about other countries and mentalities. Among others he mentions "*I frankly confess that I have also experienced qualities of the American people who have given me so much that I now even try to live by it, so I re-educate myself accordingly*". Obviously he has also had a glimpse at the "American Dream" by stating "*Quite right one infers in America that an able professional man with his success may also be of benefit to many other people, so possibly also to me, and that after all, even for myself a chance of happiness may smile*".

Sadly enough, this "*chance of happiness"* did not smile for long, because less than a year after returning from his study trip to the U.S., Kurt Rauh died from a serious illness. His last appearance at a scientific conference was probably the VDI conference on mechanism science in Berlin in October 1951 (VDI 1953). As formulated in the preface to the proceedings of this conference, issued later in 1953 as the first VDI Proceedings Volume, this was the first German conference on mechanism science after WWII. Hermann Alt as then chairman of the committee of mechanism science within the VDI also notes that choosing Berlin, and especially the facilities of the Technical University in Berlin-Charlottenburg, for the conference should also be seen as an appreciation of Franz Reuleaux as "*the founder of mechanism science*" who taught at the then "Königliche Gewerbeinstitut" (Royal Industrial Institute) between 1864 and 1896 (Braune and Corves 2012).

In his obituary in honor of Kurt Rauh, the Rector of RWTH Aachen University said, "*His great achievement was the development of teaching in mechanism science, which was performed by him in his own way. In several important works, especially in the two-volume textbook on mechanism theory, he has documented his research. The deceased was a man of high ideals and aspirations. To all his staff, he was not only an inspiring teacher, but also a companionable consultant*".

2 List of Main Works

Rauh, K. (1927a): Untersuchung und Weiterentwicklung der Getriebe mit periodischem Hin- und Rücklauf und beschleunigungsfreiem Arbeitsgang (*Investigation and development of periodic mechanisms with forward and reverse motion including partly acceleration-free operation*). Diss. TH Hannover, Bonn: Rhenania-Verlag G.m.b.H., 1927.

Rauh, K. (1927b): Prüfung eines 22 P^s Gross-Bulldog der Firma Heinrich Lanz, Mannheim (*Testing of a 22hp Gross-Bulldog of Heinrich Lanz Company, Mannheim*) Technik i.d.Landw. 27 (1927), 3)

Rauh, K. (1931): Praktische Getriebelehre. Erster Band (*Practical Mechanism Science. First Volume*). Berlin: Verlag von Julius Springer, 1931.

Rauh, K (1932): Die Ableitung einer Hubbewegung mit drei Stillständen von Koppelkurven (*The derivation of an oscillating motion with triple dwell based on coupler curves*), VDI-Z, 76 (1932), 4, pp 87–90.

Rauh, K., W. Knyrim (1933a): Die Größe und Genauigkeit der von Koppelkurven ableitbaren Stillstände (*The size and accuracy of dwells derived from coupler curves*), VDI-Z, 77 (1933), 8, pp 478–480.

Rauh, K., O. Edler (1933b): Verstellbare Koppelkurventriebe für Hubbewegungen mit einem Stillstand (*Adjustable coupler curve mechanisms for reciprocating motion with a dwell*), VDI-Z, 77 (1933), 18, pp 196–198.

Rauh, K (1934): Arbeitserleichterung durch Technik im Weinbau (*Assistance through technology in viticulture*), VDI-Z, 78 (1934), 4, pp 791.

Rauh, K. (1935a): Ich melde meine Erfindung selbst an: Vorlesungen über Patentlehre an der Technischen Hochschule Aachen zusammengefasst zu fünf Rundfunkvorträgen (1932 übertragen vom Westdeutschen Rundfunk) (*I register my own invention myself: Lectures on patent administration at the Technical University of Aachen grouped into five radio talks (1932 broadcast of the West German Radio)*). Erweiterte Ausgabe als Handschrift gedr., Köln: Borowsky, 1935.

Rauh, K. (1935b): Führungsgetriebe (*Guidance mechanisms*), Schriftenreihe Praktische Getriebetechnik, Heft 1, Berlin: VDI-Verlag, 1935.

Rauh, K., Marks, H., Bündgens, M., Otto, K. (1938): Kardanbewegung und Koppelbewegung (*Cardan motion and coupler motion*), Schriftenreihe Praktische Getriebetechnik, Heft 2, Berlin: VDI-Verlag, 1938.

Rauh, K. (1939): Praktische Getriebelehre. Zweiter Band. (*Practical Mechanism Science. Second Volume*) Berlin: Verlag von Julius Springer, 1939.

Rauh, K. (1947): Vorlesungen über Patentlehre an der Technischen Hochschule Aachen. (*Lectures on patent administration at the Technical University of Aachen*), 3., erw. Aufl., als Hs. gedr., Bonn: Soennecken, 1947.

Rauh, K. (1949a): Dozentur für Getriebelehre, Maschinenaufbaulehre und Patentlehre (*Lectureship in mechanism science, machine design theory and patent science*). In: Jahrbuch der Rheinisch-Westfälischen Technischen Hochschule Aachen, 2.1949, pp. 176–177, Buchverlag W. Girardet Essen.

Rauh, K. (1949b): Entwicklungslinien im Landmaschinenbau (*Design lines in agricultural engineering*). Essen: Girardet, 1949.

Rauh, K: (1950a): Bearbeitungsmaschinen—angewandte Getriebelehre (*Production machines—applied mechanism science*). VDI-Z, 92 (1950), 33, pp 917–922.

Rauh, K. (1950b): Aufbaulehre der Verarbeitungsmaschinen, Textband und Bildband. (*Design Theory of Processing Machines, Text and Picture Volume*), Essen: Verlag W. Girardet, 1950.

Rauh, K. (1951): ERP-Studienreise nach den Vereinigten Staaten (ERP study trip to the United States), http://www.dmg-lib.org/dmglib/main/portal.jsp?mainNaviState=browsen.docum.meta&id=4869009, Last visited July 2013.

Rauh, K. (1952): Eine Studienreise nach den Vereinigten Staaten von Amerika vom 12. April bis zum 12. Juni 1951 (*A study tour to the United States of America on 12 April to 12 June 1951.*). In: Jahrbuch der Rheinisch-Westfälischen Technischen Hochschule Aachen, 1952, pp. 147–154, Essen: Buchverlag W. Girardet, 1952.

Rauh, K. (1953a): Die Getriebeharmonischen der Schubkurbelgetriebe (*The harmonics of the slider crank mechanism*), in: Getriebetechnik: VDI-Tagung in Berlin, Oktober 1951 (*Mechanism Science: VDI-Conference in Berlin, October 1951*), VDI-Tagungsheft 1, Düsseldorf: Dt. Ingenieur-Verl., 1953.
Rauh, K. (1953b): Ermittlung von Koppelkurven für beliebige Bewegungsgesetze mittels getriebeharmonischer Synthese (*Determination of coupler curves for arbitrary motion laws using harmonious synthesis*), in: Getriebetechnik: VDI-Tagung in Berlin, Oktober 1951 (*Mechanism Science: VDI-Conference in Berlin, October 1951*), VDI-Tagungsheft 1, Düsseldorf: Dt. Ingenieur-Verl., 1953.

3 Review of Main Works on Mechanism Design and Modern Interpretation and Relevance of Kurt Rauh's Contributions

The main work of Kurt Rauh can possibly be seen in his textbooks, which stress his didactic approach towards teaching engineering subjects. Therefore the review of his main works will be concentrated on three of his textbooks, one dedicated to mechanism science, the second to agricultural machinery and the last to production machines. Thus these textbooks also reflect his stages at different scientific institutions, with the textbooks on mechanism science and production machines as the basis of his activity in Aachen and the textbook on agricultural machinery as the late outcome of his activities in Bonn. The discussion of these three books will be preceded by an initial discussion about his dissertation thesis.

3.1 Kurt Rauh's Dissertation Thesis (Rauh 1927a)

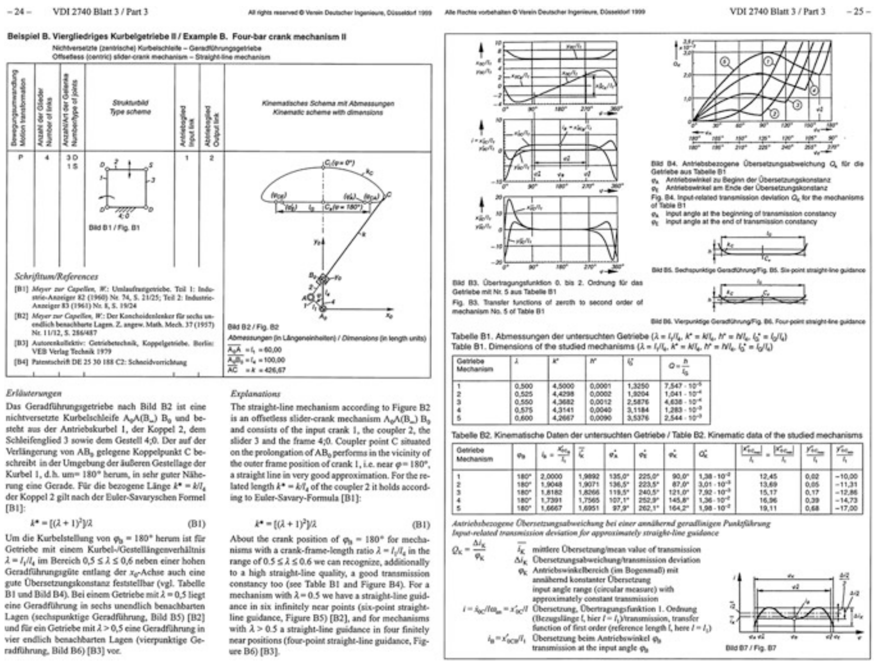
The title of his dissertation thesis in English translation was *"Investigation and development of periodic mechanisms with forward and reverse motion including partly acceleration-free operation"*. Kurt Rauh's "Doktorvater" or PhD-Supervisor was Prof. Arthur Pröll, professor for mechanics and aircraft technology already since 1913 at TH Hannover (Munziger 2013). As an Austrian, Arthur Pröll was a reserve officer in the Austro-Hungarian army during WWI until 1916 and later became head of the research group of the imperial armory fliers in Aspern near Vienna before returning to TH Hannover after WWI. Obviously the theme of Kurt Rauh's dissertation thesis was not an aircraft technology topic, but more related to the topic of mechanics.

In the introduction to his dissertation Kurt Rauh notes the key points of his dissertation: "*In mechanical engineering there is often the need for a mechanism, that realizes a periodic forward and return stroke with temporarily uniform* *velocity. For example such a mechanism can be used advantageously in automatic production machines of modern construction, in which work pieces are moving with uniform velocity through the machine. For certain operations such as punching, pressing, cutting* etc. *it is necessary that the required tools temporarily are moving with the same velocity when the operation takes place, as the work piece itself. Then the operation takes place at the time, during which there is no relative motion between tool and work piece in the direction of movement of the work piece. In that case, highest precision must be placed on the synchronicity of the corresponding mechanism, and even more so with increasing duration of the synchronicity between tool and work piece*". In fact, with these words he describes a task still valid today in many applications even if increasingly servo-controlled drive systems are used for this purpose.

Interestingly, throughout the history of mechanism theory in Aachen in the second half of the last century, mechanisms with temporarily uniform velocity have been a special topic. At least five research reports which originated under the auspices of Walter Meyer zur Capellen, the successor of Kurt Rauh as head of mechanism theory in Aachen, can be mentioned here among other publications (Meyer zur Capellen 1958; Meyer zur Capellen and Lehn 1966; Meyer zur Capellen and Schreiber 1967, 1970; Meyer zur Capellen and Willkommen 1970). Also the successor of Meyer zur Capellen, Günter Dittrich, who lead the Institute of Mechanism Theory and Machine Dynamics at RWTH Aachen University during the last three decades of the past millennium (Corves 2009), kept the topic alive as can be seen from the dissertations of Shi (1982) and Leusch (1995), which he initiated as their PhD-supervisor.

And even the author of this paper himself as chairman of a VDI guidelines committee, supported by Gottlieb Leusch, dealt with the same topic leading to the VDI guideline 2740, Part 3 "Mechanical devices for automation equipment—Mechanisms for partially synchronised motion". Based on the PhD-thesis of Leusch (1995) this guideline is meant to support the mechanical engineer in selecting appropriate solutions for a given task by defining specific properties for the comparison and evaluation of suitable solutions, which can be selected from a collection of different solutions, see Fig. 9. Similar to the mechanism descriptions presented in (Corves et al. 2006) the description of each solution contains a type scheme and a kinematic scheme which contain all symbols such as link numbers, denomination of joints and definitions of dimensions and angles. Further information such as the kinematic dimensions of the mechanism is presented. The functionality of the mechanism is described in a short text, which enables the user to create variants of the described mechanism. Additional information such as relevant transfer functions up to second order or quality coefficients related to the synchronous motion part are presented. Further reference is made to relevant papers especially regarding kinematic variants and additional calculation procedures.

Since the clarity of principles and solutions in mechanism theory shown through pictures and models is of utmost importance, it is certainly worthwhile to look at the detailed and very informative illustrations of the doctoral thesis of Kurt Rauh, which are all collected at the end of his thesis (Fig. 10).


– 24 – VDI 2740 Blatt 3 / Part 3 All rights reserved © Verein Deutscher Ingenieure, Düsseldorf 1999

Beispiel B. Viergliedriges Kurbelgetriebe II / Example B. Four-bar crank mechanism II

Nichtversetzte (zentrische) Kurbelschleife – Geradführungsgetriebe

Offsetless (centric) slider-crank mechanism – Straight-line mechanism

Bewegungsumwandlung Motion transformation	Anzahl der Glieder Number of links	Anzahl/Art der Gelenke Number/type of joints	Strukturbild Type scheme	Antriebsglied Input link	Abtriebsglied Output link	Kinematisches Schema mit Abmessungen Kinematic scheme with dimensions
P	4	3 D 1 S	Bild B1 / Fig. B1	1	2	Bild B2 / Fig. B2

Abmessungen (in Längeneinheiten) / Dimensions (in length units)

$\overline{A_0A} = l_1 = 60{,}00$

$\overline{A_0B_0} = l_4 = 100{,}00$

$\overline{AC} = k = 426{,}67$

Schrifttum/References

[B1] *Meyer zur Capellen, W.*: Umlaufrastgetriebe. Teil 1: Industrie-Anzeiger 82 (1960) Nr. 74, S. 21/25; Teil 2: Industrie-Anzeiger 83 (1961) Nr. 8, S. 19/24

[B2] *Meyer zur Capellen, W.*: Der Konchoidenlenker für sechs unendlich benachbarte Lagen. Z. angew. Math. Mech. 37 (1957) Nr. 11/12, S. 286/487

[B3] Autorenkollektiv: Getriebetechnik, Koppelgetriebe. Berlin: VEB Verlag Technik 1979

[B4] Patentschrift DE 25 30 188 C2: Schneidvorrichtung

Erläuterungen

Das Geradführungsgetriebe nach Bild B2 ist eine nichtversetzte Kurbelschleife $A_0A(B_\infty)\,B_0$ und besteht aus der Antriebskurbel 1, der Koppel 2, dem Schleifenglied 3 sowie dem Gestell 4;0. Der auf der Verlängerung von AB_0 gelegene Koppelpunkt C beschreibt in der Umgebung der äußeren Gestellage der Kurbel 1, d.h. um= 180° herum, in sehr guter Näherung eine Gerade. Für die bezogene Länge $k^* = k/l_4$ der Koppel 2 gilt nach der Euler-Savaryschen Formel [B1]:

$$k^* = [(\lambda + 1)^2]/\lambda \qquad \text{(B1)}$$

Um die Kurbelstellung von $\varphi_B = 180°$ herum ist für Getriebe mit einem Kurbel-/Gestellängenverhältnis $\lambda = l_1/l_4$ im Bereich $0{,}5 \le \lambda \le 0{,}6$ neben einer hohen Geradführungsgüte entlang der x_0-Achse auch eine gute Übersetzungskonstanz feststellbar (vgl. Tabelle B1 und Bild B4). Bei einem Getriebe mit $\lambda = 0{,}5$ liegt eine Geradführung in sechs unendlich benachbarten Lagen (sechspunktige Geradführung, Bild B5) [B2] und für ein Getriebe mit $\lambda > 0{,}5$ eine Geradführung in vier endlich benachbarten Lagen (vierpunktige Geradführung, Bild B6) [B3] vor.

Explanations

The straight-line mechanism according to Figure B2 is an offsetless slider-crank mechanism $A_0A(B_\infty)\,B_0$ and consists of the input crank 1, the coupler 2, the slider 3 and the frame 4;0. Coupler point C situated on the prolongation of AB_0 performs in the vicinity of the outer frame position of crank 1, i.e. near $\varphi = 180°$, a straight line in very good approximation. For the related length $k^* = k/l_4$ of the coupler 2 it holds according to Euler-Savary-Formula [B1]:

$$k^* = [(\lambda + 1)^2]/\lambda \qquad \text{(B1)}$$

About the crank position of $\varphi_B = 180°$ for mechanisms with a crank-frame-length ratio $\lambda = l_1/l_4$ in the range of $0.5 \le \lambda \le 0.6$ we can recognize, additionally to a high straight-line quality, a good transmission constancy too (see Table B1 and Figure B4). For a mechanism with $\lambda = 0.5$ we have a straight-line guidance in six infinitely near points (six-point straight-line guidance, Figure B5) [B2], and for mechanisms with $\lambda > 0.5$ a straight-line guidance in four finitely near positions (four-point straight-line guidance, Figure B6) [B3].

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Bild B3. Übertragungsfunktion 0. bis 2. Ordnung für das Getriebe mit Nr. 5 aus Tabelle B1

Fig. B3. Transfer functions of zeroth to second order of mechanism No. 5 of Table B1

Bild B4. Antriebsbezogene Übersetzungsabweichung Q_K für die Getriebe aus Tabelle B1

φ_A Antriebswinkel zu Beginn der Übersetzungskonstanz

φ_E Antriebswinkel am Ende der Übersetzungskonstanz

Fig. B4. Input-related transmission deviation Q_K for the mechanisms of Table B1

φ_A input angle at the beginning of transmission constancy

φ_E input angle at the end of transmission constancy

Bild B5. Sechspunktige Geradführung/Fig. B5. Six-point straight-line guidance

Bild B6. Vierpunktige Geradführung/Fig. B6. Four-point straight-line guidance

Tabelle B1. Abmessungen der untersuchten Getriebe ($\lambda = l_1/l_4$, $k^* = k/l_4$, $h^* = h/l_4$, $l_G^* = l_G/l_4$)

Table B1. Dimensions of the studied mechanisms ($\lambda = l_1/l_4$, $k^* = k/l_4$, $h^* = h/l_4$, $l_G^* = l_G/l_4$)

Getriebe Mechanism	λ	k^*	h^*	l_G^*	$Q = \frac{h}{l_G}$
1	0,500	4,5000	0,0001	1,3250	$7{,}547 \cdot 10^{-5}$
2	0,525	4,4298	0,0002	1,9204	$1{,}041 \cdot 10^{-4}$
3	0,550	4,3682	0,0012	2,5876	$4{,}638 \cdot 10^{-4}$
4	0,575	4,3141	0,0040	3,1184	$1{,}283 \cdot 10^{-3}$
5	0,600	4,2667	0,0090	3,5376	$2{,}544 \cdot 10^{-3}$

Tabelle B2. Kinematische Daten der untersuchten Getriebe / Table B2. Kinematic data of the studied mechanisms

Getriebe Mechanism	φ_B	$i_B = \frac{x'_{0C_B}}{l_1}$	$\overline{i_K}$	φ_A^*	φ_E^*	φ_K^*	Q_K^*	$\frac{\lvert x''_{0C_{max}}\rvert}{l_1} = \frac{\lvert x''_{0C_{min}}\rvert}{l_1}$	$\frac{y''_{0C_{max}}}{l_1}$	$\frac{y''_{0C_{min}}}{l_1}$
1	180°	2,0000	1,9892	135,0°	225,0°	90,0°	$1{,}38 \cdot 10^{-2}$	12,45	0,02	−10,00
2	180°	1,9048	1,9071	136,5°	223,5°	87,0°	$3{,}01 \cdot 10^{-3}$	13,69	0,05	−11,31
3	180°	1,8182	1,8266	119,5°	240,5°	121,0°	$7{,}92 \cdot 10^{-3}$	15,17	0,17	−12,86
4	180°	1,7391	1,7565	107,1°	252,9°	145,8°	$1{,}36 \cdot 10^{-2}$	16,96	0,39	−14,73
5	180°	1,6667	1,6951	97,9°	262,1°	164,2°	$1{,}98 \cdot 10^{-2}$	19,11	0,68	−17,00

Antriebsbezogene Übersetzungsabweichung bei einer annähernd geradlinigen Punktführung

Input-related transmission deviation for approximately straight-line guidance

$Q_K = \frac{\Delta i_K}{\varphi_K}$

$\overline{i_K}$ mittlere Übersetzung/mean value of transmission

Δi_K Übersetzungsabweichung/transmission deviation

φ_K Antriebswinkelbereich (im Bogenmaß) mit annähernd konstanter Übersetzung / input angle range (circular measure) with approximately constant transmission

$i = \dot{x}_{0C}/l\omega_{an} = x'_{0C}/l$ Übersetzung, Übertragungsfunktion 1. Ordnung (Bezugslänge l, hier $l = l_1$)/transmission, transfer function of first order (reference length l, here $l = l_1$)

$i_B = x'_{0CB}/l_1$ Übersetzung beim Antriebswinkel φ_B / transmission at the input angle φ_B

Bild B7 / Fig. B7

Fig. 9 Mechanism example taken from (VDI 2740 1999)

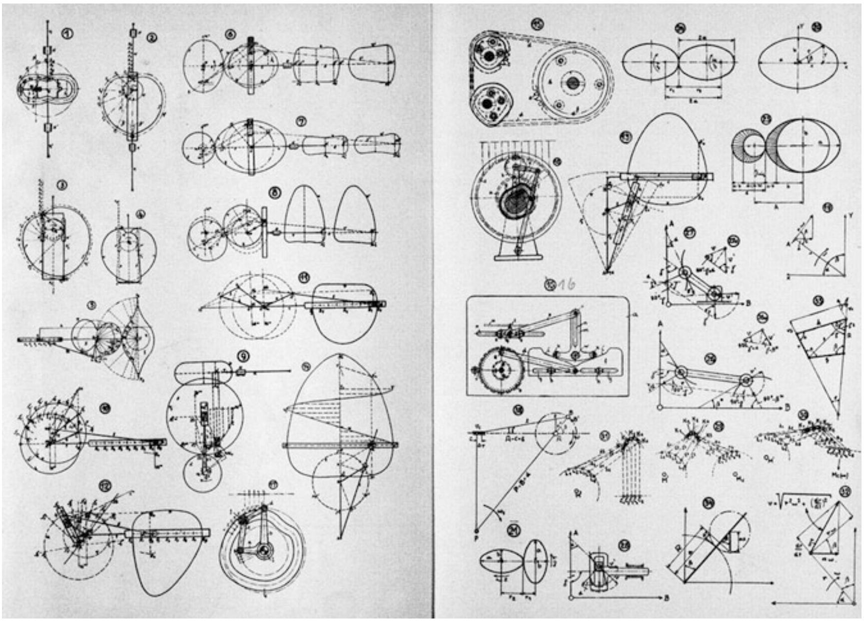


Fig. 10 Mechanism illustrations from (Rauh 1927a)

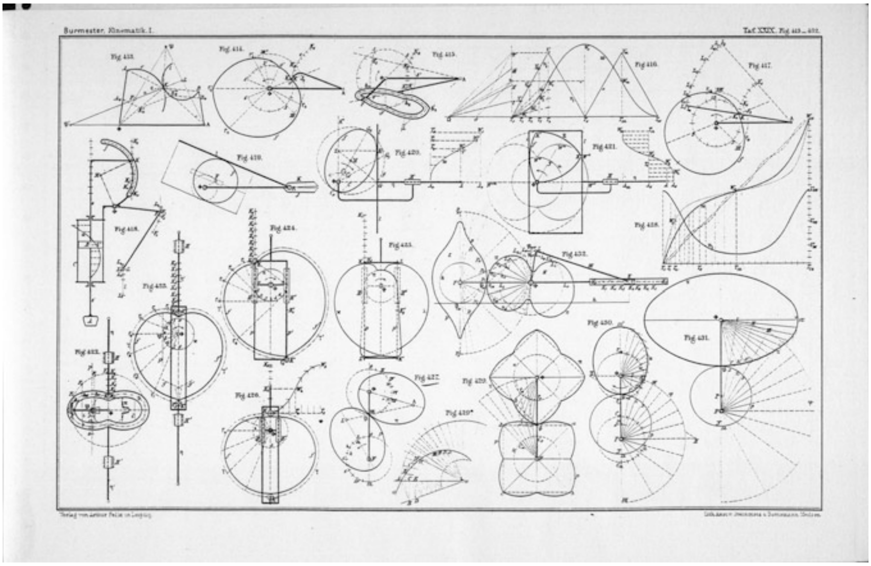


Fig. 11 Table XXIX from the Atlas accompanying (Burmester 1888)

It is not by chance, that these illustrations display a great similarity with the representation of mechanisms and curves, well known from LUDWIG BURMESTER's illustration in his textbook "Lehrbuch der Kinematik" (*Textbook on Kinematics*) (Burmester 1888). Figure 11 shows Table XXIX from the Atlas accompanying the textbook with the figures 422–425 which are almost identical to Figs. 1 through 4 in (Rauh 1927a), where he makes direct reference to (Burmester 1888) and explains the mechanisms in detail.

In fact KURT RAUH argues that so far the most complete discussion of relevant mechanisms can be found in (Burmester 1888). Looking at his own survey it becomes clear that also Figs. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 are examples already presented in Burmester (1888). In fact Fig. 14 of KURT RAUH's PhD thesis shows the well-known shaping mechanisms, which can be found especially in shaping machines. Figure 12 shows an acrylic glass mechanism model as it is still exhibited and used for demonstration purposes at the Institute of Mechanism Science and Machine Dynamics at RWTH Aachen University in Bachelor and Master Courses.

Besides other solutions taken from existing patents, KURT RAUH also cites a solution connected to his former mentor from Dresden, Prof. RUDOLF HUNDHAUSEN where the crank of a scotch yoke mechanism is driven by a combination of a five bar linkage with the "middle" joint, connecting the two links that are not frame mounted, being connected to a roller that is guided by a cam path, Fig. 13. Possibly HUNDHAUSEN had a special interest in cam path solution as can also be seen from Fig. 2.

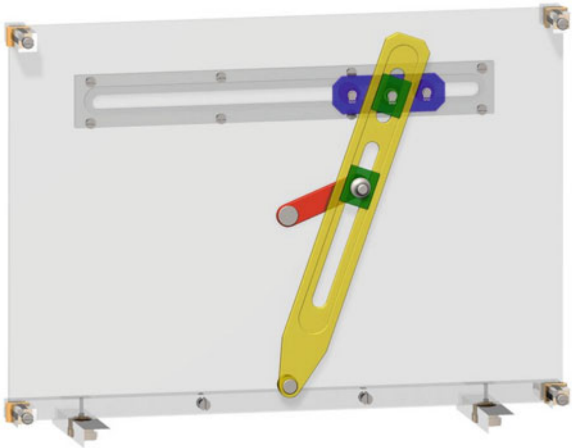


Fig. 12 Acrylic glass model of a shaping mechanism

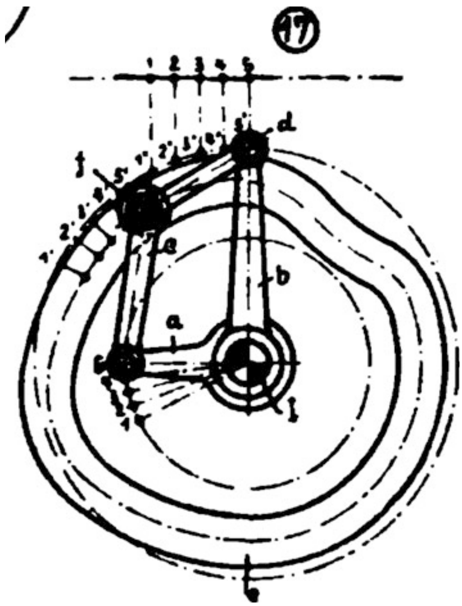


Fig. 13 Cam-guided five bar mechanism

Thus one of the cranks of the five bar is the continuously driven input crank and the second crank directly drives the crank of the scotch yoke mechanism. The fact that Kurt Rauh in his thesis shows this as a solution previously presented by his mentor in Dresden might be taken as additional evidence that already during his assignment with Rudolf Hundhausen in Dresden he had started working on his thesis. Unfortunately it must also be stated that literature citation in Kurt Rauh's PhD thesis is somewhat crude and no complete reference list is available.

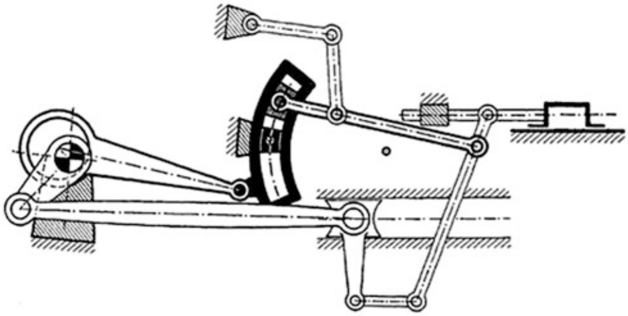


Abb. 9. Heusinger-Lokomotivsteuerung. Übliche Bauweise mit Bogenführung (Kulisse).

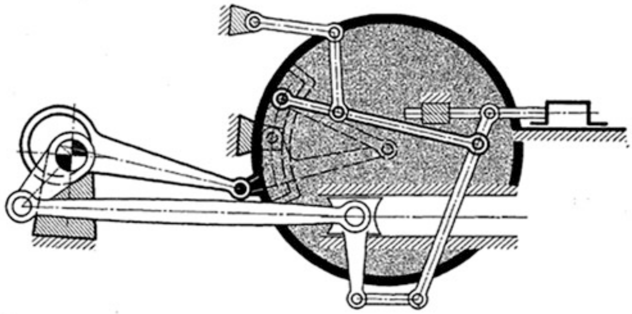


Abb. 10. Heusinger-Lokomotivsteuerung. Die Bogenführung ist zur Zapfenerweiterung ergänzt. Der graue Gleitstein der Abb. 9 wird dabei zum erweiterten Zapfen, die schwarze „Kulisse" zum erweiterten schwarzen Lager.

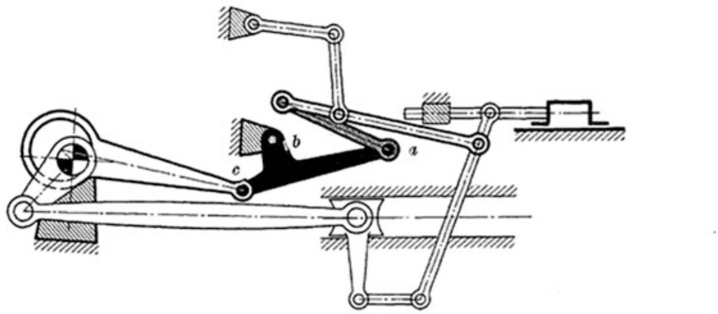


Abb. 11. Heusinger-Lokomotivsteuerung. Die Zapfenerweiterung „Grau-Schwarz" schrumpft zu einem normalen Gelenk. Das graue Glied, das außer diesem Gelenk „Grau-Schwarz" noch das Gelenk „Weiß-Grau" trägt, wird zu einem Lenker üblicher Form. Das schwarze Glied, die Kulisse der Abb. 9, das ja außer dem geschrumpften Gelenk „Schwarz-Grau" *a* das Gelenk „Schwarz-Weiß" *c* (Exzenterstange) trägt und in dem Gestell mit dem Gelenk „Schwarz-Schraffur" *b* lagert, erhält eine, diese drei Lagerungen verbindende Gestalt.

Die Umformung in Abb. 10 und 11 hat an den Bewegungsgesetzen der Abb. 9 nichts geändert.

Fig. 14 Different embodiments of HEUSINGER control for steam engines (Rauh 1931)

3.2 Mechanism Textbook (Rauh 1931)

As already mentioned in the bibliographical notes, Kurt Rauh while being a private lecturer at RWTH Aachen University and Chief-Assistant at the Agricultural Machinery Institute in Bonn, worked on his first textbook on mechanism theory. This textbook, which was meant as the start of a series of textbooks on mechanism science (Rauh 1939), was dedicated to mechanisms based on the four-bar kinematic chain. In the first section of the preface, he explains his idea about this textbook in the somewhat poetic diction of his time:

> The mental wealth of vision, the vivid imagination, that's the nature of the gift-born designer, the inventor. And this present book is dedicated to this wealth of vision, it builds on this precious gift, it uses this talent to illustrate the relationships, characteristics and laws [of mechanism science].

Actually this textbook stands out, especially considering its publishing date with a wealth of colored tables as shown in Fig. 1. Additionally it should be mentioned that Kurt Rauh placed large emphasis on practical application or as he puts it in his own words:

> The investigated and presented mechanisms are no geometric line figures, as are customary and appropriate for mathematical investigations, but they are depicted as motion devices in constructive appearance. The paths and approaches to structural design are treated fundamentally and addressed in an application environment.

Additionally it is interesting to realize that in his preface he especially mentions his "*revered teacher*" Prof. Hundhausen from Dresden University to whom the textbook according to Kurt Rauh not only owes its strict systematic approach but also its colored representations. In fact this color representation can still be found in the mechanism models of the IGM-Collection (Corves et al. 2006) as can be seen in Fig. 12.

He also states that his textbook is not intended to represent a collected edition of the complete current state of mechanism science, but a guide for the designer of practical applications working at his drawing board. Figure 14 shows a convincing example of a practical application of mechanism science showing different embodiments of the HEUSINGER control for steam locomotives, which were at their development height in those years.

Kurt Rauh puts special emphasis on the coupler curves of four-bar linkages, which he explains in great detail. In fact looking at the list of his main works, it is obvious that a lot of his research activities was aimed at this topic (Rauh 1933a, b). By using the coupler curve of a four-bar he immediately extends the scope to a mechanism with a larger number of links as is illustrated through his figures 118 and 119 shown in Fig. 15.

There he shows how one four-bar linkage can be extended towards a ten-bar linkage with three coordinated outputs with dwells. Additionally he also presents solutions using what he calls natural dwells, which he realizes by looking at the centroids of the four-bar linkage.

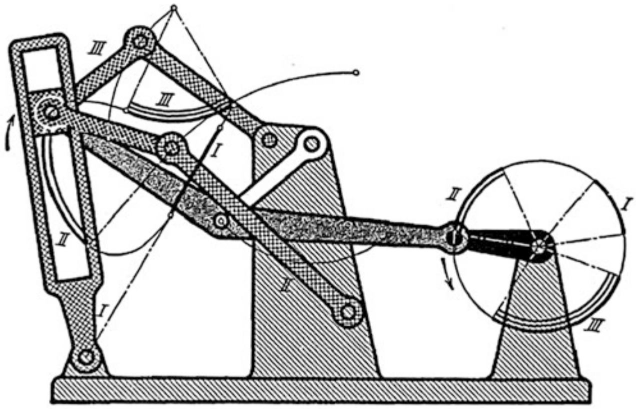


Abb. 118. Ableitung von 3 Hubbewegungen mit je einem Stillstand von einer dreieckigen Koppelkurve des Getriebes Abb. 63. (2. Koppelkurve rechts neben der Schwinge). Ein geradliniges Kurvenstück *I* (einfache starke Linie) wird entsprechend Abb. 113 ausgenützt. Für die Bewegungsableitungen *II* (starke Doppellinien) und *III* (starke dreifache Linien) werden wie bisher Kurvenstücke gleichbleibender Krümmung verwendet.

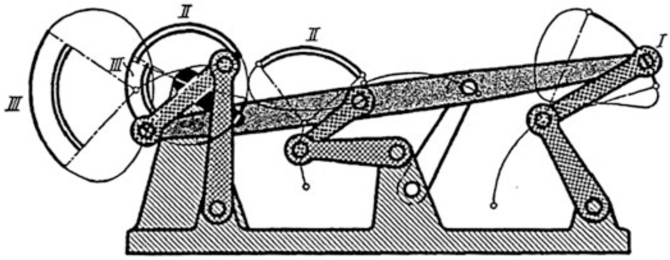


Abb. 119. Ableitung von 3 Hubbewegungen mit je einem Stillstand von 3 verschiedenen Koppelkurven des Getriebes der Abb. 56. In jedem Falle sind Kurvenstücke gleichbleibender Krümmung für den Stillstand ausgenutzt. Verwendet wurden für Bewegungsableitung *I* die 2. Dreieckskurve (Abb. 56) rechts neben der Schwinge, für Bewegungsableitung *II* eine brotförmige Koppelkurve zwischen Kurbelzapfen und Schwingenzapfen mit bemerkenswert langen Stillstandszeiten (starke Doppellinien), für die Bewegungsableitung *III* die bereits in Abb. 115 und 116 verwendete eiförmige Kurve, und zwar übereinstimmend mit der Ableitung *B* in Abb. 116.

Fig. 15 Derivation of three rocker motions with a dwell for each (Rauh 1931)

Figure 16 shows his illustration of a natural dwell, based on coupler points lying on the centroid. There he also distinguishes between mechanisms with two short dwells, one short and a longer dwell and mechanisms with two longer dwells. Most of these possibilities to use coupler curves are illustrated by applications and examples.

But his text book also presents practical applications taken from his experience which he probably gained while working at the Agricultural College in Bonn. Very interesting in this context is a special chapter of the textbook titled "*Involvement of human limbs in the formation of mechanisms*". This chapter is dedicated to analyzing human limb motion while cooperating with a mechanism or being part of a mechanism. The first example, which Kurt Rauh presents, is the rocker crank

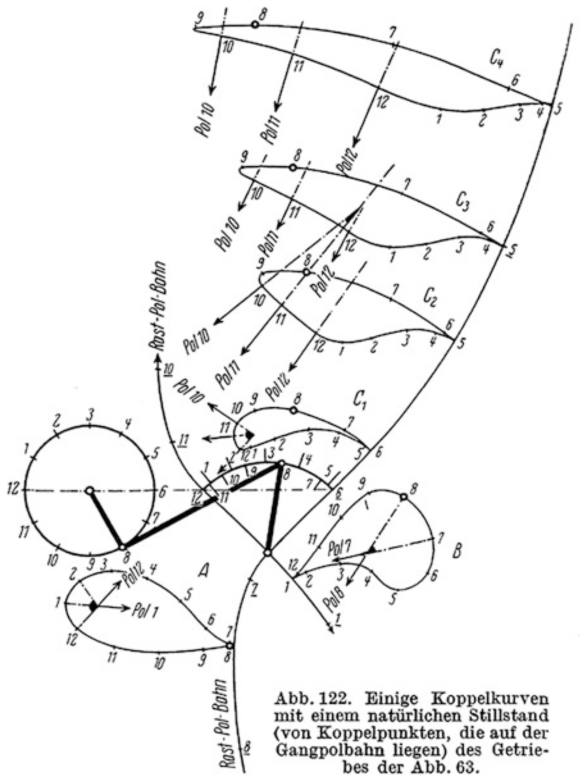


Fig. 16 Some coupler curves with a natural dwell (of coupler points on the moving centroid) (Rauh 1931)

mechanism of a bicycle rider, where the rider's thighs represent the rocker, his shanks the coupler and the crank is given by the bicycle cranks or as KURT RAUH formulates in the subtitle of his Fig. 41: "*The legs of the bicyclist together with the treadle and the cycle frame form two eccentric rocker crank mechanisms with the crank of each mechanism rotated by 180°. Buttocks and the cycle frame act as the mechanism frame, the thighs act as rockers and the shanks and foot pedals represent the couplers*" (Fig. 17).

Based on anatomic studies documented by (Mollier 1924), KURT RAUH analyzed dimensional proportions and motion ranges of human limbs including legs, arms and hands (Fig. 18, left).

The right side of this figure shows pictures of an actual research project at RWTH Aachen University (Allmendinger et al. 2012), which can be seen as today's continuation to this research topic. In fact KURT RAUH's investigations into this field, which today is very popular as biomechanics, is not only based on theoretical studies and investigations, but in his textbook he also refers to practical and experimental studies as can be seen from Fig. 19.

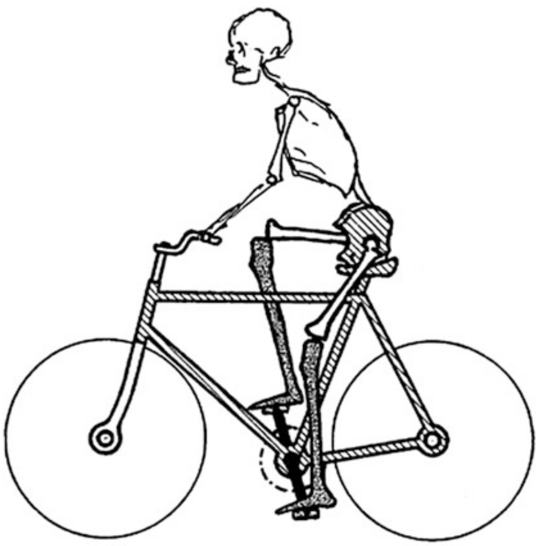


Abb. 41. Die Beine des Radfahrers bilden mit der Tretkurbel und dem Radrahmen 2 um 180° versetzte Bogenschubkurbelgetriebe. Gesäß und Radrahmen sind Steg, die Oberschenkel die Schwingen, die Unterschenkel und Pedale die Koppeln.

Fig. 17 Lower limbs of a bicyclist as part of an eccentric rocker crank mechanism (Rauh 1931)

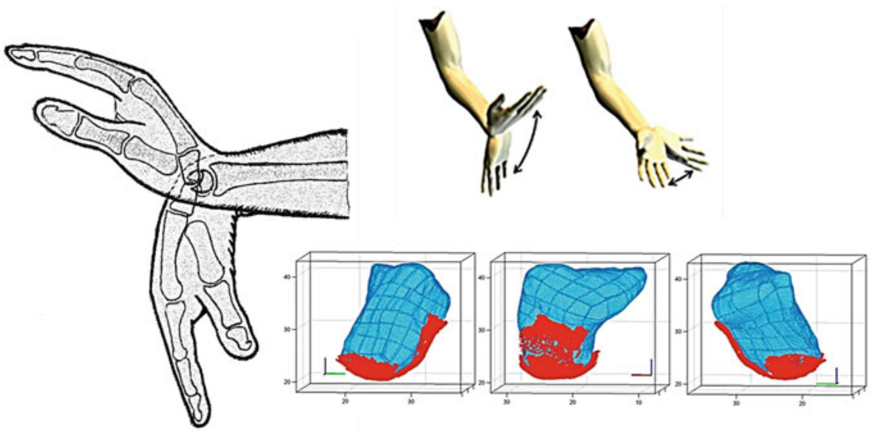


Abb. 54. Beugen und Strecken des Handgelenkes. (Nach Röntgenaufnahme.)

Fig. 18 Analysis of hand motion yesterday and today

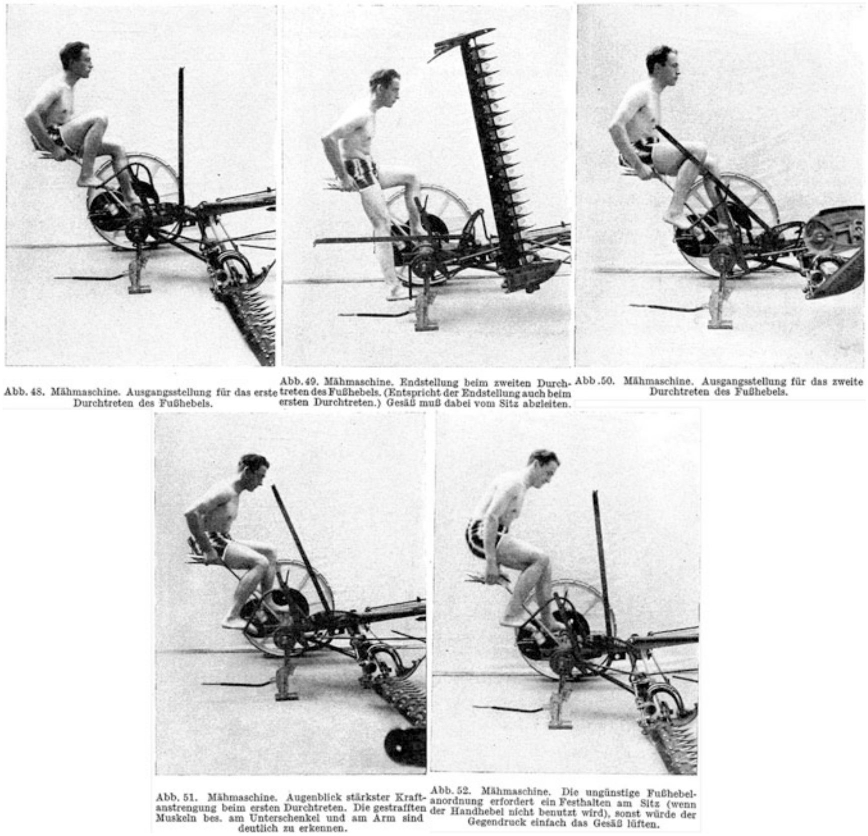


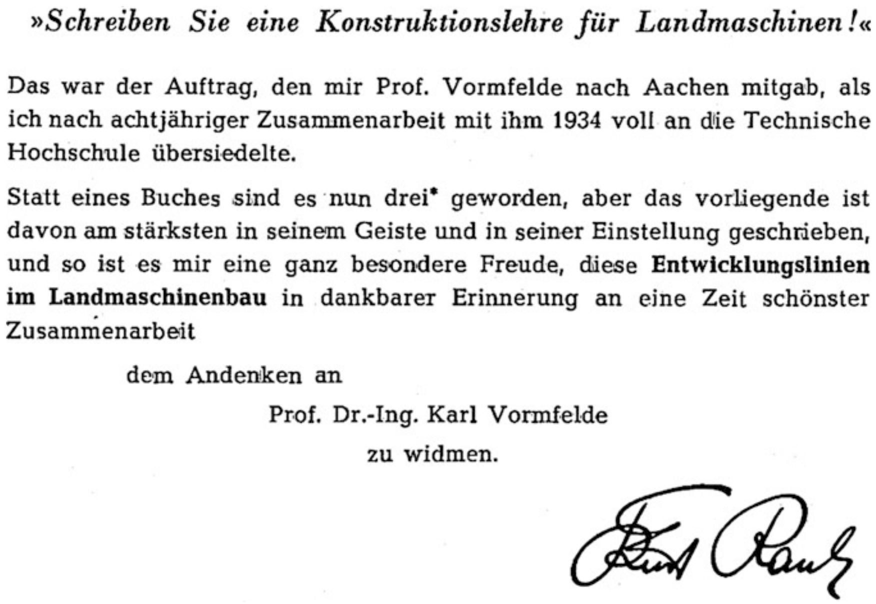
Fig. 19 Ergonomic study of the activation of a mechanism in agricultural machinery

In fact this example taken from agricultural engineering already is an introduction to his next major work:

3.3 Design Lines in Agricultural Engineering (Rauh 1949b)

As Kurt Rauh explains in the acknowledgement of this book, the idea to write this book resulted from advice of his former academic teacher at the Agricultural Machinery Institute in Bonn-Poppelsdorf, Prof. Dr.-Ing. Karl Vormfelde under whom he started his academic career in Bonn; the advice, given to him as early as 1934 when he left for RWTH Aachen University, was to write a book about machine design theory for agricultural machinery, Fig. 20.

In the following preface of the publishers, one of the first sentences is "*This book is anything else than dry machine design theory*" and further on "*Although*



»Schreiben Sie eine Konstruktionslehre für Landmaschinen!«

Das war der Auftrag, den mir Prof. Vormfelde nach Aachen mitgab, als ich nach achtjähriger Zusammenarbeit mit ihm 1934 voll an die Technische Hochschule übersiedelte.

Statt eines Buches sind es nun drei* geworden, aber das vorliegende ist davon am stärksten in seinem Geiste und in seiner Einstellung geschrieben, und so ist es mir eine ganz besondere Freude, diese **Entwicklungslinien im Landmaschinenbau** in dankbarer Erinnerung an eine Zeit schönster Zusammenarbeit

dem Andenken an

Prof. Dr.-Ing. Karl Vormfelde

zu widmen.

Fig. 20 Acknowledgement in Rauh (1949b)

the book is written sometimes downright thrilling it will primarily sharpen the view for the future design issues of German agricultural machinery, but leads, in many cases far beyond this narrow framework, showing vividly how fateful the people are connected to each other especially in the economic sphere and what role plays the development direction of agricultural machinery".

This book is very interesting in two aspects: Similar to his previous book on practical mechanism science (Rauh 1931), it shows a lot of technical details in pictures, see Fig. 21. In fact this figure shows exactly the 22-hp Gross-Bulldog Tractor from H. Lanz Company, Mannheim already mentioned previously when referring to early publications of Kurt Rauh (Rauh 1927b).

The second aspect is, that this book is not just dedicated to engineering aspects in agriculture but also to economic aspects and therefore it starts with quite detailed statements about cost effectiveness and economic efficiency in agriculture. This is reflected by its table of contents where the first chapter is dedicated to "*The Basics of Agriculture Machine Design*" with subchapters titled "*The allowable construction cost.* (*How much can you charge for the agricultural machine?*)", "*The possible price (calculation method)*", "*Losses and their influence on the machine design*" and "*The threshing machine, threshing grains of gold*". Still the second chapter, titled "*The human workforce and its influence on the price of the machine*" mainly covers non-technical issues. Only the following chapters are dedicated to agricultural machinery such as ploughs, combine harvesters (Fig. 22), threshing machines, winnowers and tractors.

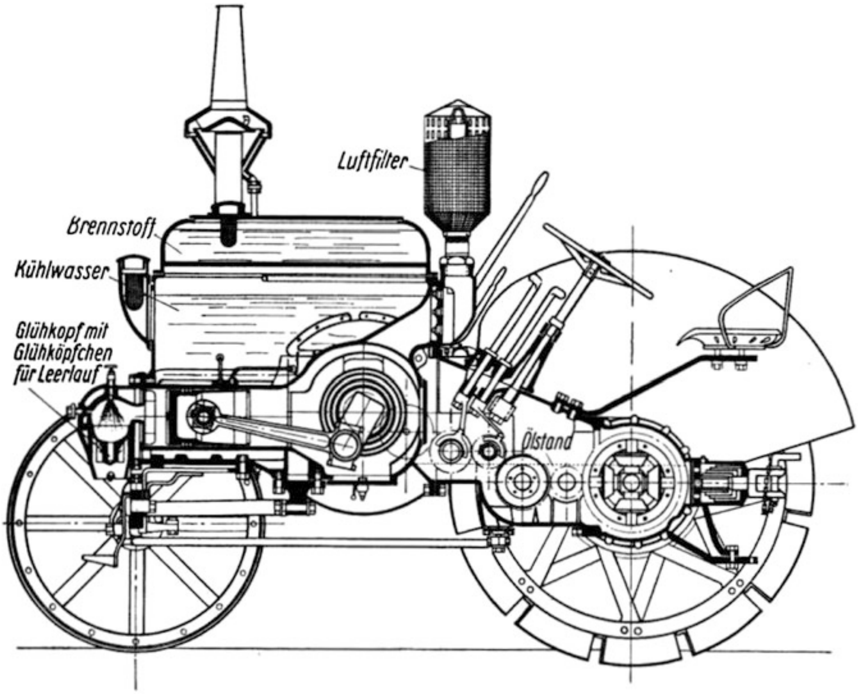


Abb. 27. Groß-Bulldog von H. Lanz, der erste wirklich ernsthafte und erfolgreiche Gegner des Fordson. Bei der neuzeitlichen Form ist die Verdampfungskühlung durch Umlaufkühlung ersetzt

Fig. 21 22-hp Gross-Bulldog Tractor from H. Lanz Company, Mannheim "The first serious and successful opponent of the Fordson" according to Rauh (1949b)

All of them are described in detail not only with respect to their design but also showing the underlying agricultural process as Fig. 22 shows quite vividly. If his book on agricultural machinery can be seen as the result of integrating agricultural engineering into Kurt Rauh's official research portfolio at RWTH Aachen University, then his activities within the area of machine design are reflected by his fourth textbook.

3.4 Production Machines: Applied Mechanism Science (Rauh 1950)

This fourth textbook of Kurt Rauh is devoted to the machine design of processing machinery in general. He mentions in his preface that it is addressed to "*every design engineer*" and is "*accordingly separated in one volume of text and a figure book for clear and easy handling*". The figure book contains the tremendous number of 453 pictures, technical drawings and diagrams. These figures not only

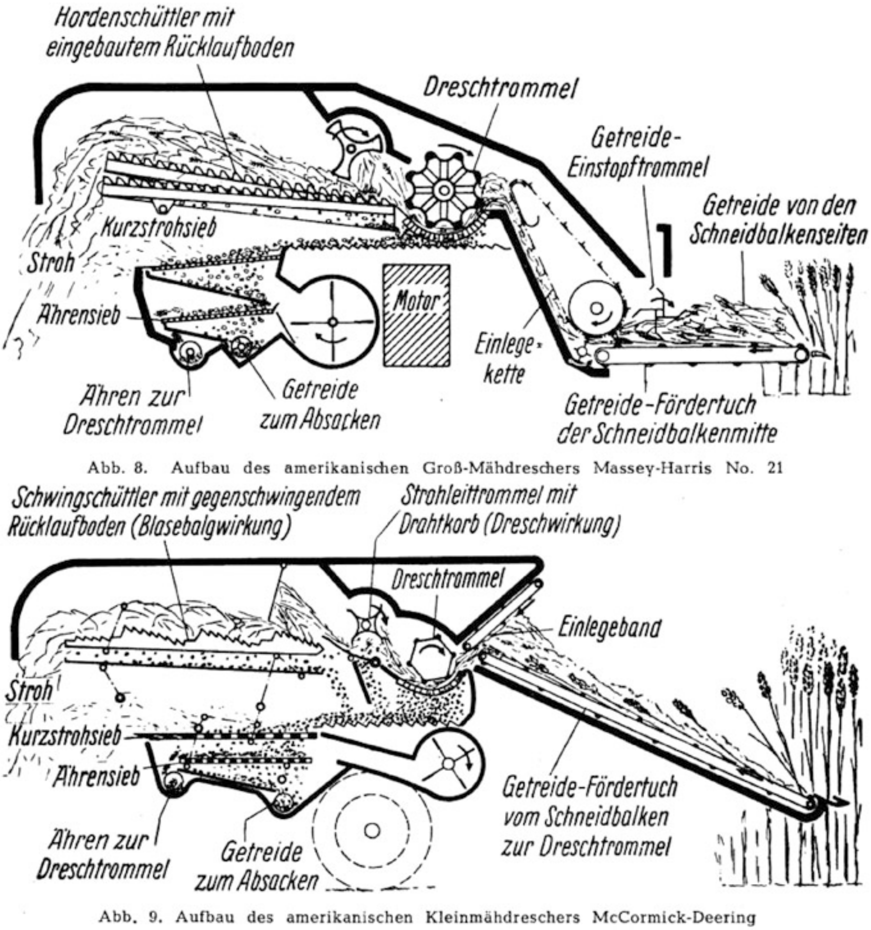


Fig. 22 Large and small American combine harvester according to Rauh (1949b)

depict processing machines or machine parts but also process related information as well as mechanism solutions, see Fig. 23. At this point it becomes finally obvious that Kurt Rauh must have been a great admirer of (Jones 1930). In fact in his textbook on mechanism science he presents a short reference list where he distinguishes between older mechanism science literature represented by Reuleaux and Burmester and younger literature among which Dunkerley represent the English mechanism science (Dunkerley 1928) and Jones represents the application oriented American mechanism science.

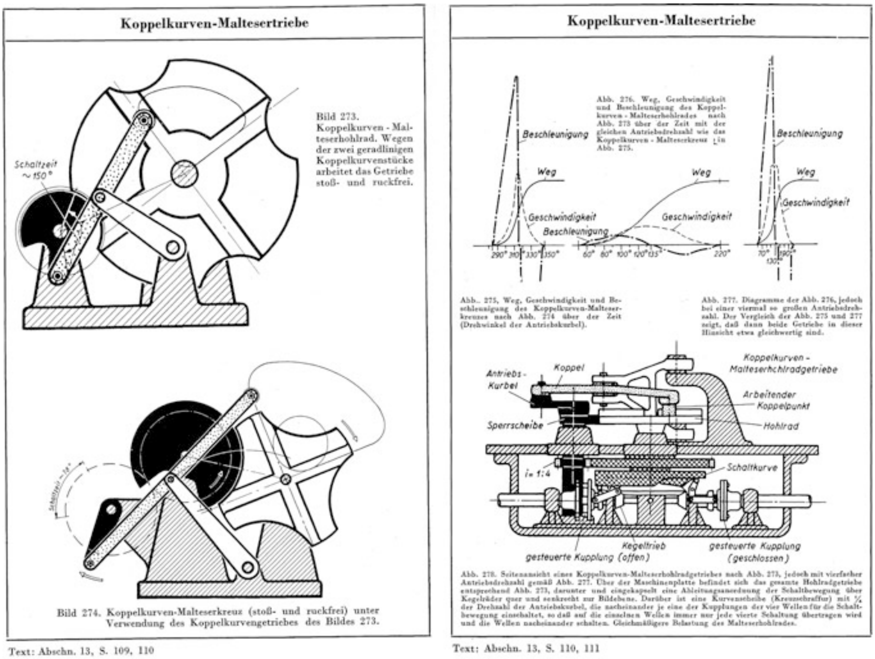


Fig. 23 Coupler curve activated Geneva Wheel (Rauh 1950)

4 Summary and Conclusion

With this paper I wanted to show the activities and research topics of Kurt Rauh especially during his academic career both at the Agricultural College in Bonn and at RWTH Aachen University. The scope of Kurt Rauh's activities in Bonn and Aachen and his publications were centered towards a systematic synthesis and selection of mechanisms of any kind, which should allow the engineer working in practice to find, to select and synthesize in a very simple and clear way an optimal solution for a given machine task.

The paper has been compiled by an engineer, who is not a "learned" historian, but judges his sources as someone specialized in the field of mechanism and machine science. A lot of the publications on which this paper is based could be retrieved with the help of the DMG-Lib internet portal. Therefore acknowledgement is given to the German Research Foundation (DFG) which supported the DMG-Lib project and also to the European Union which supported the think-MOTION project. Additionally many thanks are expressed to the archives of RWTH Aachen University, whose personnel was very collaborative in retrieving important documents.

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Leonid Nikolayevich Reshetov (1906–1998)

Valentin B. Tarabarin, Zinaida I. Tarabarina and Darya Chirkina

Abstract This paper will discuss the life and career of Leonid Nikolayevich Reshetov, professor of MSTU, Honored Inventor of RSFSR. He was a great engineer, scientist and inventor. His contribution to the science of Mechanisms and Machines is truly invaluable; he took an active part in improvement of courses in the Theory of Mechanisms and Machines and development of Machinery Design. He developed a new research area in Theory of Mechanisms and Machines: Theory of Rational Mechanisms, also known as self-aligning mechanisms. For many years he was the curator of the Collection of Mechanisms at the Department of TMM. More than 100 models were made by students at workshops of the Department under his direction and by using his inventions, pictures and his own experimental model.

1 Biographical Notes

Leonid Nikolayevich Reshetov (see portrait in Fig. 1) was born on 20th of July, 1906 in the town of Tolyatti. His father, Nikolay Dmitrievich Reshetov, was a petty bourgeois and a public servant in the Town Council of Tver at that time (Tarabarin 2009). And his mother, Lubov Ivanovna, also a petty bourgeois and a housewife, was a hereditary Honourable Citizen of Tver. After the October

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Fig. 1 Leonid Nikolayevich Reshetov

Revolution, in 1917, Nikolay Dmitrievich at first began to work at the Department of Cooperation. He later became an accountant in the Krasnogvardeysky Regional Department of Public Health Services.

During his school years, L. N. Reshetov held positions as chairman of a committee of class presidents, head of a class and the chairman of a physics circle. In 1924 he successfully graduated from primary school number 24 and secondary school number 2 in the town of Kalinin (the name given to Tver after the Revolution).

While receiving the compulsory education that was in effect at that time, he also had been, for nine months, studying courses on his own for electric substations' workers, which he successfully finished in 1922. He worked as a pro bono student-trainee for four years, from 1922 to 1924, at the town's electrical substation and at the power station of factory No. 4, where he explored the internal mechanisms of such devices as steam machines, turbines and Diesel engines while continuing to study their work in practice.

Reshetov had entered the Pedagogical University of Tver in 1924 and finished three courses at the Department of Physics and Technics in only two years. Both in school and in university he participated in repairing and creation of educational equipment. This led to a suggestion in 1926 that he continue his education in Moscow Higher Technical School, from which he successfully graduated on the 25th of March, in 1930. He had in three years mastered a five-year course in the speciality of Stationary internal combustion engines.

Fig. 2 L. N. Reshetov adjusting a controller in the Dynamo factory

After graduating from the MHTS, Reshetov was invited by Professor L. Smirnov to join the Faculty of TMM as a tutor. During that time he became head of a Department of Gearing in the MMMI (Moscow Institute of Mechanical Engineering, as MHTS was named from 1930 to 1943) as an engineer. In 1932 the Organizing Committee of the All-Russia Exhibition of gear-cutting craft suggested that he investigate and classify systems of correction of gear meshings. From 1932 to 1938 Reshetov worked on problems of cam mechanisms' design. A Decree that created the foundation of scientific degrees in the USSR was accepted in 1934, and engineer Reshetov became a Candidate of Technical Science, owing to the set of research papers he had published by then. In 1937 he became head of the Department of Applied Mechanics at the Moscow Institute of Transport Engineers (MIIT). At the same time he was teaching students of Moscow Auto-Mechanical Institute (MAMI), where in 1939 he organized a Department of TMM of which he was the first head; he held this position up to 1953 until he left MAMI. Reshetov had defended his dissertation and became a Doctor of Technical Science (Doctor of Engineering) in 1945; in 1946 he became a professor of the Department of TMM in Bauman MHTS. In 1951 he surpassed the competition and was elected as head of that Department. He held this post until 1962.

Reshetov was an Honored Inventor of RSFSR and author of more than 80 inventions, most of which were applied in industry. He closely cooperated with enterprises of various industries. During the 1930s he worked as a scientific adviser in the bureau of rolling stock at the Dynamo factory (Fig. 2), in the 1940s and 1950s he was a consultant at the Laboratory of Electrodraft of the Central Scientific Research Institute of Ministry of Railways, and in the 1960s he held a post of adviser at the Mechanical Clock Laboratory of Scientific Research Institute of the Clock Industry. He produced there the following important inventions: Cam Automatic Rheostatic Controller of a Reshetov System, a self-aligning mechanism of an electrical locomotive slip ring, a rational mechanism of the base of a cement furnace, a cam mechanism of a calendar and a number of others.

Fig. 3 L. N. Reshetov tells to colleagues from TMM department at BMSTU about new models of a collection of mechanisms. **a** The last on the *right*, photo of 1966. **b** The second on the *left*, photo of 1972

Reshetov had prepared over 25 post-graduates, many of whom received doctor's degrees. Also he founded the scientific school of bases of rational and self-aligning mechanisms design in MHTS. His book "self-aligning mechanisms" was republished four times in Russia and was translated into English, into Spanish and into Chinese. He led much public work as a juryman, and as chairman of the club of tourists at the Moscow House of Scientists. L. Reshetov was awarded the Order of the Red Banner of Labour as well as ten singular medals of the USSR for his merits. During his work in MHTS, he was a curator of the Collection of Mechanisms at the Department of TMM (Fig. 3). For many years he had tried to achieve an allocation of a special separate cabinet for storage of such a collection. But, unfortunately and for many reasons, he was unable to finish this work. He exchanged his teaching career for the post of Professor-Tutor in 1982, and in January of 1986 he left MHTS for health reasons. L. N. Reshetov died on the 8th of August, 1998.

2 The List of Main Works of L. Reshetov

There are more than 220 published papers and 80 inventions in the general list of research works of L. Reshetov. The main ones are:

1. Engineer Reshetov L. N., Ass. Prof. of KMMMI, The Correction of Involute gearing, Methods and Justifications (1935).
2. Reshetov L. N., Cam Mechanisms of Turning Automatic (1934).
3. Reshetov L. N., Cam Mechanisms (1953).
4. Reshetov L. N., Toropygin E. I., Profiling of Cams by curves of conic section (1966).
5. Reshetov L. N., Designing of Rational Mechanisms (1972).
6. Reshetov L. N., Self-aligning mechanisms. Reference book (1986).
7. Reshetov L., Designing of auditorium blackboards. Problems of the theory of mechanisms and machines (1955).
8. Reshetov L. N., Models of Mechanisms. Hand-written album (1974).

3 Review of Main Works of L. Reshetov

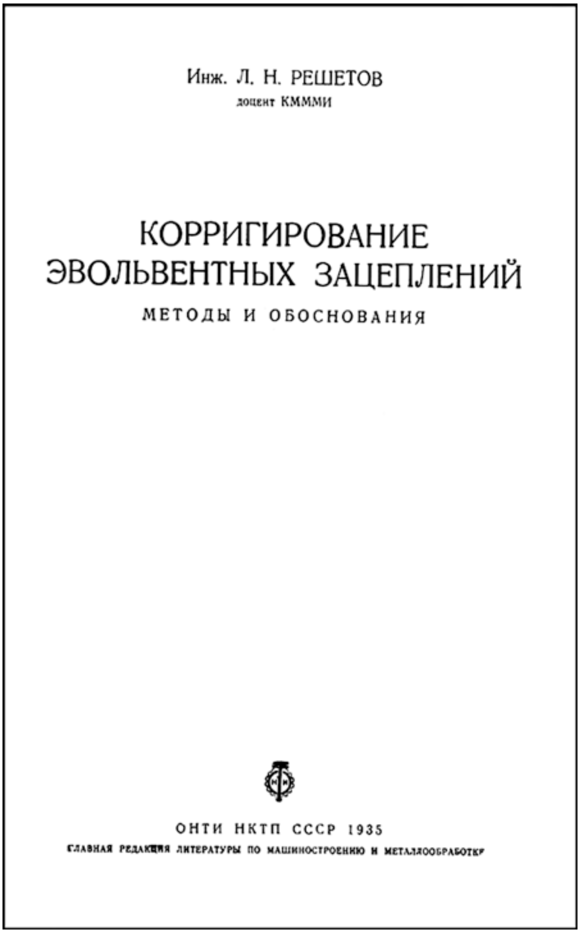
The book "Correction of involute gearing", which was published in 1935 (Fig. 4), is considered as his first significant research work. There is the following note in its introduction: in 1932 "By Exhibition Committee (of the All-Union exhibition tooth-cutting craft) it was suggested to the author as to a head of Department of Gearing of MMMI to consider and systematize current systems of correction". Analysis of current correction systems was complicated by an absence of published information, which made it impossible for the author to reveal some of the main concepts, including those in the Maag and Bilgram Methods. Therefore the author paid much attention to development of his own correction system. The theory was closely connected with the manufacturing of gears, "because of the practical importance of such and only such meshing that can be produced exactly and cheaply".

The possibility of creating an involute gear pair with maximal gear ratio and a pinion with the least number of teeth was analyzed in the first part of the book. Further there are considerations of trouble with the production of such gear pairs and ways to make decisions. Also the author has carried out investigations of teeth jamming processes on tooth fillet and cutting of a tooth basis. It was found that such problems could be overcome either by correction of circles in the gear pair or by increasing of the instrument's pressure angle. The author analyzes the influence of correction on slip of profiles and wear of teeth, on bottom clearance, and on centre distance and bending strength. Also the author considered various methods of tooth cutting of straight gears and parallel helical gears with different parameters of basic racks.

Further in the book there are descriptions of known systems and methods of correction developed by other scientists and firms for straight and parallel helical gear pairs. Nomograms (Fig. 5) and tables of choice of high-rise and angular correction coefficients are provided. Reshetov also represents and analyzes the correction systems of Lasche (1899), Young (1919), Vogel (1929), Reinecker, Glisson, Bilgram, Kutzbach (DIN), Buckingham, Schiebel, Hoppe and Maag. The most detailed description was devoted to Buckingham's system; there are shown tables for choosing gear parameters for high-rise and hybrid correction (Fig. 6). At the end of the book there is description of Reshetov's correction system created by the author. A quote from the book, presented further, shows purposes of developed correction system:

«This correction based on following goals:

1. to provide a correction, specially adapted for helical teeth;
2. to choose such a profile in which deterioration would be low and which, particularly, wouldn't be deformed except for deterioration, i.e. to satisfy the equation $AP/BP = PN_1/PN_2$;
3. to prevent tooth cutting totally because even a small cutting causes a highly negative distribution of bending and greatly reduces the strength of the tooth;



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КОРРИГИРОВАНИЕ
ЭВОЛЬВЕНТНЫХ ЗАЦЕПЛЕНИЙ
МЕТОДЫ И ОБОСНОВАНИЯ

ОНТИ НКТП СССР 1935
ГЛАВНАЯ РЕДАКЦИЯ ЛИТЕРАТУРЫ ПО МАШИНОСТРОЕНИЮ И МЕТАЛЛООБРАБОТКЕ

Fig. 4 Title page of first book of engineer L. Reshetov «Correction of Involute Gearings»

4. to provide a distance between centers as a round number even if there are an incomplete set of standard tools;
5. to provide a method of calculating a gearing with ability to enter into given distance between centers;
6. to provide an ability for exact counting of a backslash, that always applies at responsible gear pairs to prevent gear jamming process and breakage of shafts».

This system of correction, developed by Reshetov, was being tested by him while designing four models of gear pairs. Calculation results of three them have been shown in the book as examples 18–20. Nowadays those models are stored in the collection of the TMM department at BMSTU. Photos of those are shown in Fig. 7b–e. The most interesting gear pair is marked as *S*5. The author made that «for a curiosity» A pinion of that parallel helical gear pair has only one tooth. The main

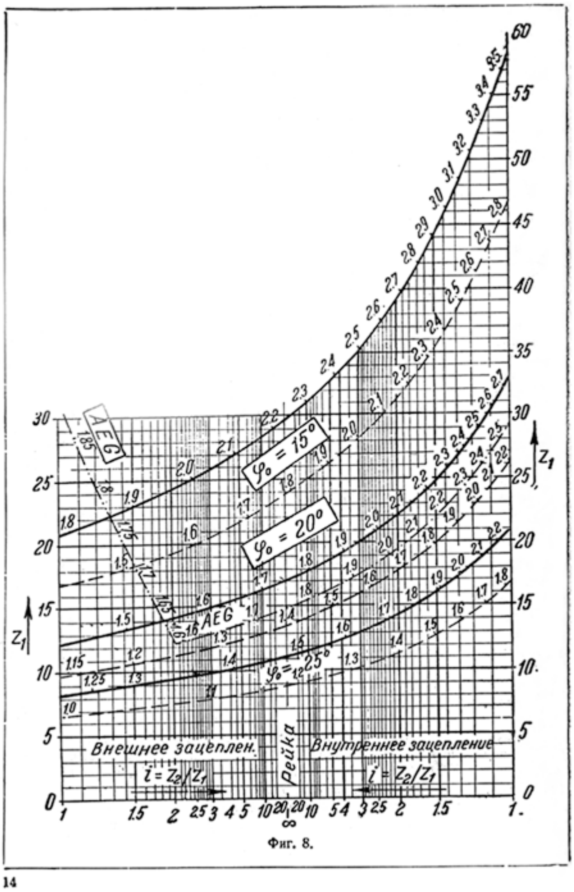

Fig. 5 Diagram of choice of gear pair parameters by Vogel system of corrections (Vogel 1929)

difficult of designing was not counting, but producing: for that Reshetov had to direct a preparation by use of a mop.

It should be noted that Reshetov's book was written by an engineer for engineers. Except for its small amount of 129 pages it consists of 20 examples of numerical solution of considered tasks.

In conclusion the author pointed that not only correction allows improvement of a quality of gearings. The pressure angle standard of basic racks was changed from 15 to 20°. Together with increasing of tooth height that made it possible to decrease the minimal number of teeth produced without cutting the dedendum from 30 to 17. Gearings without correction may be used at low-speed gear pair with small gear ratio. For application in steam turbines, diesel engines, locomotives and electric locomotives, «where conditions of durability, reliability and compactness have especial importance, advantage would be on the side of corrected profiles».

Fig. 6 Table of transverse contact and overlap ratio by Buckingham system of correction

Таблица V

Значение степени перекрытия при смешанной коррекции Бэкингэма

Число зубцов большого колеса	Число зубцов малого колеса															
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
10	0,961															
11	0,981	1,010														
12	1,000	1,030	1,052													
13	1,019	1,049	1,072	1,097												
14	1,038	1,058	1,092	1,117	1,142											
15	1 056	1,087	1,112	1,137	1,16[illegible]	1,184										
16	1,074	1,106	1,132	1,157	1,181	1,204	1,224									
17	1,092	1,125	1,151	1,176	1,200	1,223	1,244	1,266								
18	1,109	1,143	1,170	1,195	1,218	1,242	1,254	1,286	1,308							
19	1,126	1,160	1,188	1,213	1,236	1,261	1,283	1,305	1,327	1,347						
20	1,142	1,176	1,205	1,230	1,254	1,279	1,302	1,324	1,345	1,355	1,385					
2	1,155	1,191	1,220	1,246	1,271	1,296	1,320	1 311	1,362	1,383	1,404	1,424				
22	1,169	1,205	1,234	1,261	1,287	1,312	1,337	1,358	1,379	1,401	1, 23	1,443	1,459			
23	1,181	1,218	1,247	1,275	1 302	1,327	1,353	1,374	1,395	1,418	1,441	1,461	1,480	1,498		
24	,193	1,231	1,260	1,289	1,317	1,342	1,368	1,389	1,410	1,434	1,458	1,478	1,497	1,516	1,531	
25	1,204	1,243	1,272	1,302	1,331	1,356	1,382	1, 03	1,424	1,449	1,474	1,494	1,513	1,532	1 550	1,567
26	1,214	1,25	1,283	1,314	1,344	1,369	1,395	1,416	1,437	1,46	1,489	1,510	1 530	1,550	1,569	1,584
27	1,224	1,264	1 294	1,326	1,356	1,381	1,407	1,428	1,449	1,476	1,503	1,525	1,546	1,557	1,587	1,600
28	1,233	1 273	1,304	1,337	1,367	1,393	1,419	1,440	1,460	1,488	1,516	1,539	1,560	1,581	1,601	1,615
29	1,243	1,283	1,315	1,348	1,378	1,405	1,431	1,451	1,471	1,500	1,528	1,551	1,572	1,593	1,613	1,630
30	1,252	1,292	1,325	1,358	1,389	1,417	1,442	1,462	1,482	1,511	1,540	1,563	1,584	1,605	1,625	1,644
31	1,261	1,301	1,335	1,368	1,399	1,428	1,453	1,474	1,495	1,524	1,553	1,576	1,598	1,620	1,640	1,660
32	1,270	1,310	1,344	1,378	1,409	1,439	1,464	1,486	1,508	1,537	1,565	1,589	1,612	1,638	1,655	1,674
33	1,279	1 319	1,353	1,387	1,419	1,449	1,475	1,498	1,521	1,550	1,579	1,602	1,626	1,649	1,670	1,688
34	1,288	1,328	1 362	1,396	1,429	1,459	1,488	1,510	1,53.	1,563	1,592	1,615	1,639	1,663	1,684	1,702
35	1,297	1 33[illegible]	1,371	1,405	1,438	1,469	1,499	1,522	1,546	1,575	1,604	1,627	1,651	1,676	1,697	1,716
36	1,306	1,346	1,380	1,414	1,447	1,479	1,509	1,534	1,558	1,587	1,616	,639	1,633	1,688	1,710	1,730
37	1,315	1,355	1,389	1,423	1,456	1,489	1,519	1,545	1,570	1,598	1,628	1,652	1,674	1,700	1,723	1,734
38	1,323	1,364	1,398	1,432	1,465	1,499	1,529	1,556	1,582	1,610	1,640	1,664	1,688	1,712	1,735	1,757
39	1,331	1,378	1,407	1,441	1,474	1,509	1,539	1,567	1,594	1,622	1,651	1,676	1,700	1,724	1,747	1,769
40	1,339	1,381	1,416	1,450	1,483	1,519	1,549	1,578	1,606	1,634	1,662	1,688	1,712	1,736	1,759	1,781

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Reshetov's book considerably affected the direction of scientific research of the TMM department of BMSTU. It found further development in the investigations of geometry of involute cylindrical gear executed in the doctoral dissertation of V. A. Gavrilenko and described in three of his monographs. Research material and science data from Reshetov's book were used to study processes in laboratory works and course design.

In the 1930s (1932–1938) L. N. Reshetov had published a set of papers on design and investigations of cam mechanisms. At that time he was actively cooperating with the Dynamo factory and the Central Scientific Research Institute of the Ministry of Railways (CSRI of MRW) and participated in design of automatic rheostatic controllers for railway and underground cars. Cam mechanisms of an operation system, invented by Reshetov, allowed creation of high-quality controllers. Such controllers were introduced and until recently were used in transport with electrodraught. Results of Reshetov's works on this field were

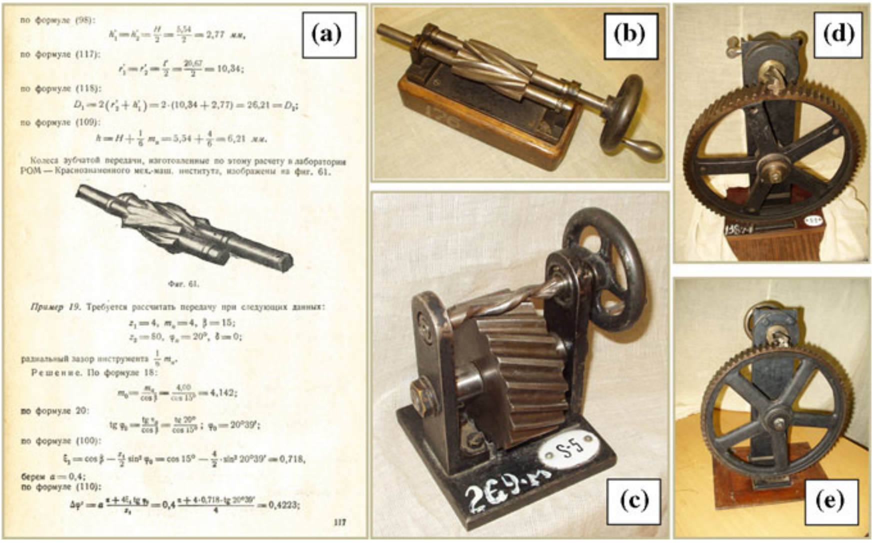


Fig. 7 The page from Reshetov's book with the example of gear pair calculation **a** and photos of models **b**–**e**, made by using his system of correction

generalized and were included in his monograph «Cam mechanisms», carried out in 1948 (Fig. 8). In the introduction the author noted that «this work is devoted to kinematics and dynamics of cam mechanisms, including their production as well. Problems of durability and also choice of material and heat treatment, cutting modes through producing and etc., as not corresponding to the tasks of this work, are not considered in the book».

The first chapter of the book is devoted to constructions and applications of cam mechanisms. There as a classification of cam mechanisms and descriptions of constructions of cam mechanisms, applied to steam machines and turbines, internal combustion engines, industry machines, electric devices (Fig. 9), mining machines, mechanisms of cars and tractors, alarm and blocking systems (on the railways), exact mechanics and devices. Methods of manufacturing of cam mechanisms are described at the end of the chapter.

The second chapter describes the process of choice of a cam follower's motion law. The main definitions of mechanism parameters are given there, also forces, affects in couples of cam mechanisms of various constructions are considered in this chapter and finally the main principles of choice of the follower's movement law on power stroke and on idling (Fig. 10).

Design methods are represented further in Chaps. 3–5, each of which is devoted to a different type of mechanisms: Chap. 3—cylindrical with axial follower, Chap. 4—mechanism with inclined follower, Chap. 5—with rotating one (Fig. 11). A profiling of a cam through exact and approximate curves and through

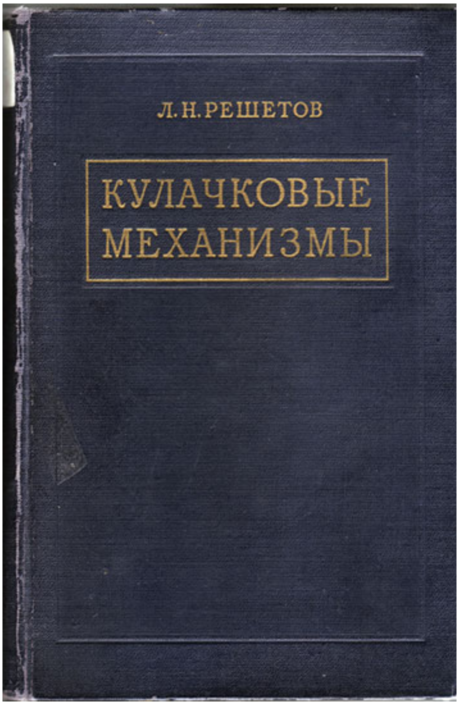


Fig. 8 Cover of the book of L.Reshetov «Cam mechanisms»

arches of circles, design of a mechanism with the least dimensions and choice of a roller sizes are also considered there.

Further there is a description of design of the following types of mechanisms: Chap. 6—disk cam with central follower, Chap. 7—with eccentric and rotating one. Chapter 8 shows process of design through given law of twisting moment changes (Fig. 12). Also there are statements of profiling process, realized through arches of circles, by constant velocity, constant pressure angle and constant twisting moment.

Chapter 9 is devoted to a description of cams of a group controller of Reshetov's system. Two cams are considered there: the major cam of a transmission and a cam of gate switcher (Fig. 13).

In Chap. 10 attention is paid to the theoretical basis of car cam differentials of raised friction. Such mechanisms are applied to cross-country vehicles for slipping reduction in the conditions of a bad cohesion of wheels with the road.

Designing of disk cams with planar are considered in the last chapter of the book. There is a description of profiling through exact and approximate curves, through arches of circles, by constant velocity and acceleration, as it was earlier in the book. Designing of cam mechanism with a triangle eccentric cam (triangle of Reuleaux and Wolf) are described. That mechanism is formed by a figure of equal width placed in a rectangular frame of a follower (Fig. 14).

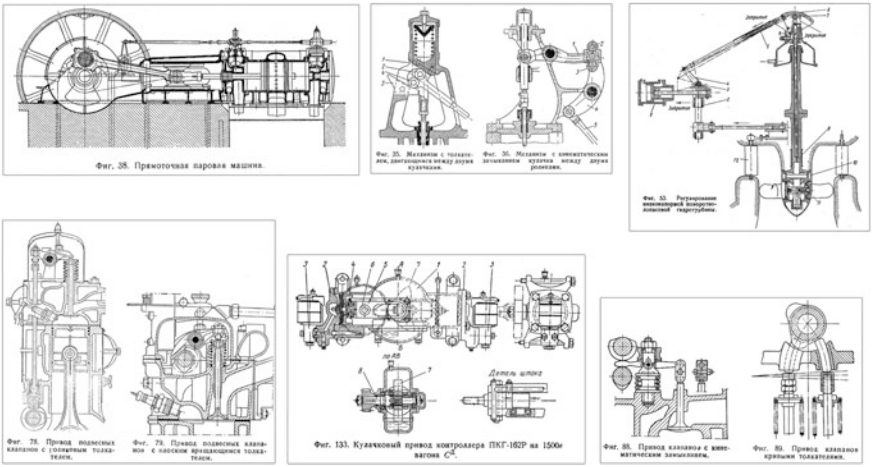


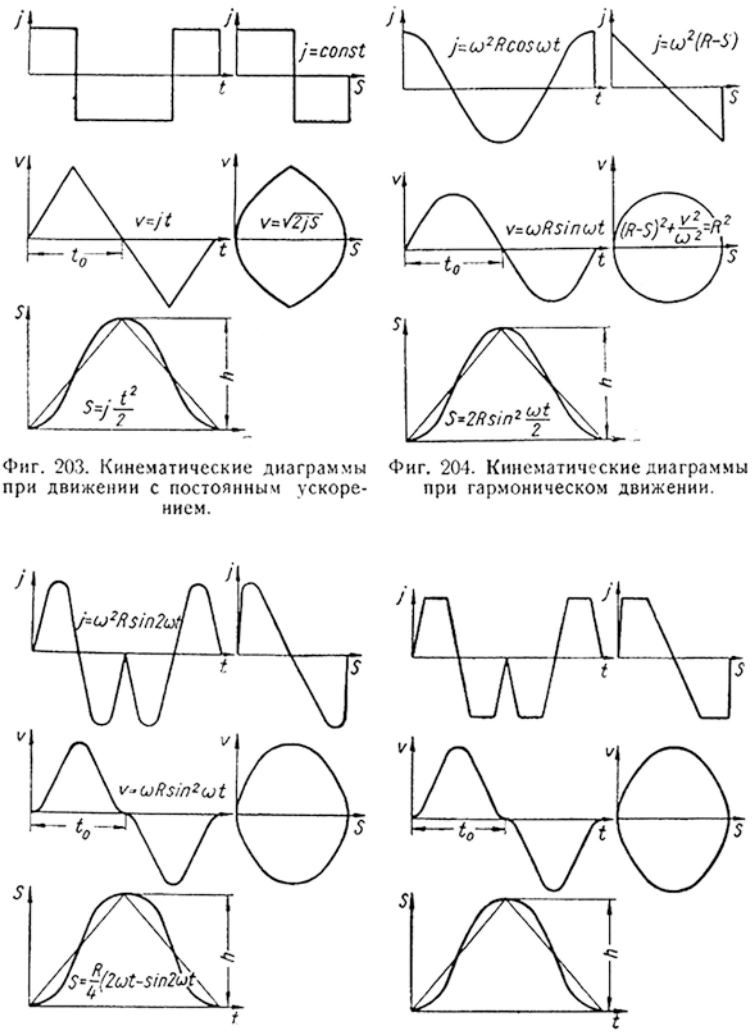
Fig. 9 Constructions of cam mechanisms and examples of their applications in steam machines and turbines, engines and electrical devices shown in «Cam mechanisms» of L. Reshetov

As was Reshetov's first book, his second book «Cam mechanisms» is written for engineers. In describing the book in Chap. 1, he writes that it meets «experts with cam mechanisms in the adjacent areas, students—with operating conditions of cams, and inventors and rationalizers—with original designs of cam mechanisms, which can stimulate their creative activity». It is noted further that in the book «much attention is given to simplicity of calculation and drawing of approximate curves. When the most favorable decision turns out sophisticated, the approximate decision close to it is offered. Thus the reader can determine deviations received both by special formulas and by the numerical examples given in the book».

The second book was devoted to cam mechanisms. «Profiling of Cams by curves of conic section» (Fig. 15) was written by L. Reshetov in 1966 in a co-authorship with E. I. Toropygin. It is possible to receive various curves in the course of section of a cone by the planes (Fig. 16). If a secant plane is perpendicular to a cone axis, then in the course of such section a circle will be received; if the plane is parallel to the cone forming line, then the section will be a parabola; a plane parallel to a cone axis gives a hyperbole and other positions of a secant plane give ellipse sections. Executing a cam profile through these curves it is possible to receive various properties of the mechanism.

The first chapter of the book was written by E. I. Toropygin and is devoted to profiling of cams through ellipses. It deals with the theory of cam profile formation from integrated arches of ellipses, comparison of cam kinematics with profiles created by arches of circles, ellipses and parabolas and kinematic schemes of mechanisms for profiling of cams through ellipses.

The other five chapters of the book were written by Reshetov. In Chap. 2 forces in course of force closure and form closure of cam mechanism pairs are considered,



Фиг. 203. Кинематические диаграммы при движении с постоянным ускорением.

Фиг. 204. Кинематические диаграммы при гармоническом движении.

Фиг. 205. Кинематические диаграммы при движении с ускорением, изменяющимся по синусоиде.

Фиг. 206. Кинематические диаграммы при движении с ускорением, изменяющимся по трапеции.

Fig. 10 Model laws of cam follower's motion

the accounting of a pressure angle at force calculation. Chapter 3 is devoted to profiling of cylindrical and disk cams through arches of hyperbolas. Profiling of cams through arches of the overturned parabola is described in Chap. 4. The two final chapters cover a theme of cam profiling under laws of linearly-decreasing (Chap. 5) and square-decreasing (Chap. 6) acceleration (Fig. 17).

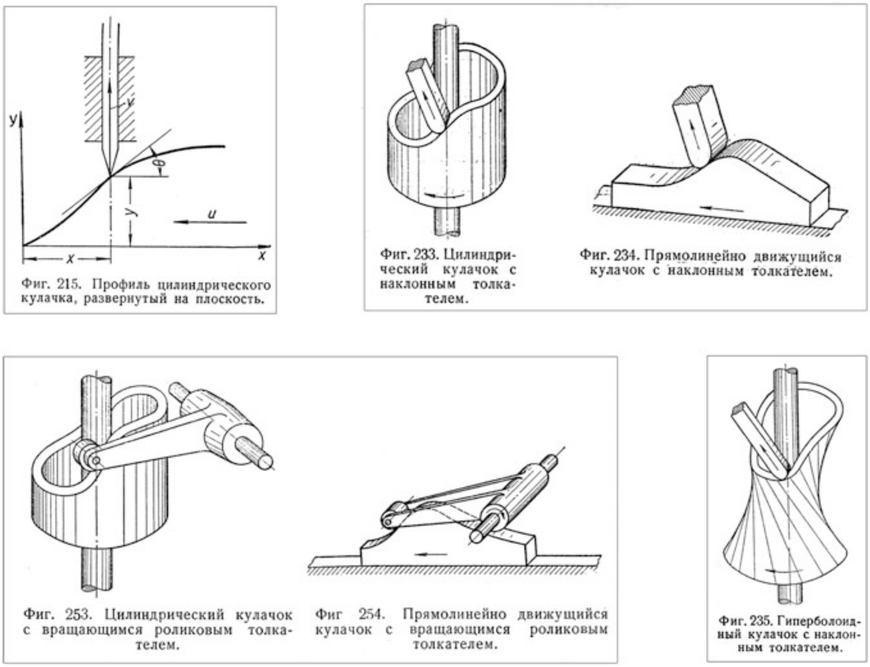


Fig. 11 Mechanisms considered in Chaps. 3–5 of the book «Cam mechanisms»

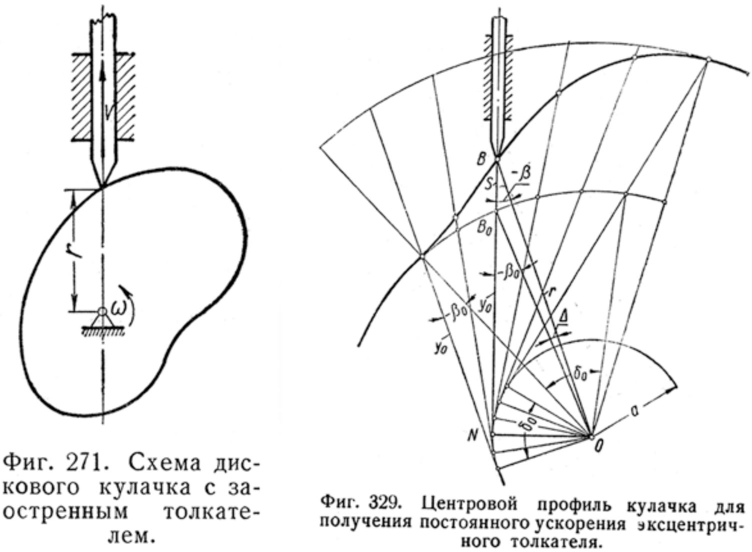
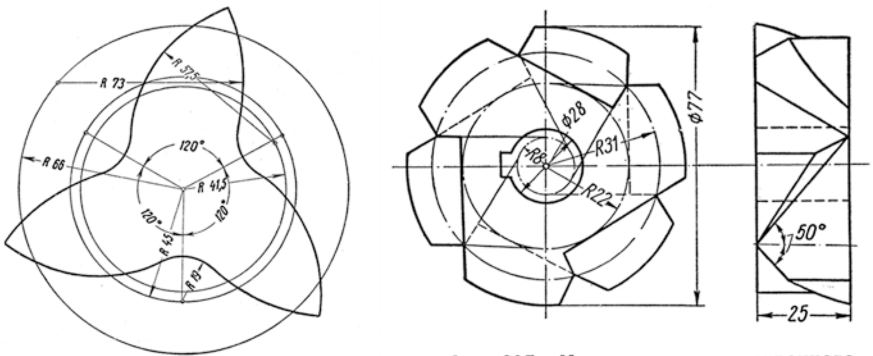


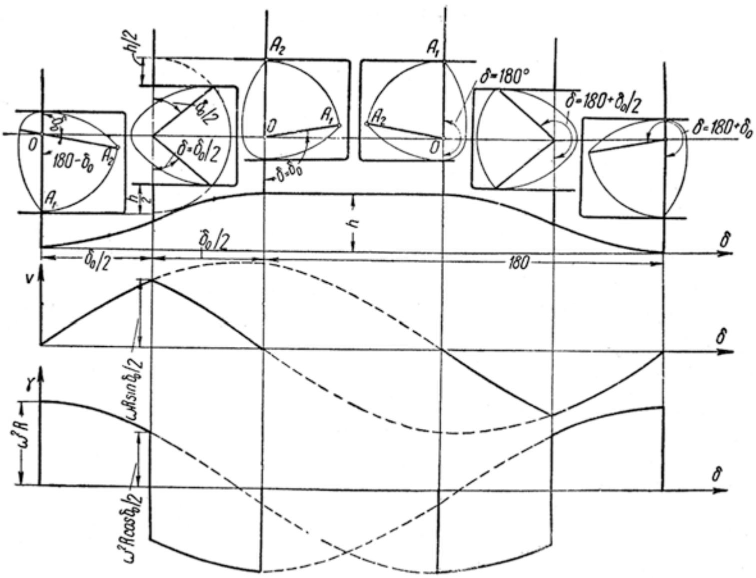
Fig. 12 Mechanisms considered in Chaps. 6–7 of the book «Cam mechanisms»



Фиг. 378. Кулачок контроллеров ПКГ-320 и ПГК-756.

Фиг. 387. Чертеж пространственного кулачка.

Fig. 13 Cams designed by L. Reshetov for group controller of electric locomotives



Фиг. 410. Работа треугольного эксцентрика.

Fig. 14 Working diagram of a cam mechanism with triangle eccentric cam

The last monograph of L. Reshetov «Designing of rational mechanisms» written in 1967 was numerously republished (1972, in further editions—«self-aligning mechanisms. Reference book», 1979, 1985, 1991). That book defines the new research direction in designing and constructing of mechanisms—creation of mechanisms without redundant and passive constraints. For a long time the approach

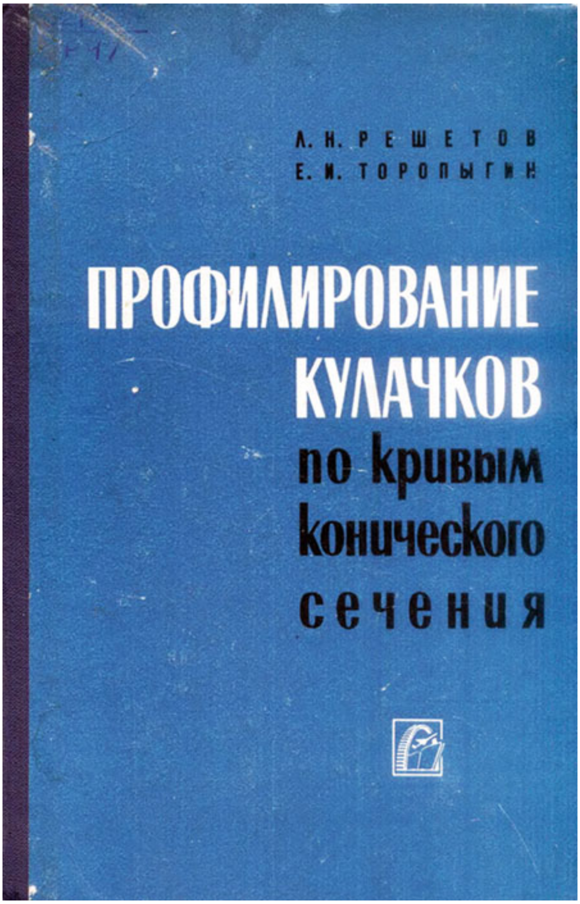


Fig. 15 Cover of a book «Profiling of Cams by curves of conic section»

offered in it encountered the resistance of experts, and nowadays the relation to these mechanisms are ambiguous. Mechanisms without redundant constraints are statically determinate; they allow decreasing requirements to manufacturing accuracy of links and kinematic pairs, to increase durability and to reduce a wear of its kinematic pairs. But thus kinematic pairs have a larger number of mobilities, they become more difficult and expensive in manufacturing, also accuracy and stiffness of the mechanism often decreases.

Mechanisms with redundant constraints provide their own operability due to backlashes in kinematic pairs, accuracy of their location and orientation and also due to pliability of links of the mechanism. Therefore a designer ought to choose between use of mechanism with redundant constraint and rational mechanism without those. Reshetov stated his opinion as follows: «In 1951 the author came to a conclusion that with a few exceptions one must apply only mechanisms without redundant constraint. Exceptions were caused by lack of suitable structure schemes. At present such schemes are found for the majority of «exceptions».

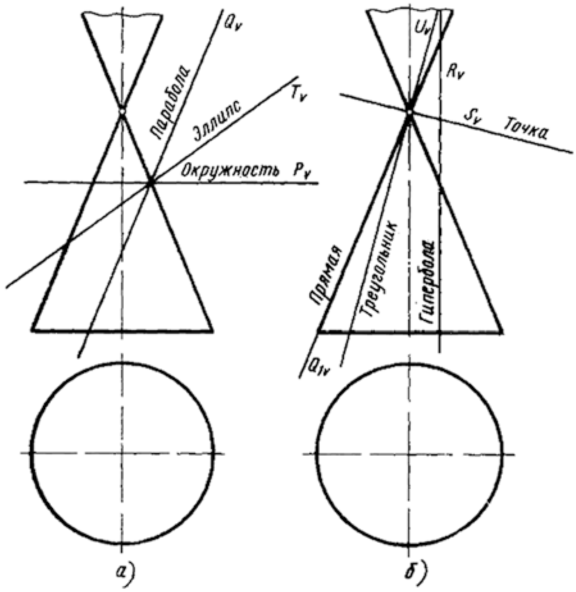


Рис 1 Пересечение конуса плоскостями различного по о жения

Fig. 16 Sections of cone and proceeding *curves*: *circle*, *ellipse*, *parabola* and *hyperbola*

Therefore in all cases they should be looked for. The principle of statical determination allows us to get a scientifically reasonable solution of which kinematic pairs and where in the mechanism should be applied, i.e. to lift a section of structure of mechanisms theory up to the science level».

The first chapter of the book was entitled "General Theory". There are basic concepts and definitions, concept formulation of statically determinate mechanism, redundant and passive constraints and local mobilities. Also it consists of a kinematic pair table (Fig. 18), including flexible tapes and kinematic connections. The structural formula of Malyshev-Somov and its specification of O. G. Ozol which allows calculation of a number of redundant constraints and also a table of kinematic joints are shown and considered, further replacing pairs with several mobilities by one-mobility pairs. In the conclusion there is the new method of identification of redundant constraints offered by L. Reshetov (Fig. 19). The author formulated it as follows: «Redundant constraints and mobilities of the mechanism may be determined by considering of mobilities at the contour, which is suitable to spread out on three axes of coordinates. For the closure of contour we need 6 mobilities: 3 linear and 3 angular. Linear mobility may be replaced by angular around the axis, perpendicular to a linear surface, if the angular mobility is redundant and if there is a joint by the rotation of which that change makes. Absence of one of the mobilities specifies tightness or redundant constraint. Presence of two mobilities of one type specifies to general or local mobility in the mechanism».

Fig. 17 Covers of Russian, Spanish and English editions of L. Reshetov's book «Designing of self-aligning mechanisms»

In Chap. 2 the influence of a friction on self-aligning of mechanism links is considered. The friction in pairs can remove a part of its mobilities, causing additional tension and deformations, and reducing accuracy of self-aligning of links. In Chap. 2 Sects. 2.2–2.5, resistance to a self-aligning in cylindrical, plane, spherical pairs and in rolling bearings is defined.

Chapter 3 is devoted to rational schemes of mechanisms with the lower pairs. It begins with rational schemes of motionless connections. Such connections apply to fastening of machines on the bases. At discrepancy of manufacturing the inhaling of a base bolt will not cause deformations of details and additional stress in them. Statically determinate motionless connection puts on 6 conditions of constraint, eliminating movement on three linear and three angular coordinates. At the beginning of the chapter motionless connections consisting of six, five, four and three kinematic pairs are described (Fig. 20). Further there are directing lines of rectilinear movement, wedge, screw, four-bar (slider-crank and crank-and-rocker) and other mechanisms with their rational structural schemes (Fig. 21).

In Chap. 4 spatial mechanisms with the lower pairs are considered. Here rational schemes of mechanisms of hydraulic actuators (4.2), helicopters (4.3), crushers (4.4), driveshaft (4.5–4.8), locomotives (4.9) and current collectors and slip rings (4.10–4.14) are provided.

Chapter 5 is devoted to kinematics of mechanisms taking into account distortions of links. Here sinus and tangential of three-dyads driveshaft mechanisms are considered.

The last Chap. 6 describes creation methods of rational schemes of mechanisms with the higher pairs. Cam mechanisms (6.1), ordinary tooth gearings (6.2–6.7), planetary mechanisms (6.8–6.11) and wave gear trains (6.12) are considered in that chapter. On Fig. 22 also some schemes of rational mechanisms, provided in it, are shown.

Таблица 1

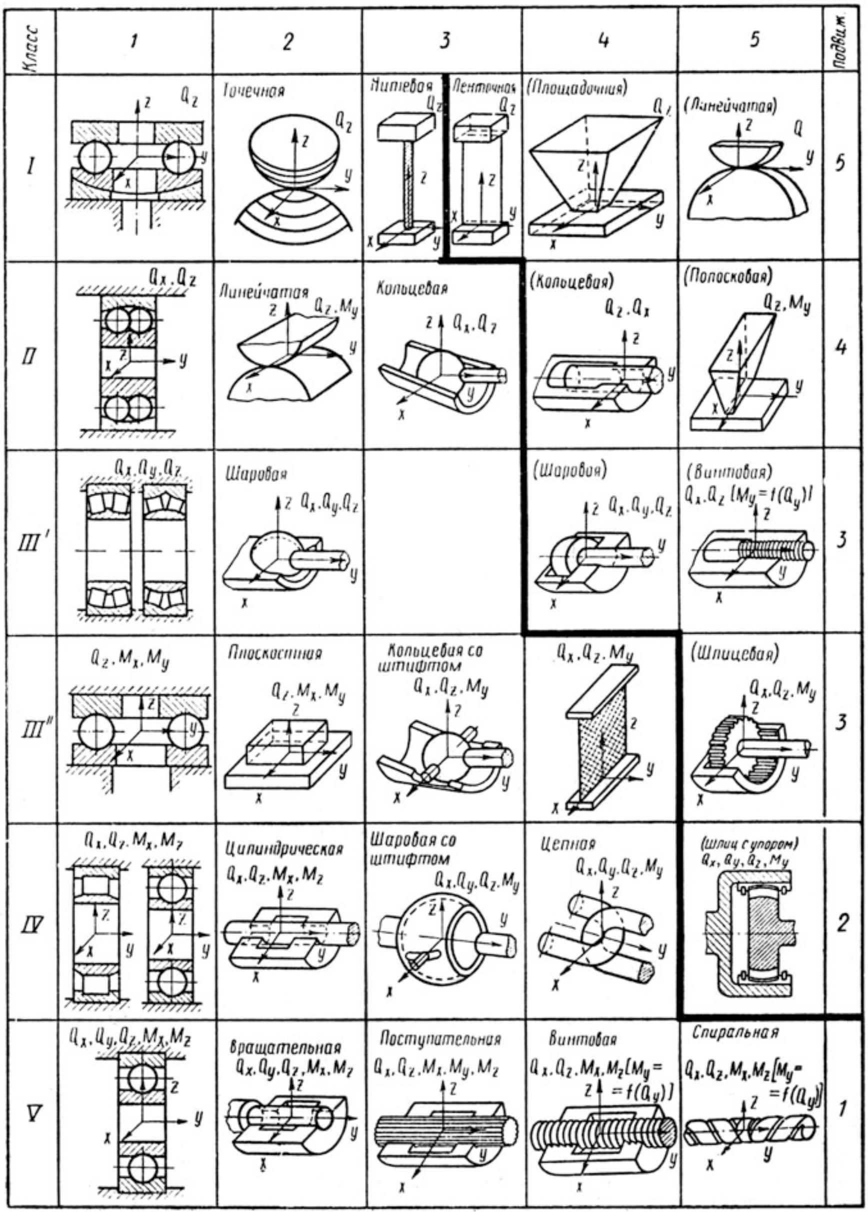


Fig. 18 Table of kinematic joints from L. Reshetov's book «Designing of rational mechanisms»

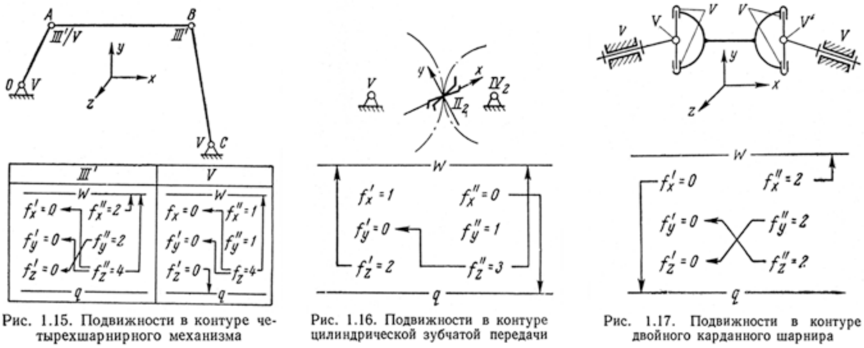


Fig. 19 Examples of identification of redundant constraints by L. Reshetov's method of analysis of mobilities

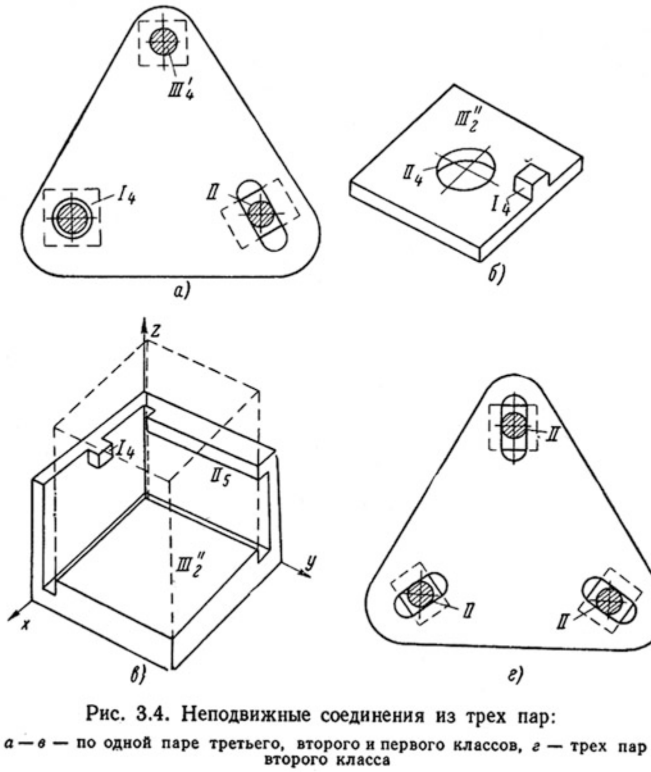


Fig. 20 Rational construction of a motionless bearing of three pairs

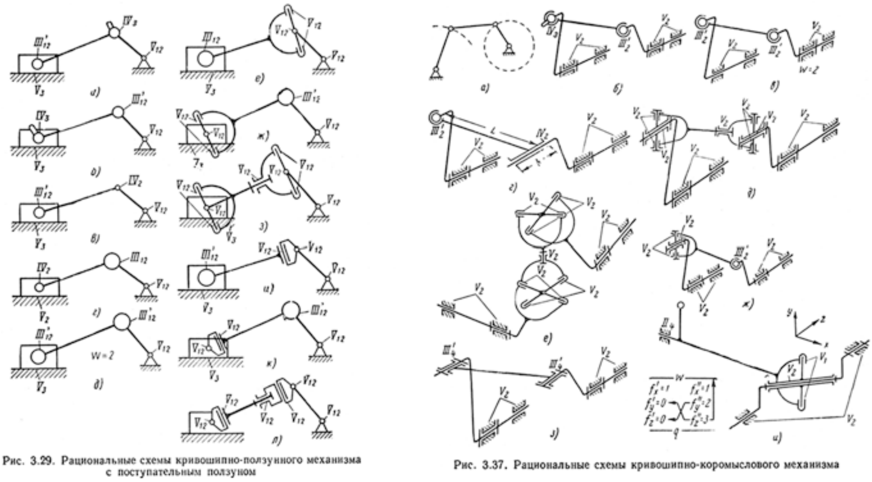


Fig. 21 Examples of rational schemes of slider-crank and crank-and-rocker mechanisms

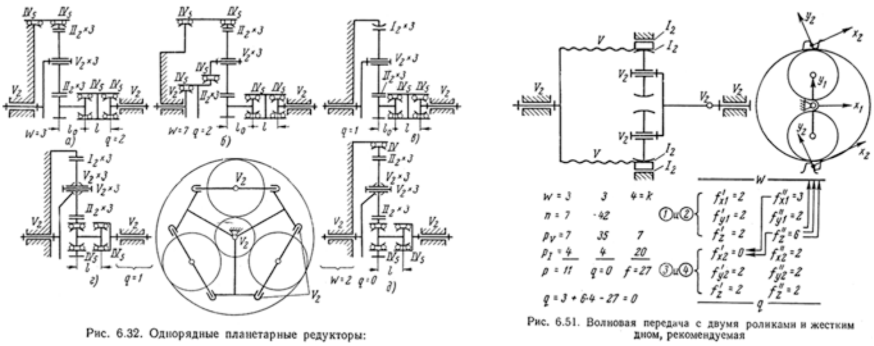


Fig. 22 Examples of rational schemes of mechanisms with higher pairs

We described the Second Edition of L. Reshetov's book, written in 1972. Subsequent editions were expanded and added to. It should be noted that this highly considered book has been published in English (1986) and in Spanish (1988).

Among L. Reshetov's numerous works we would like to look more closely at one little-known paper devoted to design of auditorium boards. From this article it is obvious that he was both an outstanding engineer-designer and a talented professional teacher. The high-class professional cares not only for the content of his lessons, but also for its quality, and he pays much attention to its representation to the audience. Further, there is a quote from this article: «The good auditorium board should satisfy three conditions: first, the board should have sufficiently squared corners; second, the board should be highly visible; third, the surface of the board should be whole, without division into parts». The size of a board is

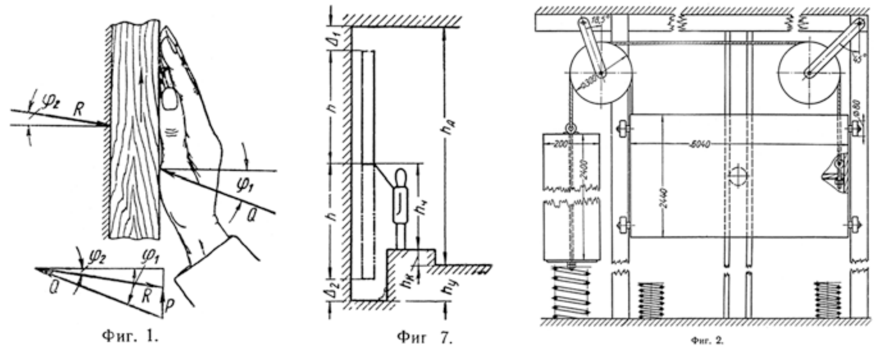


Fig. 23 Illustrations from L. Reshetov's paper «Designing of auditorium blackboards»

defined not only by the size of the audience and number of students; it is defined also by the content of the lecture.

The applied mechanics and TMM auditorium, where lectures contain complex drawings and mathematical conclusions, needs especially large boards. In the article it is recommended that one count the square of a board multiplying 1 m^2 by length of audience so for audience on 100 people the board in the square 15 m^2 was designed. {The board should be mobile so that the lecturer can write on spaces that will be higher than his head, and they would be visible to the audience. Further, the critics of the board executed in the form of a continuous tape, and a board, «consisting of two boards suspended on blocks so when the forward one rises, back falls, and on the contrary». The board should move a hand friction about its surface. The effort of movement should not be small, otherwise the board will move from a chalk friction during a writing process, but should not be big that not to tire the lecturer at all. The recommended effort amount is about 3–4 kg. Further in the paper the construction of a board designed for the audience number 319 of Bauman MHTS is described, drawings of nodes and details (the Fig. 23) are given.

4 Educational Activity

L. Reshetov possessed unique engineering intuition along with profound and versatile knowledge. He essentially transformed the methodical work of the department and the teaching processes of TMM. He constantly entered scientific and methodical seminars where in the face of the department, including staff teachers of and postgraduate students, made his own speeches. Professional development of tutors, their acquaintance with new scientific and methodical researches, was the purpose of these seminars. Reshetov insisted on obligatory participation of teachers in preparation of responses on papers, reviews and

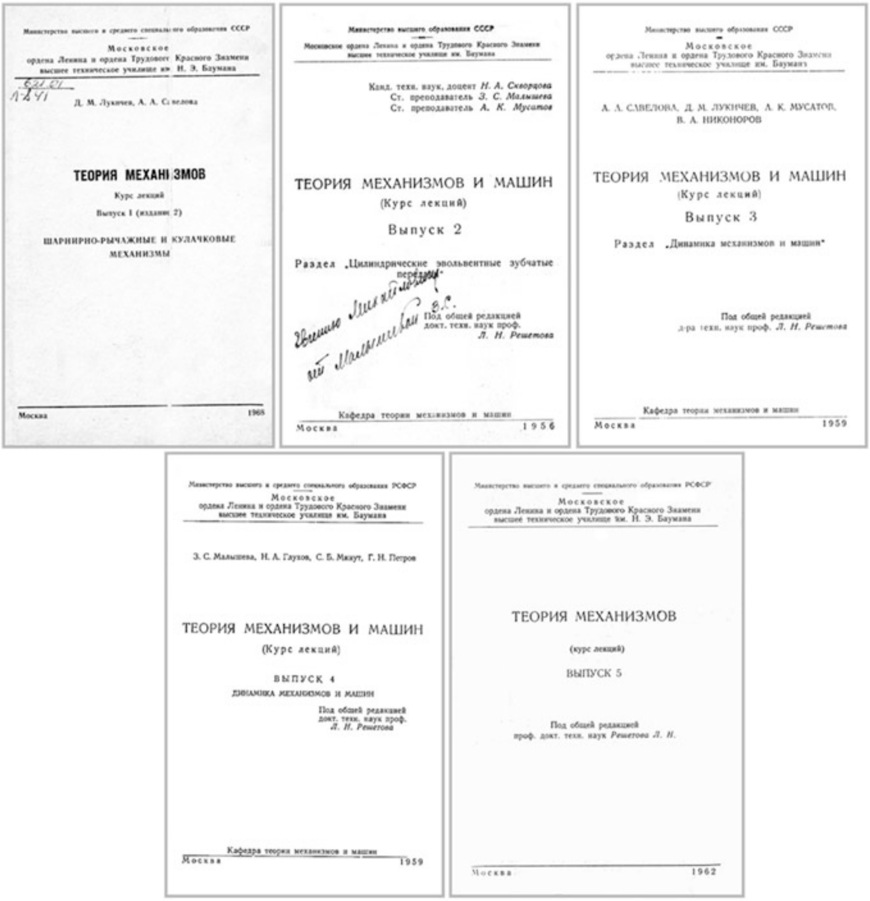


Fig. 24 Covers of course of lectures on TMM, created in a department under L. Reshetov's edition

conclusions reached according to demands for inventions. For instance, he included calculation methods of correction of involute gearings in the training course of Applied mechanics, having students carry out a calculation of meshings in their practical works.

Reshetov paid much attention to availability of lecture material for students. As lectures on TMM contain a lot of complex schemes and drawings, he demanded that all the material of a given lecture be placed on the blackboard. He was the first to try to state calculation techniques as algorithms of numerical calculation, leading them to a form convenient for calculation of processes produced on a calculating ruler. He invented a new calculating ruler which allowed carrying out some engineering calculations more simply. The algorithmic form of calculation techniques simplified further transition to calculation on the computer. Reshetov

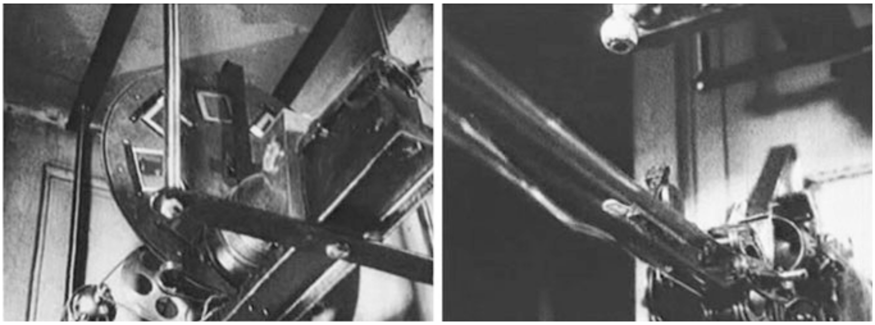


Fig. 25 Automatic projective device, created by L. Reshetov in 1932 (frames from the film devoted to MHTS 100 anniversary)

was the initiator and the editor of five releases of lecture abstracts on TMM (the Fig. 24) (Lukichev and Savelova 1968; Skvortcova and Musatov 1956; Savelova et al. 1959; Malysheva et al. 1959; Popov et al. 1962) and the coauthor of three books of problems on TMM.

Still in the 1930s he created a projective device for automatic demonstration at lectures of slides with photos of real mechanisms and machines and filmstrips (Fig. 25). In his autobiography, which stores a personal record of Reshetov, there are such words as these: «On November 27, 1931 L. P. Smirnov petitions for L. N. Reshetov's transfer into associate professors, putting the 16 help sheets onto the petition and describing the created L. N. Reshetov an automatic film projector, and highly estimating his publishing paper on cams of internal combustion engine». As it appears from the article, Reshetov was one of the authors of the collection of help sheets released under edition of L. P. Smirnov (Golovin and Golovina 2012).

5 Inventions of L. Reshetov

The essential place in L. Reshetov's scientific heritage is with respect to his inventions. In summary, he received more than 80 copyright certificates and patents, more than a half of which were produced and demonstrated. His inventions related to electrical devices and traction transmissions of locomotives and electric locomotives, mechanisms of watches and clocks, and other areas of techniques. In May of 1971 he was a first employee of Bauman MHTS to receive an honorary rank of «Honored Inventor of RSFSR». He was a chairman of the All-Union society of inventors and rationalizers of MHTS, a member of the Advisory council of the State Committee of inventions of the USSR. Many inventions had formed a basis of scientific works of his graduate students and found their reflection in the models of the mechanisms collection at TMM department of MSTU (Fig. 26).

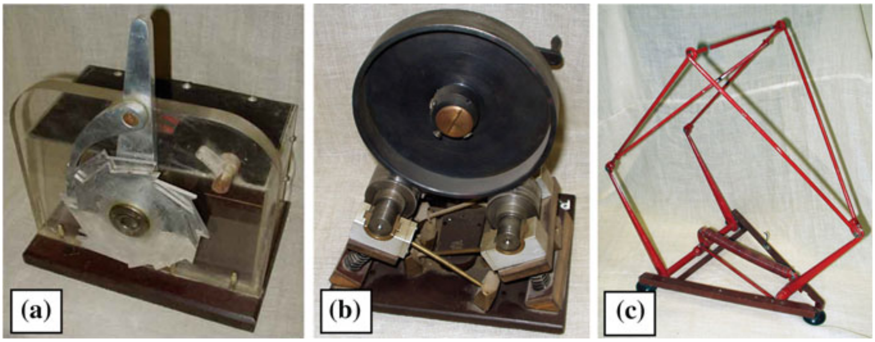


Fig. 26 Models of L. Reshetov's inventions. **a** The clock calendar. **b** The basis of cement furnace. **c** Electrical locomotive's slip ring

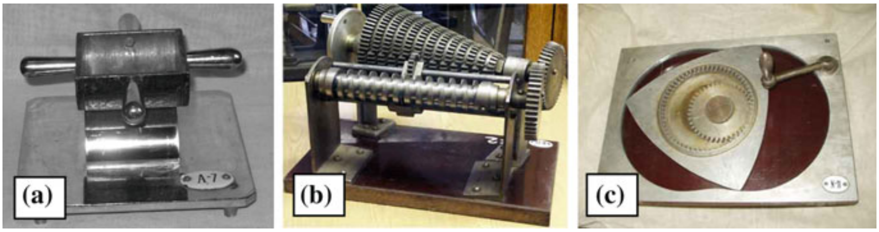


Fig. 27 Models of a collection of the TMM department created with the assistance of L. Reshetov. **a** Pair with linear contact. **b** Gear variator. **c** Vankel's engine

6 Reshetov, a Curator of Collection of Mechanisms at TMM Department

Since 1930, i.e. since the beginning of his work at the department of Applied mechanics, Reshetov had been a keeper of a mechanisms collection of the department. He performed a great work on drawing up of a catalog, ordering of the collection models according to the classification that he had created. The collection expanded with even larger numbers of new models, mostly made in workshops of a department (Fig. 27). In particular the following sections were created: kinematic pairs and motionless connections, rational lever mechanisms, simple and complex tooth gearings, cam mechanisms (Golovin et al. 2007; Golovin and Tarabarin 2008).

Prof. L. N. Reshetov made many models of mechanisms by himself. He assembled some of them previously from child-meccano details (the Fig. 28). Considerably his efforts kept a historical part of a model collection of Ershov and Reuleaux.

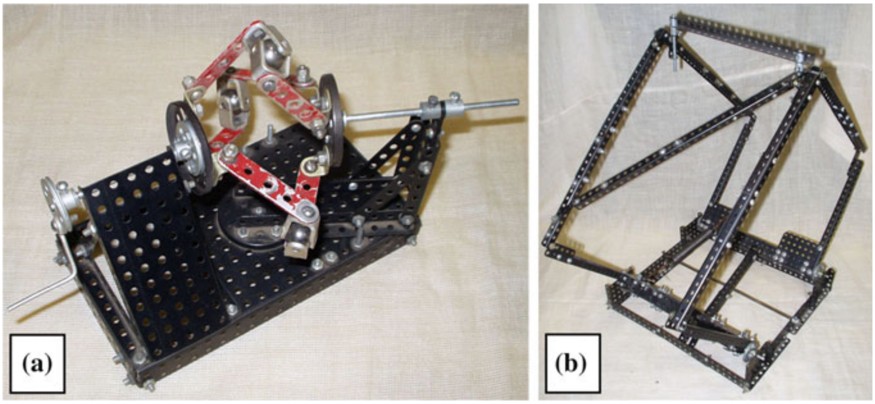


Fig. 28 Models, assembled by Reshetov from child-meccano details **a** Roller driveshift. **b** Slip ring

7 School of Sciences of Self-Aligning Mechanisms

As it was noted earlier, Reshetov had prepared more than 20 postgraduates. Their research activity was closely connected with directions of Reshetov's scientific investigations. His first postgraduates were engaged in research on tooth gearings (Malkin 1947; Bogolubsky 1951; Soldatkin 1969). Thus L. Malkin (in 1947) created a gear pair with round gears and variable transmission ratio. K. Bogolubsky (at 1951) designed a geometrical theory of spatial gearings with gear processing by ram-machines. E.Soldatkin (in 1969) was investigating gear pairs with variable shaft angles. A.Nemkevich (in 1965) led researches of typewriter linkages (Nemkevich 1965).

After 1965 works of Reshetov's postgraduate students were generally conducted in the direction of development of rational or self-aligning mechanisms. Postgraduates Solomin (1968) and Aliev (1974) were engaged in development and research of lever mechanisms of current collectors; Pavlenko (1971) carried out those with automatic drive mechanisms of an electric railroad rolling train; Ermak (1973) had been projecting counterbalancing devices of two-line tooth gearings; Samohvalov (1970) had done it with drums for assembly of auto tires; Gulida (1972) occupied with synthesis of the multispan revolving furnaces mechanisms without redundant connection (Solomin 1968; Aliev 1974; Pavlenko 1971; Ermak 1973; Samohvalov 1970; Gulida 1972). During performance of these works, mechanisms without redundant constraints were created, many of them being recognized as inventions. Development and improvement of the general theory of mechanisms structure, methods of identification and elimination of redundant constraints had proceeded. Postgraduate Pavlova (1976) developed a method of structure analysis of mechanisms, based on graph theory; postgraduates Shamaidenko (1965) and Budyka (1976) worked on creation of methods of replacements of pairs with kinematic connections and improved methods of mechanisms mobility analysis (Pavlova 1976, Shamaidenko 1965, Budyka 1976). From this incomplete list of the research works executed by postgraduate students under the direction of L. N. Reshetov, it is possible to draw a sure conclusion about creation of the science school of self-aligning mechanisms.

8 Modern Interpretation of Reshetov's Researches

Reshetov's merits in development of Theory of Mechanisms and Machines (and not only in it) are highlighted in the book «MSTU Schools of Science. The History of Development» (Scientific Schools of Bauman Moscow State University, 2005). His researches and inventions were of great importance and valuable in improvement of locomotives and electric locomotives. His designs and calculation methods for cam mechanisms continue to be widely applied nowadays in various industries. In due time they promoted creation of advanced turning automatic machines and internal combustion engines. His ideas on structural synthesis and analysis of mechanisms have been developed both in research work of his students-successors, and in research activity of other investigators (Kraynev 2003). Methods of determination of redundant constraints and local mobilities came into modern TMM course programs of Russian technical universities. Monographs devoted to designing rational or statically determinate mechanisms have appeared (Kojevnikov 1979). In this regard, a relation to Assur's structural classification has changed for the reason of its importance as an instrument for creation of rational schemes of mechanisms. Besides, a splitting of the mechanism into Assur structural groups allows making universal computer programs for force and kinematical calculation of mechanisms. Until then such programs had been made only for simplest two-dyads Assur groups. This classification extends not only to lower pair mechanisms, but also to those with higher pairs. The method of contour mobility analysis began to be used at formation of spatial groups of Assur. Recently a site under the name «Correct structure of machines» (Dobjinskiy 2002, The Internet Site), which propagandizes L.Reshetov's ideas about self-aligning mechanisms among designers—practitioners, appeared on the Internet.

9 Conclusion

L. Reshetov's researches and inventions brought an essential contribution both in theory and in practice of modern machine science. His scientific activity was devoted to gearing, epicyclical planetary trains and cam mechanisms. Reshetov's investigations have strongly affected development of railway transport. L. Reshetov found a new stage of TMM in designing rational mechanisms. The large number of postgraduates, trained and prepared by him, suggests the strong foundation of his own school of science.

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Simon Stevin (1548–1620)

Teun Koetsier

Abstract Simon Stevin was born in Brugge in Flanders. In 1581 he left Flanders and settled in Holland. Stevin is one of the few truly great Flemish/Dutch mathematicians. Stevin was a typical Renaissance scientist. He wrote extensively on many subjects: engineering, bookkeeping, algebra, perspective, astronomy, music and others. He is best known for his highly original work in statics and hydrostatics. He also applied the results of this work in the analysis and synthesis of machines.

1 Biographical Note

Simon Stevin was born in Brugge in Flanders, very probably in 1548, as a natural child. He was well educated. As an adult he read French and Latin and possibly German and Italian as well. We know that he worked as a clerk in Brugge and as a bookkeeper in Antwerp.

The war between Spain and the Republic of the United Netherlands caused a true exodus of rich and talented people from the southern provinces that left Flanders and established themselves in the Republic in the north (Fig. 1). Simon Stevin was one of the talented men who left Flanders and settled in Holland. Stevin left Flanders quite early, in 1581. The true exodus started several years later in 1585 when Alexander Farnese, the Duke of Parma, conquered Antwerp and the catholic Southern Netherlands were separated from the protestant Northern Netherlands (Fig. 2).

Stevin arrived in Leiden in 1581 and 2 years later, in 1583 he enrolled as a student in the University of Leiden. In 1582 he published his *Tables of Interest*, a

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History of Mechanism and Machine Science 26, DOI: 10.1007/978-94-017-8947-9_14,

Fig. 1 Simon Stevin (1548–1620), portrait by an unknown artist, Library of Leiden University

useful text which enabled the user to determine amounts of interest without having to do multiplications. In 1585 he published *De Tiende*, in which the use of the decimal system for fractions was recommended. Although the idea was not completely original this was at the time a revolutionary proposal and Stevin was proud of the book. It was very influential. Stevin published a French translation himself and in 1608 an English translation appeared under the title *Disme or The Art of Tenths*. In an appendix Stevin argued that the systems of measuring weights, lengths, areas and volumes ought to be organized on the basis of the decimal system.

De Tiende beautifully illustrates Stevin's approach to any subject. On the basis of clear definitions or postulates, that are not only formulated but also explained, a theory is developed which is subsequently investigated from the point of view of its usefulness. Stevin firmly believed in the unity of theory and practice. In the 1580s Stevin published books on geometry, on arithmetic, on algebra and in particular on mechanics. However, at the same time he worked as an engineer. He obtained patents for various inventions. He worked with his friend, Johan Cornets de Groot, who was mayor of the City of Delft at the time. He also worked as an

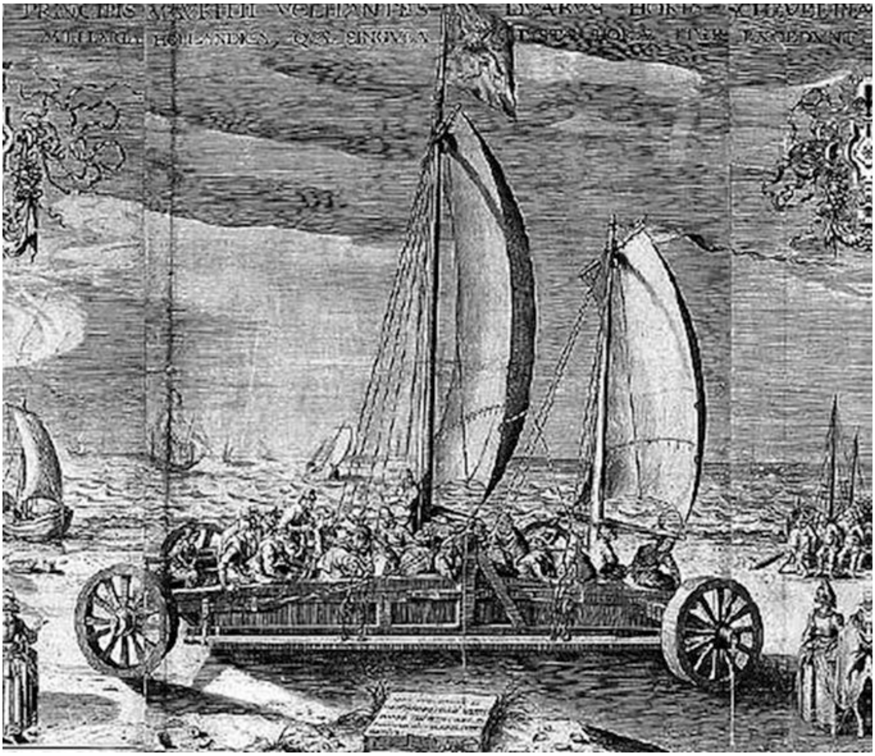


Fig. 2 Simon Stevin's sailing chariot. Central part of a drawing by Jacques Gheyn made in 1603

engineer for Prince Maurice, captain general and admiral of the States of Holland and Zeeland. He did this informally for 10 years until he was officially appointed in approximately 1993. Stevin travelled too. In the summer of 1591 he went to Dantzig in Poland.

Stevin wrote on many other subjects. He wrote on trigonometry, on perspective (because Prince Maurice wanted to learn about it), on astronomy, geography, navigation, military science, architecture, logic, music.

Around 1601 he executed a brilliant public relations stunt. He built a big sailing chariot, which Prince Maurice used to entertain his guests. The first trip was made in 1602 with Maurice and foreign diplomats on board. On the beach they covered a distance of nearly 100 km in a few hours. Although the idea of putting sails on a chariot was not new, Stevin's sailing chariot made a lasting impression. For centuries in the Netherlands Stevin's fame rested almost exclusively on it.

In 1612 he bought a house in The Hague. Between 1612 and 1616 his four children were born and Stevin married the mother of his children, Catharina Craiy, in 1616. He died in 1620.

2 The Historical Context: General

In 1579 six Dutch provinces decided to form together the Republic of the United Netherlands and they declared themselves independent of Spain. Starting from there, something amazing happened. A small country inhabited by merchants, sailors and craftsmen successfully fought the best armies in Europe and with the province of Holland in the leading role, the Republic of the United Netherlands developed in a few decades into a world power, politically, economically and culturally.

How was this possible? The inhabitants of the region north of the major cultural centers Gent, Brugge, Antwerp and Luik had the reputation of not being very subtle, but they were no barbarians. They were merchants and fishermen and they possessed a traditional superiority with respect to ships and crews. Striking is also the absence of a powerful nobility or clergy. The historian Huizinga relates these facts to the hydrography of the country: the omnipresent water inevitably led to the dominance of navigation and at the same time made the establishment of a central power difficult. Moreover, the Dutch with their boats and experience were in an ideal position to profit from the discovery of America and the route to the Indies.

Of course other factors played a role as well. The princes of Orange were capable commanders of the army and the Republic possessed the ideology necessary to fight a war against catholic Spain: Calvinism. And there were other favorable circumstances. France and England were busy solving internal problems thus creating opportunities for the Dutch. [For this section see Huizinga (1969) and Struik (1981).]

3 The Historical Context: Technical

Stevin's work in mechanics and the theory of machines is remarkable because of its emphasis on the close relationship between theory and practice. In the 16th century two kinds of texts on machines can be distinguished: theoretical texts and the so-called theaters of machines. A nice example of a theater of machines is Jacques Besson's *Theatrum Instrumentorum*, published in 1572. Stevin had access to this book. Such texts contain beautiful pictures of all kinds of real or imaginary machines. Theory is absent. Stevin had access to some of the theoretical works too. In these texts the emphasis is on principles and much less on the application of the principles to the complex machines depicted in the theaters of machines. Stevin was, for example, familiar with the pseudo-Aristotelian *Mechanical Problems* and he had read Commandino's Latin translations of Archimedes' works on statics and hydrostatics (*On the equilibrium of planes* and *On floating bodies*). Moreover, although Stevin rejected the approach of Jordanus, it seems probable that he was familiar with Tartaglia's publications on the work on the *science of weights* by this medieval author [cf. George (1934) and Koetsier (2010)]. On the other hand, it seems improbable that Stevin was acquainted with Heron's descriptions of the five simple machines when he published his major works on mechanics. He could have learned about them from Guidobaldo del Monte's *Liber mechanicorum* of 1577, but nothing in Stevin's work refers to Del Monte's book. Of all the texts we just mentioned Archimedes' works impressed Stevin more than anything else. The Archimedean Renaissance started with Commandino's translations of Archimedes' work and Commandino's book on centers of gravity. It continued with Del Monte's book on mechanics in which Del Monte's attempted to analyse the five simple machines by means of a deductive Archimedean approach. Yet in several respects in mechanics Stevin is the first true successor of Archimedes. In a very original and rigorous way he developed statics and hydrostatics deducing important new theoretical results. Moreover, he applied these results not only to the analysis of existing machines but also to the design of better wind mills.

4 Stevin's Works

In order to evaluate Stevin's work on the theory of machines we must consider the following publications on statics and hydrostatics from 1586:

- *The Elements of the Art of Weighing* (*De Beghinselen der Weeghconst*), 1586
- *The Practice of Weighing* (*De Weeghdaet*), 1586
- *The Elements of Hydrostatics* (*De Beghinselen des Waterwichts*), 1586

Moreover, we must consider the appendices to these works published in 1608 in Stevin's *Mathematical Thoughts* (*Wisconstighe Ghedachtenissen*):

- *Preamble of the Practice of Hydrostatics* (*Anvang der Waterwichtdaet*), 1608
- *Supplement to the Art of Weighing* (*Byvough der Weeghconst*), 1608

Finally we have the following unfinished texts published only after Stevin's death:

- *On the Most Perfect Cogs and Staves* (*Van Aldervolmaecste Cammen en Staven*)
- *On Mills* (*Van de Molens*).

5 Stevin's Statics: Vertical Weights

Stevin realized that Archimedes had given a beautiful theory of what Stevin called vertical weights. What was missing was a theory of oblique weights. Book I of *The Principles of the Art of Weighing* consists of two parts. Part 1 contains the theory of vertical weights, with the law of the balance as a central result. Part 2 is on oblique weights and entirely Stevin's original work. Important is Stevin's distinction between *weight* and *positional weight*. On the balance the positional weight is determined by the length of the arm and on an inclined plane the positional weight depends on the slope. Without exaggeration one can say that Stevin is the first to start the development of a *complete* coherent theory of 2-dimensional statics. Stevin did this, moreover, in a very rigid and clear way. The French historian Pierre Duhem wrote once that Stevin, even better than Euclid or Archimedes, applies definitions and postulates in such a way that the skeleton of the proofs become crystal clear and we can see exactly how its joints function/In French: "plus encore qu'Euclide et Archimède, Stevin s'efforce de mettre à nu l'ossature du raisonnement, afin que l'on en distingue tous les membres, que l'on voie le jeu de chaque articulation" (Duhem 1905–1906, p. 134).

Because Stevin's theory of vertical weights is similar to Archimedes' theory, we will skip it and illustrate the way in which Stevin applied this theory by means of some examples.

Example 1 Treadmills were at the time quite popular. Figure 3 shows a detail from a painting by the 15th century Flemish painter Hans Memling depicting a big crane that operated at the time in Brugge.

In *The Practice of Weighing* (see Fig. 4) Stevin treats a man inside a tread wheel, weighing for example 150 lbs, as a vertical downward force. In the position drawn in the picture the center line of gravity of the man is IK. The weight H is lifted by means of a windlass, a machine that Stevin had analyzed one page earlier. By means of the rope the weight H exerts a force equal to H on the axle of the windlass at a distance equal to the semi diameter GE of the axle. If GK is 4 times longer than GEB we can conclude by means of the law of the balance that the man in his present position can lift 4 times his own weight: that is 600 lbs.

Example 2 Figure 5 shows Stevin's design of a machine he called the *Almighty* (Almachtich in Dutch). Stevin refers at this point to Besson who had put a drawing in his book of the machine that Archimedes allegedly used to pull a ship from the shore into the sea, the *Charistion* (called polyspaston by others). In his *Mechanics* Heron executed similar though experiments—combining simple machines to get an enormous mechanical advantage—but Stevin presumably had no access to Heron's *Mechanics*.

Stevin said about his own design, comparing it to other solutions (see, for example, Fig. 6): "[it] is more suited to such work, for the following reasons: sturdier and more durable construction; of lower cost; by which is done more in shorter time, and (like the Charistion) of infinite power, that is to say: potentially, not actually" (Stevin 1955, pp. 354–355).

Stevin's calculation of the mechanical advantage of the gear train is based on a repeated application of the law of the lever, but he actually calculates the ratio of the number of revolutions of the crank DLMN and the axle S. Below we will see the same approach in Stevin's analysis of windmills. This leads him to the conclusion that with a force of 25 pounds (he assumes that one man can exert such a force) a force of 5,400 pounds can be exerted. This sounds good, but it is questionable whether at the time a really reliably functioning *Almighty* could have been built.

Fig. 3 Detail from a retable by the Flemish painter Hans Memling (1430–1494)

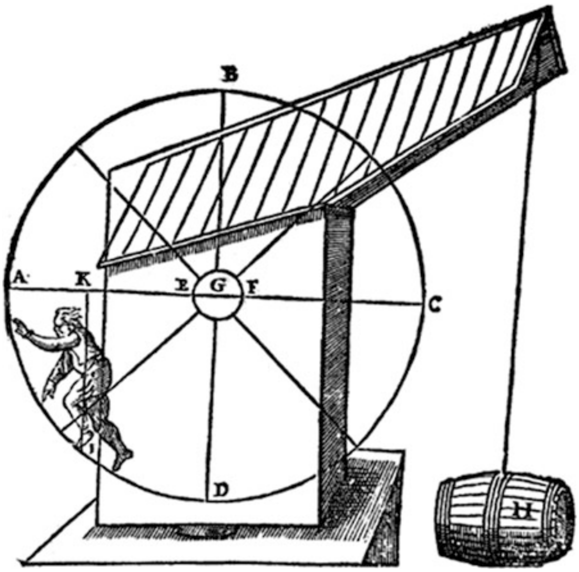


Fig. 4 Lifting a weight vertically by means of a treadmill. From "The Practice of Weighing" (Stevin 1955)

Fig. 5 Stevin's Almighty. From "The Practice of Weighing" (Stevin 1955, pp. 364, 368)

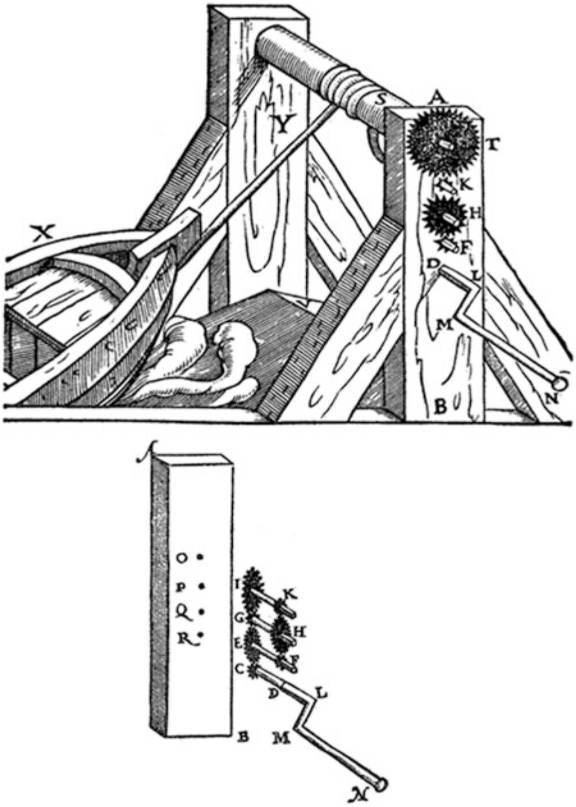
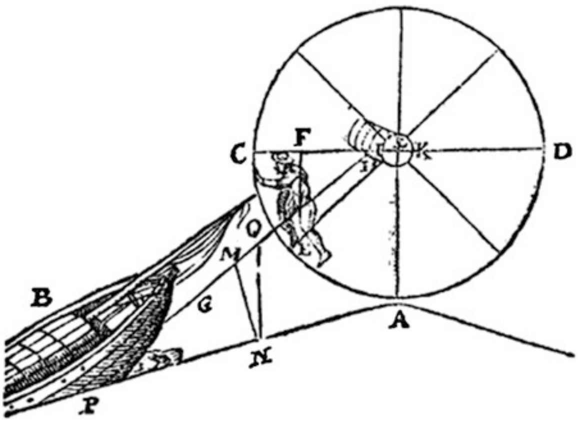


Fig. 6 Portaging a boat. From "The Practice of Weighing" (Stevin 1955, p. 354)



6 Stevin's Statics: Oblique Weights

Pulling ships out of the water requires raising weights obliquely. See Fig. 6. Stevin realized that in this case the Archimedean theory of vertical weights with the law of the balance in a central position is insufficient to determine the forces needed to portage the boat. A theory of oblique weights is needed.

The central result and the key to the treatment of oblique forces is the law of the inclined plane of which Stevin gave a lovely proof. Stevin derives the law of the inclined plane in a thought experiment by hanging a closed chain of identical iron balls on the two planes. See Fig. 7. The chain cannot start to move spontaneously, because this would give us a perpetuum mobile, which is absurd according to Stevin. Because of symmetry cutting off the lower part does not disturb the equilibrium and we see: the weights on the two planes are in equilibrium if their ratio equals the ratio of the lengths of the two planes. Feynman liked the proof. He thought—non e vero, ma e ben trovato—that Stevin had the picture put on his grave and Feynman commented: "With an epitaph like that on your grave, you are doing fine".

With a series of clever subtle thought experiments Stevin deduces other oblique forces needed to keep a weight on an inclined plane in its position (see Fig. 8) or a weight supported in one point (Fig. 9). In Fig. 8 the weights M, E, and P represent three different ways to keep the weight on the inclined plane in position. They are, respectively proportionate to, respectively, DL, DI and DC. As for weight E, Stevin's argument is impeccable. As for weight P, it is not, but his results are correct.

Although he does not explicitly phrase it, Stevin possessed the idea of the parallelogram of forces in statics.

This is in particular clear from the *Supplement to the Art of Weighing* (Stevin 1955, pp. 532–533). See Fig. 10.

The prism is hanging in the two points D and E. C is the center of gravity of the prism AB. CI represents the weight of the prism. HI is parallel to CE and KI is parallel to CD. Stevin writes: "As CI is to IH so is the weight of the prism acting on D" and "As CI is to IH, so is the weight of the prism to the weight acting on E".

7 Stevin's Hydrostatics

It is quite possible that the omnipresence of water in the Netherlands stimulated Stevin's investigations in hydrostatics. In *The Elements of Hydrostatics* he did not forget to point out to the United Netherlands the usefulness of the theory in their continuous dealings with water. Also in this book Stevin soon went beyond what Archimedes had done. It seems that Stevin was the first scientist who really understood the phenomenon of pressure in water. Many of the results are based

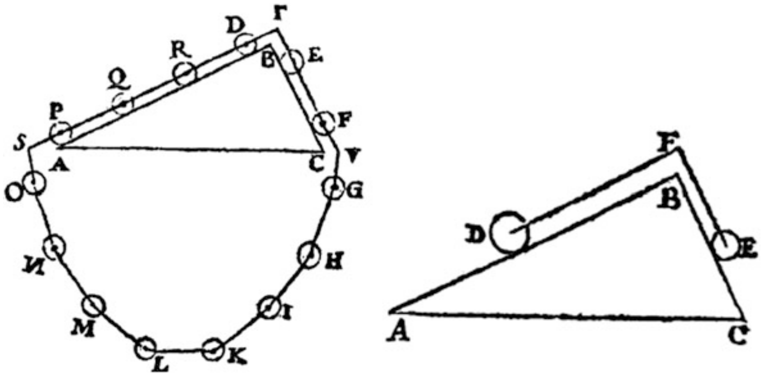
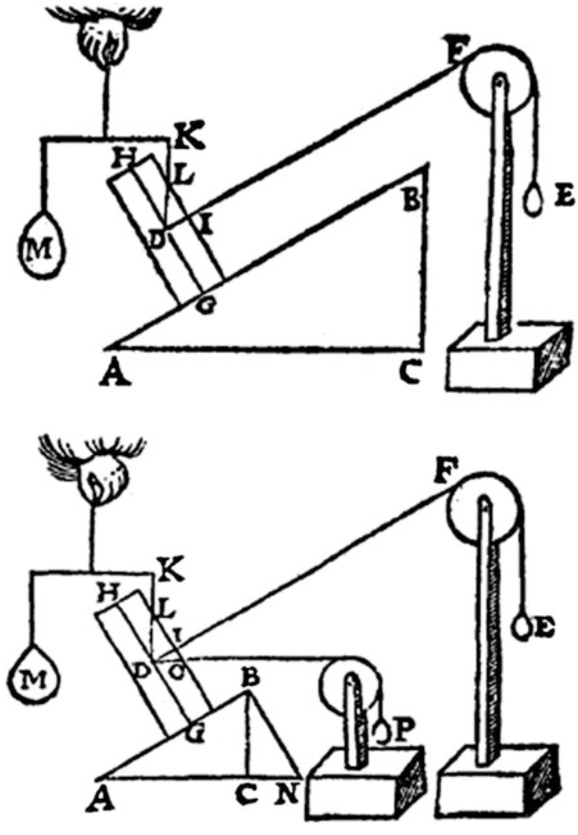


Fig. 7 *Right* Equilibrium if and only if weight D: weight E = AB: BC. *Left* The thought experiment that yields the proof. From "The Practice of Weighing" (Stevin 1955, pp. 184, 186)

Fig. 8 A weight is kept in position on an inclined plane in three different ways. The weights M, E, and P are proportionate to, respectively, DL, DI and DC. From "The Practice of Weighing" (Stevin 1955, pp. 188, 190)



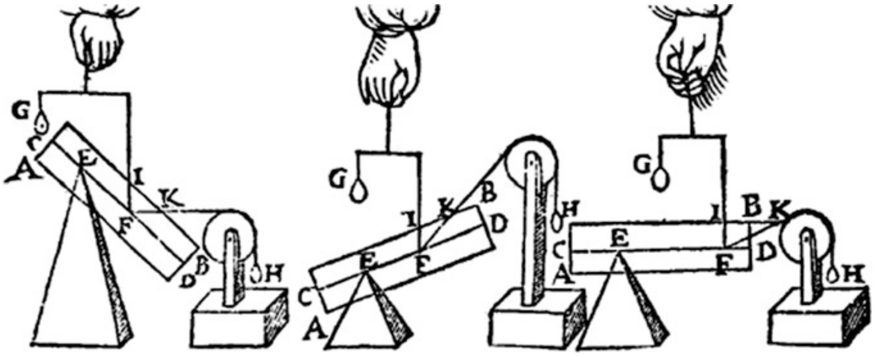
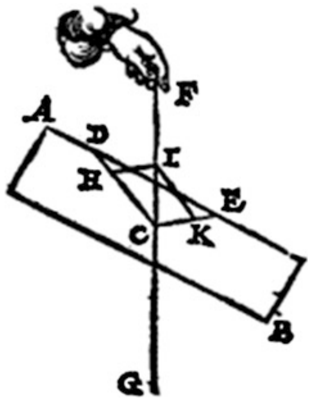


Fig. 9 The weight is kept in position in two different ways in three different situations. In each situation: weight G: weight H = IF: FK. From "The Practice of Weighing" (Stevin 1955, p. 204)

Fig. 10 Stevin has the parallellogram of forces. From the supplement to the art of weighing (Stevin 1955, pp. 532–533)]



upon a new kind of thought experiment. Stevin allows parts of the liquid mass to become solid and he assumes that this does not disturb the equilibrium.

In corollary 2 of proposition X Stevin starts with a vessel ADCB filled with water (Fig. 11, left). Stevin has just established in proposition X that the weight resting on, for example, the bottom area EF is equal to the weight of the column of water EFHG above it. If we solidify the white area, we are left with a volume of water IKFELM. Yet the weight resting on EF will not have changed. The same holds in Fig. 11 right. This phenomenon is often called the *hydrostatic paradox*, because it seems that after the solidification much less water is weighing on EF.

Clearly Stevin's results are equivalent to what is usually called Pascal's law. It led to the invention of the hydraulic press by Joseph Bramah (1748–1814). Another important new result Stevin obtained is the following. See Fig. 12. The pressure of water against a vertical wall is equal to the weight of half the prism of water. Moreover its pressure center is at one third of the height of AE.

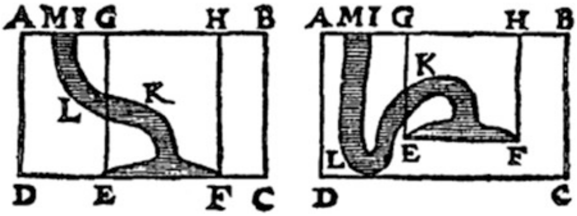


Fig. 11 The hydrostatic paradox. Picture from "The Elements of Hydrostatics" (Stevin 1955, p. 424)

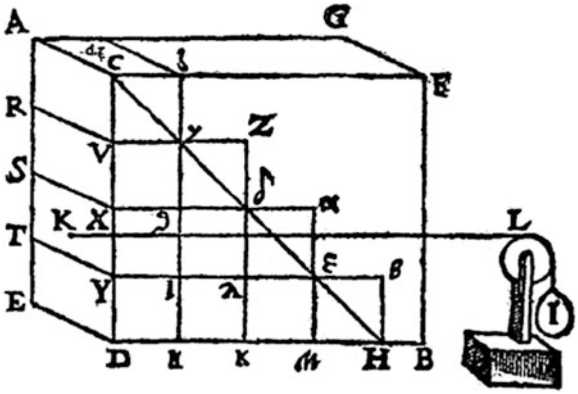


Fig. 12 Picture from "The Elements of Hydrostatics" (Stevin 1955, p. 430)

8 Stevin's Work on Windmills

Already in 1586 and 1588 Stevin obtained patents on windmill designs. Stevin also actually built such mills. They were drainage mills meant to lift water by means of a scoop wheel from a basin with a low water level to a basin with a higher water level. Particularly interesting is the case of the mill he built in a polder near the city of IJsselstein, south of the city of Utrecht. The mill was built on the basis of a new design. The contract was signed on April 8, 1589.

Stevin promised to build a mill of wood and iron for 630 Carolus Florins (Stevin 1966, p. 324). The mill, that "would draw as much water as two of the best mills of thereabouts could do", would be ready in the fall of 1589. It soon became clear that the project was vexed with problems. In the end Stevin accused the board of the polder of mismanagement and the representatives of the polder accused Stevin of mistakes in the design of the mill.

It is quite possible that the problems with the mill near IJsselstein led Stevin to write the text called *On Mills* (Van de Molens) which contains calculations concerning both mills of the traditional type and mills of a different type based on Stevin's new design. Stevin's considerations are based on an abstract kinematical model of the classical Dutch drainage mill. See Fig. 13.

He treats the gear trains in exactly the same way he had treated them in the *Almighty*. Let the numbers of teeth of respectively C, S, N and O be N_C, N_N, N_S

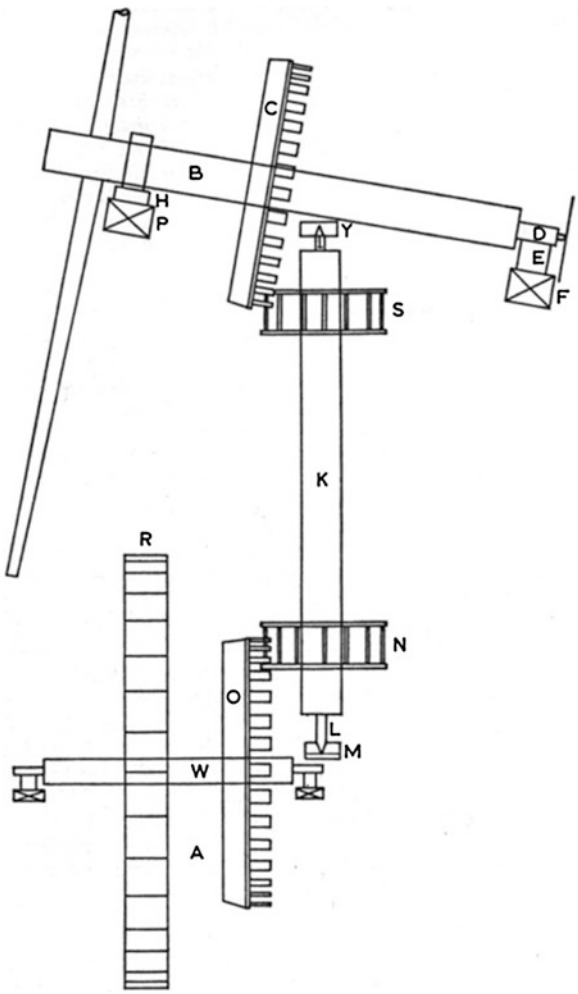


Fig. 13 The old design. The gear train between the wings and the water wheel consists of crownwheel C, lanternwheels S and N, crownwheel O (Stevin 1966, p. 315 and Plate Ia)

and N_O. Then we have for the number of revolutions $R_{windshaft}$ of the windshaft and the number of revolutions $R_{scoopwheelshaft}$ of the scoop wheel shaft the following ratio:

$$R_{windshaft}/R_{scoopwheelshaft} = (N_S.N_O)/(N_C.N_N).$$

Stevin does not use formulae, but this relation is crucial in his calculations. He used it in modern terms to determine the relation between the input moment exerted by the wind and the output moment needed to lift the water, because by repeated application of the law of the balance one can show that the ratio of these moments is equal to it.

Stevin had measured the dimensions and the numbers of teeth of the wheels in several existing windmills. His first goal was to calculate the force that the wind was exerting on the wings in these mills. In order to do this he modeled the scoop wheel as a vertical rectangular blade with low level water on one side and high level water on the other side.

His hydrostatical results (see Fig. 12) enabled him to determine the forces exerted on the scoop wheel by the water on the low level side and the water on the high level side. He determined the resulting force exerted on the scoop wheel at a distance equal to half the length of the wings! He then says: If wind shaft and scoop wheel shaft would rotate equally fast this would be exactly the resulting force exerted by the wind at a distance half the length of the wings. However, because the wings rotate $(N_S.N_O)/(N_C.N_N)$ times faster than the scoop wheel, the force exerted by the wind at half the wing length is equal to the force exerted by the water at half the wing length divided by $(N_S.N_O)/(N_C.N_N)$.

After having determined the force that the wind can exert he was ready to introduce a new design. Figure 14 shows us one version of it. Apparently his intuition told him that very wide scoop wheels—say 3.5 feet instead of 1.3 feet—would lead to more efficiency. The result was that with the same wind moment on the wings a nearly 3 times bigger moment was needed on the scoop wheel. He then determined the number of teeth needed on the four wheels in order to slow down the number of revolutions the required number of times.

In Stevin's design the wheel C on the wind shaft became a lanternwheel and the upper wheel S on the central shaft became a crown wheel. In a traditional mill we would, for example, have $N_C = 48$, $N_S = 9$, $N_N = 13$ and $N_O = 56$. Then $(N_S.N_O)/(N_C.N_N) = 0.81$. In the new design we would have $N_C = 16$, $N_S = 21$, $N_N = 12$ and $N_O = 47$ and $(N_S.N_O)/(N_C.N_N) = 5.14$. Stevin also calculated the forces that the teeth exert on each other. In particular the forces exerted by the teeth of N on the teeth of O are considerable in his new design. It is understandable that Stevin gave special attention to the position and shape of the teeth in *On the most perfect cogs and staves*.

Although the way in which Stevin designed his new mills was original and ingenious they were apparently not a great success.

9 Legacy of Stevin's Contributions

Dijksterhuis distinguished five crucial years in the 16th and first half of the 17th century when modern science was born (Dijksterhuis 1950, p. 431):

1542: Copernicus' *De Revolutionibus*,
1586: Stevin's works on statics and hydrostatics,
1600: Gilbert's *De magnete*,
1609: Kepler's *Astronomia nova*,
1638: Galilei's *Discorsi*.

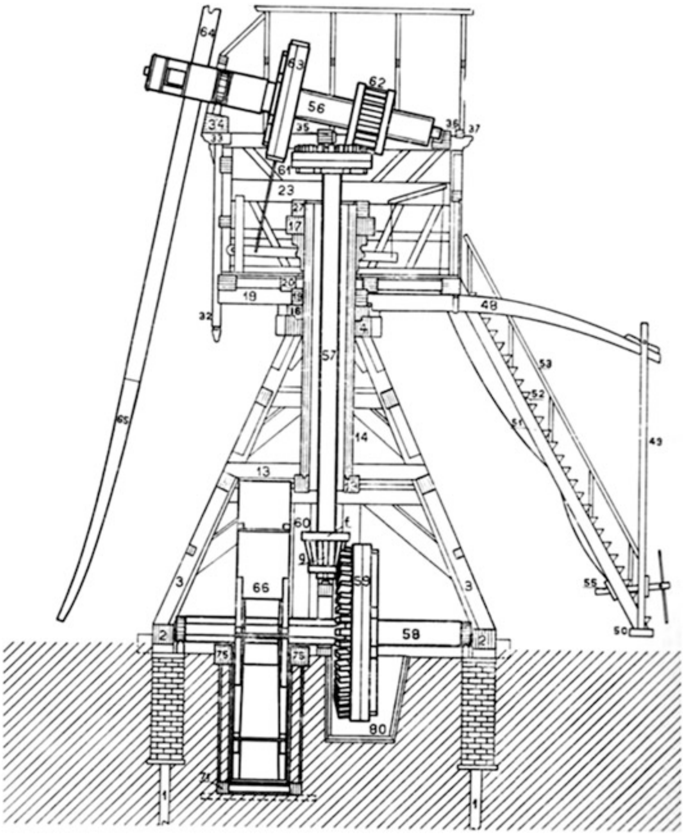


Fig. 14 Stevin's new design. (Stevin 1966, Plate Ia)

These *anni mirabiles* are well chosen. Most of Stevin's work was written in Dutch which made it less accessible for foreigners. However, in 1605–1608 some of his major works were reprinted with a number of additions: *Mathematical Thought* (Wisconstighe Ghedachtenissen, 5 vols.). This edition was translated in Latin: *Hypomnemata Mathematica* (5 vols., 1605–1608) and part of it in French. The Latin translation was made by Snellius, the Dutch mathematician whose name is associated with the discovery of the law of the refraction of light. The French translation with the title *Mémoires Mathématiques* was made by Jean Tuning. Tuning's translation did not include the works on statics and hydrostatics. These were later translated in French by Albert Girard who published them with his translation of several other texts in *Les Oeuvres mathématiques de Simon Stevin* de Bruges in Girard (1634).

The reprint of 1905–1908, *Mathematical Thought*, and the Latin and French translations were ordered by Prince Maurice, the commander of the Dutch army.

Allegedly Maurice, who had a genuine interest in mathematics, had taken lessons from Stevin and carried Stevin's texts with him in his campaigns. Fearing that he might loose them he decided to publish them in three languages (George 1934, p. 245).

It is not so easy to precisely trace the influence that Stevin's works exerted. The development of statics in the 17th century is complex. For a detailed description we refer to Duhem's classical book (Duhem 1905–1906). According to Duhem Varignon's *Nouvelle Mécanique ou statique*, posthumously published in 1725, represents the transition to a new phase in the history of statics. Varignon (1654–1722) explicitly used the polygon of forces and the funicular polygon.

Although the precise influence of Stevin's work is hard to determine exactly, it is remarkable that great men like Lagrange, Mach, Duhem, and more recently, as we have seen, Feynman, expressed their appreciation for Stevin.

Classical secondary sources for Stevin are Dijksterhuis' books (Dijksterhuis 1943; Dijksterhuis 1970). Recent books on Stevin are Jozeph (2003) and Elkhadem et al. (2004).

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Marcus Vitruvius Pollio (Second Half of the Ist Century B.C.)

Michela Cigola and Marco Ceccarelli

Abstract Marcus Vitruvius Pollio was a Roman architect/engineer, who in his treatise "De Architectura" in I B.C. described in great detail design and operation of machines for civil engineering. The treatise is a comprehensive reference from Antiquity that, having been rediscovered during the Renaissance, was studied and reprinted both for its historical background and for technical inspiration. In this chapter the focus is on machine developments.

1 Biographical Notes

Marcus Vitruvius Pollio, Fig. 1, was a Roman architect and engineer, who was active in the second half of the Ist century B.C. He is considered one of the most significant theoretician of Architecture over the time, mainly because of his treatise "De Architectura", published in ten "books" (today known as "chapters"). Very little is known of his life. It is not even certain that his "cognomen" (surname) was Pollio. Several cities in Italy, in particular Rome, Fondi, Fano, Verona, or Formia have been cited as his birthplace.

Most of the information we have about his life is derived from the introductory notes in the ten chapters of "De Architectura" where he commented on his personal experiences. An example is the text in Chap. 1: "Itaque cum M. Aurelio

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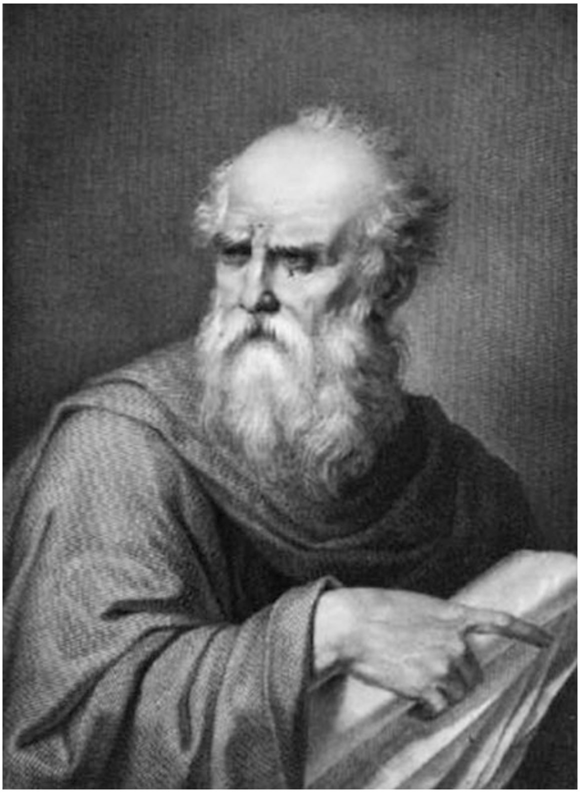


Fig. 1 Engraved portrait of Vitruvius by Iacopo Berardi in 1830 ca.

et P. Minidio et Cn. Cornelio ad apparationem balistarum et scorpionem reliquorumque tormentorum refectionem fui praesto et cum eis commoda accepi" in which he mentions co-workers for his designs of military machines. More in general, from those notes it can be understood that he was an officer responsible for war machines under Julius Caesar. Since he noted that he got an outcome from this service, as very likely a lifetime salary, he probably would have served in the Technical Military Corps of a Roman legion. The Roman Technical Military Corps were dedicated to providing the Army with constructions of military engineering and war machines. The head of the Corps was titled "Praefectus fabrum" with a high military rank. It is not sure that Vitruvius was appointed to this office but surely he was a well-reputed official of the Corps. After the death of Caesar, emperor Augustus confirmed a lifetime salary to Vitruvius, even for a continued design collaboration. However, the only design declared by Vitruvius is the basilica of the Roman city Fano (north of Rome) that was also enlarged by Augustus. The fact that the treatise "De Architectura" is dedicated to Augustus, is a clear confirmation of the link of Vitruvius with the emperor.

The treatise can be dated throughout 27 and 13 B.C., when Vitruvius was old, as he mentions in the treatise notes. Since he was in service under Caesar, who died on 44 B.C., Vitruvius would have lived at the time of Varro and Cicero, as also the treatise writing style indicates.

2 Content of "De Architectura"

The treatise "De Architectura" is composed of ten chapters (named as "books" in the manuscript in Latin and Italian editions). Each of them is introduced with a preface (called a "proemio").

Vitruvius declares the purposes of the treatise as aimed at indicating the expertise that a good architect must have in the multiple aspects of technique. A cultural purpose can be understood in giving a cultural dignity to the figure of architects much more than usually considered in Roman society, (Ceccarelli and De Paolis 2008). In fact, the aim of Vitruvius' work can be clearly understood as to outline the figure and formation of a clever architect with a strong cultural basis and a very complementary knowledge of machines, as indicated by the fact that one chapter of the ten is dedicated to machines.

Roman culture was oriented to efficiency of society and State. Thus, engineering was considered and used as a means for achieving practical goals without recognizing any scientific aim or social status to the practitioners. In fact, in the Roman world, knowledge was partitioned in two distinct frames: science was considered as a higher level of knowledge and reserved to people from upper classes; technology was reputed of a lower importance and rank, and for this reason it was dedicated to people belonging to a lower social level. This is because in Roman society any kind of manual labour, even if widely construed, was not an activity engaged in by the ruling classes. On the other hand, science was strictly connected with philosophical thought and therefore considered as higher intellectual activity, far distant from technology that was considered as being on the same level as any hand labour.

Technology was more practically oriented, with a strong pragmatic approach, which did not often use the results of theoretical Science. It is useful to remark that the scarce use of scientific knowledge in technical applications was caused also by social and economic factors; because it was not necessary to develop advanced technological tools in a society where slaves provided very cheap labour, it was not profitable to develop machine-tools for a large utilization. In addition, many ancient philosophers refused to recognize the need for any artificial tool, asserting that nature provides human beings with everything that is necessary for human life.

But although Vitruvius was conscious of the enormous potentiality of technology, he experienced in a very agonizing way the 'inferiority complex' of technicians in an outstandingly humanistic culture. In his work "De Architectura", Vitruvius tries to re-evaluate the architect's work by emphasizing the necessity of a wide and versatile formation that is not limited to technical subjects but open to humanistic education too. In this way architecture obtains a preferential position when compared with other technical disciplines and Vitruvius can claim an intellectual role for himself and for the architect's profession as well-defined inside the official culture. This awareness of the role and cultural level of architects lead Vitruvius to a rather positive attitude towards machines and human technology, against the opinion of philosophers like Seneca. Vitruvius believed in a positive function of machines, because they are useful for men and because they succeed in filling the gaps left by nature. Thus, Roman engineers were able to recover somehow an old Hellenistic way of thinking, which underlined the strict connection between nature and technique.

Although there was extensive use of slaves as in other societies in Antiquity, the Romans also developed machines as tools or systems to increase operational power. Thus, typical main Roman machines were such constructions as cranes for lifting weights (stones for roads and buildings, loads for boats, etc.), pumps for water supply, mills for grinding flour and other materials; and war machines. Those machines were somehow originally imported from conquered countries but they were soon improved in efficiency for very practical specific applications.

The Romans were attracted to technical culture in general, besides their interest in specific machines, and it is well known that the military corps, i.e. the legions, were accustomed to being fully autonomous, even from technical viewpoints of soldiers who worked with several different technical skills. In fact, military corps were used to build roads and anything they needed in war campaigns and even in ordinary peaceful life, including bridges, houses, chariots, towers, and of course weapons and war machines.

In Roman social settings, technical needs were also considered within proper organizations under the supervision and responsibility of people in very high political positions, who had the power to order activities of the military corps. They were the "aediles", high officers under the direct control of a "consul", who was sometimes even directly involved in important activity with technical contents.

Except for the above-mentioned important consideration of machinery techniques, there is no evidence of formation frames for those experts. Very probably most of the training was developed within military frames or, for civil technicians, directly on the field. Thus, the few written treatises seem to be likely handbooks or reports of activity. This is the case also for the outstanding treatise De Architectura" by Vitruvius.

The treatise has the character of a handbook for professional and lecture notes for teaching. In fact, the subjects are described with technical details as if directed to professionals and with explanations as if directed to teachers of the subjects.

In particular, the contents of the ten chapters are distributed by subjects, namely:

- Chapter 1 on definition of Architecture and required expertise of architects
- Chapter 2 on materials, wall constructions and building techniques
- Chapters 3 and 4 on religious buildings and orders of architecture (Doric, Ionic, and Corinthian)
- Chapter 5 on public buildings
- Chapters 6 and 7 on domestic buildings
- Chapter 8 on water supplies and aqueducts

- Chapter 9 on elements of Astronomy for solar and water clocks
- Chapter 10 on machines.

In particular, Chap. 1 introduces the fields of Architecture by outlining the required expertise and tasks of architects and defining the fundamentals and limits of architecture when understood as Art and Science. In this chapter Vitruvius discusses the origin of Architecture as progressing from building constructions ('fabrica') and rational design ('ratiocinatio') up to indicating its composition in various areas and the rules for successful applications. Buildings are classified as domestic and public, with the public ones being aimed at defence, religious offices, and city services. In addition, the chapter deals with the choice of location for cities, construction of defence walls and towers, and distribution of buildings within the cities.

Chapter 2 describes the first constructions and developments of buildings since the origin of mankind, and explains the materials used for buildings in terms of their natures and characters of building structures.

Chapter 3 introduces buildings structures with their symmetry and proportions and temple structures with their shapes, kinds, and orders up to a specific attention for those Ionic ones.

Chapter 4 deals with Doric and Corinthian temples as well as circular temples and shrines to gods.

Chapter 5 describes public areas and particularly forum, basilicas, curia, theatres, porches, thermae, gymnasiums, and ports.

Chapter 6 illustrates civil buildings as functions of their location, surrounding environments, their compositions and proportions as city or country houses.

Chapter 7 deals with details of characters for beauty and stability, such as plasters, pavements, marbles, mosaics, pictures for which Vitruvius gives a short treatise for proper use and preparation of colors.

Chapter 8 is a treatise on Hydraulics, referring to the nature of water and its use as well as how to find, transport, and store it.

Chapter 9 introduces Gnonomics and outlines the variety and composition of clocks including considerations on Geometry and Astronomy.

Chapter 10 is specifically dedicated to machines for both times of war and peace that an architect needs to design and operate not only for their specific use but mainly as means for works in Architecture. This paper is specifically focused on Vitruvius' work on machines as described in this chapter.

The analysis of machines starts with a concise definition of "machine" given as"a combination of materials (as components) that performs a large action for motion of weights". This definition is important since it clarifies the structure of machines and their mechanical generation as finalized to weight manipulation. It can be considered the first machine definition with engineering understanding.

It is relevant that the description of machines with technical terms are (were) useful both for operation understanding and mechanical design. We note that the Latin manuscript was rediscovered with only text whose translation was also subject of disputes both for wording and design interpretations. Drawings were added for the first time in the Frà Giocondo edition in 1511 both to help the understanding of the text and to interpret the engineering content.

In particular, Vitruvius presented mechanical systems for functioning as machines or instruments as a whole or as components, such as:

- Cranes
- Pulley systems
- Grippers
- Levers
- Scales
- Hydraulic wheels
- Screw pumps
- Gears
- Gearing systems
- Linkage systems
- Odometers

in a variety of types of applications with hydraulic or pneumatic actuations. In the last part of the chapter, specific attention is addressed to war machines with particular descriptions for catapults, ballistae, and hammers.

The presentation of the machines includes indication of paternity, whenever possible, so that Heron, Ctesibius, Archimedes, Ctesiphon, and Methagenes are cited as famous inventors and scientists of Antiquity.

He starts with the basic crane that is described as being particularly important in the construction of temples. The crane machine is described by indicating details on the components of its frame structure and on the pulley system with proper grasping device. The operation is also explained as for weight transportation and careful final location. The text is very clear and, even in early reprint editions, drawings were added to show and clarify the machine, as in the example of Fig. 2 from Barbaro's edition in 1584 in which the translation is commented as referring to those drawings indicating each part of the crane.

Other machines are discussed in the next section of this paper with details as functions of the drawings in different editions.

3 Editions of "De Architectura"

Once rediscovered, the treatise of "De Architectura" was studied and translated for publication with interpretations of machines including drawings from the editor's experience.

The first rediscovery of Vitruvius' treatise is considered as due to Poggio Bracciolini (1380–1459), who declared that he had found a manuscript with a copy of Vitruvius' treatise in the library of Montecassino Abbey in 1414. Unfortunately, no Vitruvius manuscript exists today in the Montecassino library. At that time the fame of the discover attracted great interest in the treatise, considered as an

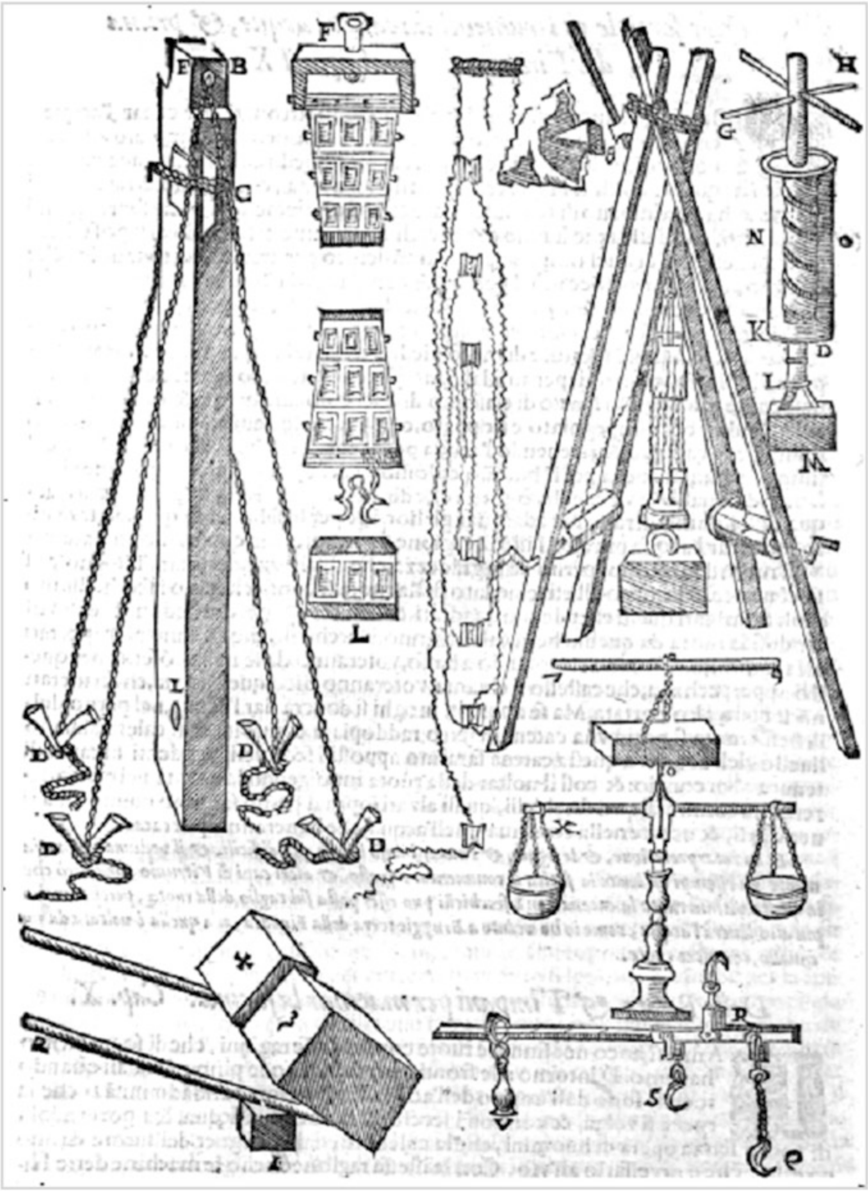


Fig. 2 Drawing reconstruction of a crane by Vitruvius as represented in Barbaro's edition in 1584 on page 459

important reference source even for new Architecture studies in the early XVth century. Thus Lorenzo Ghiberti (1378–1455) used the treatise for his work "Commentarii", Leon Battista Alberti (1404–1472) cited it explicitly for the first time in his work “De re aedificatoria”, and Francesco di Giorgio Martini (1439–1502) worked on the first translation in Italian. Many other Renaissance artists and architects, such as Raffaello, Luca Pacioli, Filarete, and Taccola. mentioned that they had studied Vitruvius’ treatise. This motivated publication of printed editions, the first of which was the one by Giovanni Sulpicio da Veroli (second half of the XV century) and Pomponio Leto (1425–1498) in 1486–1490 with no drawings.

The main published editions can be listed as:

- 1486 by Sulpicio da Veroli and Pompolio Leto, edited in Rome (“Editio princeps”[1])
- 1496 Florentine edition (no more indications)
- 1497 Veneto region edition (no more indications)
- 1511 by Frà Giocondo, edited in Venice (first illustrated edition)
- 1521 by Cesare Cesariano, edited in Como (first commented and illustrated edition)
- 1524 by Durantino, edited in Venice
- 1536 by Giovan Battista Caporali, edited in Perugia
- 1547 by Jean Martin and Jean Gujon, edited in Paris (first French edition)
- 1552 by Guillaume Philandrier, edited in Lion (first commented French edition)
- 1556 by Daniele Barbaro, edited in Venice
- 1564 by Lazaro de Velasco, manuscript (first Spanish translation)
- 1575 by Walther Hermann Ryff, edited in Basel (first German edition)
- 1582 by Miguel de Urrea, edited in Alcala de Henares (first Spanish edition)
- 1624 by Henry Wotton edited in Amsterdam (first English translation)
- 1660 by Giovanni Antonio Rusconi, edited in Venice
- 1673 by Claude Perrault, edited in Paris
- 1739–1741 by Giovanni Poleni, edited in Padua
- 1771 by William Newton edited in London (first English edition Books 1–5)
- 1790 by Bernardo Galiani, edited in Siena and Naples
- 1791 by William Newton edited in London (first English edition ten Books)
- 1831–1832, by Quirico Viviani, edited in Udine.

Still today the treatise is considered for republication of those editions and for further studies.

In the illustrated survey of this paper, attention is addressed to the editions by Frà Giocondo in 1513–1523, Cesare Cesariano in 1521, Durantino in 1524, Daniele Barbaro in 1584, Ryff in 1575 and Perrault in 1673 as examples of the interest over time on the machines in Vitruvius’ treatise.

Fra’ Giovanni Giocondo (1434–1515) was a Franciscan friar and a humanist with expertise as an architect with great interest in machines. He published the first

[1] It is named “Editio princeps”, the first printed edition of a manuscript from Antiquity or Middle Ages.

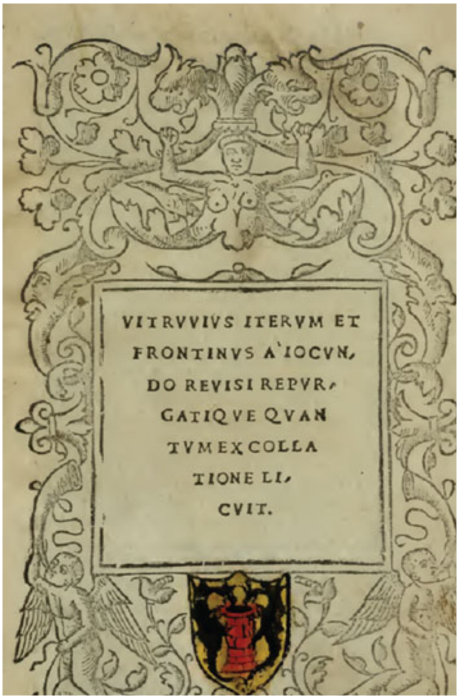


Fig. 3 Title page of the edition by Frà Giovanni Giocondo in 1513

edition of “De Architectura” with drawings in 1511 in Venice. This edition was reprinted in 1513, Fig. 3, and again in 1522 and 1523 with 136 illustrations made by xylography.

The first edition in Italian was published in 1521, Fig. 4, by Cesare Cesariano (1483–1543), who was an Italian architect and painter. This edition is provided with illustrations of improved quality and complexity as compared with those by Frà Giocondo.

Francesco Luci or Luzi (1490 ca.–1550 ca.), named as Durantino because of his birth place, was a humanist, scholar and Italian architect. He published Vitruvius' treatise in 1520 believing it to be the first Italian version, Fig. 5. The illustrations, which were very probably made by him, are very similar to those by Frà Giocondo among which those on the machines of Chap. 10 look equal.

Another important edition was worked out in 1556 by Daniele Barbaro, who was Archbishop of Venice with humanistic interest and expertise in Architecture. His edition of Vitruvius' treatise is completed with drawings made by the famous architect Andrea Palladio (1508–1580). The success of this edition is proved by reprints in 1567, 1584, Fig. 6, and 1629; and still today is one of the most referenced.

Besides editions in Latin and Italian, very soon Vitruvius' treatise was translated into other languages. In Fig. 7 the title page of the German edition in a reprint of 1575 is reported as published by Walter Hermann Ryff (1500 ca.–1548) in Nuremberg in 1543 with inspiration from the Cesariano edition.

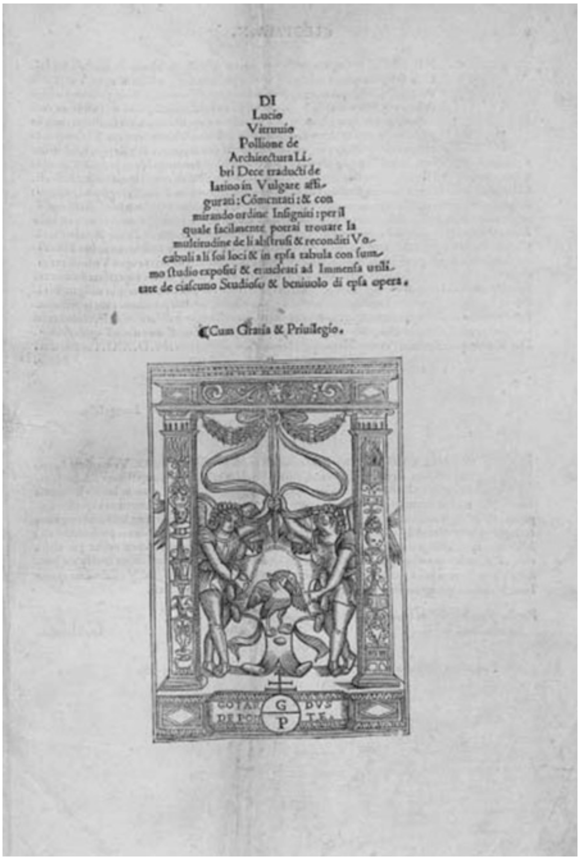


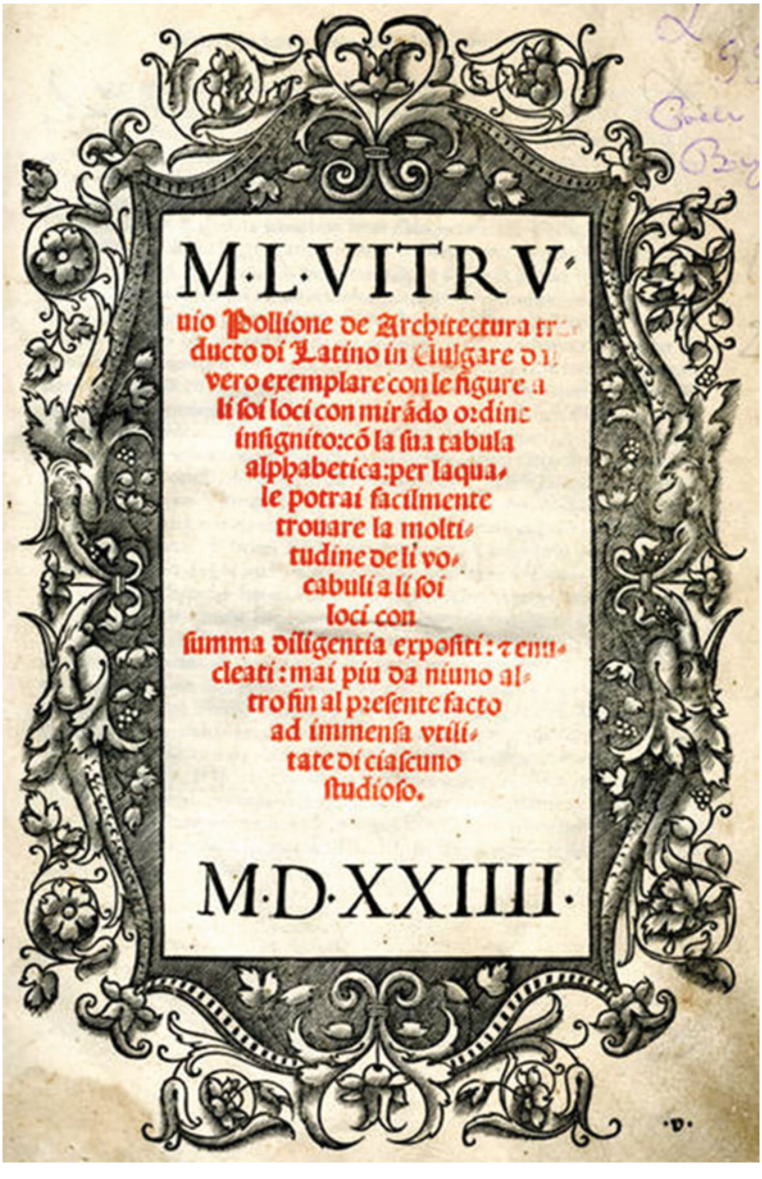
Fig. 4 Title page of the edition by Cesare Cesariano in 1521

In 1547 the first French edition was published by Jean Martin (unknown-1553). A French edition with several illustrations was published by Claude Perrault (1613–1688) in 1673, Fig. 8. Successively Perrault's edition was used as a source for other editions in several other European countries.

A first Spanish edition was published by Miguel Urrea (unknown—ca. 1565–1568) in 1582, Fig. 9.

The first English edition of the whole treatise was published in London in 1791 by William Newton (1750–1830), Fig. 10.

The treatise "De Architectura" by Vitruvius has continuously attracted interest, and investigations on interpretations of the text have been updated over time, as proved by many publications in a very rich literature in all the aspects of language, general culture, and technical expertise. Still today editions are published of the treatise with modern views.



M·L·VITRV·
uio Pollione de Architectura tra·
ducto di Latino in Vulgare dal
vero exemplare con le figure a
li soi loci con mirádo ordine
insignito: có la sua tabula
alphabetica: per laqua·
le potrai facilmente
trouare la molti·
tudine de li vo·
cabuli a li soi
loci con
summa diligentia expositi: & enu·
cleati: mai piu da niuno al·
tro fin al presente facto
ad immensa vtili·
tate di ciascuno
studioso.

M·D·XXIIII·

Fig. 5 Title page of the edition by Durantino in 1524

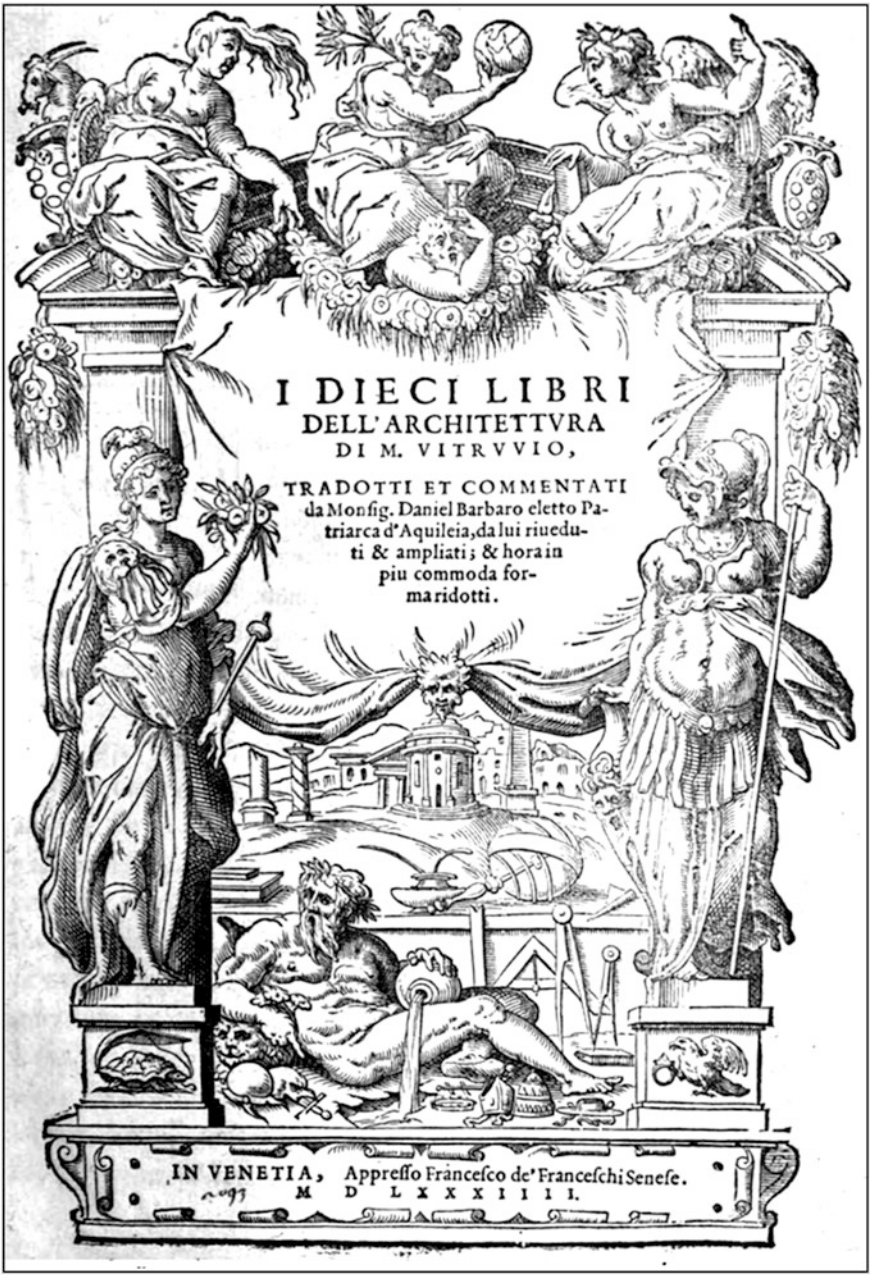


Fig. 6 Title page of the edition by Daniele Barbaro in 1584


Vitruvius

Des aller namhafftigisten vnnd Hocherfarnesten/ Römischen Architecti/ vnnd Kunstreichen Werck oder Bawmeysters/ Marci Vitruuij Pollionis/ Zehen Bücher von der Architectur vnd künstlichem Bawen. Ein Schlüssel vnd einleytung aller Mathematischen vnnd Mechanischen Künst/ Scharpffsinniger fleissiger nachtrachtung oder Speculation künstlicher Werck: Auß solchē hohem verstand/rechtē grund/sattem vñ gewissem Fundament aller löblichen Künst/ Der massen fleissig vnd ordenlich in Schrifften verfasset/ das hierin ein jeder Kunstbegiriger Leser der Architectur vnnd künstlichen Bawwercks vnterwisen wirt/ vnd der Architectur angehörigen Mathematischen vnnd Mechanischen Künsten ein rechten verstande/leichtlichen erlernen vnd fassen mag. Alles mit schönen künstlichen Figuren vnnd Antiquiteten/ vnd sonderlichen Commentarien zu mehrerem bericht vnd besserem verstand gezieret vnd erkleret.

Allen Künstlichen Handtwercken/ Werckmeystern/ Steinmetzen/Bawmeystern/ Zeug vnd Büchsenmeystern/Brunnenleytern/Berckwerckern/ Malern/Bildhawern/ Goldtschmiden/Schreinern/ vnd allen denen/welche sich des Zirckels vnnd Richtscheids künstlichen gebrauchen/ zu sonderlichem nutz vnd vilfeltigem vortheil/ Erstmals verteutscht/ vnnd in Truck verordnet/

Durch/

D. Gualtherum H. Riuium Medic. & Mathem.

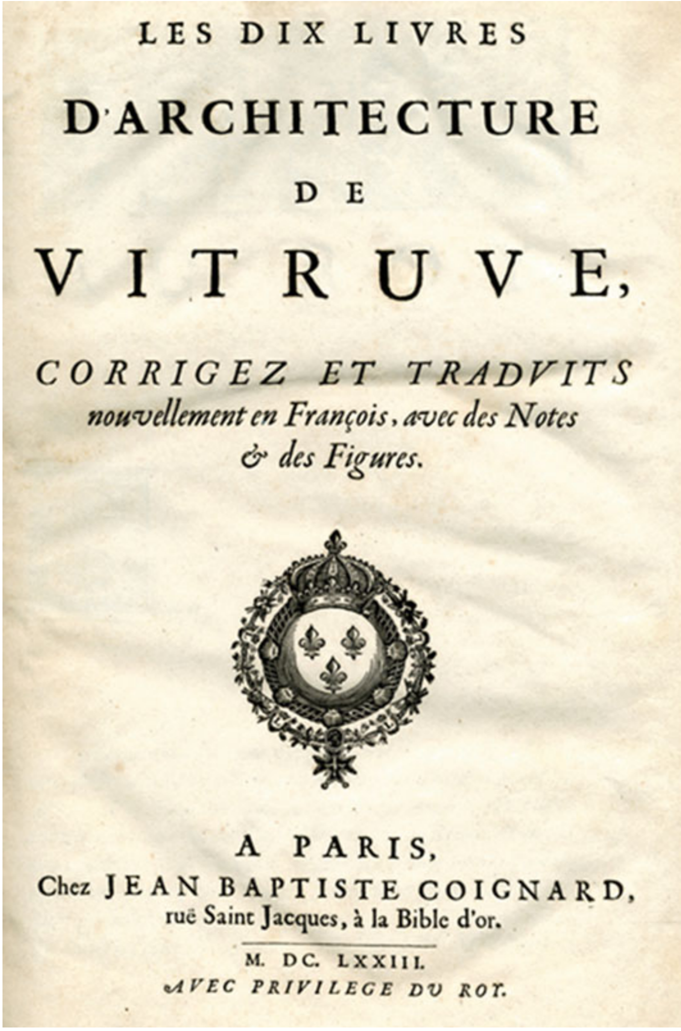
Vormals in Teütsche sprach zu transferieren/noch von niemand sonst vnderstanden/ sonder für vnmüglichen geachtet worden.

Mit Keyserlicher Maiest. Gnadt vnd Freyheit.

Getruckt zu Basel durch Sebastian Henricpetri.

1575

Fig. 7 Title page of German edition by Walter Hermann Ryff in 1575

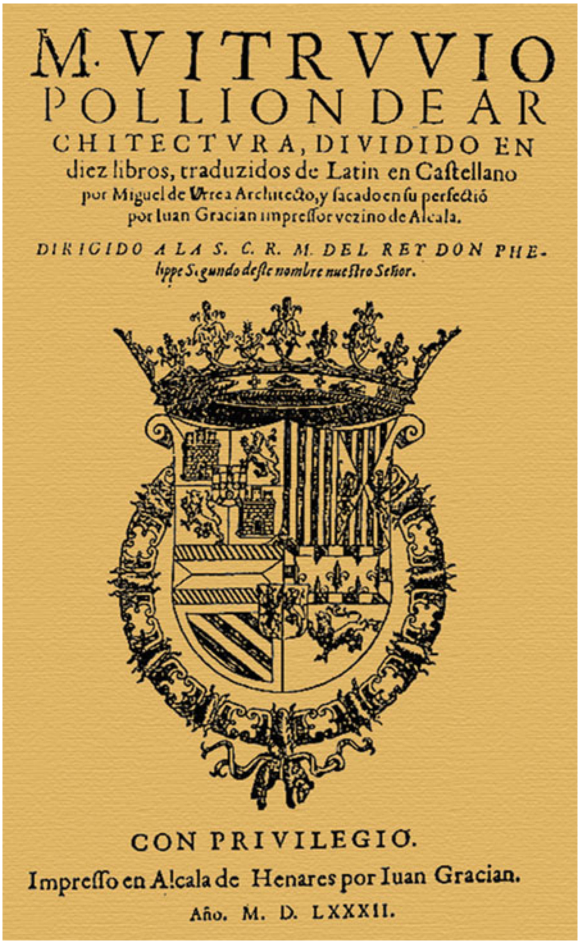

LES DIX LIVRES
D'ARCHITECTURE
DE
VITRUVE,
CORRIGEZ ET TRADVITS
nouvellement en François, avec des Notes
& des Figures.

A PARIS,
Chez JEAN BAPTISTE COIGNARD,
ruë Saint Jacques, à la Bible d'or.
M. DC. LXXIII.
AVEC PRIVILEGE DU ROY.

Fig. 8 Title page of French edition by Claude Perrault in 1673

4 Drawing of Machine Representation

In this paper, attention is focused on machine designs as described in Chap. 10—machines and elements of mechanics, as referring to the main editions of reproduction of Vitruvius' treatise by Frà (1513), Cesariano (1521), Durantino (1524), Barbaro (1584) Ryff (1575) and Claude Perrault (1673). In particular, the study has been worked out by looking at machines for civil applications and war machines, indicating evolution of interpretations and machine designs through the representative drawings.



M· VITRVVIO
POLLION DE AR
CHITECTVRA, DIVIDIDO EN
diez libros, traduzidos de Latin en Caſtellano
por Miguel de Vrrea Architecto, y ſacado en ſu perfectió
por Iuan Gracian impreſſor vezino de Alcala.
DIRIGIDO A LA S. C. R. M. DEL REY DON PHE-
lippe Segundo deſte nombre nueſtro Señor.
CON PRIVILEGIO.
Impreſſo en Alcala de Henares por Iuan Gracian.
Año. M. D. LXXXII.

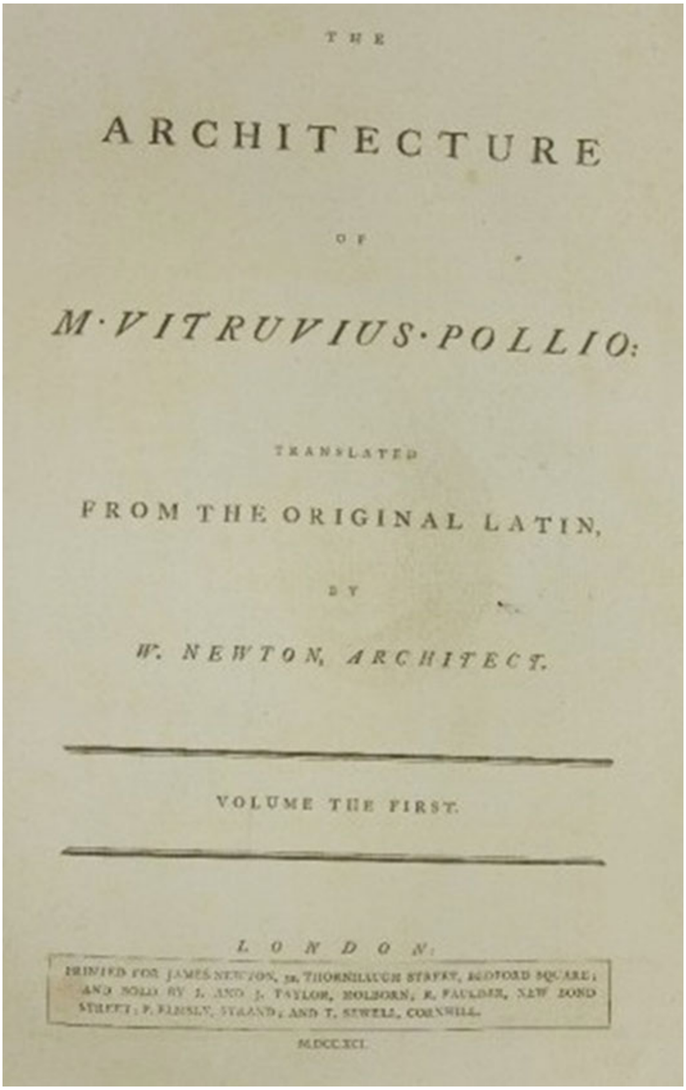
Fig. 9 Title page of Spanish edition by Miguel de Urrea in 1582

In general, the drawings by Frà Giocondo show the functional structure of a machine with indication of its main components by small letters. The operation is quite easily understandable, although a possibility of practical implementation lacks details in design parts and connections.

Machine designs by Cesariano are illustrated with a lot of details and main parts are indicated with small letters that are used in the text for comments. The machine designs look like solutions from current practice of Cesariano's time, perhaps to stress practical feasibility of the Vitruvius machines.

Durantino uses drawings that are strongly inspired (if not copied) from the edition by Frà Giocondo, as a sort of proof of an agreed interpretation of the proposed mechanical designs.

The representations by Barbaro present a mixture of characters of the previous works by Frà Giocondo and Cesariano. Namely, the machine designs are clearly


THE

ARCHITECTURE

OF

M·VITRUVIUS·POLLIO:

TRANSLATED

FROM THE ORIGINAL LATIN,

BY

W. NEWTON, ARCHITECT.

VOLUME THE FIRST.

LONDON:

PRINTED FOR JAMES NEWTON, THORNHAUGH STREET, BEDFORD SQUARE; AND SOLD BY I. AND J. TAYLOR, HOLBORN; R. FAULDER, NEW BOND STREET; P. ELMSLY, STRAND; AND T. SEWELL, CORNHILL.

MDCCXCI.

Fig. 10 Title page of English edition by William Newton in 1791

represented to show the overall design and its conceptual operation. But details of constructions are given only partially. Barbaro always includes figures of persons in the drawings to both help understanding of the operation and to stress the size and power of the machines. The drawings by Ryff contain many details that are very similar to those by Cesariano, but with awareness of technological feasibility and efficiency. The evolution of machine technology is more evident in the illustrations by Perrault, who shows drawings with clear very well established tradition in those machines.

In general the understanding of Vitruvius' text and machine interpretations was achieved by using machine expertise of the editors and their collaborators. It is remarkable that the details of Vitruvius' descriptions made possible, since the beginning of the study of his treatise, a full understanding of the high level of machine technology, not only during the Roman Empire but in Antiquity at large.

A specific remark of note is that the drawings used in all editions of Vitruvius' treatise not only help in understanding the text but make the treatise a machine handbook relevant to the time of the printed editions. This last aspect can be appreciated with a modern vision, thus making past experience useful in the current practice of machinery. In fact, in most of the drawings machines are represented with many more components and mainly with clear operation in practical applications. In this aspect, mainly in the richest drawings, the editors worked out somehow an extension of Vitruvius descriptions demonstrating technical values as inspiration for advances in machine technology.

The case of crane solutions shows very different approaches in describing cranes and they are a clear example of how much interpretation there is in obtaining different views from different authors by taking into account theoretical considerations and practical features of implementations of reported machines. But only one structure of cranes is described in drawings as referring to the one with the three-bars frame.

Frà' Giocondo shows the essential parts of a crane as in a driving capstan, a cable drum, fixed and mobile pulleys, and a gripping system for weight payloads. Cesariano gives many more details and solutions as from current practices of his time, even by emphasizing applications for large weight and movements. Durantino shows mainly the operation of a crane but the mechanical design is not fully shown, the important connection of the pulley system with the frame being hidden. Barbaro shows basic components of the simplest crane, but he gives hints on the operation mechanics through schemes of levers and balances. Ryff illustrates cranes similarly as Cesariano with several solutions and even design details very likely from the current practice of his time. Finally Perrault reports three cranes that differ from one to another only by the driving of the belt and grasping extremity, but with a clear illustration of the pulley systems.

From drawing viewpoints Frà Giocondo, Fig. 11, shows the crane in an environment with synthetic representation through a few lines. The attention is centred on the machine but the drawing seems not to contain everything so as to suggest a continuation behind the drawing corners. The components are drawn with a 3D representation which nevertheless is not clear in indicating the coupling among them, as it can be noted by looking at the top cross of the bars.

In Fig. 12 Cesariano gives a richer presentation both in 3D view and machine components. Within the drawing table Cesariano offers a multitude of devices to lift weights with an approach that is opposite to the essential drawing of Frà Giocondo. The machines are located one in front of the other with the aim to give the drawing depth as to be pleased of the high skill in 3D drawing technique with use of shadows.

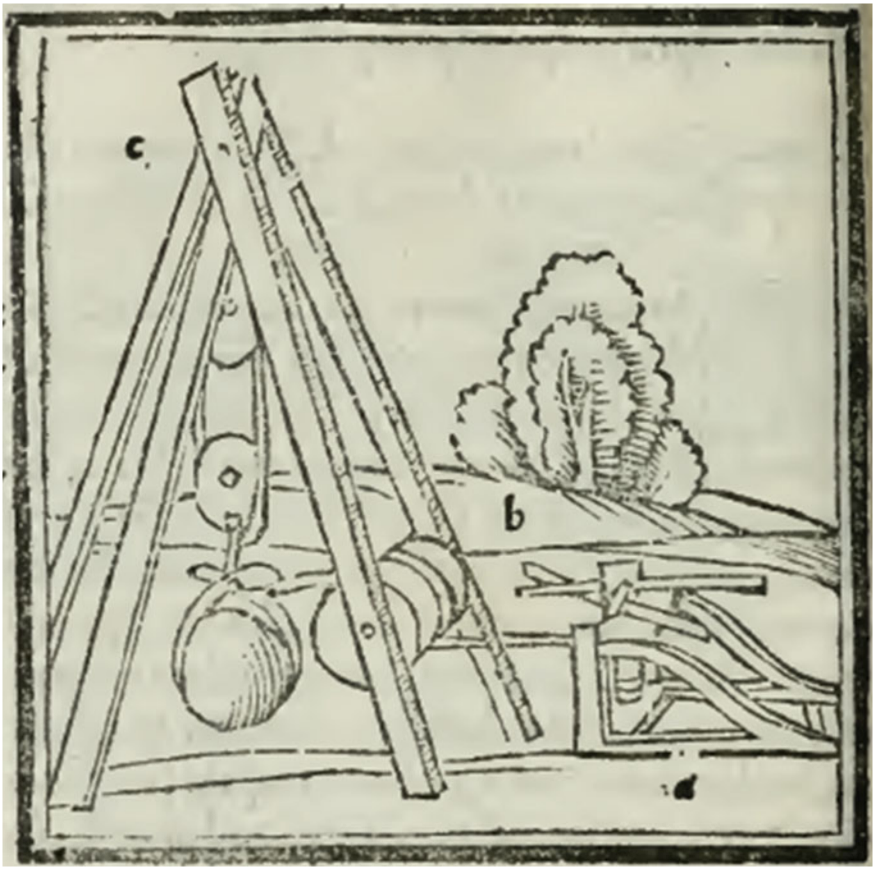


Fig. 11 Drawing of a crane in Frà Giocondo's edition in 1513 on page 164 v

In Fig. 13 Durantino shows a crane in a natural environment like Frà Giocondo whom probably he copied or took as strong inspiration. But the drawing gives some more details and the graphical representation is improved with better chiaroscuro that helps in explaining the machine assembly. The presence of four human operators at the capstan is useful both to give size and power of the machine crane.

The Barbaro drawing in Fig. 2 looks to have more technical awareness, not only due to the later time of the edition, even through an essential representation of the mechanical design of parts and whole assembly. The Barbaro drawing in Fig. 2 shows a graphical representation which is innovative for the time as due also to Cesariano's edition, since it draws first the main machines and then the smaller components to fill completely the room of the drawing table. In this case the depth, shadowing, and chiaroscuro are very accurate and more precise with respect to

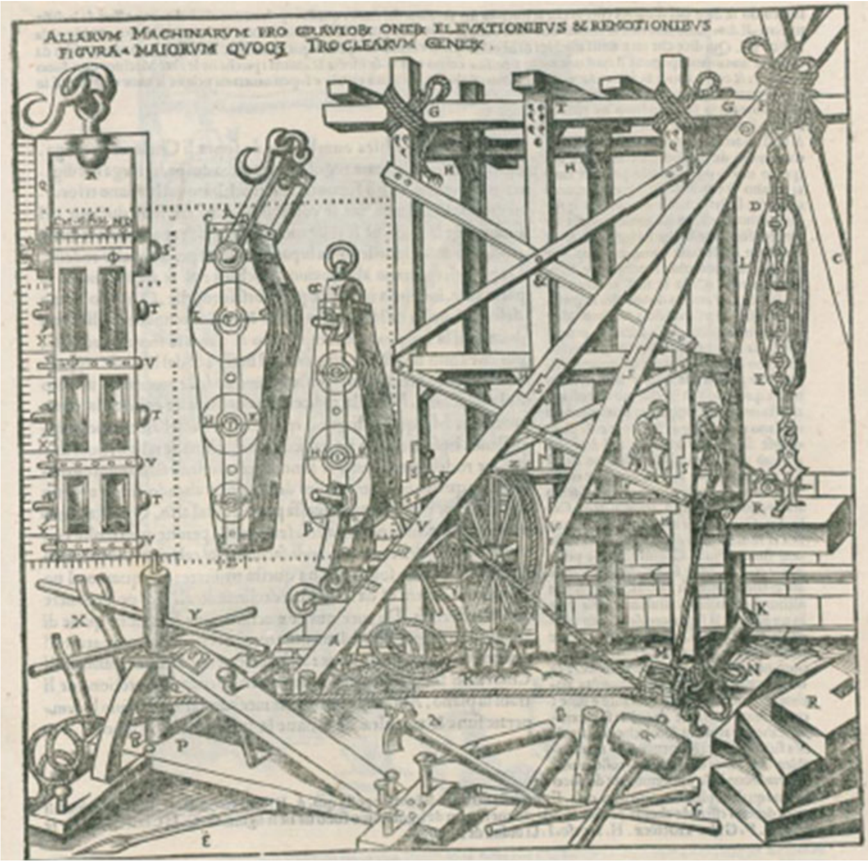


Fig. 12 Drawing of a crane in Cesariano's edition in 1521 on page CLXV r

previous editions, also because the author of the drawings in Barbaro's book was the famous architect Andrea Palladio (1508–1580).

Ryff's drawing in Fig. 14 recalls Cesariano's drawing in Fig. 12 with all details but with a mirror representation. A building is added in the scenario and several other human operators, perhaps to emphasize size and capability of the tower crane.

In Fig. 15 Perrault seems to summarize the previous experiences of representation by indicating several solutions of cranes in several situations of application. The scenario refers to building constructions and the absence of human operators seems to emphasize technical aspects of the machine that are well represented by a 3D view with a clever use of chiaroscuro.

Flour milling machines are represented together with their hydraulically powered systems as an interpretation of final practical goals indicated in Vitruvius' text. Nevertheless, main attention is addressed to the transmission to convert the axial rotation of the hydraulic wheel to the vertical rotation of the mill wheel.

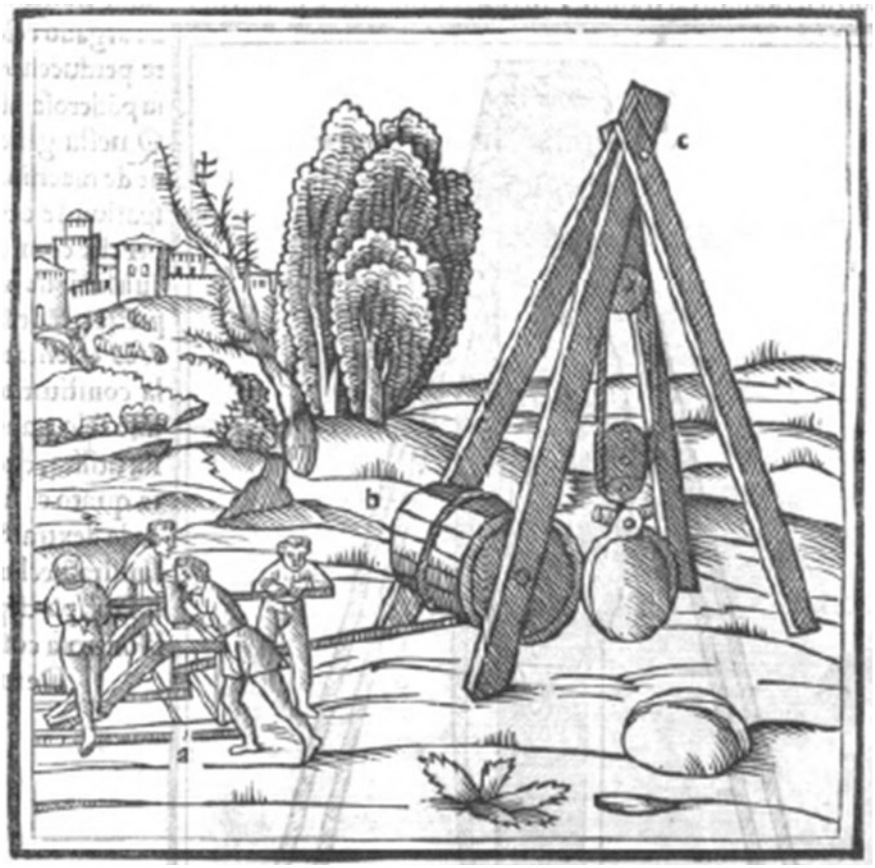


Fig. 13 Drawing of a crane in Durantino's edition in 1524 on page 96 r

Frà Giocondo represents the main parts with no details for connections and component sizes. Cesariano shows the full machine in real proportions including details for the hydraulic wheel. Durantino puts main attention to the milling will and the gear system, although well reported, is not fully illustrated with its connections to the milling wheel. Barbaro seems to focus attention on the mill action even through human operators but the mechanical design of gear transmission is completely illustrated even if not with a proper engagement. Ryff in repeating the figure by Cesariano gives mechanical details for all the components of the milling systems. Perrault's representation is much more technical due to his time, since the overall system is shown with an equal importance of the components. In all the cases the core of the machine is considered in the mechanical transmission that is shown with the same design with a vertical lamp cage engaged by rod teeth to a large flywheel, as emphasized in the Vitruvius text.

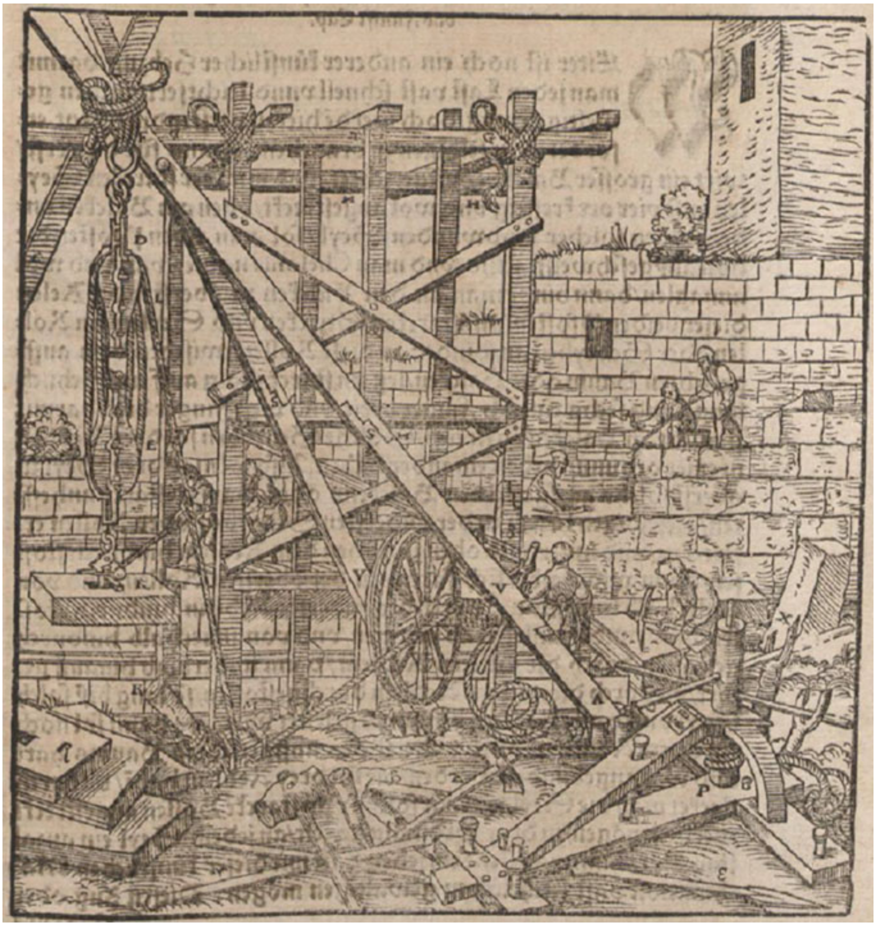


Fig. 14 Drawing of a crane in Ryff's edition in 1575 on page DCXXVII

From a drawing viewpoint, Frà Giocondo, Fig. 16, gives a lean representation of the mill machine with few chiaroscuro parts and few lines indicating the action of the water running the paddle turbine. The building frame is represented as a box with the back wall drawn with diagonal strong lines.

In Fig. 17 Cesariano shows the mill within its natural environment with rocks and trees on the background drawn with great attention mainly on the water flow. Interesting is the almost frontal view of the machines with respect to the observing direction from the hydraulic wheel in order to represent the building rotated and to show complementary devices at the bottom left of the drawing.

In Fig. 18 by Durantino the water mill is represented with a view that is similar to the one by Frà Giocondo. But two flour bags with the logo of the publisher are added in front so as to emphasize the products and the capacity of a water mill. The gearing system is somehow hidden in a shadowed background.

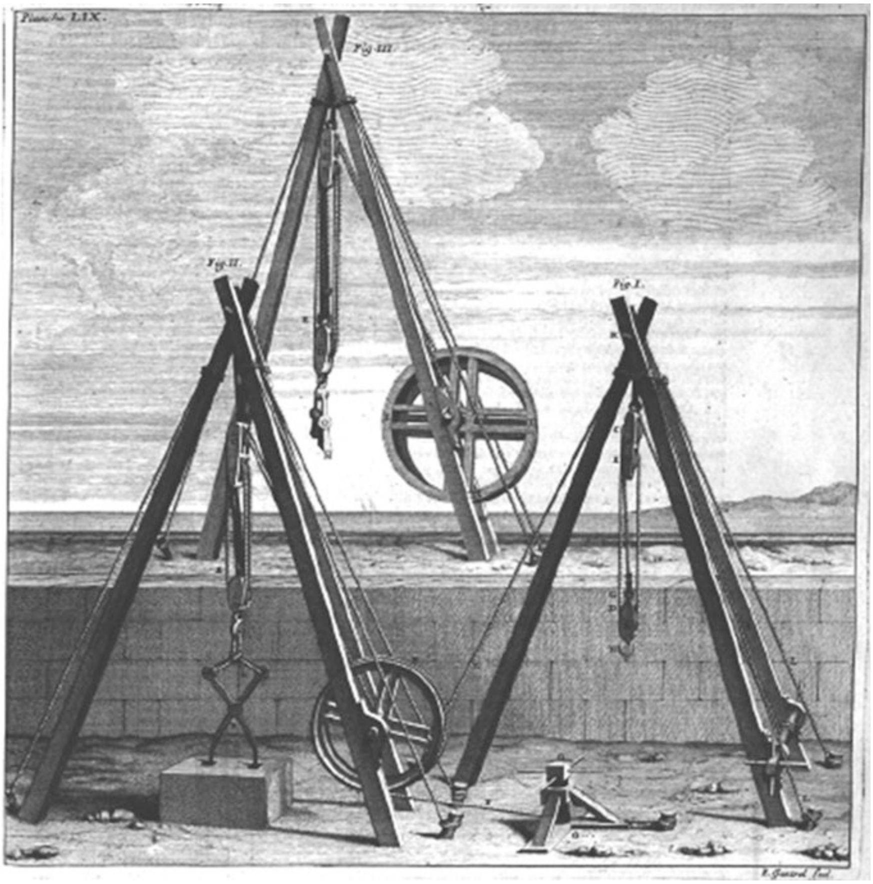


Fig. 15 Drawing of cranes in Perrault's edition in 1673 on table LIX

In Fig. 19 Barbaro enriches the drawing with two figures of millers to give indication of the size of the mill. The drawing has the same view as the one of Frà Giocondo with the paddle turbine that is almost hidden as limited between the building wall and drawing border. The naturalistic representation is centred on the milling action and the environment becomes poorly represented just by a profile of a mountain on the background, and with few lines for the sky and water flow.

Ryff represents a water mill in Fig. 20, again with a mirror copy of Cesariano's drawing in Fig. 18 but without the details of the immersed parts of the water wheels.

In Fig. 21 Perrault shows the water mills like an industrial plant with an industrial-like building of two floors and the machines are part of it. In the same table several solutions of water wheels are also specifically represented.

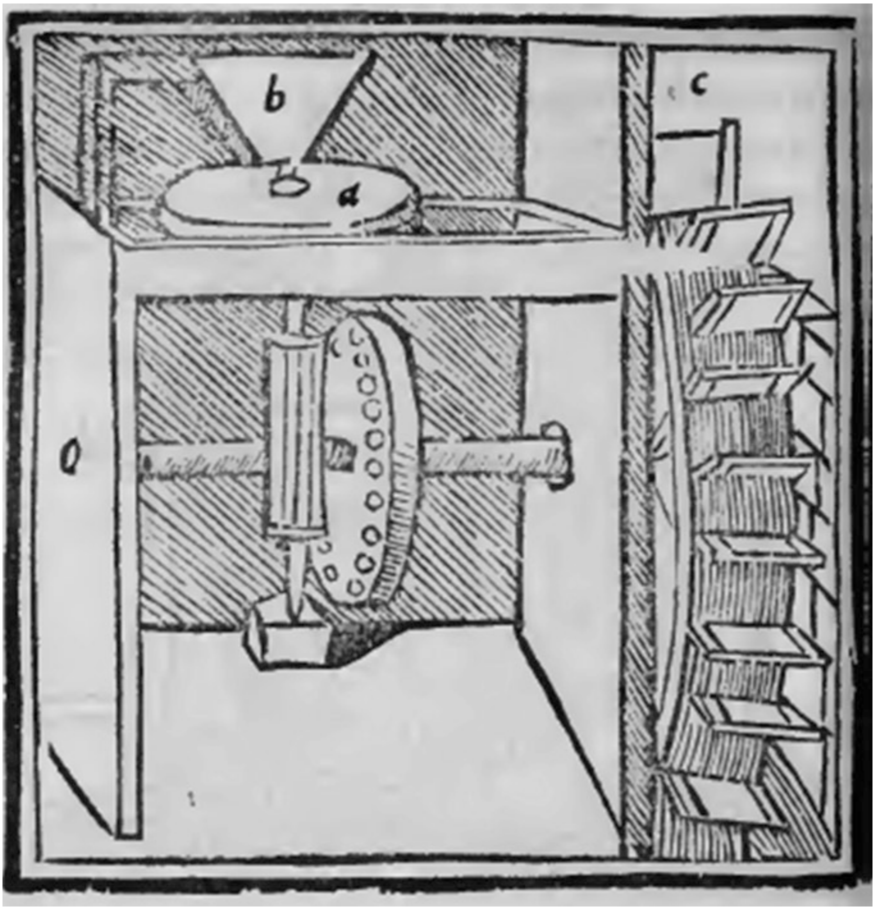


Fig. 16 Drawing of a water mill in Frà Giocondo's edition in 1513 on page 171 v

The design of Archimedes' screw is discussed in detail both in its design and practical application as a pumping system.

While Frà Giocondo, Durantino and Barbaro give a quite similar design with general features, Cesariano reports details also with three different representations of the screw pump, although in all of them it is not clear from where the power for the operation comes. In the first three cases a large turbine wheel is represented as co-axial to the screw but the function of the assembly is not evident. Ryff gives the same detailed representation of Cesariano's mechanical design including a geometrical scheme of the structure of a screw. Perrault emphasizes the overall design even with huge proportions, but still keeps the central attention to a screw pump with a similar shape of the Frà Giocondo drawing, so as to state the clear description of Vitruvius' text in the structure and operation of Archimedes' screw.

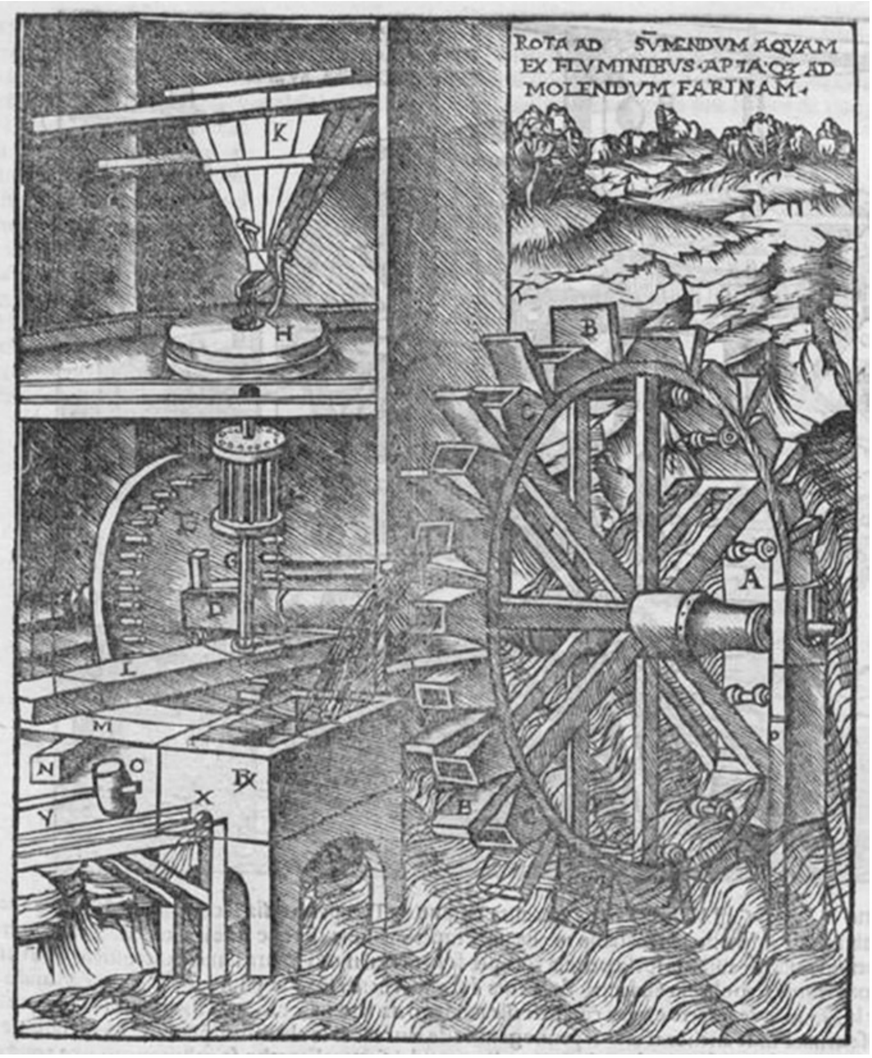


Fig. 17 Drawing of a water mill in Cesariano's edition in 1521 on page CLXX

From a drawing viewpoint the representation by Frà Giocondo in Fig. 22 is very synthetic and half of the figure is empty after the horizon. Careful attention is addressed to the water flow and machine parts that dipped in it as well as the environment is reported carefully with a tree on the left and broken river banks. Nevertheless, the drawing looks planar with no 3D indications expect for the chiaroscuro in the vertical frame bar of the pump.

The drawing by Cesariano in Fig. 23 is much more accurate thanks to a 3D view with chiaroscuro applications to everything and ruffling flow of the river

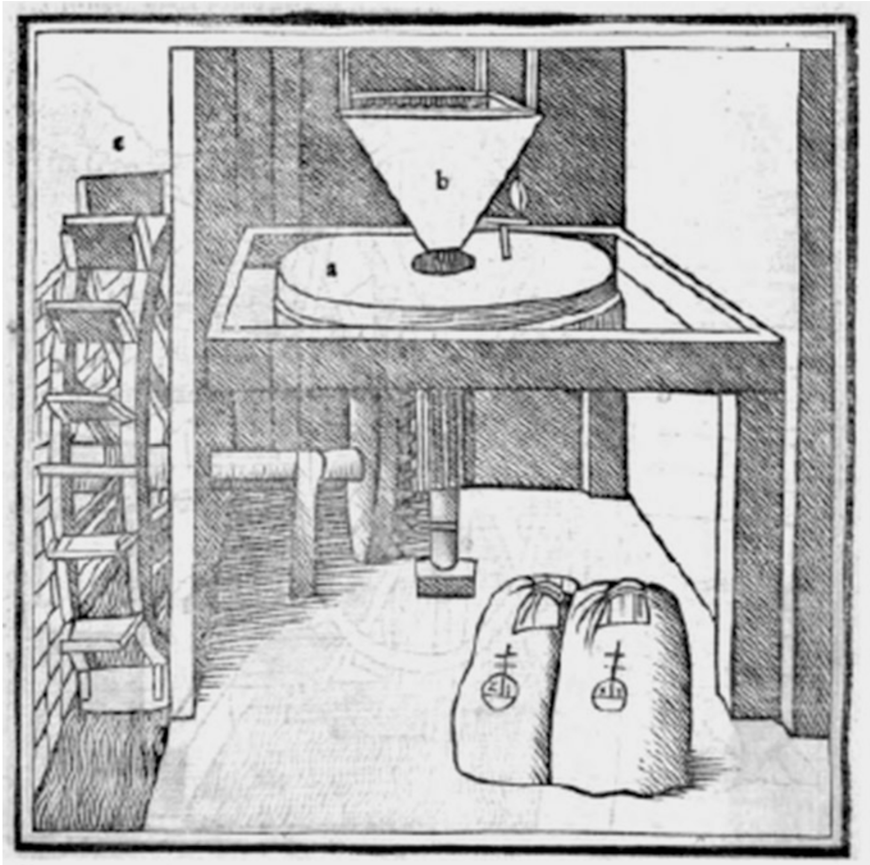


Fig. 18 Drawing of a water mill mills in Durantino's edition in 1524 on page 101 v

water. Cesariano gives also clear indications on the working of the screw pump through a scheme in the left that represents the screw starting with a pictorial naturalist representation for the first below part and with a very schematic design of the screw at its top. This can be understood as an early kinematic scheme with a modern vision for the time.

In Fig. 24 Durantino shows an Archimedes screw pump again as a mirror image of the drawing by Frà Giocondo but he adds a detailed pictorial representation of the water flow with vortices and a road coming to the pump. The screw is not represented with any additional details with respect to Frà Giocondo's drawing as to indicate the well established/understood mechanical design for it.

In Fig. 25 Barbaro makes a drawing similar to the one by Frà Giocondo, although with some more details on the naturalistic representation of the background. He represents two persons near the screw to give indication of the size of the machine, but curiously one of them is dressed in Turkish clothes and a turban.

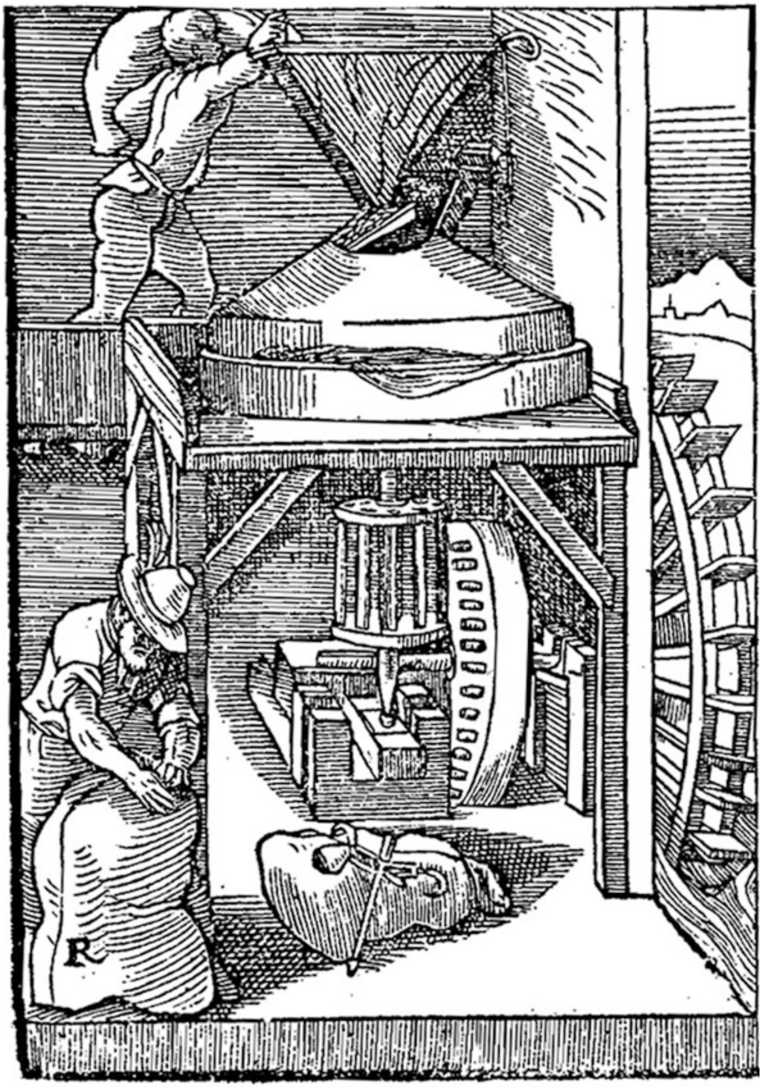


Fig. 19 Drawing of a water mill in Barbaro's edition in 1584 on page 463

Again in Fig. 26 the German edition by Ryff gives a representation of the machine very similar to the one by Cesariano.

In Fig. 27 by Perrault the representation is much more technical with modern-like aspects both in the details of the upper scheme and the assembly at the bottom. The huge size of the screw pump is indicated by a human operator on the wheel on the screw as to indicate a much larger mechanical power that this device has

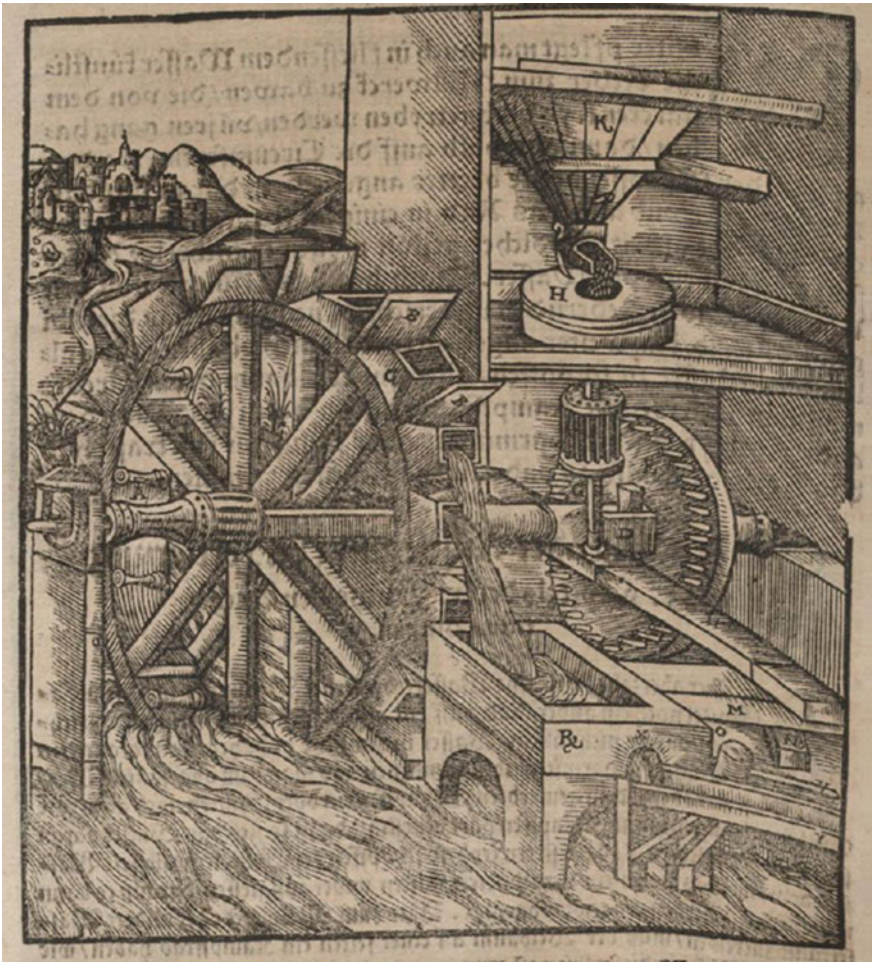


Fig. 20 Drawing of a water mill in Ryff's edition in 1575 on page DCXLVII

reached at Perrault's time. But the mechanical design is still the same as indicated by Vitruvius and represented by Barbaro.

The case of war machines is the most indicative of the complexity in understanding the Vitruvius text and in giving proper representation of war machines from Roman times.

Frà Giocondo gives an attempt of mechanical design of a ballista, but although several components are indicated, its operation is not clearly represented as from lack of connections of parts driving the system. Cesariano shows a scenario from a Renaissance battle in which war cars, war hammers, and catapults are shown together with guns not existing at the time of Vitruvius. Barbaro does not give any representation of war machines perhaps because of his religious position.

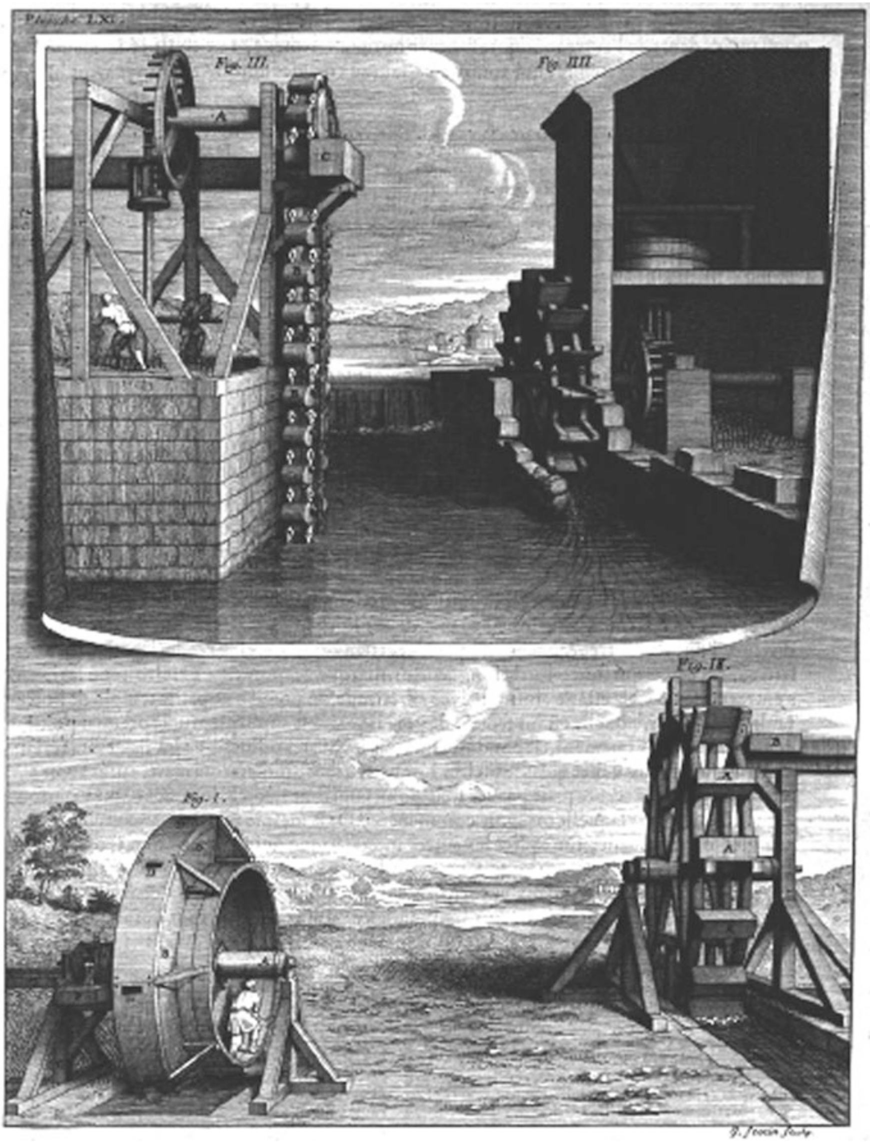


Fig. 21 Drawing of a water mill in the Perrault edition in 1673 on Table LX

Durantino and Ryff use the representation of Frà Giocondo with a detailed frame structure but the driving power is not clearly illustrated since the bars with tendon are not clearly assembled for an inputting action so that it seems that Vitruvius was clear in describing the components but not the operation of the mechanisms. Perrault gives more emphasis again on a large size that a machine can have and he

Fig. 22 Drawing of an Archimedes screw pump in Fra Giocondo's edition in 1513 on page 172 v

shows with more details the whole of the machine rather than the mechanism of it as did in all the other editions, as mentioned above.

From a drawing viewpoint Frà Giocondo, Fig. 28, shows the ballista as suspended in an empty unnatural space and the only naturalistic view is limited to the materials for the extremity of the arrow in its feathers. The war machine is represented in pseudo-prospective view that gives depth to the drawing indicating the relative position of the parts.

Like the previous drawing on cranes, in Fig. 29 Cesariano shows a crowded scenario of war machines within a battle field. Thus, there are soldiers with hammers and others with catapults in a pictorial view with clever chiaroscuro whose darkness even for the sky contributes to a dark atmosphere that is well due to war situations. Cesariano does not give central attention to the ballista since it is

Fig. 23 Drawing of an Archimedes screw pump in Cesariano's edition in 1521 on page CLXXI v

represented as overwhelmed by human operators and details of mechanical design are not appreciable.

In Fig. 30 Durantino shows an exact copy of Frà Giocondo's drawing, as to indicate an acceptance of the interpretation of Vitruvius's text. This is confirmed also in Fig. 31 by Ryff.

In Fig. 32 Perrault shows a ballista of large dimension to emphasize the power of the mechanical design but details of the mechanisms are not shown.

The reported illustrated survey shows a clear understanding of Vitruvius's text although in some cases details are not fully reported. These illustrations are significant not only for interpretation of Vitruvius's description. These details were also added in the editions to show the practical efficiency of those machines from Antiquity, always focused on current applications and declaring the technical value of Vitruvius's treatise much more than only as historical literature.

Fig. 24 Drawing of an Archimedes screw pump in Durantino's edition in 1524 on page 102 r

Fig. 25 Drawing of an Archimedes screw pump in Barbaro's edition in 1584 on page 463

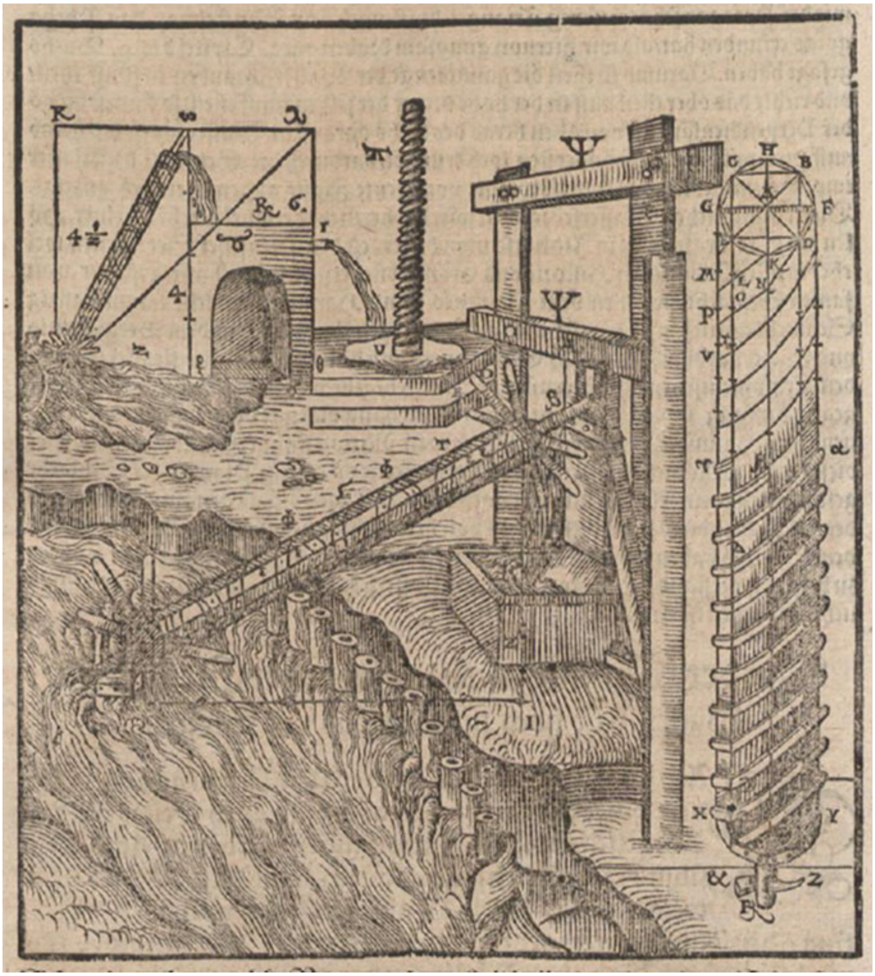


Fig. 26 Drawing of an Archimedes screw pump in Ryff's edition in 1575 on page DCLI

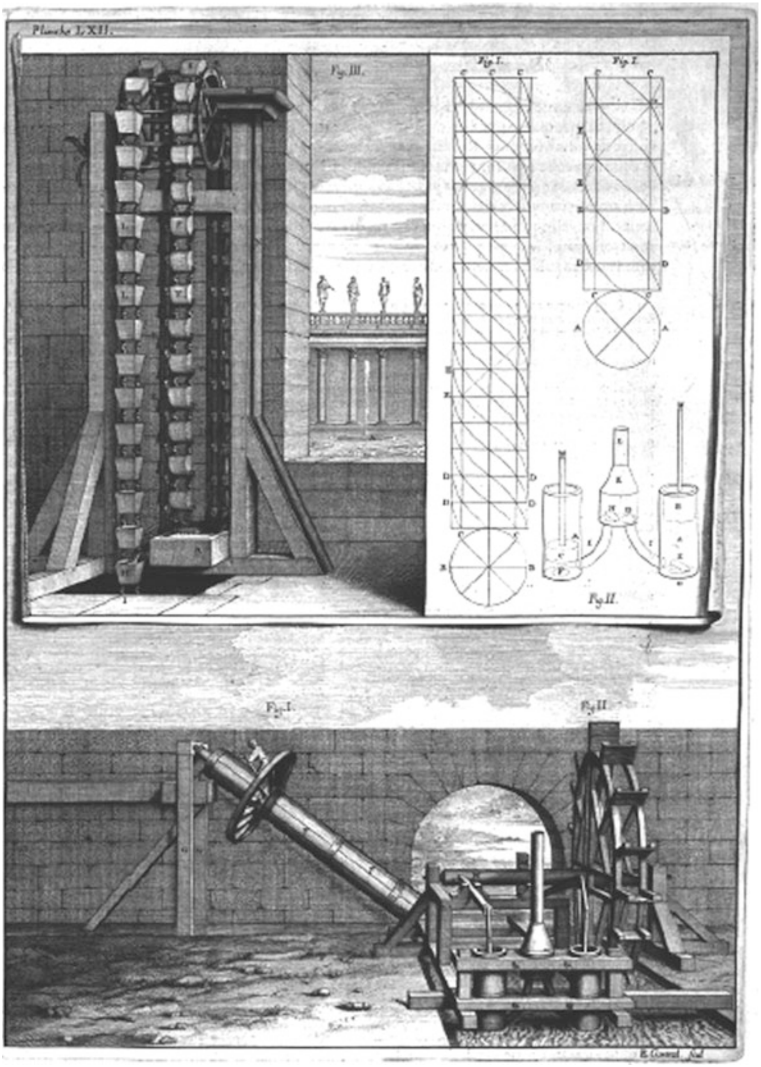


Fig. 27 Drawing of an Archimedes screw pump in Perrault's edition in 1673 on Table LXII

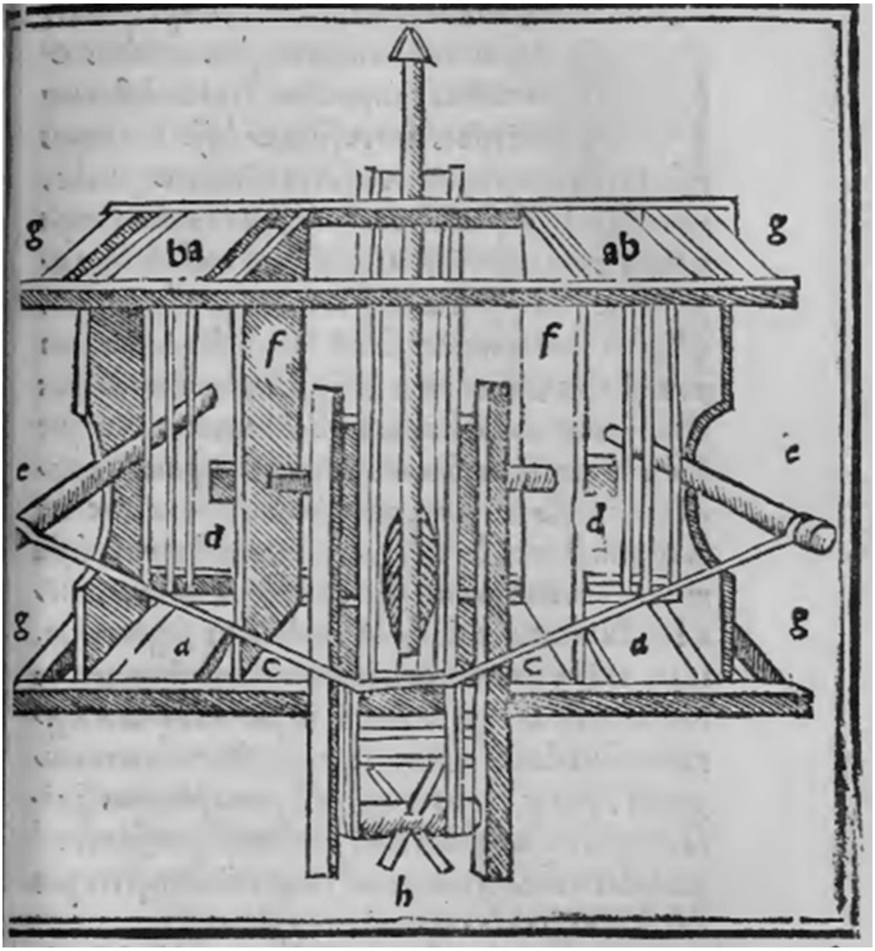


Fig. 28 Drawing of a balista in Frà Giocondo's edition in 1513 on page 179 r

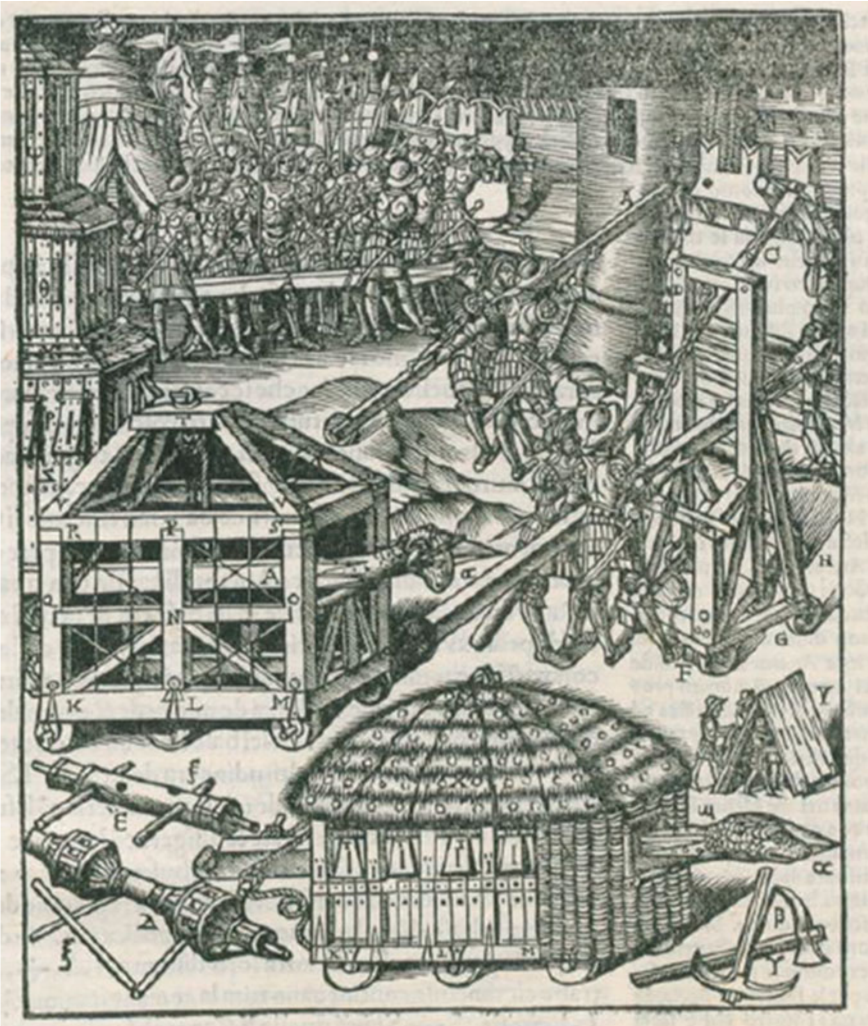


Fig. 29 Drawing of war machines in Cesariano's edition in 1521 on page. CLXXVIII v

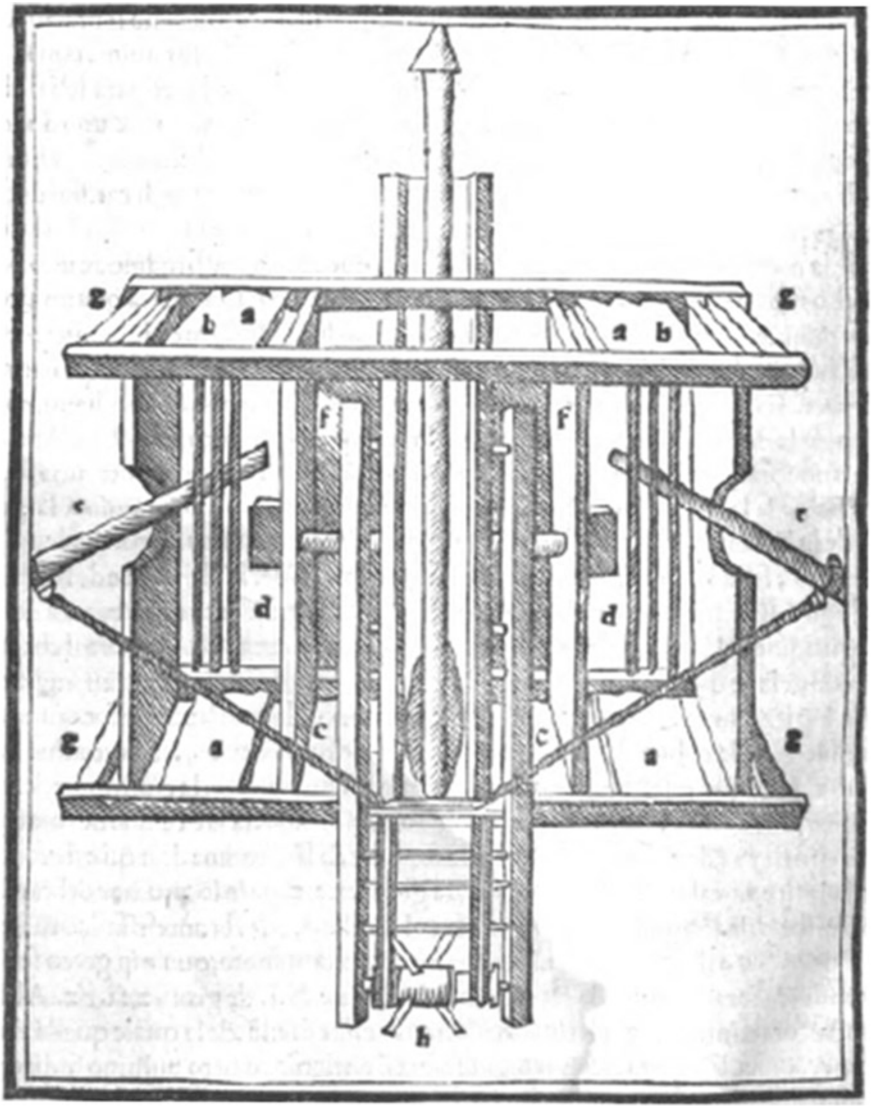


Fig. 30 Drawing of a balista in Durantino's edition in 1524 on page 105 v

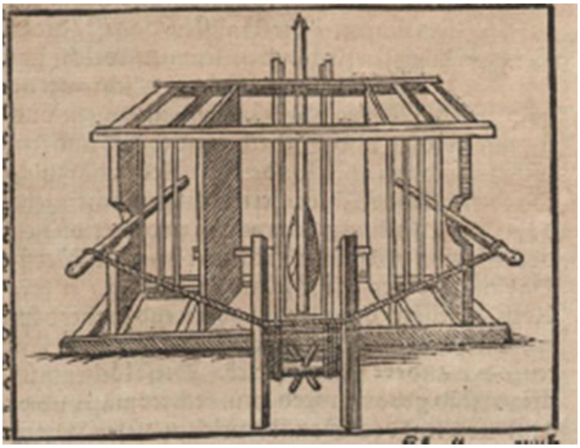


Fig. 31 Drawing of a balista in Ryff's edition in 1575 on page DCLXIII

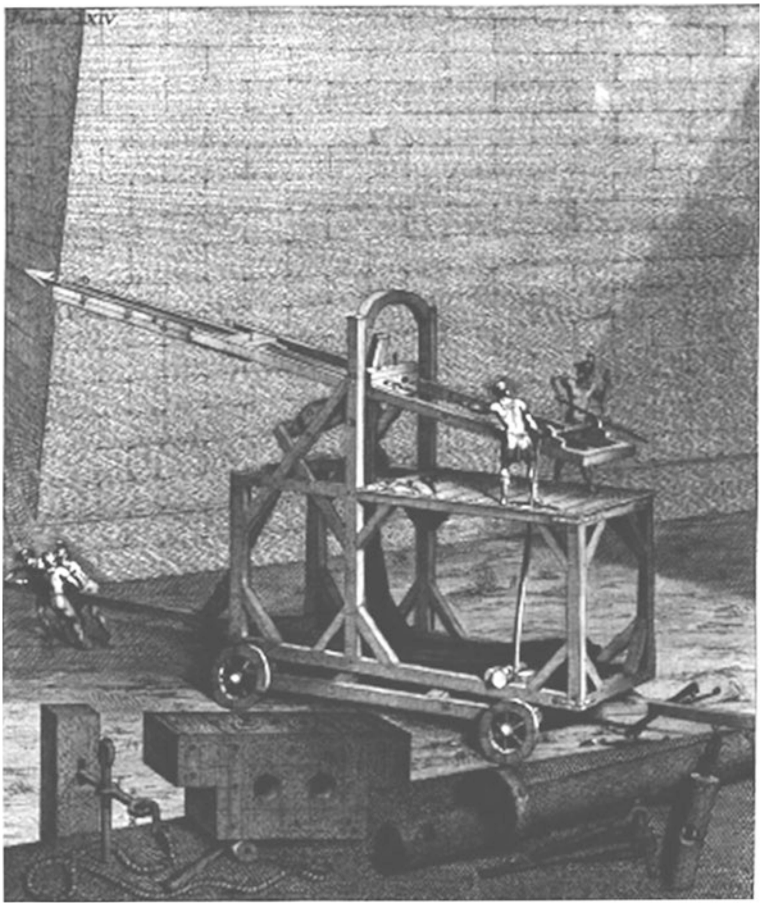


Fig. 32 Drawing of a ballista in Perrault's edition in 1673 onTable LXI

5 Conclusions

Vitruvius addressed specific attention to machines in his treatise De Architectura in I B.C. as an important part of a handbook of technique from Antiquity. The specific survey of machines in Chap. 10 of the treatise was used during the Renaissance as background and inspiration for a rigorous consideration of machine design with the dignity of a discipline. In addition, the machines that Vitruvius described in his treatise were considered important machines and received attention even from theoretical viewpoints after this reconsideration of their mechanical designs and operations.

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Barbaro D (1584) I dieci libri dell'architettura di M. Vitruuio, tradotti, & commentati da monsig. Daniel Barbaro Patriarca d'Aquileia, da lui riueduti, & ampliati; et hora in più commoda forma ridotti. Venezia

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Cesariano C (1521) Vitruvius, Di Lucio Vitruuio Pollione De architectura libri dece : traducti de latino in vulgare, affigurati, comentati, & con mirando ordine insigniti: per il quale facilmente potrai trouare la multitudine de li abstrusi & reconditi vocabuli a li soi loci & in epsa tabula con summo studio expositi & enucleati ad immensa utilitate de ciascuno studioso & beniuolo di epsa opera. Como

Durantino FL (1524) M. L. Vitrvuio Pollione Di architettura dal vero esemplare latino nella volgar lingua tradotto: e con le figure a suoi luoghi con mirãdo ordine insignito. Anchora con la tauola alfabetica: nella quale facilmente si potra trouare la moltitudine de vocaboli a suoi luoghi cõ gran diligenza esposti : e dichiarati: mai piu da alcuno altro fin al presente stampato a grande vtilita di ciascuno studioso. Venezia

Frà G (1511) M. Vitruvius per Iocundum solito castigatior factus cun figuris et tabula et iam legi et intelligi posuit. Venezia

Frà G (1513) Vitruvius iterum et Frontinus a Iocundo revisi repurgatique quantum ex collazione liquit, Hoc opus præcipua diligentia castigatum & cura summa excusum est Floretiæ sumptibus Philippi de Giunta Florentini anno domini M.D.XIII. mense Octobri. Firenze

Perrault C (1673) Les dix livres d'architecture de Vitruve, corrigez et traduits nouvellemnt en francois, avec des notes & des figures. Paris

Ryff WH (1575) Zehen Bücher von der Architectur und künstlichem Bawen. Ein Schlüssel vnd einleytung aller Mathematischen vnnd Mechanischen Künst Scharpffsinniger fleissiger nachtrachtung oder Speculation künstlicher Werck …; Alles mit schoenen künstlichen Figuren vnnd Antiquiteten vnd sonderlichen Commentarien … gezieret vnd erkleret. Basel

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