Todor Pantelić (1923–1999)

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Abstract By transforming fundamental theoretical solutions into functional mechanisms, Todor Lazar Pantelić became a pioneer of innovative structural synthesis. Most of his work evolved to the level of patents and industrial products. Professor Pantelić's specialty was the four-bar chain in innumerable varieties such as walking, imprinting, and shutter mechanisms. The crown of his innovative work was the helical conveyor, theoretically established, patented, designed, and prototyped. Loved and admired by his students and colleagues, he made a point of introducing engineering talent and creativity into the science of machines and mechanisms. He was one of the founders of the International Federation for the Theory of Machines and Mechanisms (IFToMM) and the first president of its Commission for Collaboration of Science and Industry.

Biographical Notes

So much of who we are – we owe to our teachers. In the constellation of all the great masters I have met, shines brightly the giant star of Professor Todor Pantelić.

Todor Lazara Pantelić (Fig. 1) was born on 2nd July 1923 in Belgrade (then the capital of the Kingdom of Yugoslavia) to a family of a small merchant. He had a carefree childhood in a Belgrade suburb, spending every waking hour in his brother's workshop for mechanical calculators. His regular schooling at King Alexander's Lyceum was interrupted before he was 18 by the bombing of Belgrade on 6 April 1941, which was the beginning of the Second World War in Yugoslavia. Resourceful and restless, he soon took part in the antifascist resistance movement in occupied Belgrade. When the war finally ended in 1945, he was demobilised and became a student of the Belgrade Polytechnics.

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M. Ceccarelli (ed.), *Distinguished Figures in Mechanism and Machine Science: Their Contributions and Legacies, Part 2*, History of Mechanism and Machine Science 7,
DOI 10.1007/978-90-481-2346-9_11,

Fig. 1 Prof. Todor Pantelić at the international symposium machines and mechanisms, Belgrade, September 1997

His academic career started right after graduation: he became Junior Engineer in 1950, Teaching Assistant in 1954, Assistant Professor in 1960, Associate Professor in 1966 and, finally, Full Professor at the Faculty of Mechanical Engineering, University of Belgrade in 1971 (Evaluation report...).

He has published extensively at home and abroad (180 works and 4 books) and was the author or co-author of 23 national and five international patents. Marked by books, students, travels, patents, friends and family – his life was indeed an amazing one.

Prof. Pantelić was one of the founders of The International Federation for the Theory of Machines and Mechanisms (IFToMM). The decision was made in Varna (Bulgaria) in 1965, during the first Congress in that field, which assembled representatives of 16 countries. The committee including Prof. I. I. Artobolevskii (И. И. АртоболевскИй), Prof. F. R. E. Crossley, Prof. M. S. Konstantinov, Prof. W. Meyer zur Capellen, Prof. G. Bianchi, and Prof. Todor Pantelić, among others, organised the founding conference of IFToMM in Zakopane (Poland) in 1969. The next one was held in 1971 in Kupari (Yugoslavia), hosted by Prof. Pantelić (Fig. 2).

That grandiose gathering, with over 800 participants, has been considered a model of a successfully organised international scientific conference coloured by national charm. The exhibition of applied mechanisms was particularly successful: members of the Executive Board of IFToMM, very impressed, later pronounced Prof. Pantelić as chairman of the Commission for Collaboration of Science and Industry.

The Committee's seat therefore moved to Belgrade, to the Faculty of Mechanical Engineering. Innovative and brilliant, Prof. Pantelić established the Machine Mechanics Institute, and developed it into an incubator where scientists and innovators came for consultations and help with their evolving solutions and prototypes.

Many years later, in 1995, during the Ninth World Congress of IFToMM in Milan, I met Prof. J. R. Phillips who had travelled all the way from Australia to Belgrade in order to work with Prof. Pantelić on a model of mechanism analysed

Fig. 2 Kupari, Third IFToMM World Congress 1971. *Left* to *right*: (1) Ž. Nikolić [Yu], (2) I. I. Artobolevskii [USSR], (3) unknown, (4) P. Genova [Bul], (5) G. Boegelsack [GDR], 6) W. Roessner [GFR], 7) and 8) unknown, 9) N. I. Manolescu [Rom], 10) R. Unterberger [GFR]

in a doctoral thesis. At that time, the Machine Mechanics Institute was already renowned for application of the theory of machines and mechanisms.

The walls of the Institute still bear marks of the creative atmosphere of that time: a photograph (Fig. 3) taken at the Leonardo da Vinci Museum during the Congress in Milan shows the Yugoslav team led by Prof. Pantelić and accompanied by Prof. A. Morecki from Poland (the previous president of the IFToMM), Prof. B. Roth from USA, and Prof. A. P. Bessonov (А. П. Бессонов) from Russia. As I realised only recently, a model of Leonardo's helicoid stands out in the background of the picture, adding a touch of magic: in the preceding years, a helical conveyor had become the crown of Prof. Pantelić's innovative work.

Clearly, it was the Professor's idiosyncrasies that led to this patent conceived apparently contrary to the fundamental principles of mechanics. Namely, the only way to make a helicoid belt revolve around a central post without friction was to convert it into a solid body; for the belt as a floppy form, the task would be impossible. Many were sceptic, but Prof. Pantelić succeeded.

Recognition of creative powers and already achieved results of Belgrade's IFToMM centre came in 1974 with the Symposium on Application of the Theory of Machines and Mechanisms in Dublin (Ireland). Prof. Duffy from the Liverpool Polytechnic was chairing the Organising Committee, and Sir Crossley, president of IFToMM, personally entrusted Prof. Pantelić with chairing the event.

Fig. 3 Milan, Ninth IFToMM World Congress 1995. At the Leonardo da Vinci Museum (with a model of a hellicoid in the background), left to right: Lj. Miladinović [Serbia], A. Sekulić [Ser], A. Veg [Ser], N. Pavlović [Ser], M. Vukobratović [Ser], B. Roth [USA], A. Morecki [Pol], A. P. Bessonov [Rus], unknown, L. Cvetičanin [Ser], M. Pantelić (Prof. Pantelić's wife) [Ser], T. Pantelić [Ser]

In 1997, 26 professors from all parts of the world came to Belgrade Symposium on the Theory of Machines and Mechanisms, organised in his honour: Prof. M. Ceccarelli from Italy, Prof. T. Leinonen from Finland, Prof. E. J. Hahn from Australia, Prof. F. G. Dedini from Brazil, Prof. S. Kato from Japan, and Prof. G. Bőgelsack from Germany.

In 1999, while bombs were falling on Belgrade (again), Prof. Pantelić received an invitation to chair the Tenth World Congress of IFToMM in Oulu (Finland). He thanked for the honour but stayed at home.

Later that year, when he suddenly and unexpectedly died, his wife and three daughters received condolences from all over the world.

Main Works on Mechanism Design

Prof. Pantelić's main works include:

– A four-bar mechanism applied to operations on pieces on a conveying line (Pantelić 1974, 1977b). It represented a new type of mechanism that replaces intermittent mechanism, and it was used for manufacturing 120 pastry production lines (*Minel* Company, Pančevo, Serbia).

- Settlement of motion equivalence between four-bar and slider-crank mechanisms (Pantelić 1976, 1981b), which enabled synthesis of a family of extended slider-crank mechanisms with a member performing approximate curvilinear translation (Pantelić 1975a, 1975b , 1976, 1977b, 1980, 1981a, Stoimenov and Pantelić 1976). It was used for highly efficient pastry production lines, in which the translatory member carries the tools for executing individual operations. One of its inversions was applied to the model of the *walker* mechanism (Pantelić 1980, 1981a, 1981d, 1983a, Stoimenov and Pantelić 1981).
- Synthesis of six-bar linkage with three dwells in the motion of its driven bar (Martinović R and Pantelić 1975a, 1975b). It was the first practical solution of the problem since 1932. It was used to double or treble the number of rows in conveying lines, with the respective dwells in the motion phased by π, or 2/3π.
- An advanced numerical method of the inertial forces harmonic analysis (Četić D and Pantelić and Sekulić 1971; Pantelić, 1981c) applying Bessel functions for balancing inertial forces of basic linkages. The results of this work were applied to balancing the new family of slider-crank mechanisms used for Prof. Pantelić's *walker*.
- Synthesis of four-bar with additional dyad (Pantelić 1977a, 1980, 1981). It generated a mechanism for a deep drawing machine press with very fast approach, relatively slow imprint, and fast return. Compared to the conventional machine presses, productivity of the new one was doubled.
- Research of kinematic chains with zero degrees of freedom, mainly for steel and chain conveyor belts, which contributed to optimisation of their drive and control (Četić D and Pantelić 1980).
- Helical conveyor and overcoming Euler friction (Bukumirović and Pantelić 1975a, 1975b), as the most serious challenge of Prof. Pantelić's career.

Neither a groundbreaking theorem nor a revolutionary new theory is what Prof. Pantelić is to be praised for. He did something else: he made a point of introducing engineering talent and creativity into the science of machines and mechanisms. His art was *simple and efficient transformation of an idea into a product*.

And to that vision he dedicated his whole career, his life too. Working with him, generations of students discovered the beauty of engineering creation, learned to love their profession and to enjoy every day of creative work and every achievement they made.

At the peak of his career, Prof. Pantelić found himself in a unique position to connect creative work of academic communities of all 17 members of the IFToMM within the Commission for Collaboration of Science and Industry, the so-called Commission C.

He invested all his talent and enthusiasm into realisation of the IFToMM *Programme on Collaboration of Science and Industry in the Theory of Machines and Mechanisms*.

Establishing of the Commission C was proposed in 1971 in Düsseldorf (Germany) at the meeting of the IFToMM Executive Council. An action plan in 12 steps was formulated, and Prof. Pantelić (nominated by Academician Artobolevskii) was elected President of the new commission (Fig. 4).

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ACKNOWLEDGEMENTS

The Chairman of the Organising Committee wishes to express gratitude to the Convention Bureau of Ireland and to Professors P Leahy and J R McCraith of University College, Dublin for their assistance and cooperation in organising the Symposium.

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Fig. 4 Proceedings Dublin 1974, front page

The first meeting of Commission C was held in 1971 in Kupari (Yugoslavia), the second one in 1972 in Miskolc (Hungary), the third one in 1973 in Bucharest (Romania). The pioneering job of harmonising creative work of university researchers and industry designers was soon in full swing, as can be seen from the proceedings of the 1974 IFToMM Symposium in Dublin.

Obviously, Prof. Pantelić was not leading such a creative army only because of his brilliant managerial skills; it was also because he had a gift for closing up the golden engineering triangle *idea → concept → product*.

An eye for harmony and beauty helped him create elegance without effort. “A beautiful construction is certainly a functional one, that’s for sure,” he used to say.

Design without effort came from the synergy of his exceptional visualisation, thorough understanding of fundamental sciences, and fascination with mechanisms.

Naturally, it resulted in axiomatic design. Although the following examples (chosen from among numerous successful constructions of Prof. Pantelić) seemed technically incomparable, he still found their common point and used it as a basis for conceptual design, which then led to two outstanding solutions (Pantelić 1965, 1983).

The first one is applied to an automatic bun production line (Fig. 5), and the second – to an orthopaedic device.

It all started with a mechanism for imprinting buns on a conveying line. A standard industrial solution widely applied in similar technologies was available: a configuration with coupled motions – horizontal, which follows a bun, and vertical, which imprints it in the process. The challenge was to simplify the configuration by implementing a single member with the resulting path.

The first attempt was synthesis of a four-bar chain where the coupler generates the desired path. But the search went on.

The same operation can be performed by adding new links to a kinematic chain, which follows the same path (Fig. 6). In that case, a link’s endpoint in two inverted slider-crank mechanisms performs curvilinear translation, that is follows exactly the desired path. The solution was modified into an eight-link mechanism by omitting one slider and adding one link. The search for more efficient solutions continued.

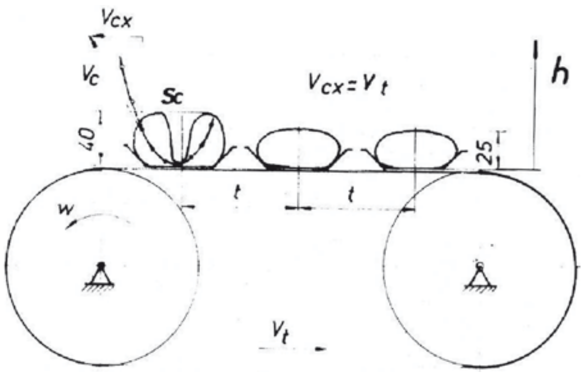

Fig. 5 Path analysis of the bun imprinting tool (Pantelić 1975b)

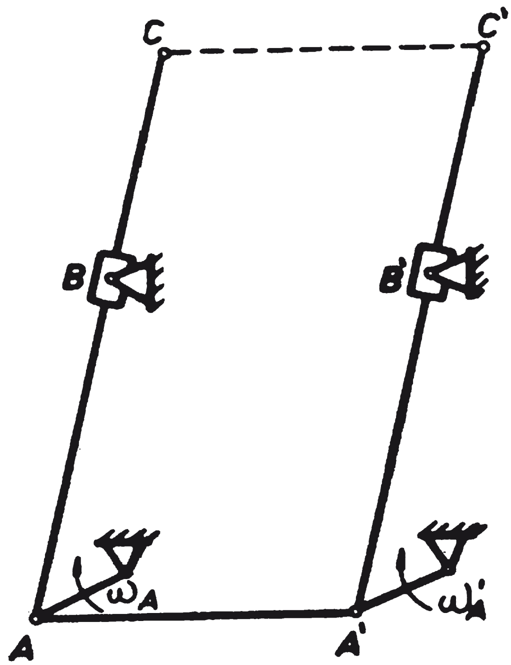

Fig. 6 Inverted slider-crank (Pantelić 1975b)

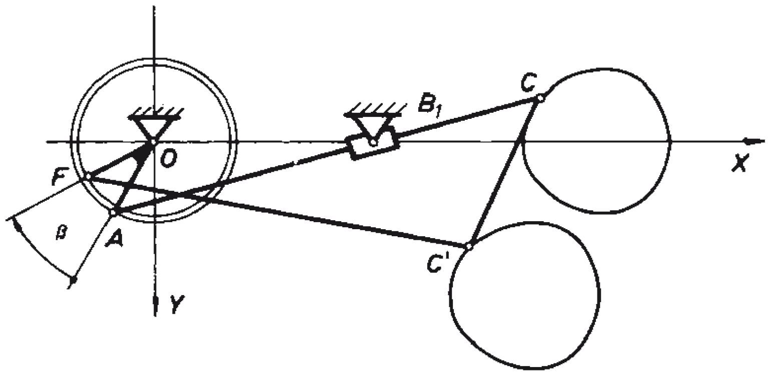

Fig. 7 Slider-crank mechanism with additional dyad – curvilinear translation (Pantelić 1975b)

Prof. Pantelić came up with a new task: to create a six-link inverted slider-crank mechanism with additional dyad, in which coupler CC' performs curvilinear translation with the given path. It took quite a while to finalise the solution of this problem, which had not been solved up to that time.

In the inverted slider-crank mechanism with additional dyad (Fig. 7), translatory motion of the link CC' is due to points C and C' following approximately the same path. Such a simplified configuration was far more suitable for application to production lines.

Once established, synthesis of the extended inverted slider-crank mechanism with a member that performs approximately curvilinear translation, enabled a whole generation of innovative modifications.

The breakthrough occurred when Prof. Pantelić noticed hidden similarities in two apparently very different processes: bun imprinting and – human walking! In operational cycle of the imprinting mechanism (Fig. 8/1) there is a fragment with

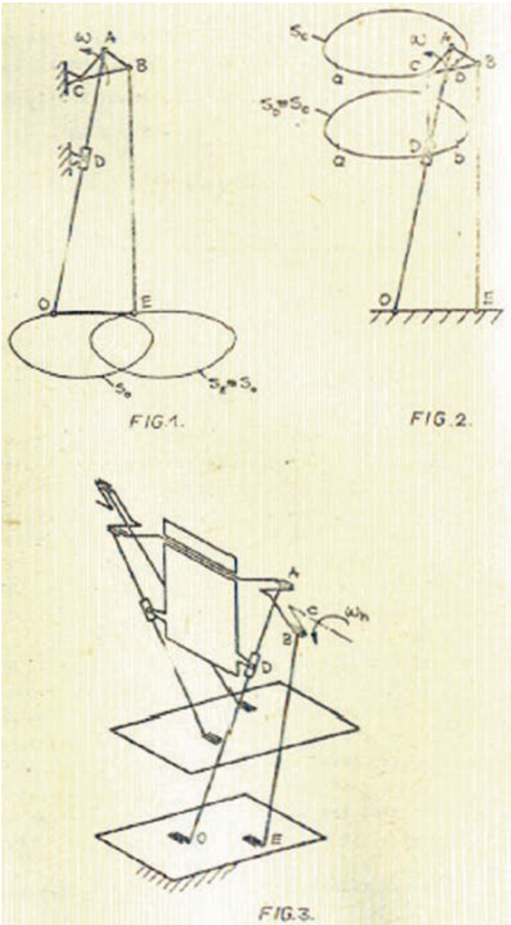

Fig. 8 Slider-crank mechanism with additional dyad: (1) imprinting inversion, (2) walker inversion, (3) walker composition (Pantelić 1981b)

no relative motion between the link CC' and the bun; similarly, from time to time, there is no relative motion between the foot and the floor.

Looking at the new inversion, the so-called *walker* mechanism (Fig. 8/2), one sees that its coupler CD performs curvilinear translation, which enables the *walker* to make a step forward relative to the floor. The basic structure of this mechanism is a four-bar OABE, extended with a coupler CD and a slider D. The transition from the raw concept to the actual "walking model" was long and winding, but Prof. Pantelić had a clear guiding vision.

Two identical walker mechanisms were placed in parallel planes, with cranks shifted for half a cycle and embedded in the point C (Fig. 8/3). The grounding of each walker acts as a foot; when one of them is firmly on the ground, the other is in the air and, due to rotation of the crank, performs a step forward. Alternating and synchronised lifting and dropping of the feet, and their curvilinear translation forward appears amazingly similar to human walking. A rocker also had to be added in the model in order to shuttle its centre of gravity from one plane to the other, enabling the foot in the air to walk freely.

The Walker (Fig. 9) was a revelation of the 1981 Bucharest Symposium *Theory and Practice of Mechanisms*: an intricate motion, similar the human walk, was realised in a very simple manner. Unfortunately, the avalanche of new, easily marketable ideas and patents at the Machine Mechanics Institute in Belgrade diminished the interest for this project, although it was recognised as striking and successful.

A special place in the creative opus of Prof. Pantelić belongs to his helical conveyor. He was persistently working on the idea despite the sceptic attitude expressed in some of the related disciplines. Unlike most of his works which were broadly published, he kept this one to himself, far from the international scene. Except for four master theses, one vague paper on the idea of the helical conveyor, one review paper at the 1997 Belgrade Symposium and a functioning model, there is no other technical evidence that usually accompanies projects of such relevance. Prof. Pantelić himself probably had his doubts: would everything work out as in his vision? All the elements necessary for a successful project were there – except a market boom.

There was a clear need in the food industry to transport pastry in the process of warming, baking, and cooling not through the endless line tunnels (30–70 m long!) but through a helicoid, inside a compact thermodynamically controlled space.

The main problem of this idea was obviously Euler friction; there was also the speed difference between the inner and the outer edges of the belt, as well as the inconformity of upward and downward motion of the helical belt.

The following overview is an attempt to reveal the path of the invention's evolution.

Prof. Pantelić's inspiration was an already existing idea of a helical transporting belt which ascends around the central post. It folds around the dragging roller at the top, then descends, and folds again around the tightening roller at the bottom. The problem is that friction between the stable post and the sliding belt, according to Euler's formula, grows exponentially.

There was also a version with a rotating post that drags the belt upwards; then, after a short linear part, the belt descends the second rotating post and proceeds linearly to the starting point.

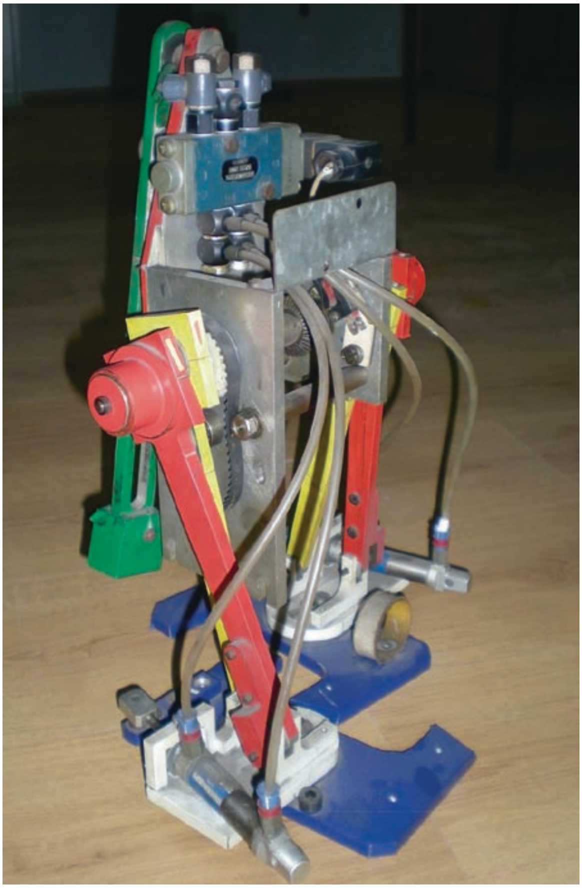

Fig. 9 Mechanical Walker (Photo A. Veg, 2008)

A serious disadvantage of the first solution was the enormous dragging force needed to overcome enormous friction. In the second one, combination of curved and linear paths of the belt, driven in free contact with rotating posts, caused various functional difficulties.

The creative illumination came when Prof. Pantelić wrote down all the necessary conditions and limitations for his helical conveyor:

– The helical belt should not touch the central post.
– Within the helical guides, belt chain members must loose all degrees of freedom, so the belt could rotate as a rigid helicoid (in such a way the dragging force of the helical conveyor becomes approximately equal to the dragging force of the correspondent line conveyor, (Miljković M. and Pantelić 1997)).
– The inner diameter of the solid helicoid must be significantly greater than the diameter of the central guiding cylinder.

– Coming out of helical guides, and also engaging with the driving rollers, belt chain members regain necessary degrees of freedom, so the belt could behave as a solid body.

This was the basis for Prof. Pantelić's new solution. In a consistent and focused developmental phase (Fig. 10), he defined the geometry of the belt; defined the

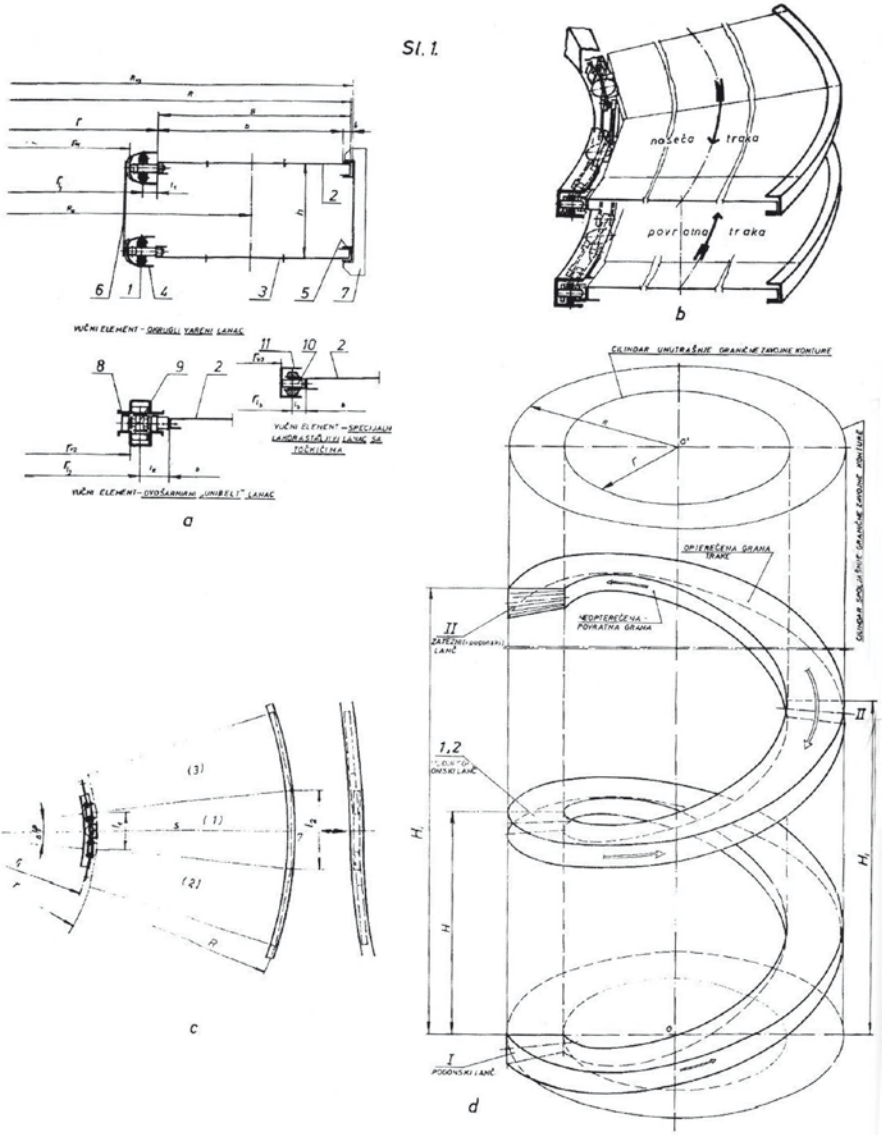

Fig. 10 Draft of the helical conveyor (Bukumirović and Pantelić 1975b)

upward and downward trajectories; constructed the helical guides; calculated contact radii of the driving roller; optimised speeds of the belt chains, that is developed a prototype (Fig. 11). Two models of the helical conveyor were made and they both fulfilled all the technical requirements.

Following the development of this project through documents, I concluded that it was the most serious challenge of Prof. Pantelić's career. Like a sport champion after achieving a record that will obviously stand for many years, he lost any further wish to compete.

The moment prototype of the helical conveyor came to life, all doubts of his colleagues disappeared and, even more importantly, his personal hidden doubts too. I think it was the last and the greatest creative flash of Prof. Todor Pantelić.

From then on, resigning the post of a great inventor, he focused on his teaching mission, leaving space for the upcoming younger colleagues.

Fig. 11 Helicoid prototype (Photo A. Veg 2008)

On the Circulation of Works

There are several aspects of Prof. Pantelić's conspicuously dynamic career.

Firstly, he did all he could to disseminate the theory of machines and mechanisms in the territory of former Yugoslavia. He had postgraduate and doctoral students from all the emerging Yugoslav centres – Niš (Serbia), Skopje (Macedonia), Mostar and Sarajevo (Bosnia and Herzegovina), Podgorica (Montenegro) – as well as from the centres which already had scientific reputation, only not in the field of mechanisms – Ljubljana (Slovenia) and Zagreb (Croatia). Most of those postgraduate and doctoral students became professors at their home universities, broadening the scientific community dedicated to the theory of machines and mechanisms and related fields.

He travelled and lectured extensively and organised symposia on the theory of machines and mechanisms in all those academic centres.

Another significant aspect of Prof. Pantelić's career was theoretical elaboration of insufficiently studied issues in the theory of machines and mechanisms which were needed for his technical innovations.

Application of those newly created mechanisms represents the third aspect of his career – undoubtedly its crown, since it has confirmed all his creative visions. An army of young enthusiastic engineers pursuing their dreams were involved in realisation of his projects. Prof. Pantelić offered a chance to all of them – 22 doctoral, 47 postgraduate, and more than 400 graduate students. They all worked towards their degrees in the innovative atmosphere of the Machine Mechanics Institute in Belgrade.

Prof. Pantelić was the intellectual and spiritual leader of his academic community, powerful, friendly, and informal. Working sessions at the Machine Mechanics Institute would start with his brief announcement: "Gentlemen, I signed a new contract, now let's make it happen." Ideas would come pouring in – what needs to be solved, done, connected, and in what way – from students, assistants, and researchers alike, who were all in a creative fever. At the end of a session, Professor would say: "If anything is still unclear or controversial, make the travel arrangements through the secretariat and go wherever they worked on it before, but come up with a solution in 20 days." And then there would be 20 days of hectic racing, sleepless nights, and excitement so much like the first romantic ones. Such was the creative magic of Prof. Pantelić.

But he did so much more.

He showed us there were no unconquerable fortresses; he showed us how to use a hook, how to catch small and big fish; what to wear to a business meeting; where to find the best men's shoes in the world; where to drink the finest espresso; that Volvo launched its Golden Series – small things like that, and so much more: how to enjoy every moment of life; how to sing in the company of friends; he even used to play for us if an accordion was somewhere in sight.

Finally, he directed his patent rights (1968) to the *Lazar Pantelić Foundation* (named after his father) in order to provide scholarships for excellent but poor students of machine engineering. It was indeed an honour to win them, as some 30 engineers who managed to do so still proudly point out (Contract on patents...).

Acknowledgement This text would have been impossible to write had it not been for the years I have spent learning, working, and forming scientific visions under the guidance of my teacher and mentor Prof. Todor Pantelić.

I wish to thank Prof. Pantelić's close friends and colleagues who helped me reconstruct his creative work and ideas (in random order): Prof. Gerhard Boegelsack (TU Illmenau, Germany), Prof. Života Živković (MEF Niš, Serbia), and Prof. Aleksandar Sekulić (MEF Belgrade, Serbia).

The documents I relied upon were mainly from the library of the Machine Mechanics Institute, as well as from the library and the archives of the Faculty of Mechanical Engineering, University of Belgrade. I am grateful to all the librarians and archivists who kindly helped me find my way around while preparing this text.

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