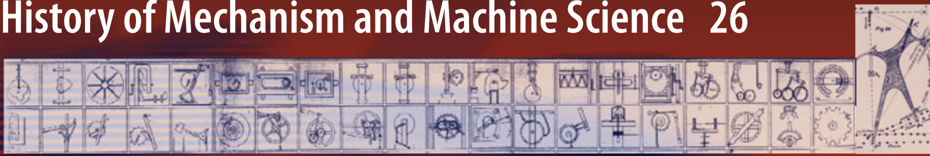
History of Mechanism and Machine Science 26



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

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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

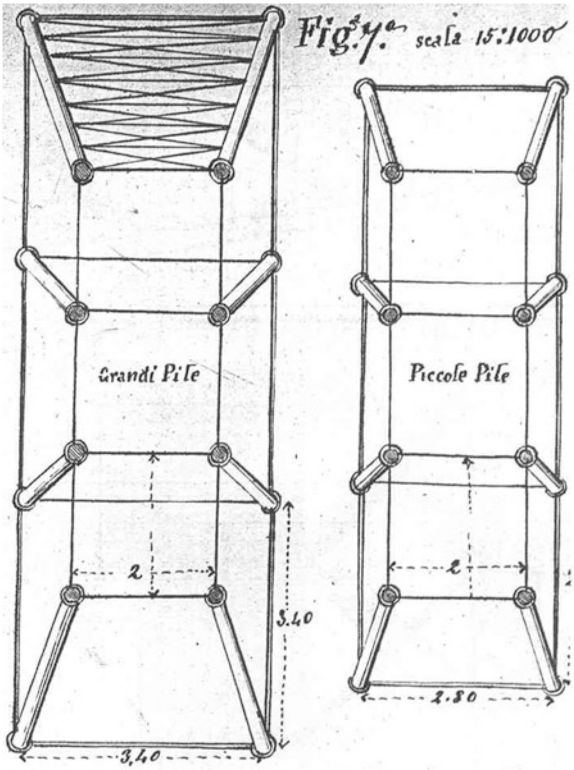


Fig. 2 Schemes of pylons in the thesis for an Engineering degree by Lorenzo Allievi (Courtesy of Mirta Lancellotti)

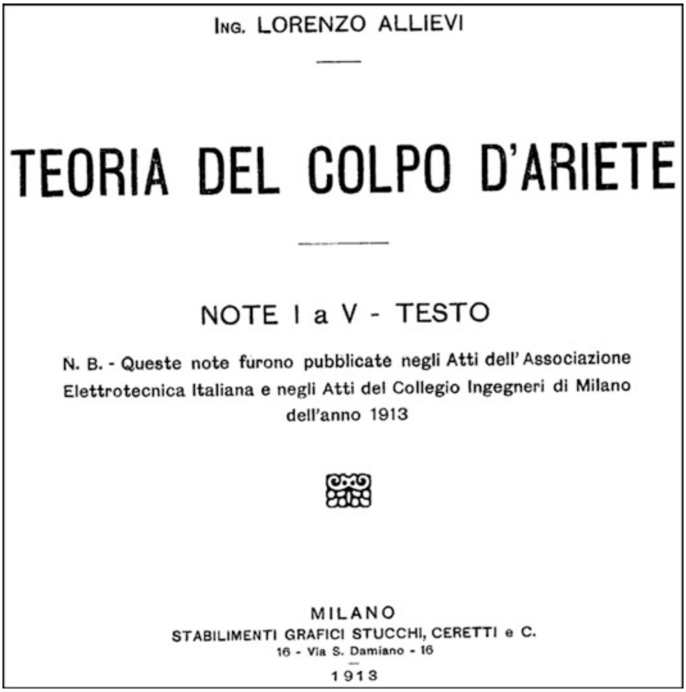
title page of the most widely distributed version from 1913. He continued to work on the theory of the Water hammer but never again considered problems of the Kinematics of mechanisms, the subject of his first scientific publication (Allievi 1895).

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

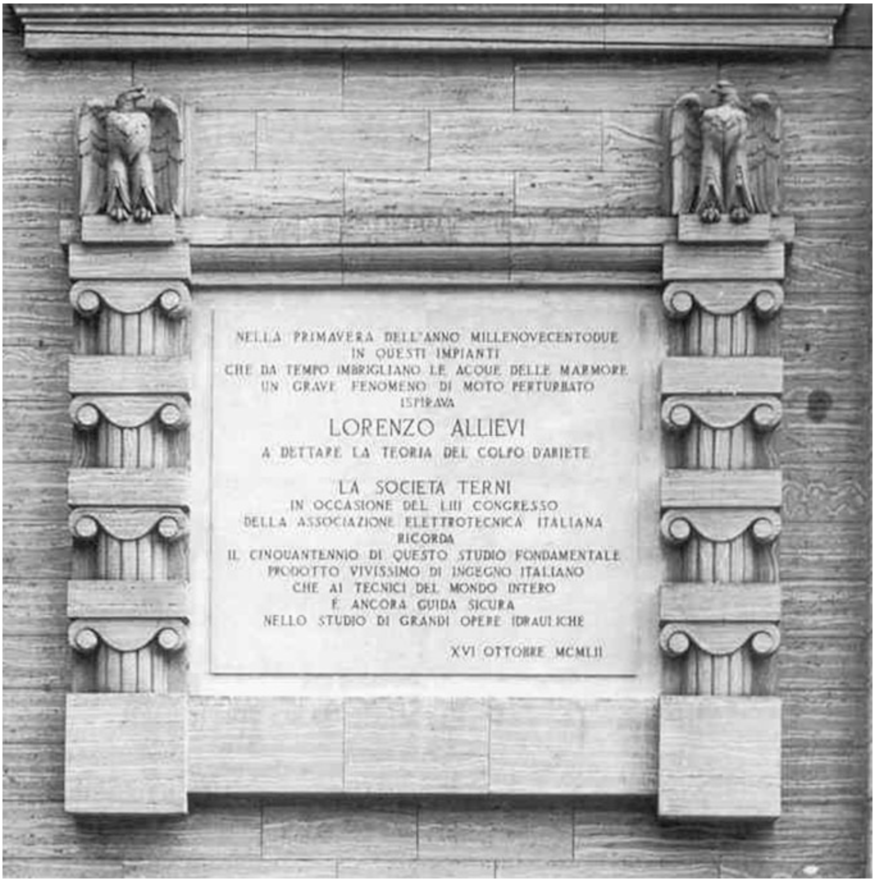
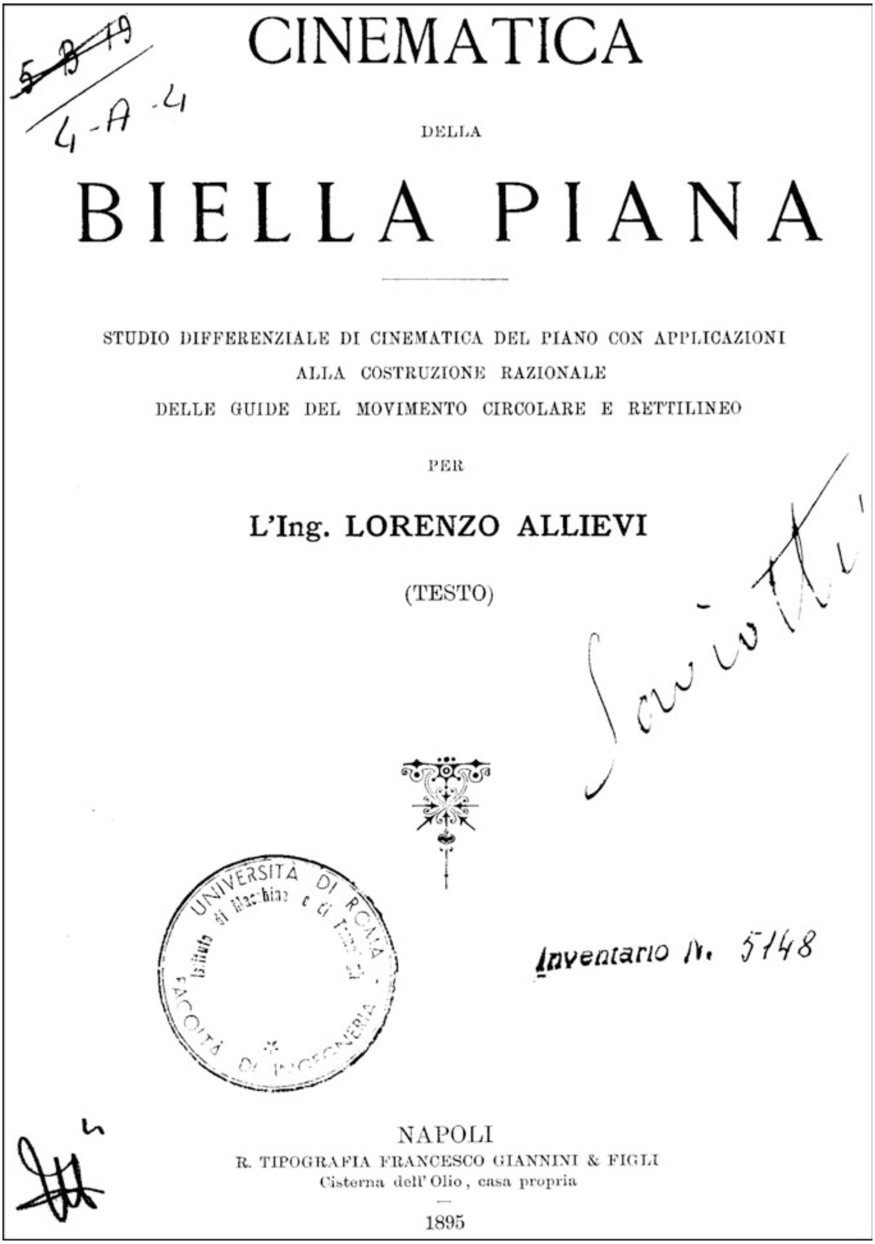


Fig. 5 The marble plaque acknowledging Allievi's contributions to the water hammer at Papigno plant in Terni

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

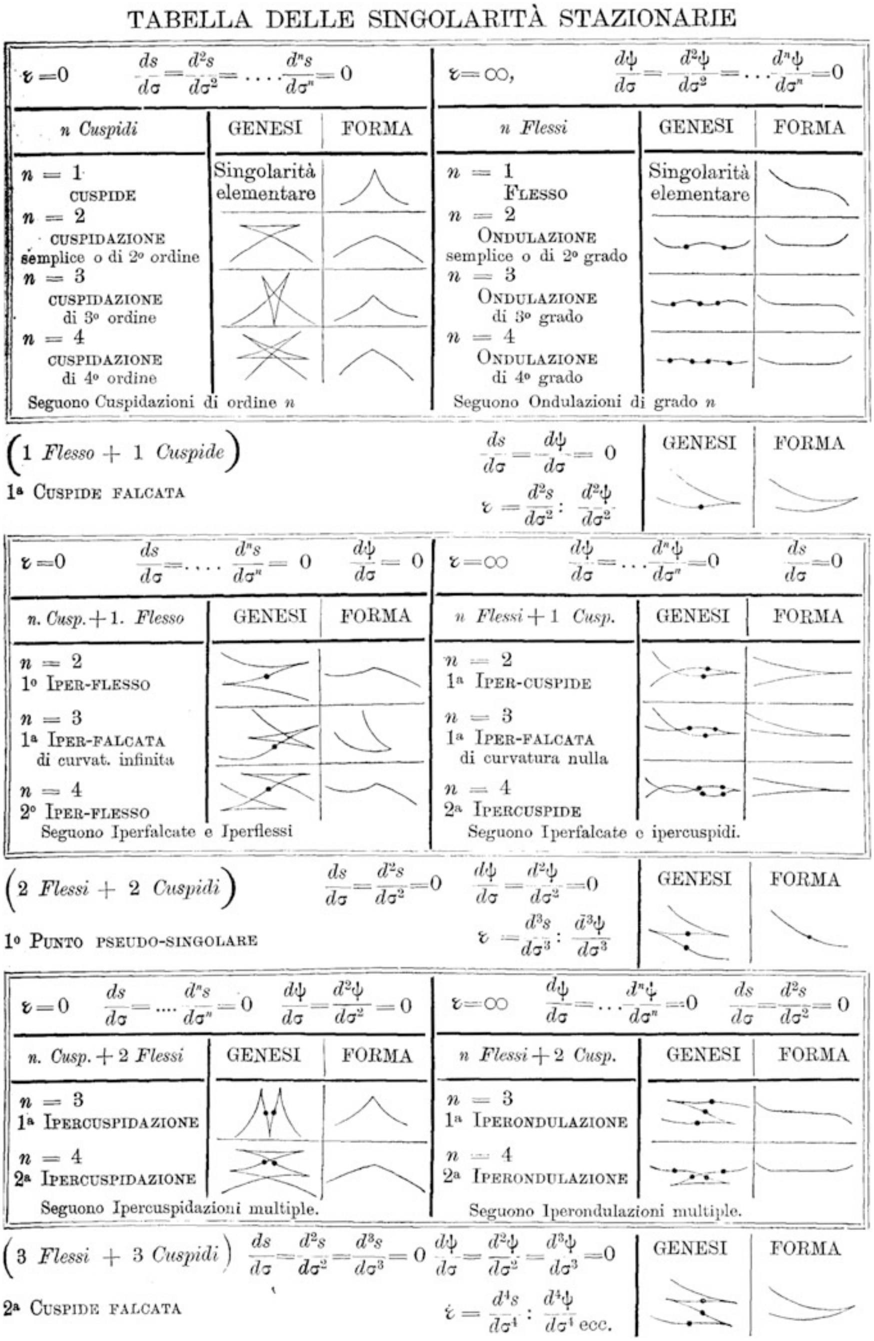


TABELLA DELLE SINGOLARITÀ STAZIONARIE

$\varepsilon = 0$ $\frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = \ldots \frac{d^ns}{d\sigma^n} = 0$			$\varepsilon = \infty,$ $\frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = \ldots \frac{d^n\psi}{d\sigma^n} = 0$		
n Cuspidi	GENESI	FORMA	*n Flessi*	GENESI	FORMA
$n = 1$ CUSPIDE	Singolarità elementare		$n = 1$ FLESSO	Singolarità elementare	
$n = 2$ CUSPIDAZIONE semplice o di 2° ordine			$n = 2$ ONDULAZIONE semplice o di 2° grado		
$n = 3$ CUSPIDAZIONE di 3° ordine			$n = 3$ ONDULAZIONE di 3° grado		
$n = 4$ CUSPIDAZIONE di 4° ordine			$n = 4$ ONDULAZIONE di 4° grado		
Seguono Cuspidazioni di ordine *n*			Seguono Ondulazioni di grado *n*		

(*1 Flesso* + 1 *Cuspide*) $\frac{ds}{d\sigma} = \frac{d\psi}{d\sigma} = 0$ GENESI FORMA

1ª CUSPIDE FALCATA $\varepsilon = \frac{d^2s}{d\sigma^2} : \frac{d^2\psi}{d\sigma^2}$

$\varepsilon = 0$ $\frac{ds}{d\sigma} = \ldots \frac{d^ns}{d\sigma^n} = 0$ $\frac{d\psi}{d\sigma} = 0$			$\varepsilon = \infty$ $\frac{d\psi}{d\sigma} = \ldots \frac{d^n\psi}{d\sigma^n} = 0$ $\frac{ds}{d\sigma} = 0$		
n. Cusp. + 1. *Flesso*	GENESI	FORMA	*n Flessi* + 1 *Cusp.*	GENESI	FORMA
$n = 2$ 1° IPER-FLESSO			$n = 2$ 1ª IPER-CUSPIDE		
$n = 3$ 1ª IPER-FALCATA di curvat. infinita			$n = 3$ 1ª IPER-FALCATA di curvatura nulla		
$n = 4$ 2° IPER-FLESSO			$n = 4$ 2ª IPERCUSPIDE		
Seguono Iperfalcate e Iperflessi			Seguono Iperfalcate e ipercuspidi.		

(2 *Flessi* + 2 *Cuspidi*) $\frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = 0$ $\frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = 0$ GENESI FORMA

1° PUNTO PSEUDO-SINGOLARE $\varepsilon = \frac{d^3s}{d\sigma^3} : \frac{d^3\psi}{d\sigma^3}$

$\varepsilon = 0$ $\frac{ds}{d\sigma} = \ldots \frac{d^ns}{d\sigma^n} = 0$ $\frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = 0$			$\varepsilon = \infty$ $\frac{d\psi}{d\sigma} = \ldots \frac{d^n\psi}{d\sigma^n} = 0$ $\frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = 0$		
n. Cusp. + 2 *Flessi*	GENESI	FORMA	*n Flessi* + 2 *Cusp.*	GENESI	FORMA
$n = 3$ 1ª IPERCUSPIDAZIONE			$n = 3$ 1ª IPERONDULAZIONE		
$n = 4$ 2ª IPERCUSPIDAZIONE			$n = 4$ 2ª IPERONDULAZIONE		
Seguono Ipercuspidazioni multiple.			Seguono Iperondulazioni multiple.		

(3 *Flessi* + 3 *Cuspidi*) $\frac{ds}{d\sigma} = \frac{d^2s}{d\sigma^2} = \frac{d^3s}{d\sigma^3} = 0$ $\frac{d\psi}{d\sigma} = \frac{d^2\psi}{d\sigma^2} = \frac{d^3\psi}{d\sigma^3} = 0$ GENESI FORMA

2ª CUSPIDE FALCATA $\varepsilon = \frac{d^4s}{d\sigma^4} : \frac{d^4\psi}{d\sigma^4}$ ecc.

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

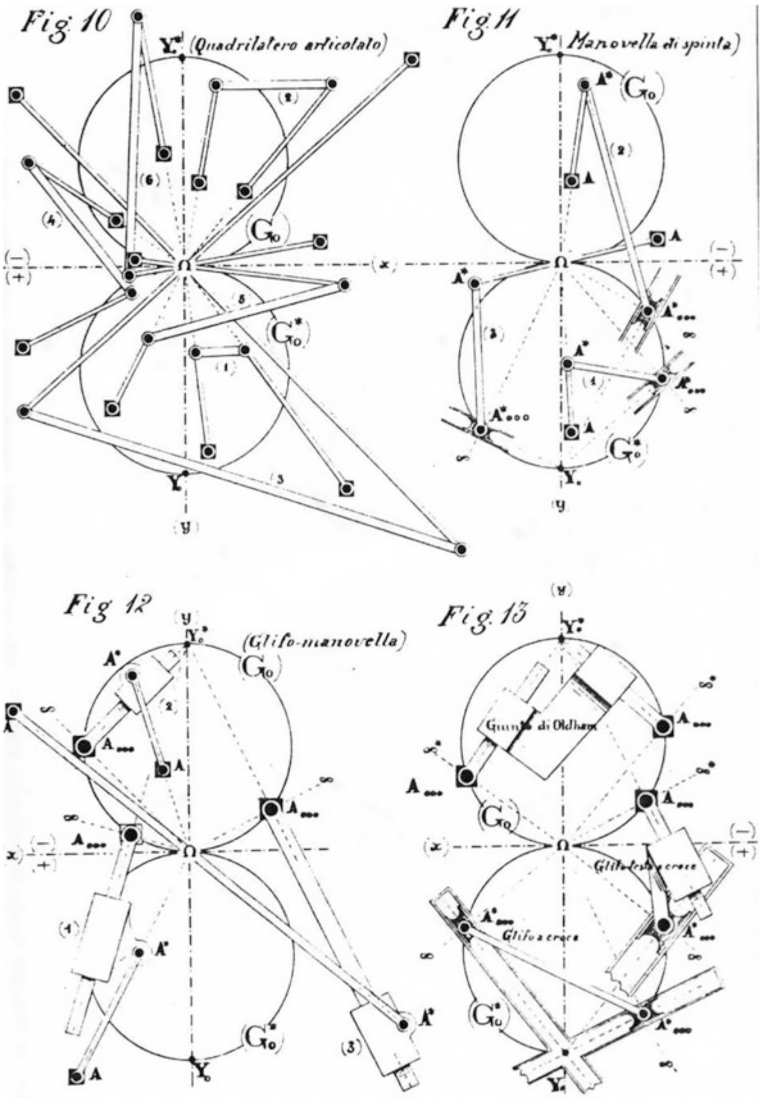


Fig. 8 Six elementary mechanisms for generation of planar coupler curves from Figs. 10 to 13 in Allievi's treatise

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

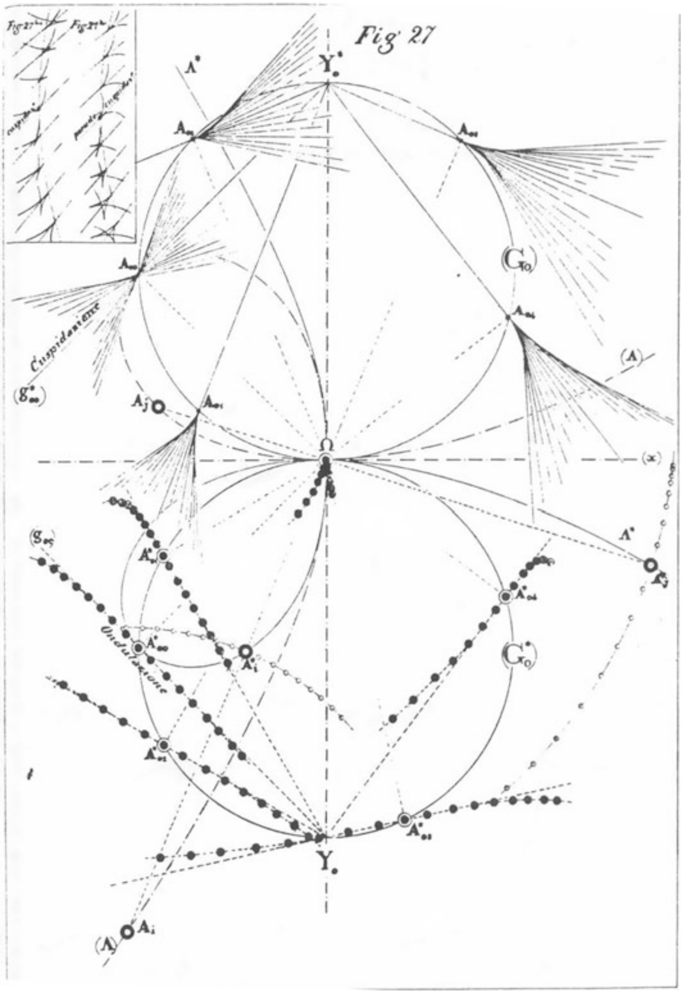


Fig. 9 Graphical representation of characteristics of points of inflection and cusp circles, from Fig. 27 in Allievi's treatise

$$\left(x^2 + y^2\right)\left(\frac{1}{Ry} + \frac{1}{Sx}\right) = 1$$
$$\left(x^{*2} + y^{*2}\right)\left(\frac{1}{Ry^*} + \frac{1}{Sx^*}\right) = 1 \qquad (1)$$

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.

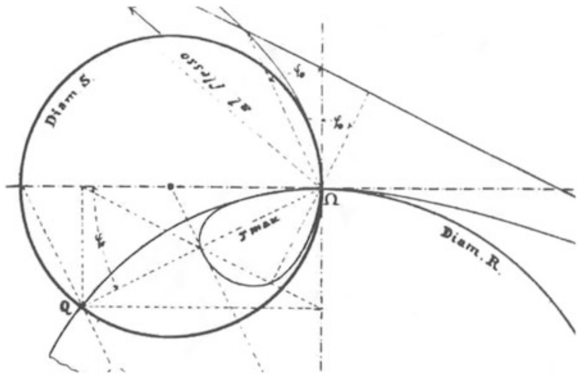


Fig. 10 Graphical interpretations of coefficients in the cubic of stationary curvature, from Fig. 22 in Allievi's treatise

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.

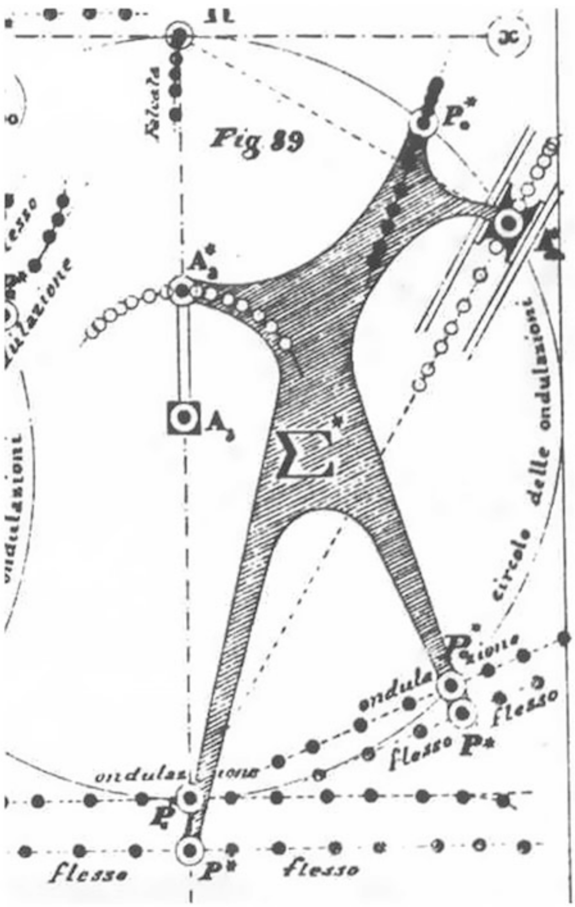


Fig. 11 An example of detailed design solutions for guide mechanisms from Fig. 89 in Allievi's treatise

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.

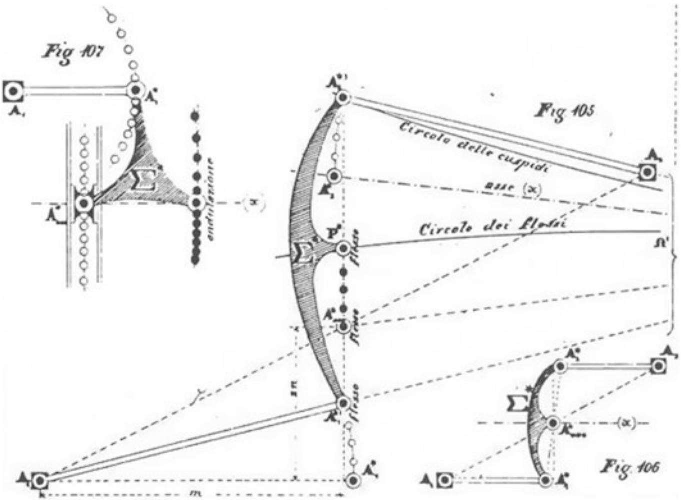


Fig. 12 Schemes and solutions for a practical approach to designing an approximate *straight-line* mechanism with a *Watt coupler curve* from Allievi's treatise

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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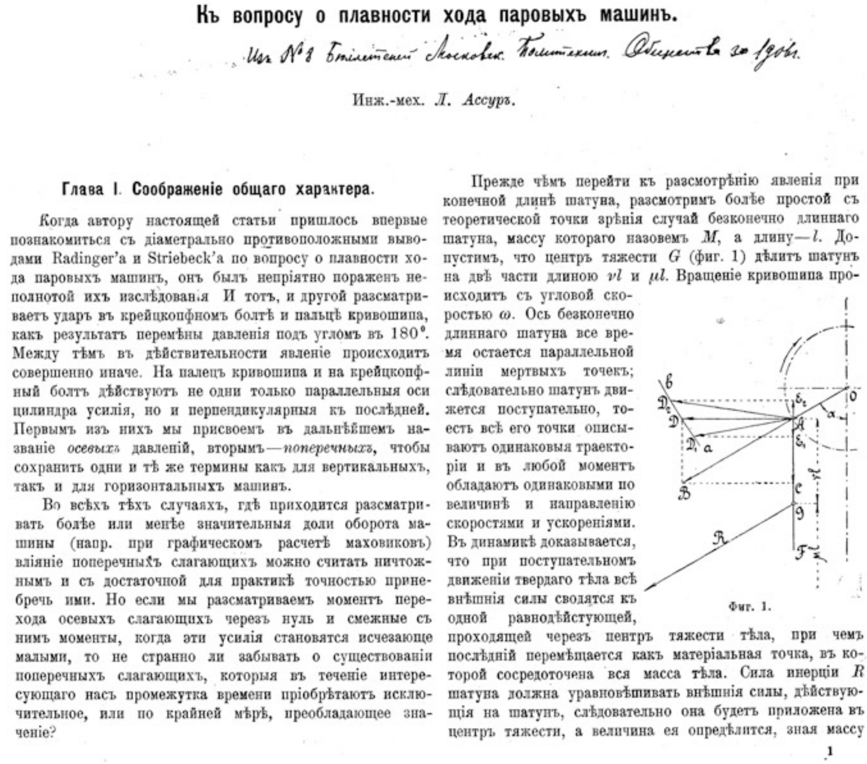
Fig. 1 L. Assur—in gymnasium (This photograph is from Ivan Assur's family archive. A copy of the photograph was given to one of the article's authors. Ivan Vladimirovich Assur (1929–2006) is the son of Leonid Vladimirovich Assur's younger brother, Vladimir Vladimirovich Assur. The photograph was published 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 равнодѣйствующей, 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).