Feodor Orlov 1843–1892

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Abstract Professor Feodor Orlov was one of the founders of the Moscow School of Applied Mechanics. His activities from the year 1872 until his death in 1892 were connected with the two biggest academies: the Moscow University and the Imperial Moscow Technical School (IMTS). He had graduated at the Moscow University and then worked there as an invited professor at the chair of applied mechanics. The chair of Applied Mechanics of IMTS (now TMM) has existed as an independent educational department since 1872, in other words, since the time when Orlov began to teach his course. In 1868, the Imperial Moscow Technical Secondary School (IMTS) was by law confirmed as the Supreme Educational School. It had the following divisions: Mechanical, Chemical and Mechanical-Building. The academy status required an important rise in the scientific level of all courses. Orlov's main course was that of applied mechanics, which he, according to the Great Russian mathematician and mechanician Professor N. Zhukovsky, was the best in Russia. Moreover, Orlov prepared and read courses about thermodynamics, hydraulics, steam engines and the resistance of materials. The creating of the mechanic collection in the Moscow University and the IMTS was Orlov's greatest service. In the IMTS (today it is called the Bauman Moscow State Technical University), the main part of this collection, gathered by Orlov, is housed. Orlov dreamt about going in for abstract mathematics. But his financial position made him spend most of his time working with applied disciplines. However, he had written a number of unique mathematical articles. He was one of the founders of the Polytechnic Society and its vice-president.

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Biographical Notes

Feodor Orlov (Fig. 1) was born in 1843 in a village, Velikoe, of the Novgorod province (Yershov 1854; Orlov 1885/86; Zernov 1895/96; Zhoukovsky 1898/99, 1921; Scientific School of Bauman Moscow State Technical University 1995; Volcnkevich 2000). He was the son of the medical officer who graduated at Moscow University. After his father's death in 1851, he left for Moscow. Because of his difficult financial position, Feodor Orlov had been admitted to the Yaroslavl gymnasium at public expense. In Yaroslavl, he lived under the guardianship of his uncle, who was a professor of Yaroslavl's seminary. The deep religious upbringing of Orlov can be explained by the moral influence of his uncle. Orlov graduated from the gymnasium with a gold medal in 1859 and then entered Moscow University, where he graduated in 1863. Because of the poor financial status of his family Orlov, had to give private lessons. In the University, he was one of the elite students who came to the professor of the mechanics. Brashman took their meetings very seriously and he organized them every weekend. After graduating at the University, Orlov did not leave it and continued working at the Chair of Abstract Mathematics to get ready for receiving his master's decree. In 1867, he published his first scientific work "The proof of Euler's theory". In 1869, he supported his dissertation, which was called "About reciprocity of differential equations", for the degree of master. After the death of Professor A. Yershov, the chair of Applied Mathematics in the Moscow University became free. The Council of the University decided that this place must be occupied by a person who had a very good grounding in mathematics, which would guarantee good knowledge of Mechanics, and recommended Orlov for this position. At the same time, the Council interceded with the Ministry for Orlov to be sent abroad in preparation for his future job. Orlov agreed to move abroad not without doubts because he had his own scientific plans in the field of Mathematic. Though he understood that this offer

Fig. 1 Feodor Orlov (1843–1892)

could help him get a well-paid job and become the provider for his family. In September 1869, he left for St. Petersburg where he met two great Russian scientists: P. Chebyshev and J. Vyshnegradsky. They gave Orlov some practical advice about living abroad and handed him letters of recommendation to European scientists. Chebyshev told Orlov about a new leading mechanism which let Chebyshev create a unique construction of a steam engine. During the period between 1869 and 1870, Orlov attended the Abstract and Applied Mathematics lectures in Zurich in Switzerland. He also translated Chebyshev's article about parallelograms for the "Civilingeneur" magazine. In 1870, he was elected to be the head of the Practical Mechanics and Thermodynamics' chair in IMTS. In the summer of that year he also attended the lectures of professors F. Reuleaux and Christoffel at the Gewerbe-Academie and Weierstrass and Kronecker in the Berlin University. Orlov was mostly influenced by the director of Gewerbe-Academie F. Reuleaux. Orlov listened to the course of kinematics, read by F. Reuleaux with great interest. Many of Reuleaux's ideas, which were not very popular in Russia those days, Orlov used in his educational activities later. He wrote: "Reuleaux gives very good experience of setting forth kinematics with another point of view. The formula with which he shows the structure of mechanism and methods, opened by himself, lead him to the most unexpected results". The demonstrations of machine and mechanism models, by Reuleaux had, made an impression on Orlov. It is necessary to say that of the problems delivered by the rector of IMTS, V. Della-Vos, to Orlov was to study the possibility of getting new models for the chair of Mathematics, established by Professor A. Yershov. Then Orlov attended the mathematics lectures of Professor Katalan at Liege University until the end of 1871. Katalan met the young Russian scientist and became interested in his dissertation for the degree of master and then asked Orlov to translate it into French. This translation was presented to the Belgian scientific academy. Katalan offered Orlov the chance to take part in the competition for the Belgium Academy Prize the works in the field of the theory of surfaces. But Orlov refused to do that as he thought that it would be a denial of his main duties. In his diary he wrote: "I am beginning to suffer from remorse because for the last days I have left applied mathematics and become enthusiastic about my past love – abstract mathematics." Later, Orlov removed to France. He lived in Paris until the autumn of 1872, where he attended the lectures in the Ecole Centrale, Ecole Polytechnique, Sorbonne and the College de France. In the autumn of 1872, he returned to Russia and from that year until his death in 1892, Orlov followed practical mechanics courses at the Moscow University and the IMTS. His inaugural speech, which was read in the Moscow University and the IMTS, was the lecture "About machines". There the development of Reuleaux's ideas about kinematics and kinematic pair was stated for the first time. The professors of the IMTS lived in flats, which were allocated to them by the university administration, not far from the University. Orlov settled in one of them with his family, which consisted of his mother and sister. At the same house, where Orlov's flat was, lived Professor Zhukovsky, who became a friend of Orlov. On the basis of his university preparation and the materials which had been collected abroad, Orlov gave several lecture courses. Firstly, we should discuss his main course – "Applied Mechanics". Moreover, he prepared and read thermodynamics, hydraulics, steam engines and resistance of materials lectures. All the courses reflected not only the modern state of science at that time, but were also methodically worked on. The teaching of the applied mechanics at the Moscow University and the IMTS was raised by Orlov to a high level like at no other University in Russia. Professor Zhukovsky stated that those were the best courses in Russia.

Orlov was curator of the applied mechanics room at the Moscow University and the IMTS. The main part of his collection was acquired from Hustav Voight, who had been given the right to make and sell some of the models from the Reuleaux collection in the 1980s. Besides, Voight's models, models of Alexander Clear from Paris, Joseph Shröder and many others were bought.

The models were bought only after thorough selection as the financing had been very limited. Since Orlov's death, many people noticed that the room of mechanisms was set in an ideal situation. Besides that room, Orlov had organized very good sketching and projection classes. He spent much time working individually with his students. He helped them choose a theme for writing their candidate's work, and lent books from his own library. About half of all candidate's works in the Moscow University were written on applied Mechanics.

In 1874, the Scientific Council of the IMTS despatched Orlov, with scientific aims, to Moscow, Nizhegorodsk and Vladimir province. He examined the manufacturing and factory industries there. In 1876, he was assigned to the Philadelphia exhibition to study the state of techniques in the USA. In 1878 he was sent to the World exhibition in Paris. From all these places, Orlov brought a vast amount of stuff which, unfortunately, was not elaborated upon and printed.

In 1875, a group of students made an offer to the rector of the IMTS, V.K. Della-Vos, to organize a society, which would have such a purpose as "intellectual and moral unity and pecuniary mutual aid to the graduated students". The necessity of such a society appeared because most of the graduated students, especially in the first years after graduating at the IMTS, could find a job with merited payment. The offer was supported by the honorary trustee, prince Sergei Alexandrovich Obolonsky. On 14 May 1877, the Emperor enjoined (1) to organize the Polytechnic Society in the IMTS (2) to give 3,000 rubles to the main fund of the Society from the reserve capital of the IMTS.

The first meeting of the Polytechnic Society took place on 4 January 1878. Orlov actively participated, not only in the organization, but also in the work of most of the departments of the Society. He was one of the authors of the charter and in 1886 was elected to be the vice-president. The society consisted of four departments: the Engineer-Mechanical, Engineer-Technological, Editorial and Inquiry. The Editorial department was headed by Orlov and was occupied with edition the works of the Society and scientific-technical magazines such as "Transactions of the Polytechnic Society" (1879), "Proceedings of the Polytechnic Society" (1882), "Bulletin of the Polytechnic Society" (1888), etc. The Inquiry department was occupied with looking at work for different Russian factories and manufactures for the Mechanic Engineers and processing engineers who had graduated at the IMTS. Facts were listed about the quantity of places and quantity of students who had found a work in the reports of the Society. Some graduates were helped materially.

At the suggestion of Orlov in 1887, a new department of the Society was set up – the Department of Technical Education.

Orlov had more than once addressed meetings of the Society. His lectures were accompanied by demonstrations of new models from the mechanics room of the IMTS. Thus on 18 November 1879, Orlov gave a lecture about the leading mechanism of Hart a lecture about the double detector of Sheffer and Budenberg on 15 January 1881. On 21 November 1891, Orlov delivered his last lecture “About the astatic regulators”. On 20 January 1892, Orlov died in the hands of his sister. He is buried in the Alekseevsky cloister next to his mother. In January 1892 after Orlov’s death, members of the Polytechnic Society collected funds and established grant in Orlov’s name for students.

List of Main Works

1. Orlov F.E. The proof of Euler’s theory. Mathematic manual, Volume 2, University Printing Office (Katkov & Co), Moscow, 1867 (in Russian)
2. Orlov F.E. The dissertation about correlation of differential equations. Dissertation was written for receiving the degree of master of abstract mathematics. University Printing Office of A. Mamonov, Bolshaya Dmitrovka, 7, Moscow, 1868 (in Russian)
3. Orlov F.E. Lecture about machines. Inaugural lecture, read at the Moscow University on the 21st of October, 1872, Moscow, Moscow Mathematical Society that belongs to the Moscow University, 1873, reprint from Mathematical Manual published in 1873, Volume 6, 17 pages (in Russian)
4. Lectures about Applied Mathematics that were read by Prof. F.E. Orlov and assembled by students of the 2nd special class, the Practical Academy of Commercial Science, Moscow, 1873, 462 pages, lithographic edition
5. Orlov F.E. Economical significance of machines. The speech of the Imperial Technical School’s professor Orlov F.E. The report of Imperial Moscow Technical School for the year 1878, the second publication, Moscow, University Printing Office, 1879
6. Orlov F.E. The theory of resistance of materials. Notes made from lectures of Prof. Orlov. The first course of special class. 1880, 340 pages
7. Hydraulic engines. Lectures of Prof. F.E. Orlov, 1881. The first special class of IMTS – Moscow; ITMS – 286 pages, illustrations, lithographic edition
8. The theory of steam engines. Lectures of Prof. F.E. Orlov. From the books of Prof. A.P. Gavrilenko. 1881/82, Moscow; IMTS – 246 pages, illustrations (lithographic edition)
9. The theory of steam engines. Lectures of Prof. F.E Orlov, 1882/83, Moscow, IMTS, 286 pages, illustrations, lithographic edition
10. Hydraulics. Lectures of Prof. F.E Orlov. 1882, Moscow, IMTS, 238 pages, illustrations, lithographic edition

11. Orlov F.E. The theory of roulette. Odessa, Printing Office of P.A Zelenskii. Extract from the Notes of mathematical department of Novorossiysk Society of Natural Sciences, 1884, vol. 5
12. Orlov F.E. About the quadrature of roulette. Lecture was read on the 15th of November, 1883, Moscow, Moscow Mathematical Society which belongs to the Moscow university, extract from the Mathematical Manual, 1884, vol. 11, 60 pages
13. Orlov F.E. Applied Mechanics, Moscow, the Printing Office of Zubarev, 1885, 453 pages, lithographic edition
14. Lectures about the theories of steam-engines which were read by Professor F.E. Orlov in 1886/87 academic year and then written down by the student of the third year in the Moscow University A. Sidorov, Moscow, MU, 249 pages, illustrations, lithographic edition
15. General theory of machines. Lectures of Prof. F.E. Orlov, the fourth term, Moscow, of Blagushin, 1887, 148 pages, lithographic edition
16. Steam-engines. Lectures of Prof. F.E. Orlov, the second and third courses of St. Petersburg IMTS,1890, Moscow, IMTS, 276 pages, illustrations, lithographic edition
17. Applied mechanics. The lectures of Prof. F.E. Orlov, 1891/92, Moscow, parts 2 and 3, Moscow, the Printing Office of Bogomolov, 1892, printed with a duplicating machine
18. Thermodynamics. The lectures of Prof. F.E. Orlov, 1891/92, Moscow, IMTS, 246 pages, illustrations, lithographic edition
19. Steam-engines. The lectures of Prof. F.E Orlov, a course of the second special class of engineer-mechanical section, Moscow, IMTS, 1892, 357 pages, printed with a duplication machine
20. Theory of machines. Lectures which were read by Prof. F.E. Orlov in IMTS in 1892, edited in 1893 and allowed by Prof. D.S. Zernovoi, lithographic edition
21. Orlov F.E. Diary of the foreign trip 1869–1872, Moscow, Printing Office of G. Lissner and A. Geshel, 1898, 346 pages

Review of Main Works on Mechanism Design

The main directions of Prof. F. E. Orlov's activity were:

- Establishing the applied mechanics course involving theory of mechanism and machines.
- Creating offices of mechanisms to practically support the applied mechanics course.
- Establishing courses "Theory of Resistance of Materials and Theory of Elasticity", "Theory of Steam Engines", "Steam Engines", "Hydraulics".
- Enthusiasm for problems of abstract mathematics.
- Social and educational activity. Orlov's educational work can be clearly represented by his opinion of establishing the applied mechanics course. Other ones can be described briefly. Five intravital lithographic courses of applied mechanics (1887/88, 1889, 1890/91, 1891, 1892), and one posthumous course of the theory

of machines (1893), are stored in the IMTS library. Orlov gave the applied mechanics course in Moscow University (MU) and Imperial Moscow Technical School (IMTS). The former course was obviously more theoretical while the latter was practical. The persevering educational policy of Orlov was to combine analysis of theoretical problems with a demonstration of their practical solution. Orlov improved his course during the 20 years of his educational activity. One of his last courses is presented below.

Applied Mechanics

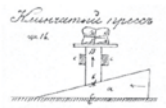
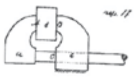
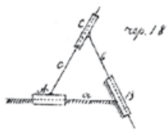
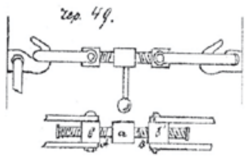
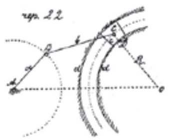
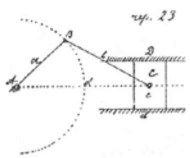
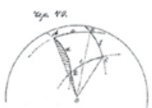
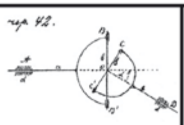
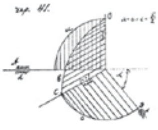
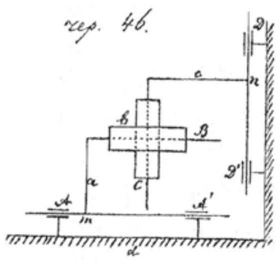
Part 1 – Theory of Mechanisms (224 pages, 232 illustrations); Part 1 consisted of introduction, general theory of mechanisms and analysis of three classes of mechanisms classified according to connection type of their elements. Introduction. Classification of kinematic pairs according to their DOF. Lower and higher pairs. Mechanism is a system with DOF = 1. Like Professor A. Yershov, Orlov used a two-level classification. The first level was classification based on the type of connection of mechanisms elements. The second level was Willis's classification based on a type of moving transformation. Professor Orlov changed the sequence of relation of materials and theoretical level, as opposed to professor A. Yershov (Fig. 2).

Fig. 2 Foedor Orlov's "Applied Mechanics" (part 1)

General theory of mechanisms. Mechanisms with lower kinematic pairs. Mechanisms with prismatic kinematic pairs. Wedge press, grip. Mechanisms with revolute pairs. Four-bar linkage, parallelogram, antiparallelogram. Crank-slider mechanism. Ellipsograph, Oldhem's clutch, sinus-mechanism, etc., Hooke's joint and his analogues, control mechanism for railway semaphore. Mechanisms with screw pairs. Mechanism with three screw pairs. Practical application. Transformation of crank-slider mechanism. Examples of the mechanisms listed here can be seen in Table 1. A further three classes of mechanism classified according to the connection type of mechanisms elements (Willis's classification) are considered.

Class 1. Moving transmission by direct contact. Willis's momentary gear ratio theorem. Teeth-wheels (constant and variable gear ratio with constant indicium). The methods for profile tracing (Poncelet, Camus, Reuleaux). External and internal involute gearing. Cycloidal gearing. Pin gearing. Teeth profiling by two points. Teeth profiling by arcs of a circle (Willis's method). Hooke's wheels. Rotation axes meet, bevel gearing. Skew rotation axes, hyperboloid wheels, screw and worm gearings. Unicycle elliptical wheel. Cam mechanisms (variable gear ratio with variable indicium). Examples of cams with rectilinear and rotary movements. Types of cam mechanisms. Example of practical application.

Table 1 Examples of mechanisms with lower kinematics pairs

Examples of mechanisms with lower kinematics pairs			
1. Mechanisms with prismatic kinematics pairs			3. Mechanisms with screw pairs
 Wedge press	 Grip		 Coupling
2. Mechanisms with revolute pairs			
 		  Hooke's joint	 Control mechanism for railway semaphore

Mechanisms with a constant gear ratio with variable indicium. Examples. Ratchet mechanisms, including clockworks.

Examples of the mechanisms listed here can be seen in Tables 2 and 3. A transmission designed by Orlov and manufactured at the IMTS workrooms is one of them. Unfortunately, it was impossible to find this model. It should be mentioned that Orlov gathered a considerable collection of mechanisms made in Germany and France.

Class 2. Moving transmission by coupler. Mechanisms with parallel axes. Four-bar linkage (instantaneous center of zero-velocity, possible variants of moving transformation, parallelogram, antiparallelogram, Grassgoff's theorem). Crank-slider mechanism, sine-mechanism, ellipsograf. Crank – shaft and eccentric. Hooke's joint.

Class 3. Moving transmission by flexible elements or liquid medium. Belts and ropes.

Part 2. Theory of machines (344 pp., 247 ill.) This part accords to the second stage of "Applied mechanics" course (Golovin and Danilenko 2000), namely, the problems of friction and dynamic theory of machines (Table 4), theory of motors (Tables 5 and 6). Dynamic theory of machines. Machine and mechanism. The foundation of machine dynamics. Kinetic energy and dissipation. Speed control of machine and reason for using fly-wheel: gain in mass of fly-wheel or gain in mass of coupler, for example? About regulation: Watt's inertia governor, parabolic and pseudoparabolic governor, etc. Problems of friction. General problems. Some

Table 2 Examples of moving transmission by direct contact (gearing)

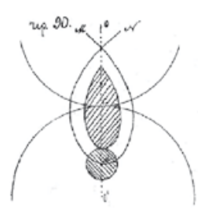
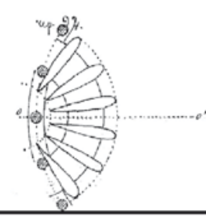
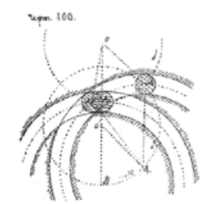
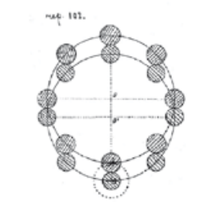
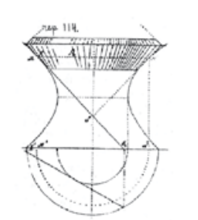
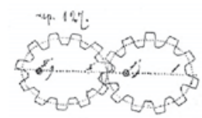
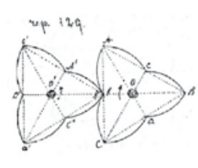
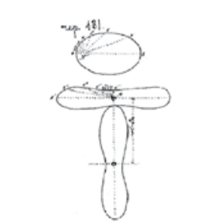
<table>
<tr><td colspan="4">Examples of moving transmission by direct contact (gearing)</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Gears of Reaulaux</td><td colspan="2">Orlov's gearing, fabricate in EMTS</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Hyperboloid wheels</td><td colspan="2">Different gearings</td></tr>
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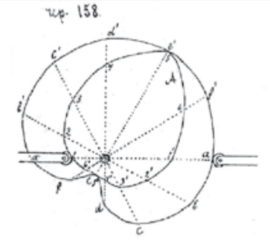
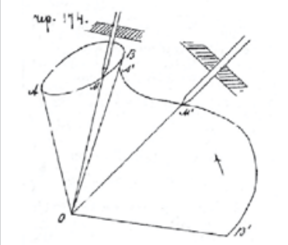
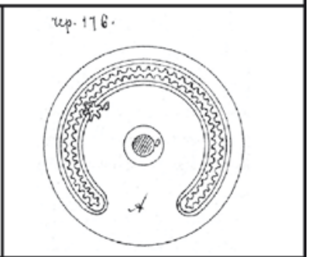
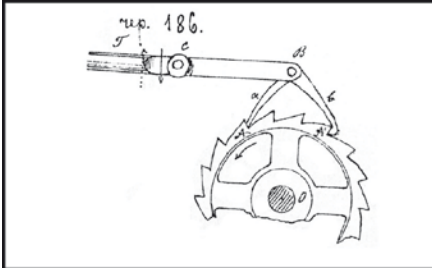
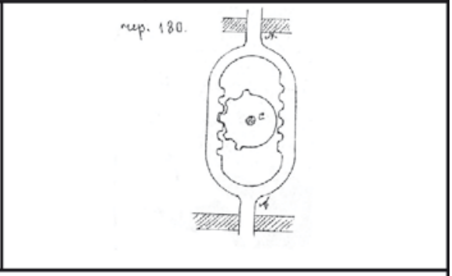
Table 3 Examples of moving transmission by direct contact (cams and other mechanisms)

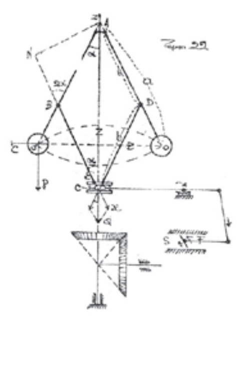
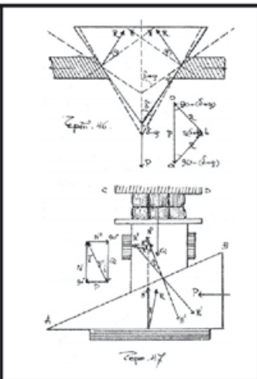
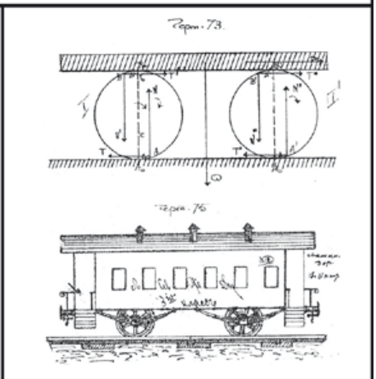
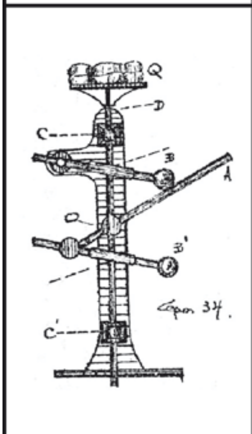
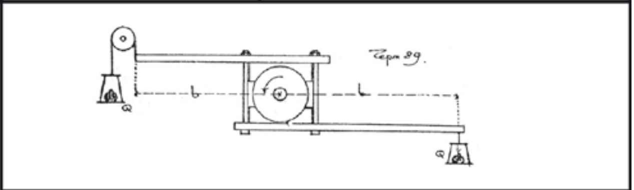
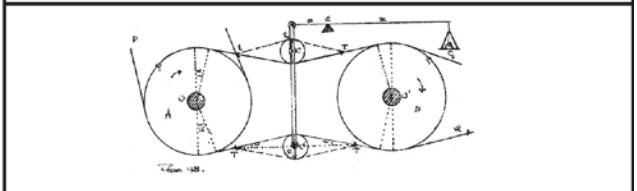
Examples of moving transmission by direct contact (cams and other mechanisms)		
		
Cams of Morin	3-D cams	Ratchet mechanism
		
Other mechanisms		

devices that use the friction effect. Determination of friction coefficient experiment. Prismatic pair: wedge, horizontal and vertical slider. Revolute pair. Screw pair. Teeth-wheels. Transmission of work by friction: friction wheels, friction couple etc. Rolling friction and its application. Friction of flexible bodies. Transmission of work by endless belt. Brakes. Dynamometer of Navier, Imre, Hachette, Watt, etc.

Examples illustrating the problems of friction and dynamic theory of machines can be seen in Table 4. Theory of motors. Living motors. Hydraulics. Hydrostatics. Mains pressure. Equilibrium of body submerged in liquid. Equilibrium of floating body. Determine of mains pressure ponderable liquid. Hydrodynamics. Flowing pressure. Liquid streaming from filler. Liquid moving in pipes. Liquid flow in rivers and canals. Water as motor, dams. Hydraulics machines. Water wheels. Turbines (eight types). Air as motor. Examples considering this part of the course are shown in Table 5.

Thermodynamics. General questions. About fallowes. Caloric machines. Work measuring of steam engine. Steam engines. Papin – Savary steam engines. Installation of Papin's steam engine in Peter the Great's garden in St. Petersburg in 1718. Newcomen and Kawlay. Watt's steam engine. Systems of steam engines and devices. Steam boxes. Furnace, steam boilers. Outfits of boilers (accessories). Manometers, float-gauges, float level gauges, safety valves, feed of boiler. Refrigerators. Examples considered this part of the course are shown in Table 6.

Table 4 Some examples from theory of machines

Some examples from Theory of Machines		
		
Watt's inertia governor	Horizontal and vertical slider	Rolling friction
		
	Prony's wheel brake	
		
Lifting jack	The belt dynamometer of Briggs	

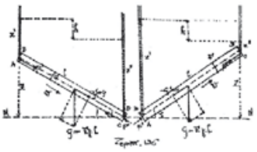
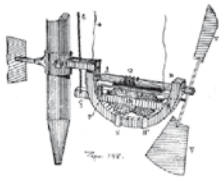
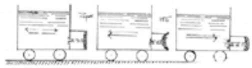
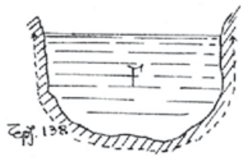
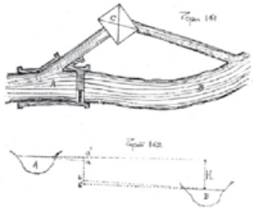
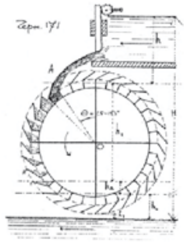
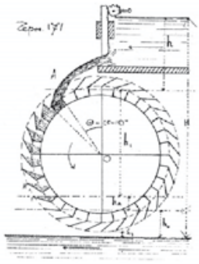
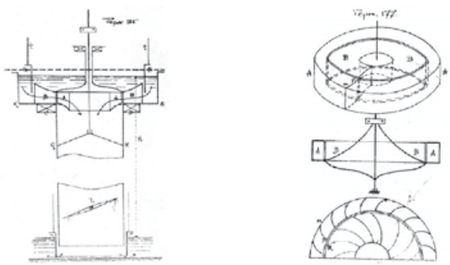
Theory of Resistance of Materials (Part 1) and Theory of Elasticity (Part 2)

Title page of the book published in 1880 reads as follows: "Excerpts from Prof. F. E. Orlov's lectures; Course of 1st Special class" (Fig. 3).

Contents of Part 1 (300 pages) corresponds to the classical contents of such courses. The following sections (in modern terms) are analysed consecutively:

Stress and strains, Hooke's law. Geometric properties of sections. Tension and compression. Pure bending. Tangential stress. Eccentric compression. Equation of deflection curve (now referred to as Krylov's method). All cases of two- and multi-support beams.

Table 5 Some examples from theory of machines (motors). Hydraulics

Some examples from Theory of Machines (Motors). Hydraulics		
		
Liquid moving in pipes	Voltman's propeller flowmeter	Water as motor
		
Liquid flow in rivers and canals	Dam, dyke	Overshot water wheels
		
Lovershot water wheels	Turbines	

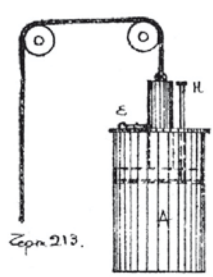
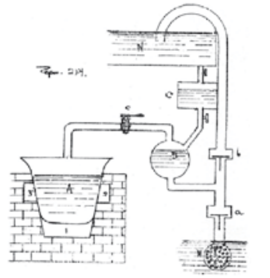
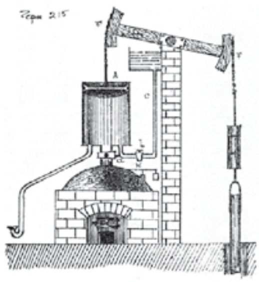
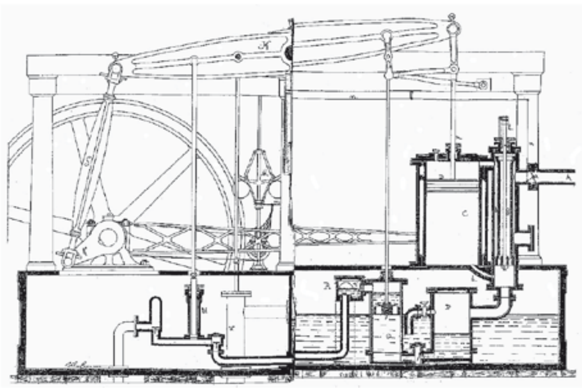
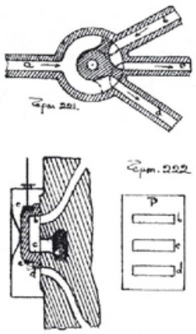
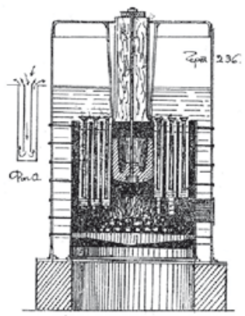
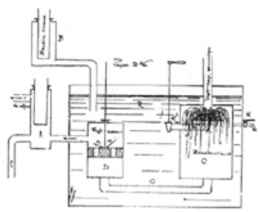
Stability of compressed beam. Flexure of curvilinear beam. Torsion. Momentless theory of shells.

Theory of elasticity – Part 2 (40 pages) is presented briefly. Actually (in modern understanding, too) the paper presents components of stress and strain tensors, Cauchy's surface, and Lamé's ellipsoid. Correspondence between theory of elasticity and resistance of materials is shown.

Theory of Steam Engines

Title page of the book published in 1881–1882 reads: "Prof. F. E. Orlov's lectures" (Fig. 4). In fact it is an extended course of thermodynamics presented in the

Table 6 Some examples from theory of machines (motors)

<table>
<tr><td colspan="3">Some examples from Theory of Machines (Motors)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Steam engine of Papin (1690)</td><td>Steam engine of Savary (1698).</td><td>Steam engine of Newcomen (1705)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Steam engine of Watt</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Steam box systems</td><td>Boiler of Fild</td><td>Refrigerator</td></tr>
</table>

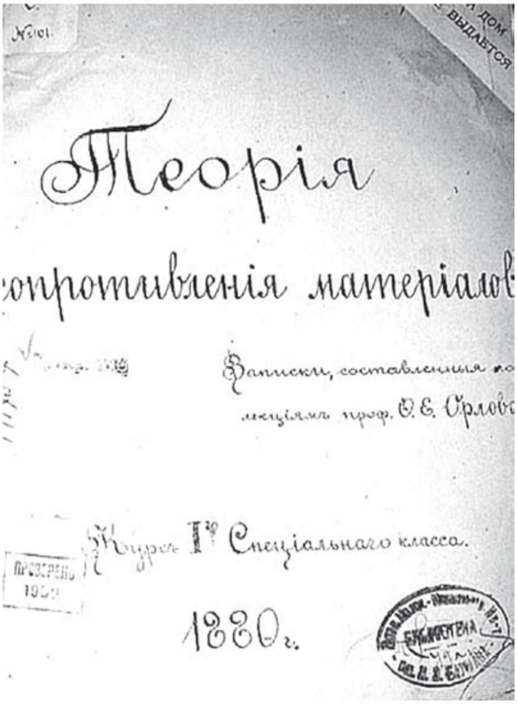


Fig. 3 Orlov's book of 1880

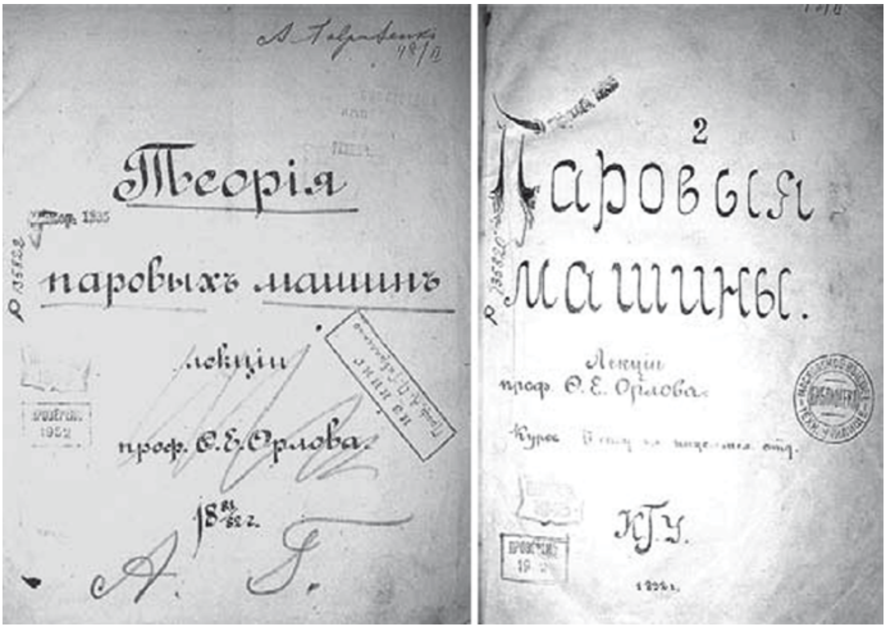


Fig. 4 F. Orlov "Theory of Steam Engines" and "Steam Engines"

course “Applied Mechanics, Part 2 – Theory of Machines”. The course is presented as 23 lectures on 197 pages. Part 1 (Thermodynamics, 91 pages) presents the fundamentals of thermodynamics, atmospheric and thermal machines. In the second section (on steam, 42 pages) steam types are considered. All then existing kinds of steam engines are analysed in the third section (theory of steam engines, 68 pages). History of steam engines: Hero of Alexandria, Solomon de Coos, D. Papin, T. Savery, T. Newcomen, J. Watt. Steam engines of Leupold and I. Polzunov are not considered.

Steam Engines. Title page of the book published in 1892 reads: “Prof. F. E. Orlov’s lectures, course for Mechanical Engineering Department” (Fig. 4). Book comprises 364 pages. Types of steam engines, indicators and their peculiarities (also defects), are analysed. Theory of double-acting steam engine with one cylinder of a complex steam engine, is presented. Analyses for all units of a steam engine are performed. Dynamic problems (travel adjustment, flywheels, maximum number of turns) are investigated. Railway engines: design, locomotive resistance (friction, air resistance, shocks on splice joints, etc.) steamships.

Hydraulics. Title page of the book published in 1882 reads: “Prof. F. E. Orlov’s lectures” (Fig. 5). In fact it is an extended course of hydraulics presented in the course “Applied Mechanics, Part 2 – Theory of Machines”. Book consists of 238 pages and two sections: hydrostatics and hydrodynamics. Problems of practical hydraulics: fluid flow in tube and channel, complex pipeline and manifolds, dams and embankments, methods to measure parameters of hydraulic systems, are solved.

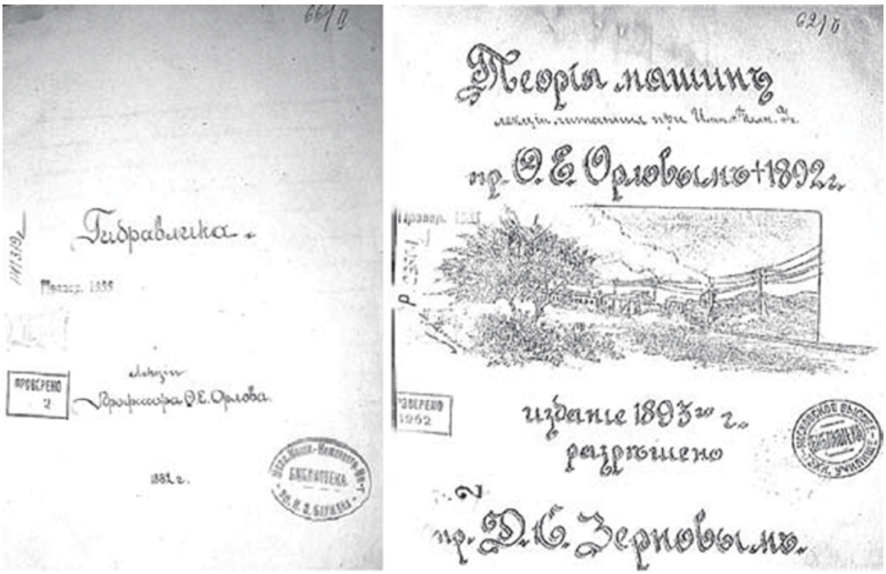


Fig. 5 F. Orlov “Hidraulics” and “Theory machines”

Theory of machines. The book was written in 1892 and published posthumously in 1893 (Fig. 5). It comprises 196 pages. Actually it is an arranged edition of Part 2 of Applied Mechanics.

Certainly, Orlov's main works were coherent with his teaching activity. However, he wrote several original works on abstract mathematics. Orlov the mathematician can be represented by two papers:

Proof of Euler's theorem (1867). The derivation is proposed for condition given by Euler for integrability of differential expression

$$f(y, x, y', y'', \ldots y^{n})\, dx,$$

Theorem defines necessary and sufficient conditions for the function integrability. Orlov proposed a more simple and elegant proof. His derivation may be extended to both direct and converse Euler theorems. On Reciprocity of Differential Equations (1868). This was his thesis on the Master Degree in mathematics. Along with the given autonomous differential equation

$$F\left(x, y, y'\right) = 0,$$

Orlov proposed one more equation which he refers to as one reciprocal to the given one

$$f(\omega', p\omega' - \omega p) = 0,$$

where ω is a straight line segment cut off by the tangent on the axis of ordinates, argument – slope of tangent to axis. It is proved in the paper that the integrals of these two equations are identical. The author gives integration examples for differential equations of various kinds, and notices the connection between the equation's reciprocity and the last multiplier theory. In the conclusion, the reciprocity idea is extended to partial derivative equations. Further development of this work was presented in Orlov's article "Finding the Integrating Factor" published in the fourth volume of the Moscow University Mathematic Collection in 1869.

Excerpts from the Roulette Theory. At the VII Congress of Russian naturalists and doctors, which took place in 1888 in the city of Odessa, Orlov gave the "Excerpts from the Roulette Theory" report. It was published in the Proceedings of the Novorossiysk Naturalists' Society. The problem of analysing movable and fixed centroids for a body whose one point describes a straight line, is solved in the report. This solution involves the theorem on acceleration centers for a body being in a uniform rotary motion, while one of this body's point moves in a straight line. Such a body has all its even order acceleration centres on the said straight line, while odd order acceleration centers are on another line perpendicular to the former one (Fig. 6). Orlov derived the second-order differential equation whose integration can lead to roulettes if the dependence between the radii of the curvature for the centroids is known.

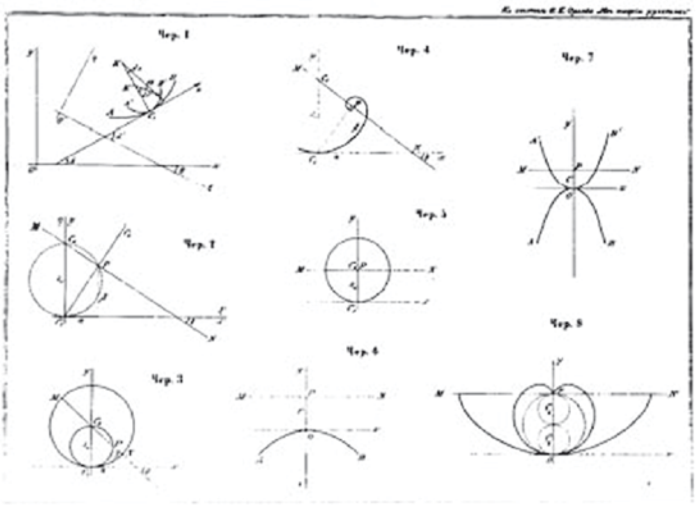


Fig. 6 Pictures from Orlov's article

The solution is illustrated by examples. In particular, on contacting the conjugate convex curves, both cetroids are parabolas and the point describing the straight line is the focus of the movable centroid. A wooden model of Cheby-shev's antiparallel link mechanism (Fig. 7) was fabricated in the IMTS workshop. In this model, the crank point moves along a line close to the straight one. The model also has a movable centroid linked to the crank, and a fixed one linked to the column. This model is supposed to be made by Orlov to visualize the theory presented in the report. This work was continued in the "On the Roulette Quadrature" article. This paper deals with interesting but little-known equations on the roulette quadrature derived in a more general form with the analytical methods being developments of Darboux's method. The said approach allows to define the area between some point's roulette, two perpendiculars constructed from its ends to a fixed centroid, and its contour. Orlov found that all points of the movable figure's plane whose roulettes have the same area, are on concentric circles. Orlov refers to the centre of these circles as the centre of roulette's area. With this point, the roulette areas can be represented by where r – distance from a point to the roulettes' area centre, E_0 – constant, ϑ – rotation angle of the figure under analysis.

Economic Role of Machines (1879). While abroad, Orlov took an interest in societies that supported workers. He visited meetings of these societies in Liège, Zürich and Berlin. The objectives of such societies were treated as follows: "…they are aiming at spreading education to the working class that is the first step towards socialism and the only way to solve the workers' problems". Impressed by these ideas, Orlov came to the conclusion that a scientist can help the working class by improving small thermal machines, and methods of long-distance power transfer from big machines. In his speech, he exploded a theory that the progress of technology and engineering worsens the workers' situation. On the contrary, he was sure

Fig. 7 Model of Chebyshev's "Excerpts from the Roulette theory" antiparallel link mechanism

that the machines would facilitate manual labour. Orlov presented these ideas in his inaugural speech in Moscow University on 21 October 1872. In the conclusion of the speech Orlov told students: "… they would not forget that their high calling is to facilitate human labour by natural force, and that power over this force is given by knowledge, and that knowledge is power".

Cabinet of Applied Mechanics in the IMTS and Moscow University

Orlov supervised offices of practical mechanics in Moscow University and the IMTS. Going abroad on business trip (Fig. 8), and satisfying requests from director of the IMTS V. Della-Vos, Orlov took an interest in collections of mechanisms in different European universities, and he acquired some models. During his trips, Orlov familiarised himself with collections of mechanisms, equipment of lecture halls, drawing offices, and workshops in universities and the technical schools of Zurich, Frankfurt, Berlin, Aachen, Margeburg, Karlsruhe, Liege, Paris, etc. This allowed him to form a clear picture of possible equipment for a mechanical office. Orlov wrote to Relaud "…about the mechanical laboratory organised at the Technical School aiming to be a necessary element of every special technical institution to acquaint students with methods and technique of experimental research".

Fig. 8 The show-window cupboards made in the nineteenth century at the beginning of the formation of the collection

Professor A. Yershov laid the foundation of mechanism collection at the IMTS. Orlov sufficiently updated and replenished the applied mechanics offices. Since the funds to acquire the models were modest, Orlov was thorough in selecting them to resupply the collections. In the 1880s, Hustav Voight in Berlin, Joseph Sröder in Darmstadt, Pierre and Alexandre Claire in Paris, started to manufacture models of mechanisms. Models by Reuleaux and Voight were the most perfect and thus they were preferably bought both for the IMTS and for the university. Some original models were elaborated by Orlov himself and manufactured in the IMTS workshops. Unfortunately, these models are now lost. But during Orlov's lifetime, the mechanism office was in perfect tune.

Toward the middle of the nineteenth century in Russia and abroad, engineering departments were formed at universities, and many higher technical schools and institutes were established (Rubio and Cuadrado 2000). Applied mechanics was one of the basic courses in their curricula. During that time, model offices were created in St. Petersburg (M.F. Okatov), Kiev (I.I. Rakhmaninov), Kharkiv (V.G. Ishmenitsky) universities and many technical institutes. Orlov had a great influence both on the contents of applied mechanics courses in these universities and on model selection for the mechanism offices. At the Polytechnic Society meeting devoted to the memory of Orlov, many spokesmen emphasised his merits of equipping applied mechanics offices. Orlov "…loved the Technical School and took great care to replenishing the main library with the best books in applied mechanics, and of acquiring valuable machines and instruments for the mechanical office under his supervision" (I.V. Aristov, IMTS director in 1883–1902) (Zhoukovsky 1893).

A.K. Eshliman: "Orlov inherited the mechanical office in an unenviable state. Despite the niggardly yearly allowance for office renewal, he succeeded in turning it into a highly valuable manipulative item, following his strict selection criteria. He acquired the collection of guides, models of recent steam distributors and inertia governors. A novice teacher would find strict order and rich content in the mechanical office" (Zhoukovsky 1893).

At the Polytechnic Society meeting on 23 November 1891, Orlov made his last report "On Astatic Governors" with a demonstration of new models from the mechanical office of the IMTS (Zhoukovsky 1893). Pictures of these governors are shown in Fig. 9.

Course of Lectures and Contemporaries

Together with Professors A. Yershov, N. Zhukovsky, D. Zernov, Orlov is by rights one of the founders of the Moscow School of Science of Machines. The great Russian engineer V. Shukhov, who had matriculated to the IMTS in 1876, listened to Orlov's course. Successors of Orlov were Professors L. Smirnov and N. Mertsalov whose pupil is the famous scientist academician I. Artobolevsky.

Courses established by Orlov, primarily of applied mechanics, and also courses of hydraulics, thermodynamics, and steam engines, corresponded to the modern state of engineering and scientific thought in Russia and abroad. Lithographic notes of Orlov's courses are extant. In fact these were the first Russian lectures designed for higher education. They laid the foundations of such disciplines as thermodynamics, steam engines, hydraulics and hydraulic machines, resistance of materials, theory of elasticity, theory of machines and mechanisms.

Fig. 9 The models of centrifugal governors, which were purchased by Orlov in Germany

Modern Interpretation of Main Contributions to Mechanism Design

In 1868, the Moscow Industrial Engineering School (MIES) was transformed into the Imperial Moscow Technical School (IMTS) whose administration established and developed the chairs on the basis of the MIES departments. First, the chairs of general mechanics (1868, Prof. F. Korolev), machine building (1868, Prof. D. Lebedev), general mechanics and machine building (1869, Prof. D. Lebedev; 1872, Prof. F. Orlov), were founded. In 1878, the general mechanics and machine building chairs were transformed into the applied mechanics chair headed by Orlov who is thus an acknowledged founder of the Applied Mechanics chair of the IMTS. In the same year, the theoretical mechanics chair headed by Professor N. Zhukovsky was organized. In the BMSTU, the official date of the applied mechanics chair foundation is regarded as 1873 when Orlov began to deliver a systemised course of applied mechanics. Friendship between Zhukovsky and Orlov greatly influenced the making of the applied mechanics course. The high level of the theoretical mechanics course allowed the improvement the theoretical level of the applied mechanics course. This level was maintained by Orlov's successors, Profs. D. Zernov and N. Mertsalov until the October revolution of 1917. Later, the level dropped due to the change in the student body.

The first systemised course of the theory of mechanisms in Russia is known to be Prof. A. Yershov's work "Foundation of Kinematics or Elementary Theory about Mechanisms of Machines Especially" published in the Moscow University printing house in 1854 (Yershov 1854). It was a kind of encyclopaedia of mechanisms organised according to Willis's classification (Golovin and Mkrtychyan 2007). Orlov's course was designed to a sufficiently advanced basic level and was replete with high theory. The course was perfected by Orlov's successors Profs. N. Mertsalov and D. Zernov whose textbook had several impressions over more than 30 years (Golovin and Tarabarin 2004). In the Theory of Machines and Mechanisms courses, especially since the 1940s of the twentieth century, much attention has been paid to various analyses. Mechanism properties lectures were essentially less attended. However, the very mechanism properties were thoroughly investigated in Orlov's course. For example, the quality analysis for components of the equation of motion is greatly influenced by the mathematical part of Orlov's talent. This tradition was continued in courses by D. Zernov, N. Mertsalov (also a graduate of the mechanical-mathematical department of the Moscow University), and others (Golovin and Tarabarin 2004).

Orlov's activity in the Polytechnic Society not only made a great contribution to the establishment of the Russian, later Soviet, engineering school, but also helped graduates of the IMTS and other technical schools to solve their problems. The society's activities (taking into account the time) can be compared to the modern activity of the ASME.

The collection of mechanisms is a special part of Orlov's work. The foundation of this collection was begun by Prof. A. Yershov who not only bought mechanism models from abroad, but also manufactured some models in the MIES (later IMTS) workshops (Golovin and Mkrtychyan 2007). Orlov continued this tradition, although funds to replenish the collection were limited. Orlov not only extended the collection, but also gave the problemoriented feature to it by taking into account the course needs. This work was continued by D. Zernov, N. Mertsalov, L. Smirnov, V. Gavrilenko (Golovin and Tarabarin 2004, 2005; Tarabarin et al. 2006). Actually, the collection consists of more than 600 exhibits, and is therefore one of the most comprehensive mechanism collections in the world. Moreover, it can be treated as an historical monument of science and technology. Besides, the collection is used as educational media. For example, the model of Watt's steam engine and its parts can demonstrate the common principles of machine design (multiple alternatives of engineering decisions), and of linkage design; fragments of a worn gear set serves to help understand the mechanism of the wearing of a kinematic pair of higher degree, etc. (Borisov et al. 2004).

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