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TRIBOLOGY DEVELOPMENT IN RUSSIA AND BELARUS

Nikolai K. Myshkin[1], Denis V. Tkachuk[1]
[1]V. A. Belyi Metal-Polymer Research Institute of NAS, Belarus, nkmyshkin@mail.ru

Abstract: *The paper presents a brief overview of the achievements of the Russian and Soviet tribology schools. The contribution of the Soviet tribology leader Prof. Kragelskii into the science of friction, wear, and lubrication is discussed. The basic results of tribologists from the main research centers in Russia are considered. The development of tribology in Belarus is outlined with particular attention to the studies carried out at the Metal-Polymer Research Institute of National Academy of Sciences of Belarus. Some new achievements in friction contact mechanics are reported and new instruments for studying surface forces in friction contact and tribotesting at microscale are described. A new instrument for tribodiagnostics – in-line optomagnetic detector is presented.*

Keywords: *tribology, friction, wear, lubrication, scale factor, surface forces, tribodiagnostics.*

1. INTRODUCTION

The science of friction, wear, and lubrication has roots stretching back into antiquity. Its prime fell on the second part of the 20^{th} century when progress in physics, chemistry, mechanics and other disciplines had contributed to its evolution to a special domain of engineering. Nowadays fast-developing machine building, instrument making, electronics, medical engineering etc. pose a number of new specific problems for tribologists; their scale corresponds to the boundaries of human understanding of the world – from friction in space vacuum to the dynamic contact of atomically smooth surfaces. A new era in tribology has dawn related to studies of friction and wear at micro- and nanolevel, the development of special instruments and techniques for examining roughness and monomolecular boundary layers, measuring the adhesion of precision surfaces and recording very low friction forces. The so-called "smart" lubricants – magnetic nanofluids – have come into use. A new effect of superlubricity is found when applying both known solid lubricants and the comparatively novel tribological objects, i.e. diamond-like films. Needs to reduce costs for the maintenance and repair of machines and equipment promote the evolution of the diagnostics and conditional monitoring of friction units. Built-in and portable instruments for tribodiagnostics are produced commercially and are being currently improved; new techniques of tribomonitoring appear based on the application of expert systems. In this paper we present a retrospective review of achievements of tribology in Russia and Belarus.

2. HISTORICAL BACKGROUND

Tribological studies in Russia go back to the eighteenth century when the pioneered works of M. Lomonosov dealing with abrasion had been carried out. In the nineteenth century Russian researcher N. Petrov had published his works on hydrodynamic lubrication which are now widely recognized by tribologists. D. Mendeleev, an outstanding Russian chemist, also contributed to tribology studying the control of friction in precise instruments and the synthesis of lubricating oils.

However, systematic studies in the field of tribology in Russia started in the twenties of the last century when V. Kuznetsov had published his paper dealing with external friction and P. Rehbinder had discovered the effect of adsorption decrease of the surface strength.

The thirties have become the decade of a significant leap in tribology. Particularly, in 1934 B. Deryagin had forwarded his theory of friction based on intermolecular forces. At the end of the thirties the leading Russian tribologist I. Kragelskii formulated the molecular-mechanical theory of friction similar to the adhesion-deformation theory of P. Bowden and D. Tabor. Since then, the dual nature of friction has become generally recognized.

During this period A. Akhmatov had published his first studies on boundary lubrication and M. Khrushchov had laid the foundations of abrasive wear research. In the middle of forties elastohydrodynamic lubrication theory was developed by in Russia.

In the forties and fifties tribology continued to evolve accumulating the experience of researchers in hydrodynamics, fatigue wear, and thermotribology. By the late seventies it had become an interdisciplinary domain of engineering including fundamental and applied aspects of friction contact mechanics, materials science, boundary lubrication theory, contact hydrodynamics, and wear theory.

3. SOVIET AND RUSSIAN TRIBOLOGICAL SCHOOL

Among global stream of tribological research the Soviet school figures prominently. It will suffice to mention the names of I. Kragelskii, G. Vinogradov, A. Chichinadze, N. Bushe, and D. Garkunov who won the Tribology Gold Medal – the highest honour in this field awarded annually by the International Tribology Council.

We should emphasize the great role of Prof. Kragelskii, the leading Soviet tribologist who raised this science on the state level [1]. He was one of the brightest figures in Russian engineering science and attained the status of legend during his lifetime. Through the course of his scientific life he progressed from a student to the founder of the scientific school that gained worldwide recognition.

The range of Kragelskii's scientific interests was very large; it encompassed many problems, from well-known scientific research in the field of textile and agricultural mechanical engineering to pioneering works connected with the development of space equipment. However, the fundamental problems of friction and wear were always his main focus.

Kragelskii developed the bases of the molecular-mechanical theory of friction and the fatigue theory of wear, as well as engineering methods for calculating the contact of rough bodies, rheological processes in friction, and friction force and wear of machine parts. The rule of the positive gradient of mechanical properties and the concept of the third body in friction contact have become fundamental in the theory of external friction. Kragelskii was one of the authors of the discovery "Selective Transfer in Friction". A number of antifrictional and frictional materials that have promoted progress in the engineering of many types of equipment were created under his direct management. The concept of the contact of rough bodies is of paramount importance for tribology, and Kragelskii also achieved much in this area [2]. These ideas were developed further in the works of N. Demkin, V. Kombalov, and other scientists, and evolved into the theory of friction contact.

The works of Kragelskii on the fatigue nature of wear are equally worthy of attention. The theory of wear developed by Kragelskii [2] is based on the hypothesis concerning the fracture of contacting surfaces as a result of cyclic interaction between their asperities leading to the accumulation of defects, i.e. the fracture nuclei. Its physical simplicity and mathematical elegance made it the basis for the development of numerous engineering methods for calculating the wear of machine parts and friction units realized by Kragelskii and his disciples, in particular, E. Nepomnyaschii, G. Kharach, V. Alisin, and others.

Kragelskii published more than three hundred scientific works including twenty monographs. His fundamental monographs "Friction and Wear" and "Friction and Wear Calculation Methods" which have been translated into English are still valued today. The number of references to the works of Kragelskii that can be found in the Internet is estimated at thousands. While serving as the Vice President of the International Tribology Council, he did much for the development of connections between Soviet and foreign tribologists. In 1975 he became the first Soviet scientist to receive the highest award in this area of knowledge – the Tribology Gold Medal. In 1980 he was awarded the Gold Medal of the American Society of Mechanical Engineers.

During the sixties and seventies a system of scientific centres involved in tribological research was formed under the coordination of the Scientific Council on Friction and Lubricants founded in 1961 by the head of Soviet space program S. Korolev. Among the leading organizations were the Institute of Machines Science, the Institute for Problems in Mechanics, the Institute of Physical Chemistry, the Institute of Petrochemical Synthesis, and the Institute of Elementorganic Compounds (Moscow). In the Ukraine these centres included the Institute of Problems for Materials Science and the Institute of Superhard Materials in Kiev as well as the Physical-Technical Institute of Low Temperatures in Kharkov. In Belarus tribological research were concentrated at the Institute of Reliability and Durability of Machines and the Physical-Technical Institute in Minsk as well as at the Metal-Polymer Research Institute in Gomel. We also mention here the institutes of the Siberian Branch of the USSR

Academy of Sciences in Novosibirsk, Tomsk, and Yakutsk. A great number of institutes of higher education and branch institutes were involved in tribological studies.

Among the tribological centres is the A. A. Blagonravov Institute of Machines Science of the Russian Academy of Sciences holds the leading position. It was founded in 1938 and has become the basis for the most prominent tribological school in the Soviet Union and later in Russia. Research on friction and wear in this institute was initiated by M. Khrushchov famous for his studies of abrasion and the running-in of bearing alloys. We also mention here the names of above-mentioned I. Kragelskii; A. Dyachkov and M. Korovchinskii contributed greatly the hydrodynamic lubrication theory and the development of theoretical foundations of sliding bearings; A. Petrusevich who was one of the originators of the elastohydrodynamic lubrication theory and whose papers influenced deeply methods of calculating gearings; S. Pinegin – an eminent specialist in contact strength, friction and lubrication of machine parts who did very much for the development of bearing industry in the USSR; R. Matveevskii made an important contribution to the theory of boundary lubrication.

The studies of the well-known tribologists from the Institute of Machines Science such as A. Chichinadze, A. Semenov, Yu. Drozdov, I. Buyanovskii, V. Pavlov, V. Alisin, and others receive recognition both in Russia and abroad. The achievements of this school are reported in monograph [3].

The works of Soviet tribology leaders exerted strong influence on the development of other tribological schools in the USSR. For example, the scientific school on contact problems of tribology headed by professor I. Goryacheva, the present Chairman of the Interdepartmental Scientific Council on Tribology, currently operates at the Institute for Problems in Mechanics of RAS (Moscow). These results are presented, particularly, in the studies of N. Mikhin, I. Goryacheva, M. Dobychin, and others [4–6].

The school of N. Bushe and S. Zakharov operates at the All-Russia Research Institute of Railway Transport. The works of the Kiev school founded by professor B. Kostetskii are also widely known. Studies of friction and wear are carried out at the Southern Scientific Centre of RAS and at the Rostov State University of Communications led by professor V. Kolesnikov, Chairman of the Russian National Committee on Tribology, at the Tver State Technical University by the group of N. Demkin, and at the State Engineering University of Armenia under the direction of A. Pogosyan. The works of the Bryansk school, headed by A. Suslov, were started by E. Ryzhov who was one of Kragelskii's disciples.

4. TRIBOLOGY IN BELARUS

In Belarus, one of the most developed republics of the former Soviet Union, interest in problems of friction and wear was permanently demonstrated by engineers and researchers in various branches. During the sixties the tribological school had been formed whose origination is directly related to the name of professor V. Belyi. He founded the first tribological laboratory at the Belarus Institute of Railway Engineers in Gomel which later on developed into one of the famous Soviet tribological centres – Metal-Polymer Research Institute currently named after V.A. Belyi. In the sixties and seventies studies on friction and wear were launched at the Physical-Technical Institute and the Institute of Reliability and Durability of Machines, Belarus Scientific and Production Association of Powder Metallurgy, Belarus Polytechnic Institute, Gomel State University, and at some industrial works.

The results of Belarus tribologists received the first recognition in 1969 when the international symposium "On the Nature of Friction" took place in Gomel. Among the participants were almost all the tribology leaders of the Soviet Union and researchers from eighteen foreign countries including R. Courtel (France), A. Cameron and T. Childs (Great Britain), R. Sable (USA), and others.

Nowadays research on friction, wear, and lubrication is carried out in Belarus by more than thirty centers and groups of which the Metal-Polymer Research Institute holds the key position. Some of the basic results are listed below.

Presently, there is a strong trend towards transition from macro- to micro- and nanoscale that gives a new insight into the basic problems of tribology, e.g. the correlation of deformation and adhesion mechanisms of friction. A new domain of tribology, termed micro- and nanotribology has become a basis for the development of novel classes of mechanical devices – microelectromechanical systems (MEMS). In these systems adhesion and surface forces are very important and call for novel solutions to the tribological problems.

The trends in tribology from macro to nano are presented in Fig. 1. The factors include mechanical properties of the materials in contact, surface topography, atomic and molecular forces, and frictional heating [7].

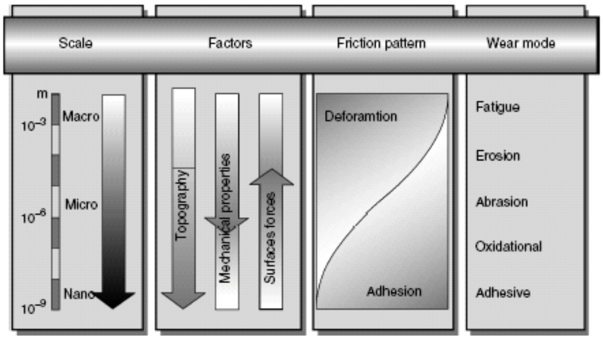

Figure 1. Combination of factors affecting friction and wear

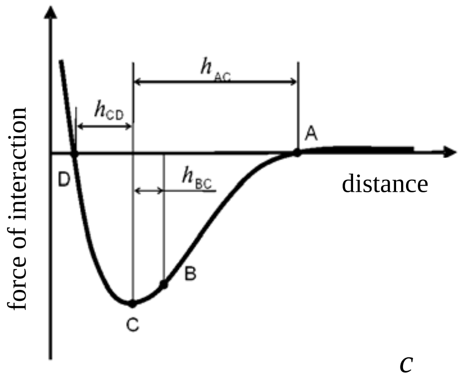

Figure 2. Typical force–distance curve

The problem of wear remains topical as modern technical equipment evolves, only the scale of the processes shifts to micro- and nanolevel. An effort to evaluate microscale wear was made at the Metal-Polymer Research Institute. These experiments were carried out using the atomic force microscope whose diamond tip with a radius of about 100 nm scratched a silicon surface under a load of 0.5 mN. The dependence of the scratch depth on the number of tip passes was closely similar to the common wear curve at the running-in and normal wear stages except for the fluctuations which could easily be explained by the effect of wear microparticles deflecting the tip.

The problems of micro- and nanotribology researchers faced have promoted the development of new precision tools for understanding the friction, wear, and adhesion of solids at the corresponding scale levels. One example of such tools is the contact adhesion meter developed at the Metal-Polymer Research Institute and intended for measuring surface forces [8]. The instrument design involves a vertical torsion balance with negative feedback that eliminates problems with equilibration and errors caused by friction in the balance support. The range of measured forces is from 10 μN to 10 mN at distances from 1 nm to 10 μm.

Figure 2 illustrates the dependence of the force of interaction on the distance between the surfaces. The point *A* corresponds to the onset of interaction between the approaching surfaces. The segment *AB* corresponds to interaction without actual contact of the bodies. After passing the point *B* force interaction and elastic deformation appear simultaneously. At the point *C* the force of elastic resistance to probe penetration becomes dominating. The point *D* corresponds to the instant when the force of interaction becomes equilibrated by the adhesive force of attraction.

A ball-on-plane reciprocal tribometer was also developed to study friction at microlevel [9]. The characteristics of the tribometer are selected with account for the loading conditions of MEMS, i.e. the normal load is from 10 mN to 1 N and the sliding velocity is 0.1–10.0 mm/s. The ball diameter is selected from the 1–5 mm range depending on the required contact pressure. Coatings are deposited on the plate made, as a rule, of silicon. The coating under study can also be deposited to the ball to widen the range of friction pairs. The tribometer is equipped with a unit for recording acoustic emission. The software controls the sliding velocity, normal load, and the friction track length as well as provides the recording of the friction force and coefficient, the count rate and amplitude of acoustic emission signals.

Main trends in the development of space vehicles of the next generation imply considerable prolongation of their life. Among other tasks this demand poses is the provision of the required durability of friction units operating in the outer space. Presently, testing of advance antifriction and wear-resistant materials for space applications is planned within the framework of the “Kosmos-SG” project. An analog of the on-board tribometer intended for ground experiments was developed at the Metal-Polymer Research Institute [10]. Its specific feature is the use of a collector-free synchronous motor excited by rare-earth permanent magnets and having digital control. The advantage of this type of drive is that it allows one to implement a number of geometries and methods of tribotesting requiring usually the application of apparatuses with different designs. The drive provides the operation of the tribometer under the effect of space factors at temperatures from 170 to 420 K in vacuum up to 0.01 Pa.

The main goal of tribodiagnostics is to implement the possibility of the real-time assessment of the operation mode of a tribosystem, predict its wear and take the required measures to provide its long trouble-free operation with the optimal tribological characteristics. Wear monitoring is generally defined as the complex of means and methods of the continuous determination of the tribosystem characteristics in real time, mainly to avoid emergencies caused by catastrophic wear.

A practical illustration of the applicability of tribodiagnostics and monitoring principles to real engineering problems is the optomagnetic detector (OMD) (Fig. 3) developed at the Metal-Polymer Research Institute of Belarus National Academy of Sciences and the Korea Institute of Science and Technology [11].

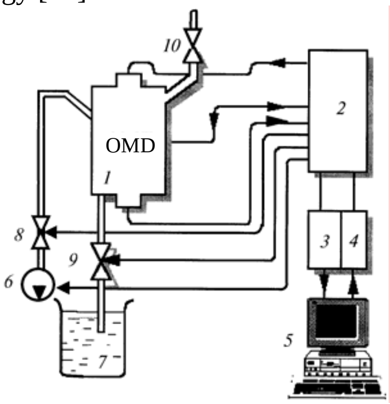

Figure 3. In-line wear monitoring optomagnetic detector: *1* – sensor; *2* – electronic unit; *3* – ADC; *4* – input/output unit; *5* – PC; *6* – pump; *7* – oil tank; *8*, *9*, *10* – electromagnetic valves

The condition monitoring of tribosystems with the OMD is based on the two characteristics, i.e. the total oil contamination and wear. The total oil contamination is determined from the difference of the optical densities of the fresh and used oil. The wear characteristic is assessed by the difference of the optical densities of the used oil before and after the application of magnetic field. Laboratory test results show the linear dependence of the optical density of the oil on the content of particles in it within the broad concentration range.

The principle of construction of smart systems in tribodiagnostics and monitoring is another new and interesting page in tribology [11].

5. CONCLUSION

Finally, we say some words about the importance of collaboration of tribologists from the former Soviet Union. Their fruitful cooperation in the expanses of the new independent states is possible, particularly, via the scientific journal "Trenie i Izons" which is published since 1980 under the aegis of the National Academy of Sciences of Belarus at the Metal-Polymer Research Institute. The simultaneous English translation of the journal has been launched in the USA since the moment of its foundation ("Journal of Friction and Wear"). The journal is the most representative source of information on research in friction, wear, and lubrication and their practical aspects in the former USSR. Starting from 2007, its English version is issued simultaneously with the Russian edition and is distributed on-line via one of the largest scientific databases – Springerlink.

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