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EDITOR'S PREFACE

The problem of improving the reliability and longevity of machines and mechanisms is currently one of the highest priorities in engineering. Attempts to solve it take many directions, and improvement of technical-diagnosis procedures and systems is one of them.

Although considerable progress has been made in the science of friction and wear, many problems bearing on improvement of wear resistance and reduction of frictional losses remain unsolved. This is due primarily to the fact that many mechanical and physicochemical phenomena, each with its influence on friction and wear, arise simultaneously in the zone where rubbing surfaces make contact. Simultaneous multiparameter analysis of all of these phenomena is impossible, and an effort is therefore made to get by with a small set of informative parameters that still describe the tribological system completely enough. However, practical experience has shown that such traditional parameters of a tribosystem state as the coefficient of friction, contact-zone temperature, and speed and rate of wear cannot always give a satisfactory appraisal of the state of the system or yield a sufficiently accurate prediction of its life expectancy. In addition, it is not always possible to monitor the state of a tribosystem without stopping and disassembling it.

The present monograph attempts to unify the diversity of data available in the literature on application of acoustic and electrical methods in frictional-interaction diagnosis. The authors, however, have not undertaken to describe all of the existing control and diagnosis techniques. The purpose of the book is to draw the attention of specialists in friction and wear to the most important trends and promising new methods for diagnosis of moving joints, such as acoustic emission, which has not yet been given the recognition that it merits and has been applied to triboengineering problems only during the past decade. The authors have attempted to present the material in such a way that the reader will gain a grasp of the physical background of the methods described and opportunities for using them in his practical activity. Numerous experimental results are cited to illustrate the behavior of acoustic and electrical phenomena in response to changes in service conditions.

In preparing the monograph, the authors made extensive use of the abundant material available in the scientific literature, along with the results of their own. In our view, the book should be of interest to scientific workers, instructors, postgraduate students, and engineers concerned with the development, design, and operation of machines, since problems in the diagnosis, nondestructive inspection, and control of the characteristics of moving joints in machines are at the cutting edge of scientific and technological progress.

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FOREWORD

The development of the science of friction, lubricants, and the wear of solids has always kept pace with the development of technology, and with new scientific-technological advance, specialists in this area have been confronted with sets of problems posed by the appearance of new types of machines, their operation under more difficult conditions, and demands that they perform more efficiently. Solution of triboengineering problems became particularly urgent when the Resolutions of the Twenty-Seventh Congress of the Communist Party of the Soviet Union (CPSU) called for accelerated development of the country's machinery-manufacturing complex and improvement of the reliability and longevity of all types of machines and equipment.

In spite of the clearly practical orientation of the science of friction, it is still highly appropriate to quote Leonardo da Vinci: "Science is the captain and practitioners are his soldiers." This has become abundantly clear during the last two decades, when application of advances and techniques from the natural sciences to the study of friction problems and attempts to penetrate deep into the nature of friction phenomena produced important practical results with the discovery of anomalously low friction and wear-immunity effects, structural adaptability, tribopolymerization, heat-activation effects, etc.

All triboeffects have macroscale manifestations, but the phenomena that cause and attend them take place at the microscopic level. During our lifetime, a transition has been made from hoary purely mechanical concepts of the physical processes in the frictional interactions of solids to atomic-molecular concepts. From the time of Aristotle, who introduced the concept of attrition more than two thousand years ago, the friction process have been evaluated in terms of purely external factors, such as resistance to motion, changes in dimensions and shape, heating, noise, vibration, and electrification of the interacting bodies. Beginning with Leonardo da Vinci, many attempts were made to describe the laws of friction quantitatively, and, as machinery manufacture appeared and developed, to use accumulated knowledge consciously in the design of machines and mechanisms. The 1930s and the middle of the present century saw the beginning of the new forward surge in the development of the friction and wear theory based on the results of penetration of research to the microscopic level of the phenomena under study. The main result of this process has been the formation of molecular-mechanical and deformation-adhesion concepts of friction and the differentiation of types of wear based on elementary physicomechanical surface-destruction processes.

The rapid development of space exploration, aviation, electronics, and transport has imposed much tougher service requirements on friction assemblies, and this, in turn, has strongly stimulated a basic-research effort directed primarily at study of the structural changes that take place on contact surfaces between interacting bodies. It became realistic to propose such research only due to coordination of the efforts of scientists in various specialties – physics, chemistry, and mechanics – based on application of the latest physical and physicochemical structural-analysis techniques and computer-aided mathematical-modeling and data-processing techniques.

The use of optical, electronic, X-ray, and ion microscopy has made it possible to study changes in crystal structure during friction and the influence of dislocations and other defects on restructuring; Auger spectrometry and electronic spectroscopy in chemical analysis make it possible to evaluate elemental composition and chemical-bond types in extremely thin surface layers; tribostructural transformations in materials and lubricants can be pinned down quite accurately with the aid of infrared spectrometry, electron paramagnetic resonance and mass spectrometry, nuclear magnetic resonance and other analysis techniques and combinations thereof.

The present stage of scientific-technical progress in machinery manufacture is characterized primarily by an accelerated rate of automation, with the introduction of control systems and processor and computerized complexes. Accordingly, there is great interest in lag-free methods of diagnosis and nondestructive quality control, which can be used in systems with feedback to obtain flexible adaptation to changes in external conditions. Acoustic and electrical techniques are highly efficient in this respect, since the physical background of the processing of electrical and acoustic signals and apparatus for registration and analysis of these systems have been developed to a high level.

The authors saw their main objective in systematization of existing data on acoustic and electrical phenomena in the frictional interaction of solids with the object of arriving at recommendations for their practical use. The fact that acoustic and electrical techniques can be used widely to monitor running-in, wear, lubricant-effect regimes, etc., is given basic emphasis.

The basic responses of acoustic and electrical processes to changes in such service factors as speed, load, friction distance, presence and quality of lubricant, composition of the atmosphere, and the roughnesses and physicomechanical properties of the materials of the contacting solids are described and discussed.

In compiling the book, the authors have tried to cover as completely as possible all known Soviet and foreign information sources on the theory and practice of acoustic and electrical methods in triboengineering. The results of research done by the authors themselves are also reflected, and acoustic and electrical diagnositc methods and instruments and equipment for their implementation are described.

The authors find it a pleasant duty to thank V. A. Belyi, Academician, Academy of Sciences, Belorussian SSR, who has been instrumental in setting and developing research objectives at the Institute of the Mechanics of Metal-Polymer Systems, AS BSSR, and the Institute staff members who assisted in the performance of these studies and participated in discussion of the results.

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ACOUSTIC AND ELECTRICAL METHODS IN TRIBOENGINEERING

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BASIC PROBLEMS OF TRIBOENGINEERING

1.1. CONTEMPORARY CONCEPTS OF FRICTION, LUBRICATION, AND WEAR

The design and use of increasingly complex mechanical systems with recognition of what we know concerning friction, wear, and lubrication, has made it possible to solve a battery of priority problems. With each passing year, triboengineering succeeds in devising new ways to save energy, labor, and materials, raise productivity, reliability, and longevity, broaden load and speed ranges and the range of acceptable environments, improve working conditions, and mitigate harmful ecological consequences. Still, it must be acknowledged that the potential for the development of fundamental and applied knowledge in the area of friction and wear is not being developed rapidly enough to meet the needs of scientific-technical progress. During the last two to three decades, therefore, problems of friction and wear, which are estimated to cost many billions of rubles, have been receiving a great deal of attention in all industrially developed countries [70, 85].

Analysis of scientific publications and the subject matter of major joint and specialized scientific-technical conferences held in recent years and the view of numerous prominent tribologists forms a basis for designating six major current and prospective research trends in modern tribology as a field of knowledge and its applications: triboanalysis (theoretical premises of tribomechanics, physics and chemistry); tribomaterials science (study and control of the properties of materials used in moving joints); tribotechnology (technological methods for control of contact frictional characteristics); triboengineering (the aggregate of engineering systems in which friction and wear processes occur); tribomonitoring (the aggregate of tribosystem diagnosis, monitoring, and testing systems and procedures); triboinformatics (the aggregate of systems and procedures for processing and storing tribological information.

Triboanalysis is the most important subdivision of tribology which treats the problems of accumulating and systematizing scientific information on the fundamental laws of the basic friction processes and modeling of these processes with the objective of predicting the results of contact interaction between solids under specified conditions.

The present stage in the development of triboanalysis is characterized by differentiation of friction phenomena, an effort toward appreciation of the depth of the molecular processes that take place on the interacting surfaces, the use of efficient physical, chemical, and mathematical methods and electronic control and computer equipment. Important progress has been made toward understanding of the nature and mechanism of friction and wear under various sets of external conditions when the interacting surfaces are in various states and are separated by solid, liquid, and gaseous lubricant layers. Here triboanalysis has been aided by advances in the field of contact mechanics, which have made it possible to evaluate stresses and strains and the boundary conditions under which physical and chemical processes take place on the contacting surfaces; the results of systematic study of adhesion in friction, structural transformations, and the rheology of the surface layers; attempts to unify observed phenomena on the basis of energy relations in friction assemblies, etc. [27,28,37,51,78,81,134,138,206].

Introduction of a new concept, that of the actual contact area, which takes account of the roughness of the real surfaces, was a very important advance in the study of the geometry and mechanics of rubbing-surface contact. This notion formed the basis of two most widely used theories of friction – molecular and adhesion-deformation [51,81,136]. Calculations of actual contact areas with allowance for the elastic, viscoelastic, and plastic behavior of the contacting bodies demonstrated convincingly that high pressures, speeds of displacement, and temperature flashes occur in the contact zone [37,78,138,256]. But when we introduced roughness as a consequence of surface machining into the calculations, we have taken only the first step toward the understanding of the actual contact-interaction picture. Development of the so-called "multistory models" of the actual surface with the objective of bringing analysis of contact problems closer to the atomic-molecular level of the physicochemical friction effects appears promising [216].

The use of statistical methods to evaluate surface roughness and the mechanical interaction of asperities offers significant progress and produces reliable data [173,175,218,219]. However, the use of multilevel models of roughness is being hampered by the lack of direct experimental methods for evaluation of the mechanical aspect of the surface interaction at the "molecular-roughness" level.

In investigation of the physical and chemical aspects of the frictional interaction, special attention is being given to the results obtained on single-crystal and juvenile surfaces with the aid of modern physical research methods [28,168]. For example, direct methods have confirmed a dislocation mechanism for surface-layer slip and initial cracking and have been used to evaluate the roles of intermolecular and interatomic-bond anisotropy, oxide films, and surfactants in friction [28,153]. To this day, however, the question as to the nature of the molecular forces that result in adhesion and its anomalous manifestation in seizure and pitting of rubbing surfaces remains open. Use of the theory of the fluctuating electromagnetic field to describe and calculate the molecular forces appears highly promising [81,86,230,231]. For example, the adhesive component of friction can be estimated quite reliably for polymer contacts from the infrared spectra of the interacting materials [38].

The significant structural and phase transformations that occur in the frictional interaction, and the tendency of the entire superficial material system to find the most favorable energy and structural states, which is known as structural adaptability [134], play an important part in investigation of friction and wear mechanisms. A typical manifestation of structural transformations in materials is found in the various emission processes that can be recorded in the friction-loading zone: triboluminescence, emission of fast and slow electrons, acoustic emission, electromagnetic radiation, etc. [81,93,238].

Studies conducted with the aid of subtle physical methods have demonstrated that mass transfer takes place in a variety of ways during friction, with formation of continuous and island-type films ("third-body" fragments), especially at polymer-polymer and metal-polymer contacts. Transfer occurs most intensively under such specific conditions as vacuum and passage of electric currents through the contacts; it is also observed in process media in the presence of boundary friction. If no lubricant is supplied from the outside, the "third-body" film that forms as a result of frictional transfer and its dimensions, structure, composition, and "lifetime" determine the friction coefficient and the rate of wear of the mated bodies [37,249]. In recent years Soviet specialists have made great advances toward understanding of the selective-transfer mechanism [70,153].

The theory of wear incorporates a large number of hypotheses and concepts. The adhesion, fatigue, and abrasive theories have been developed farther and can be applied more successfully than others [51,138]. However, the modern physical theories of friction and the most recent advances in the area of surface effects are not taken into account adequately in existing theories of wear. This is obviously one of the basic causes of the frequently observed large disagreements between calculated and experimental data. Difficulties in the modeling and analytic description of wear can also be explained by the fact that several mechanisms are usually at work simultaneously in this specific form of surface destruction: fatigue with corrosion, adhesion and abrasive effects, erosion with cavitation, etc. [120,138].

The energy approach to description of friction effects is versatile and offers broad opportunities for modeling and generalization [134,200]. By far the greater part of the mechanical work expended on friction and wear is converted to heat [256]. High heat-effect densities may tend to transfer material in microscopic contact volumes from the solid to the liquid, gaseous, or plasma state. Temperature is the main controlling factor in most structural transformations at rubbing surfaces; it activates the formation of microscopic cracks, all of the tribochemical reactions, and "third-body" formation.

The ranges of experimental-research conditions have been broadened significantly in recent years (high loads and speeds, hard vacuum, high and cryogenic temperatures, nontraditional liquid and gaseous environments, high-energy irradiation); this has led to the detection of interesting effects and phenomena that, in turn, have enabled us to study specific mechanisms of friction and wear: selective transfer and anomalously low friction, hydrogen wear, tribopolymerization, friction and wear in biological objects, aspects of tribological behavior at zero gravity, strong thermal effects, high speeds, electric fields, etc. [70,115,127,256]. Here we might note that "instant" nondestructive physical methods for study of the frictional interaction are becoming much more important at the present stage in the development of triboanalysis; important among these are methods based on the use of acoustic and electromagnetic radiation.

Tribomaterials science is a specific subdivision of general materials science – the science of industrial materials, their structure, and their properties – and is the connecting link between the results of theoretical tribological research and the aggregate of knowledge that forms the scientific foundations of triboengineering and tribotechnology.

Triboengineering materials are usually classified on the basis of composition into the following groups: metals and alloys, composites with metallic and polymer matrices, ceramic composites, lubricants and additives, and