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BASIC TRENDS OF FRICTIONAL INTERACTION AND TRIBODIAGNOSTICS

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Abstract: This paper contain develop nent the theory and pra :tice of the tribology and tribo-diagnostics. It is includes the main directions in tribology, magnetofluid tribosystems, classification of the technical objects, tribomonitoring systems, thin layer activation, restoring of tribosystems without its disassembling, tribosystems with wear autocompensation, controlling tribochemical regime.

Key Words: Condition monitoring; corrosion; friction; lubrication; theory; tribo-diagnostic; wear.

INTRODUCTION: The most widespread cause of machinery operational performance deterioration is wear combined in some case with corrosion. It is wear that limits useful service life of any machine. If the wear of critical component parts exceeds some reasonε le value, further operation of machine becomes non-effective, dange. ,us, and ecologically intolerable.

The main trends in **tribological developments** are given in table 1 [1, 2].

It is now believed that proper attention to tribology, especially in education, research and application, could lead to economic savings of between 1.3% and 1.6% of GNP [3]. Prof.P.Jost, President of the International Tribology Council(London), as the result of the developments in the world of the past 20 years, the subject of Tribology were to be divided into its main constituents, i.e. in its input areas, the division could be as follows (table II) [3]:

Condition Monitoring and Tribo-diagnostic could lead to economic savings near 0.1% of the GNP, it is, for example, for USA make 7 billion dollars.

Table I

The main trends in tribological developments

Theory of friction, wear and lubrication				
Theory of hydrodynamic and elastohydrodynamic lubrication	Physico-chemical processes in friction and wear	Contact mechanics	Theory of dry friction	Theory of wear
Study of friction, wear and lubrication by experimental methods				
Applied directions				
Wear-resistant materials	Technology of surface friction modification and reinforcement	Efficient lubricants and additives		
Calculation, design and manufacture of friction units, machines and instrument with optimal properties				
Rolling and sliding bearings	Brakes and clutches	Sealing devices	Lubrication systems	Machines, equipment and instruments
Tribo-diagnostics, condition monitoring				
Friction units	Machines	Instruments	Other technical arrangement	

Table II

Main constituents in Tribology

a) Materials Science & Technology	40%
b) Mechanical Systems	30%
c) Lubrication and Lubricants	20%
d) Condition Monitoring, Tribo-diagnostics, Instrumentation, Tribo-information (Data Banks & Others)	10%

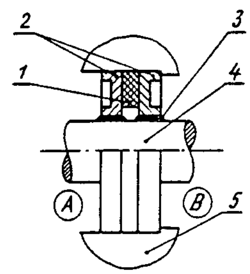
Classification of the technical objects: The technical objects may be divided in two groups.

The first one contains the objects which wear condition may be judged by variations of their operating performance characteristics, e.g. sensitive decreasing of speed of icebreaker cutting a passage through floating ice due to corrosion wear of her hull, drop of compression and variation of exhaust gas composition in internal combustion engines due to wear of cylinder-piston group, increasing of a gap in transmissions and gearboxes, significant rise of leakage in mechanical seals. Wear condition of engine may be judged by its vibrational characteristics, amount and composition of wear particles contained in lubricating oil, and a number of other means. An estimation of parameters which characterize the operational performance of an object is based on a measurement of an integral characteristic of object subsystems state which is related with joints wear.

The second group involves the objects which may be in operation up to the time instant when those operational capability loss occurs drastically as in the cases of magnetofluid seal hermetization loss or pipeline breakage. State variations of such objects, i.e. change of magnetic fluid composition and its magnetization or loss of material from inner surface of pipe resulting in wall thinning, does not affect practically on the operational performance. The development of methods for diagnostics and estimation of residual service life of such systems is very important problem. On the board of orbital space station "Mir" several dozens of magnetofluid seals are installed. Breakage any one of them sealing mechanisms transferring motion from inner compartment to the outer space causes loss of station hermetization. Breakage of gas or oil pipeline results to product delivery interruption and environment pollution with disastrous ecological consequences.

Magnetic fluids systems: Magnetic fluids represent a qualitatively new class of synthetic material which possess unique properties. The application magnetic fluids for tribotechnical purposes, such as seals, bearings, machine friction units with magnetic lubricants, was the result of the development of technology in space research [4]. Magnetic fluids are stable colloids of ultradisperse magnets in a neutral carrier fluid. The stability of such colloids is provided by using special high molecular weight substances with active surfaces. Water, hydrocarbons, oils, silicon fluids, esters and even liquid metal have been used as carrier fluids [5]. Such materials, retaining their fluid properties in the magnetic field, are magnetic controlled. A magnetic fluid, disposed on a flat glass plate and kept at a distance from a magnetic field, is illustrated in Fig. 1. In technical arrangements, the magnetic fluid is drawn into the clearance in the maximal magnetic induction area under the action of the magnetic field. This builds up an elevated pressure which provides hermetical sealing or lubrication. Of the magnetofluid tribotechnical systems, the most widely used application was seals (Fig. 2, Fig. 3). Such arrangements have been in use

Fig 1. Magnetic fluid on a glass plate in a magnetic field.



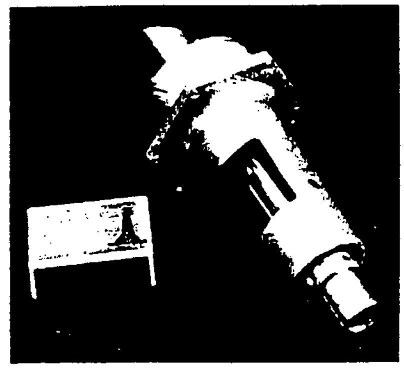


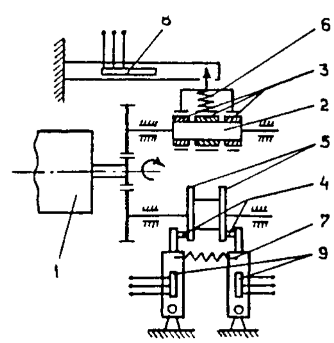
Fig. 2. Magnetofluid seal: 1, permanent magnet; 2, polar stands; 3, fluid; 4, shaft of magnetic material; 5, housing.

Fig. 3. Arrangement for the transmission of motion from the inside of a spacecraft to an outboard fixture: reverse rotatory 0.16 Hz; rotation angle, ±30°; temperature interval, ±50°.

for a long time on some Russian spaceships. They are capable of maintaining their service properties in outer space for a period of more than 5 years. When the magnetic fluid used in sliding bearings, it ensures a spatial stabilization with a low rotation resistance. When it used in dampers, it give big possibilities to monitoring of the damper characteristic and to construct the system with back bond, as, for example, in the holder solar panel of the space station or suspension bracket of the perspective cars.

We would like to draw your attention to an unusual application of tribological development. At the present time, magnetic fluids are used in medicinal drugs and used for treating fistula and ulcers. The fluid is administered by any means to the patient at the required site, and remains therein with the help of a magnet fixed on the part of the body being treated.

Tribomonitoring systems: One of the important part of the tribo-diagnostics or tribo-monitoring systems there are measuring systems and systems for transfer the information. On the Fig.4 and Fig.5 are presented friction simulator which proved to operate successfully in



1 - drive
2,3 - shaft-bush
4,5 - pin-disk
6,7 - spring
8,9 - tensobeams

Fig. 4. Friction simulator: scheme.

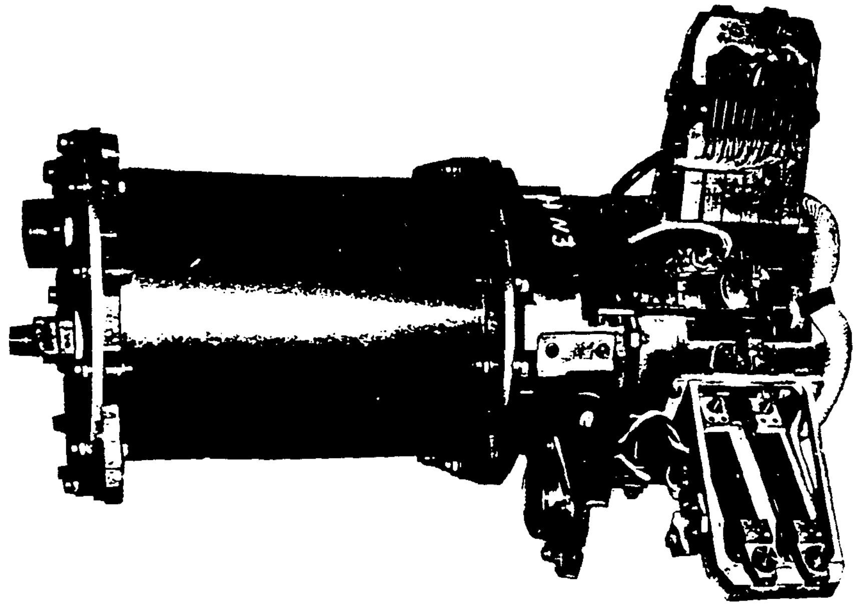


Fig. 5. Friction simulator: external view.

open space around moon. It was build on the Lavochkin`s plant. The friction simulator allows one to test materials and coatings for friction and wear simultaneously in nine friction pairs: three pairs by the "shaft-bush" scheme, six pairs by pin-on-disk rotary motion. The simulator is supplied with tensometric apparatus sending an output signal to a telemetry system and recording device. The same device may be used to measure friction in strong radiation, in aggressive media and another cases.

Thin layer activation: There are several methods allowing to measure local wear of machine components. Between of them the most remarkable one is the surface activation method (thin layer activation). This method, as a version of tracer technique, is very useful in a non-destructive wear and corrosion control. It is based on the irradiation of selected areas on rubbing surfaces by high-energy particle beam in order to create self-activity of areas mentioned. These prepared radioactive labels are used for wear measurements of irradiated components after their installation into the machine. Activity induced does not exceed 10 microcurie and this method may be used without any special protection. For example, it enables to measure cylinder insert wear of marine diesel without disassembling and provides continuous wear condition control during ship voyage using measurement equipment installed out of the engine. Numerous works with combustion engines carried out in different countries are well known and do not need additional illustrations. There were studied the choice of design and material, running-in and operation life, wear profile of the piston ring, influence lubricating oils, fuels and much other. The works on thin layer activation application for the wear control of cutting tool and different type of the bearing are often described as well. There was also a large variety of technical objects studied - from precise ball bearings, recorder heads and artificial mitral valves to rotary excavators, mining scroll centrifuge and in many another cases.

The technique allows to solve a great variety of problems: a) on-line state control of important parts and units of unique and dangerous machines in operation; b) operative examination of different technical ideas concerning new technics; c) evaluation of operation life, i.e. mean-cycles between failure time in order to replace or to repair the equipment; d) the choice and optimization of operating conditions; e) qualify materials and media closely involved in the operating process, e.g. lubricants, fuel, gas mixture etc.

The main material of modern human civilization is yet iron and its alloys. Its charged particles irradiation generates the radionuclides of cobalt, being perfect indicators with a very convenient half-lives and gamma-ray energies. There is state standard on the application thin layer activation technique [6].

It seems now that one of the promising the surface activation method application is the wear and corrosion control of gas-oil pipe-lines and the equipment of oil-refining and chemical plants. The next schematic diagram shows a picture of a screw with the radioactive insert and the whole control system (Fig.6). Such screws are installed in the pipe-line walls and serve as wear and corrosion indicators. The results received are in good agreement with the gravimetric data of standards. This system are developments in the Institute of Physics and Power Engineering in Russia [7].

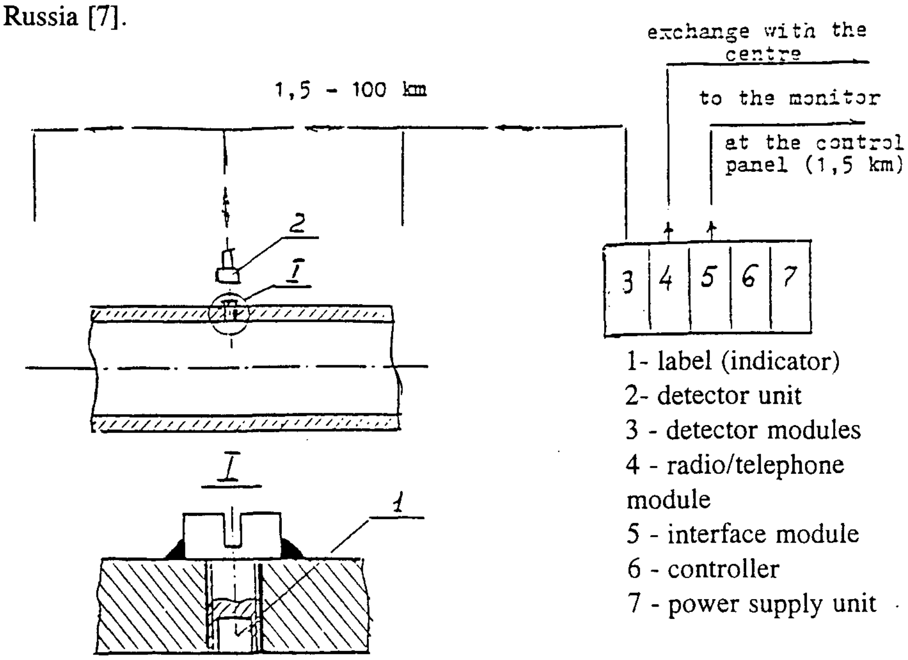


Fig. 6. Schematic diagram of pipe-line wear and corrosion control.

Two difficulties were met in this problem - a long control time (10 years and more) and large depth loss, reaching in some cases 3-5 mm. Their solution was found in the use of classical radiotracer technique. The corrosion indicators in the form of thin flat insert are manufactured from the same steel as objects under control with addition of cobalt (1-2%). Their activation by thermal neutrons in nuclear reactor gives 60 Co having very long half-life (5,24 years) and intensive high-energy gamma-radiation, convenient for remote monitoring through thick absorber. Error of the wear measuring is not more 5-15%. The laboratory studies of this material physical and chemical properties did not indicate any remarkable departures from those of initial metal.

The monitoring system for different technical objects is worked out and includes the following: *a) wear and corrosion indicators* placed inside without distortion of the flow and without any influence on physical and chemical properties of the surface under control; *b) detection units* mounted at the outward side of the pipe or facility; *c) system of automatic data collection and processing* which can also receive the information from a number of other monitors (temperature, pressure, flow rate and another) placed at the equipment

So in many cases diagnostics allows to estimate machine state without any influence on rate of its operational capability loss.

RESTORING OF TRIBOSYSTEMS WITHOUT ITS DISASSEMBLING: There are more complex systems which diagnostics is related with tribosystems operation control, for example, by changing the composition of fuel supplied to engine or by influencing on lubricant applied providing adaptation of tribosystem to varying operational conditions. Restoring of worn cylinder-piston group of engine is possible without its disassembling by introduction of appropriate chemical species into combustion chamber, motor oil or engine fuel. Such means of nondestructive engine restoring are well approve now and widely used in practice. In table III are presented the results of the restoring old combustion engines with help lubrication composition PIK-02 [8].

Table III

Restoring of car engines without its disassembling

Type car	Run car before restoring, km	Compression on cylinders, kg/cm^2							
		before restoring				after restoring			
		1	2	3	4	1	2	3	4
Volga GAZ-3102	305074	7.0	7.0	7.5	6.0	10.0	10.0	10.0	9.0
Volga GAZ-2412	148154	9.5	9.0	8.0	9.5	10.5	10.5	9.5	10.0
Volga GAZ-2410	166688	9.5	9.0	9.0	9.0	10.5	10.5	10.5	10.5

Tribosystems with wear autocompensation: It is possible to create tribosystems with wear autocompensation and restoring of degraded lubricant properties. This possibility is based on deep investigations and discovery of means to control these processes. As an example of such approach one can regard the use of polymerforming additives or additives producing selective transfer phenomenon. These additives form self-restoring antifriction films on rubbing surfaces. Due to friction reduction these films enhance significantly the service life of tribological joints.

The selective transfer phenomenon is accomplished by using chemical compounds or dispersion of very small copper (or another metals) particles as additives in oils or greases, as well as if one of the elements of the rubbing pairs is made of a copper-containing alloy, for example steel-bronze pairs, while the lubricant medium contains corresponding surface-active substances [9]. In the case of friction in polyatomic alcohol (glycerol and xylitane) the diffusion process is accompanied by surface layer depletion of doping elements and the formation of a rich of the vacancies plastics copper film located on a support. Owing to the high degree of smoothing of the friction surface, substantial growth of the real contact area of the interaction bodies takes place, as a result the pressure peaks decrease at the contact surfaces and reduce the conditions of the formation of microcrack centers and reduce following formation of the wear particles.

Test: The experiments were carried out in condition of sliding by testing machine SMT-1, roller specimens with diameter 35 mm made from steel, bronze pads, synthetic oil "Shell Tivella" and the additive SURM-3 manufactured in Russia. Nominal pressure - 30Mpa; nominal area of contact - 100 mm^2; friction distance - 3000 m. Such parameters as friction moment, wear, bulk oil temperature and electric conductivity were continuously measured during the test. The experimental data were acquired through data acquisition card PCL 812 by the computer IBM PC, what allowed torealize measurement procedure and treatment of experimental results outomatically.

The results of testing: The dependence of friction coefficient on sliding velocity is showing Fig.7. Friction coefficient measured for oil "Shell Tivella" is between 0.018 and 0.021, what confirm high lubrication ability of the oil and allows to consider it as one of the best oils.

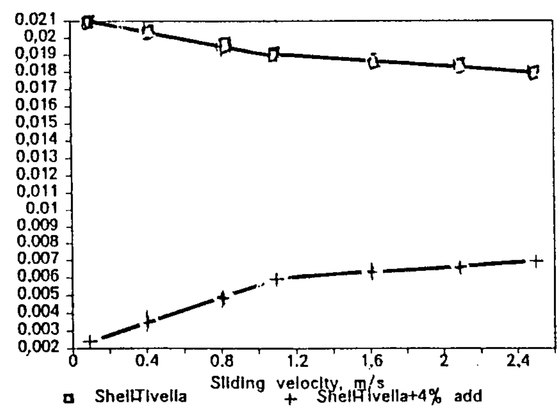


Fig. 7. Friction coefficient vs sliding velocity (m/s).

Application of the additive SURM-3 results in friction coefficient diminishing up to 10 times for the sliding velocity 0.1m/s and up to 2.5 times for sliding velocity 2.5 m/s (after sliding velocity 1.0 m/s perceptible influence hydrodynamic lubrication). The values of friction coefficient become equal to 0.0025 and 0.007 respectively what is close to the values of friction coefficient in hydrodynamic regime of lubrication. The dependence of the pad undimensioned wear ($I_h = h/L$, where **h** is linear wear, **L** is friction distance) on sliding velocity is shown in Fig. 8.

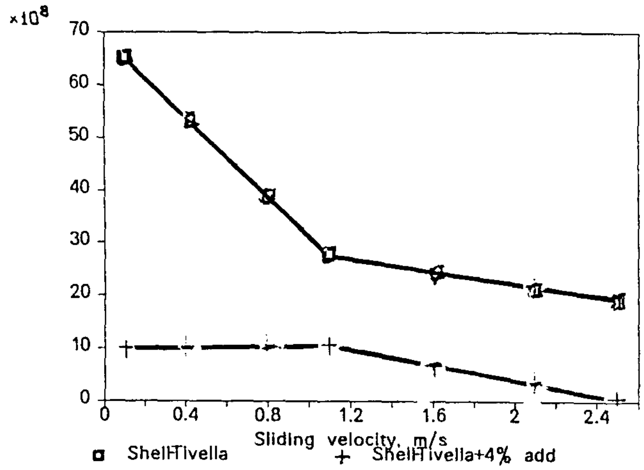


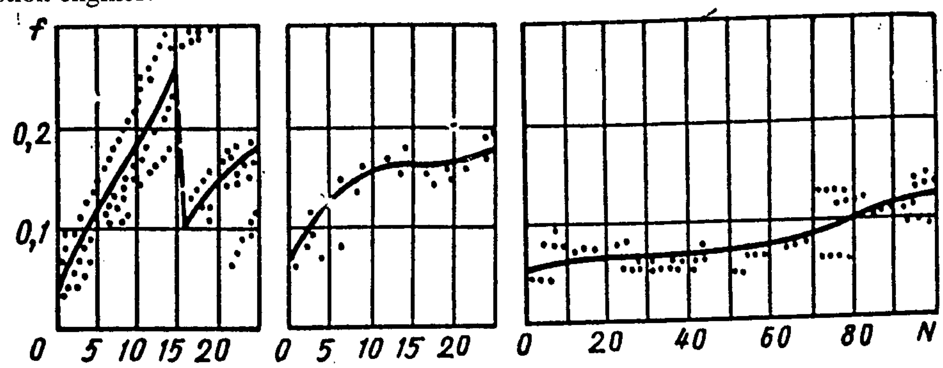
Fig. 8. Undimensioned wear vs sliding velocity (m/s).

Undimensioned wear of the pad decreases as result of the additive SURM-3 application in 6.5 times for the sliding velocity 0.1 m/s. The influence of hydrodynamics effects increases with the rise of the velocity, however, the additive is effective in all investigated region of sliding velocities, undimensioned wear is decreased in 2.5 times as a result of the additive application for sliding velocity 2.5 m/s.

Analysis of the experimental results allows to conclude that application of the additive SURM-3 essentially changes the mechanism of friction interaction what results in tribotechnical characteristics improvement.

Show the example to using the greases, which development as realization selective transfer phenomena, in very stress joints of the changing geometry aircraft wing. On the Fig. 9 presented dependent of the friction coefficient to number of the using this joints with single lubrication. There are limit of the friction coefficient 0,2. Lifetime of the joints increase more than 10 times [9].

Controlling tribochemical regime: It is known that chemical reactions occurring in the zones of contact of rubbing bodies lead to a deterioration of the lubricant properties. The main reason for this are the temperature flashes at the contact points, contact strains as well as oxidation of lubricants. If we are concerned with friction units and machine aggregates, the wear products of the rubbing parts, the dust particles and the combustion products from the engines all contaminate the lubricant. All this leads to aging of the lubricant compositions, deterioration of their serviceability and, as a result, to an increase in wear intensity. Therefore filters are used in these aggregates to remove solid inclusions and lubricants are employed which are more stable to chemical attack during the friction interaction processes. However, when traditional approaches are used, no permanent work of the oil can be reached in the case of overstressed running of the machine units and their aggregates, for example, of the combustion engines.



Lubricant TSIATIM - 201 Lubricant SVINTSOL - 01 Lubricant VNIINP - 254

Fig. 9. Friction coefficient vs to number of the using joints of the changing geometry aircraft wing.

One of the effective means in this area is the special device for combustion engine which contains chemical species affecting on the pumped-through motor oil [10]. These species restore lubricant properties and form on rubbing surfaces of cylinder-piston group, bearings and another moving joints the organometallic antifriction films containing Na-Sn alloys, metallic iodine, and hydrocarbons. The film thickness is about 200 Å. As the film possess poor mechanical properties, they can easily wear out, but can continuously be restored and it is possible to reach theoretically a dynamic equilibrium state at a definite chemical reaction rate. In practice, the application of this method leads to an increase in the capabilities of the combustion engine by a factor of several times with permanent oil work (Fig.10).

N = 735 kW

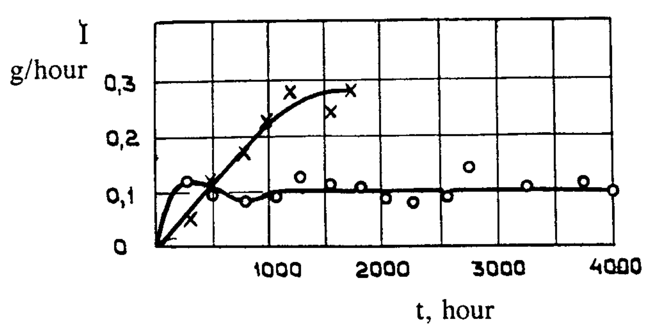


Fig. 10. Wear intensity vs. time: x, standard diesel; o, diesel with special device.

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