October 2009, Serbia

Advances and Challenges in Tribology

Prof. Nikolai Myshkin, Full Member of Belarus National Academy of Sciences

Metal-Polymer Research Institute of Belarus National Academy of Sciences, Gomel, Belarus, <http://mpri.org.by>

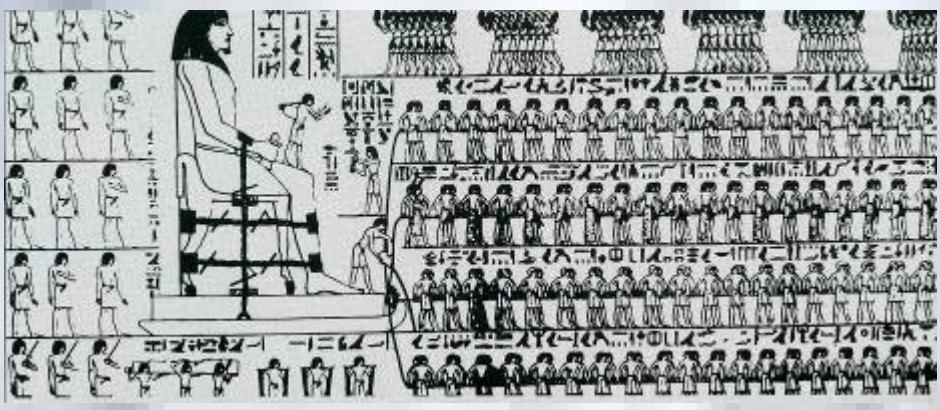
- Tribology as young as well as an ancient science
- Stages of development and advances
- Understanding of system approach
- Jost comission and creation of the notion
- Tribology in Russia and Belarus as a segment of global one
- Challenges of XXI century – from macro to nano, extreme conditions, tribotesting development
- Information highway in tribology

The ancient roots of tribology

First experience

Rubbing as a source of fire in the Ancient Egypt

Axle and bearing in Messopotamia (3500 b.C)

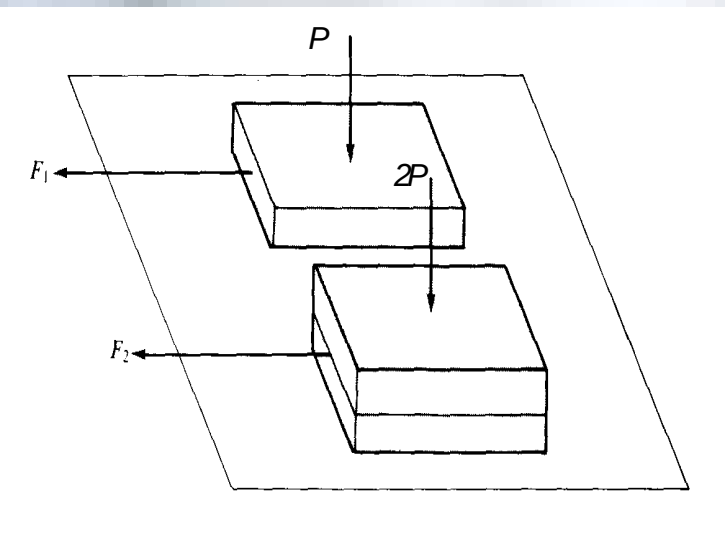


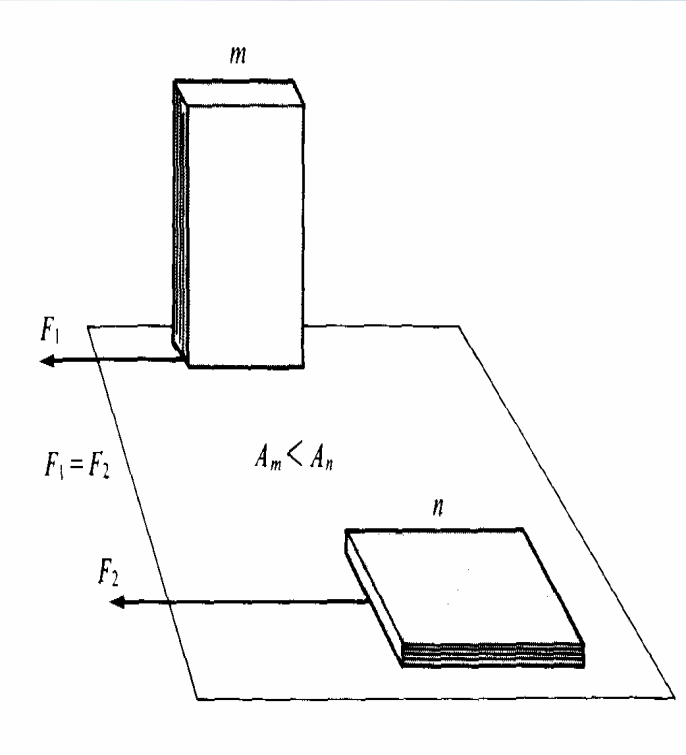
Lubrication in the Ancient Egypt (2000 b.C)

Ancient lubrication engineer

Leonardo – first fundamentalist in tribology

- friction force is dependent on load and independent on the shape and area of nominal contact;
- friction coefficient is equal to 0.25;
- friction coefficient is dependent on the contact area





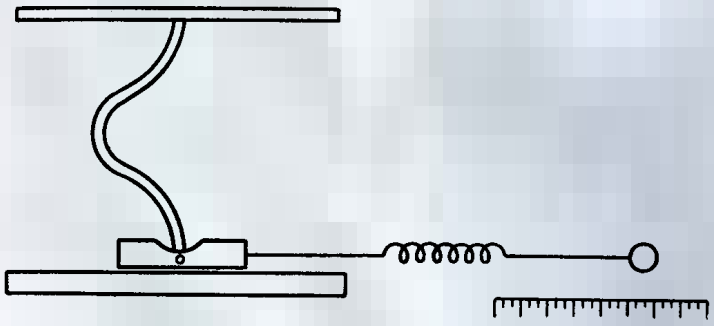
Mechanics of Friction

Amontons, 1699

friction is proportional to load

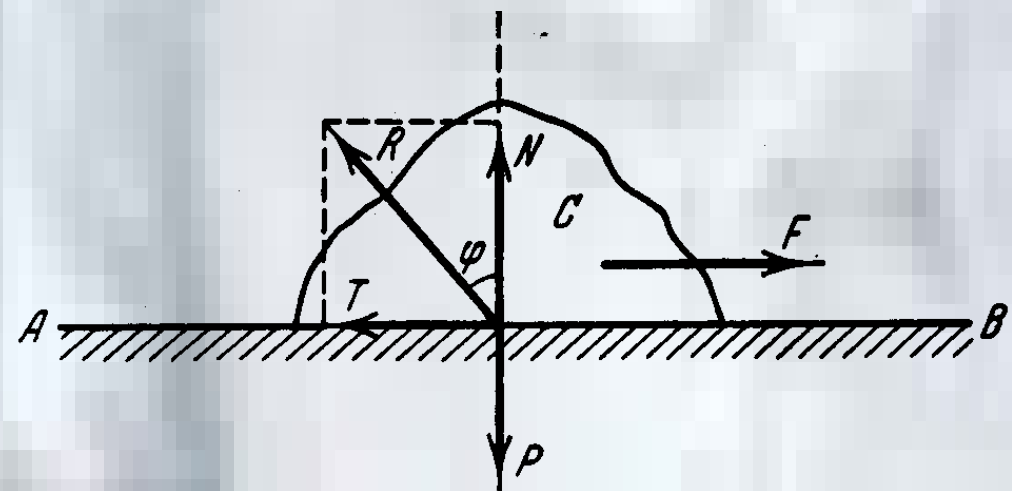
friction is not dependent on the nominal area

friction coefficient is equal to 0.3



De la Hire, 1700

Deformation of surface roughness asperities as a source of friction



Parent, 1704

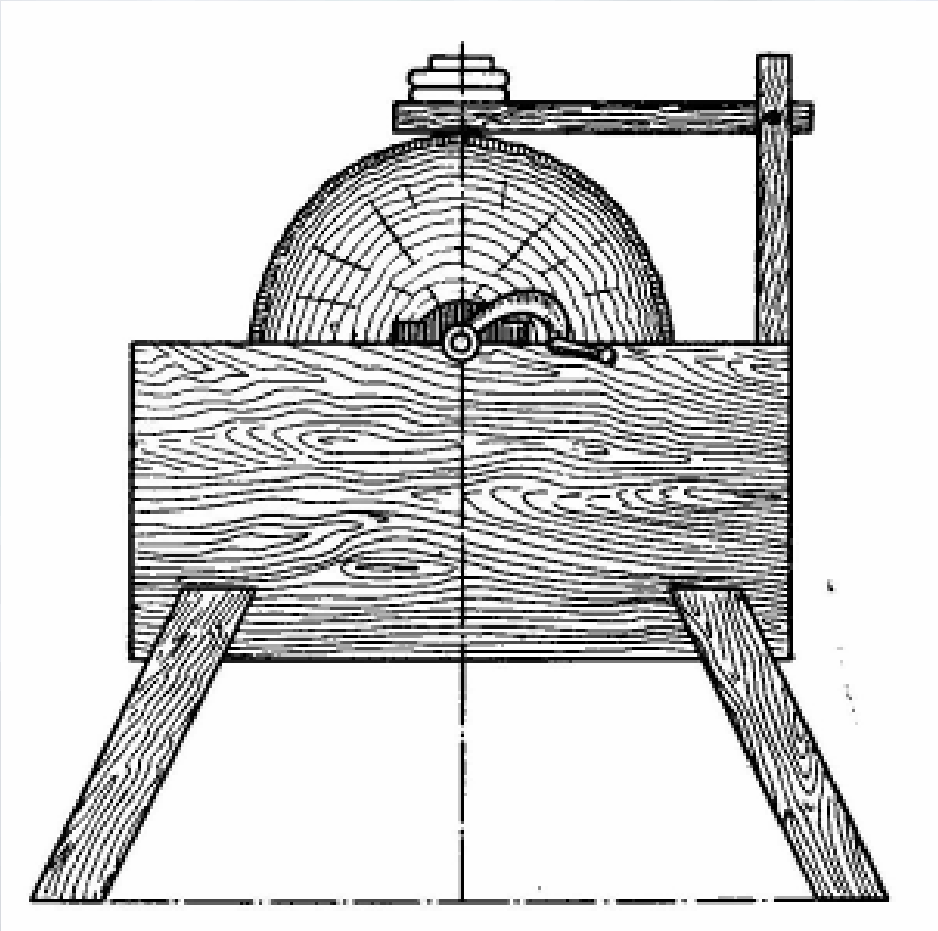
angle of friction

$F = tg\ \varphi$

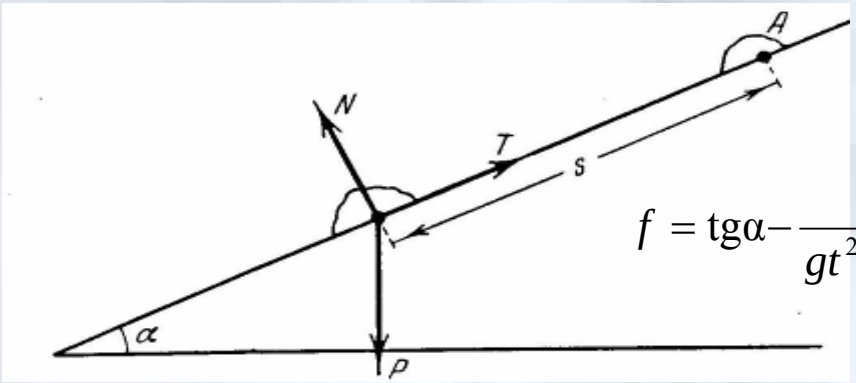
Origination of Tribology in Russia

Mikhail Lomonosov, 1752

abrasive wear tester



Leonard Euler, 1748

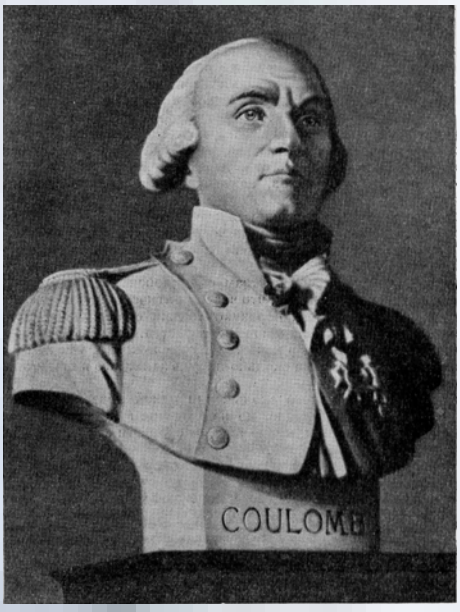


$$f = \mathrm{tg}\alpha - \frac{2S}{gt^2 \cos\alpha}$$

Molecular Theory of Friction

Desaguliers, 1734

roughness decrease→ approach of bodies→ molecular forces increase→friction force increase

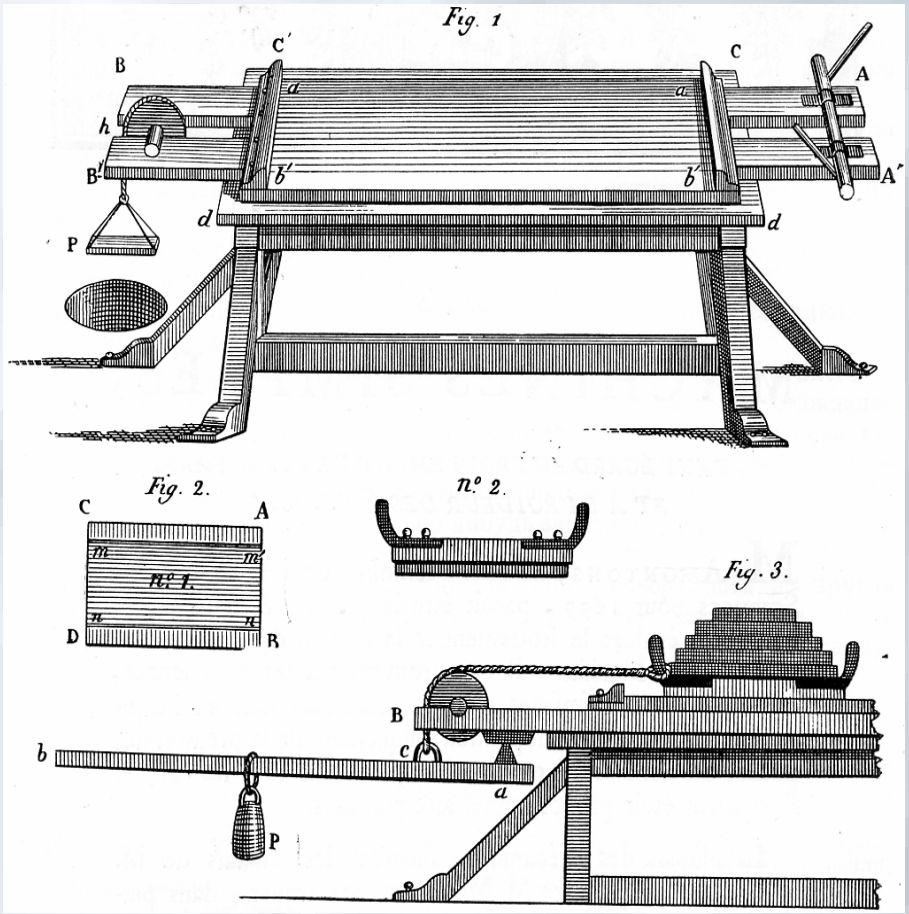


Coulomb, 1785

two-term friction law

$$F = A + fN$$

***A* – adhesion dependent on contact area**



Coulomb friction tester

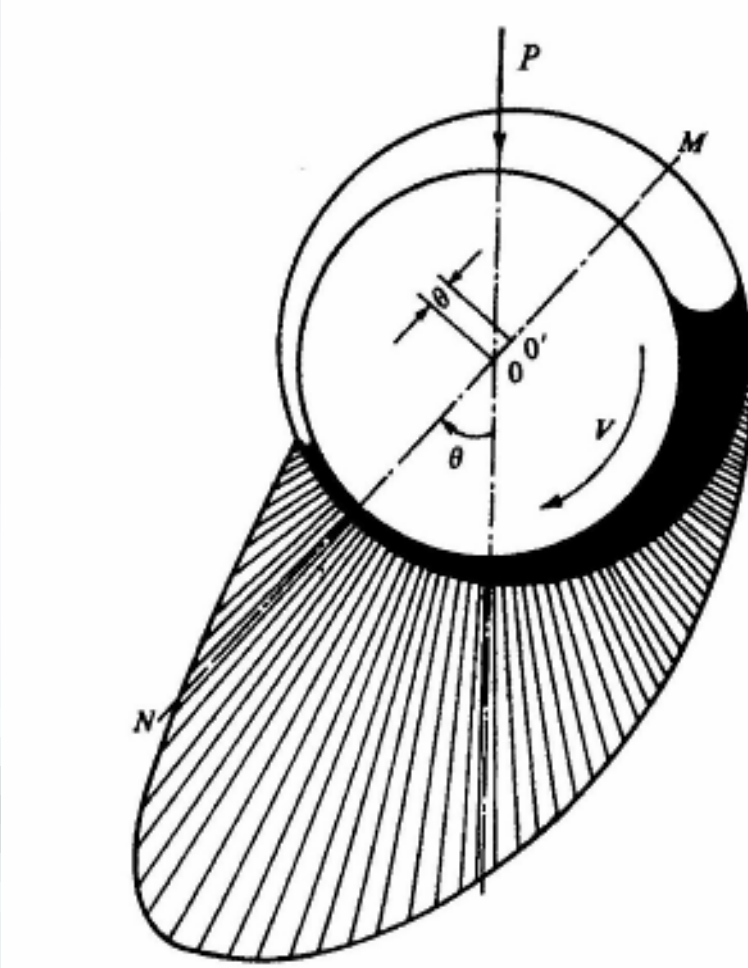
Theory of Lubrication

Dmitry Mendeleev, 1980s

Lubrication in watches, fundamentals of lubricant production from oil

Nikolai Petrov, 1883

$$f = 2\pi\eta\frac{\omega R^2 L}{Wc}$$

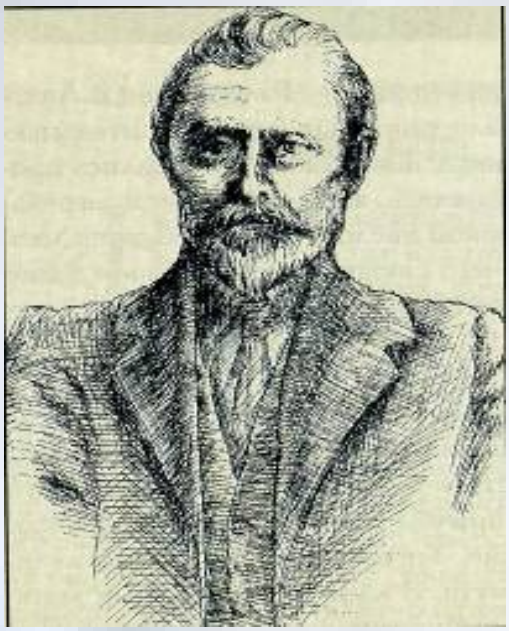


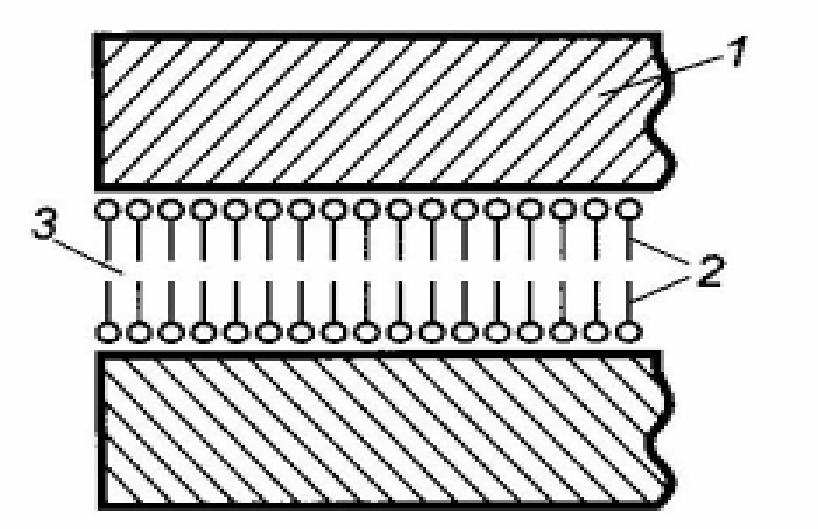
Osborne Rainolds, 1886

$$\frac{dp}{dx} = 6\eta V\left(\frac{h - h_0}{h^3}\right)$$

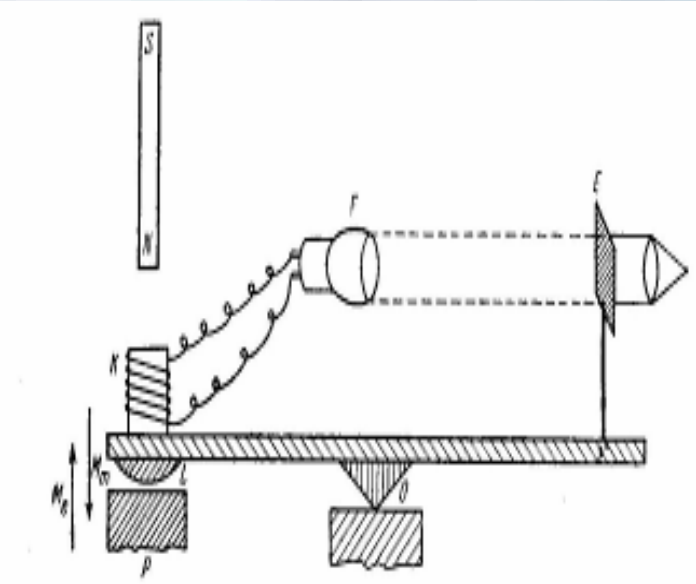
Boundary Lubrication

William Hardi, 1919





Boris Deryaguin, 1934



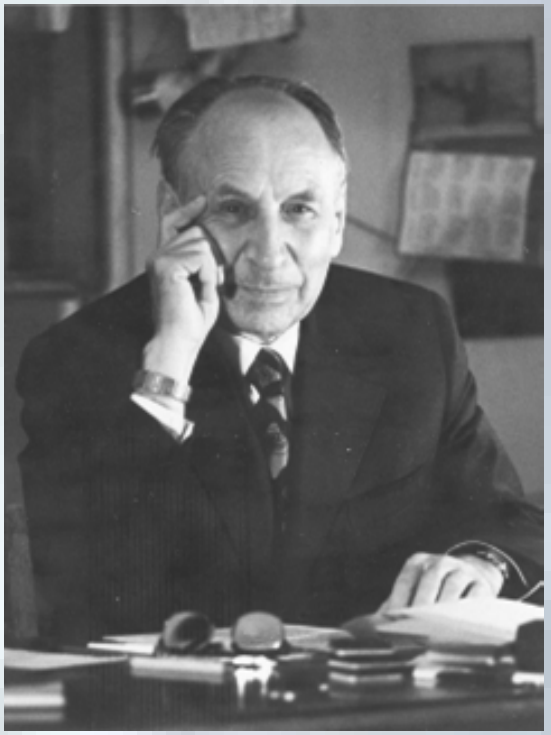
Two-term friction law

$$F = f(N + p_0 A_r)$$

Dual Nature of Friction

Adhesion-deformation theory

Fillip Bowden,



Igor Kragelsky

David Tabor

Tribology Origination (1966)

Tribology – a science of solids being in relative motion

Volume 733
No. 74

Thursday
11th August 1966

HOUSE OF COMMONS
OFFICIAL REPORT

PARLIAMENTARY DEBATES
(HANSARD)

11 AUGUST 1966 *Written Answers* 402

Jost Report

Mr. Lubbock asked the Minister of Technology if he will make a statement on the Jost Report.

Mr. Benn: Yes. In December, 1964, at the invitation of my noble Friend the former Minister of State for Education and Science, a Working Group was formed under the Chairmanship of Mr. H. Peter Jost with the following terms of reference:

"To investigate on an informal basis the present state of lubrication education and research and to give an opinion on the needs of industry in respect thereof."

My right hon. Friend the Secretary of State for Education and Science and I have now considered the recommendations contained in the Working Group's Report which was published earlier this year. We are satisfied that there is considerable scope for savings in this field and we accept the Working Group's recommendations in principle as useful indications of ways in which the needs of industry might be met. My right hon. Friend has drawn the attention of the educational authorities concerned, and the appropriate Training Boards, to the recommendations in the Report which are of interest to them.

In accordance with the Report's recommendations I propose to set up a Committee on Tribology, a word which the Working Group has used to cover lubrication and bearing technology and associated fields. It will include members from industry, the universities and professional institutions, as well as from the government departments and other agencies chiefly concerned. The functions of the Committee will be to advise me on how the objectives of the Report can be most effectively pursued. The Committee will also be able to advise government departments and other bodies as requested. In particular, I will ask the Committee as a matter of priority to consider whether the use in industry of the latest technologies and best designs can be most successfully fostered by the establishment of one or more Institutes of Tribology or by other means.

Peter H.Jost

House of Commons debates (1966)

Tribology Gold Medal Laureates

Igor Kragelsky (1975)

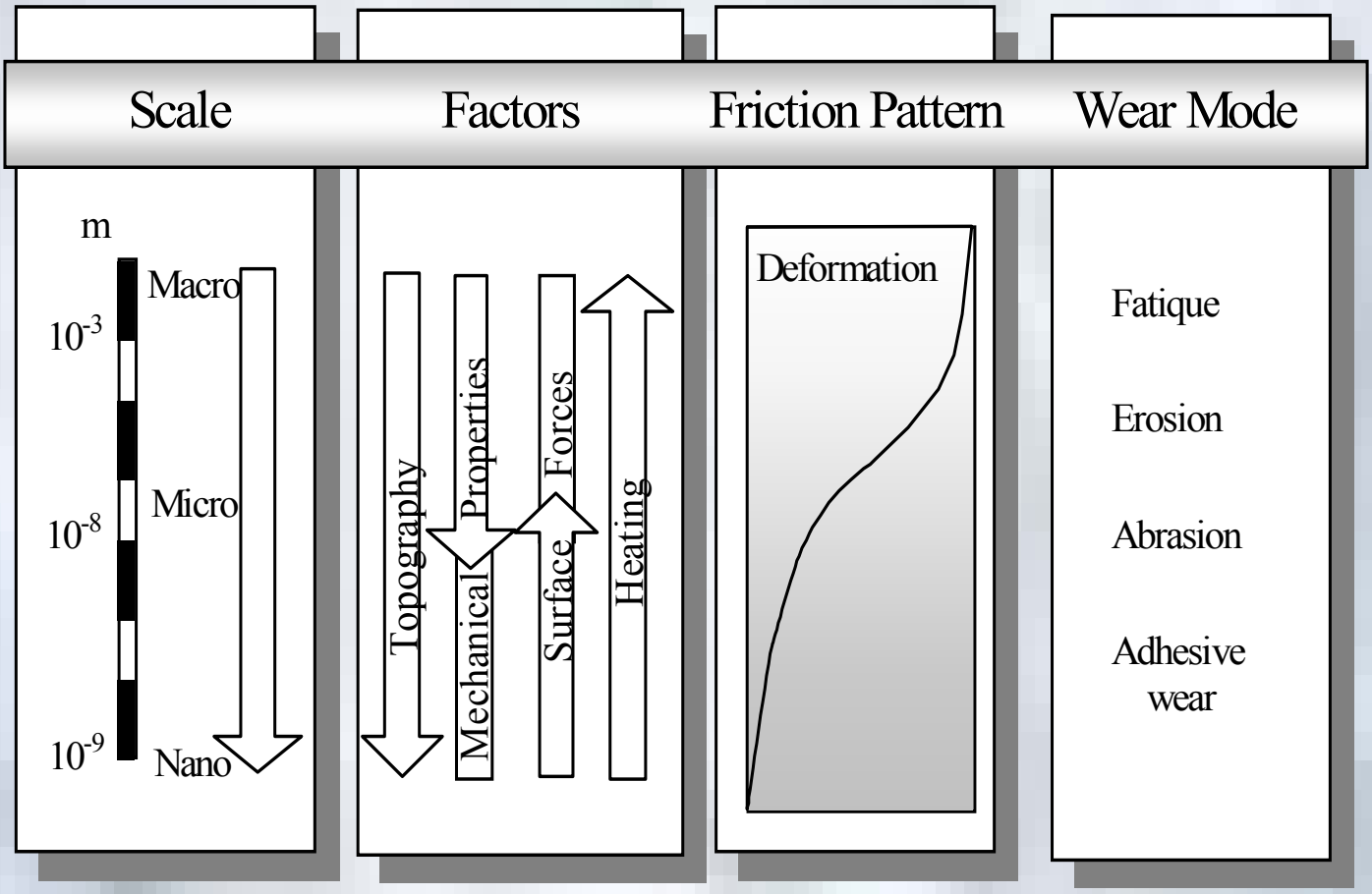
Georgy Vinogradov (1982)

Avtandil Chichinadze (1991)

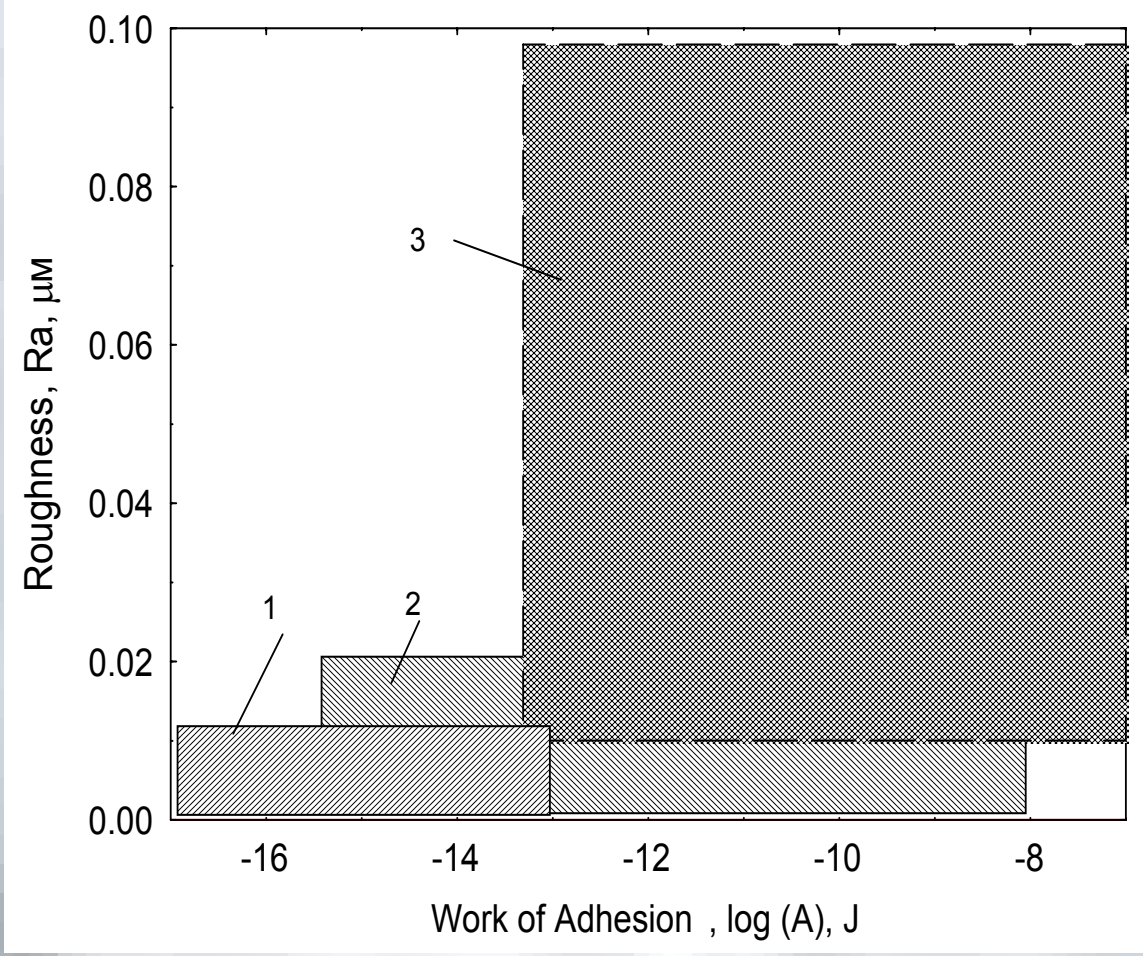
Nikolai Bushe (2002)

Dmitry Garkunov (2005)

SCALE FACTOR IN TRIBOLOGY

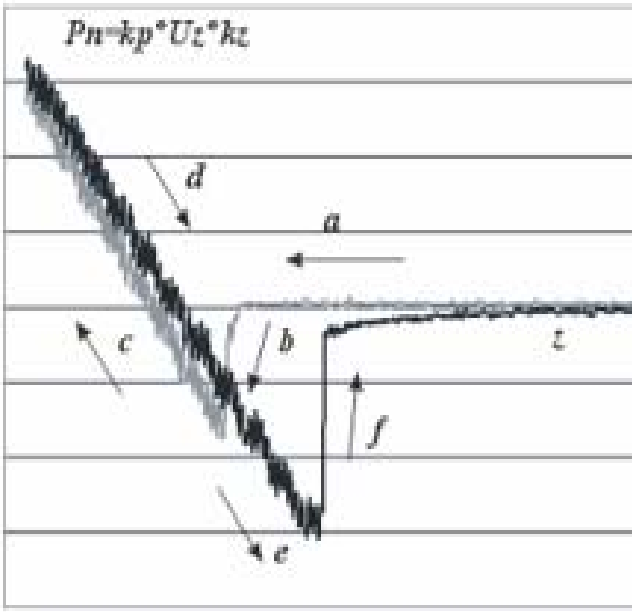


Resolution of devices used in micro/nanoscale

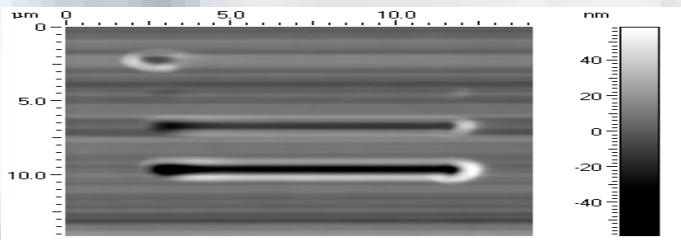


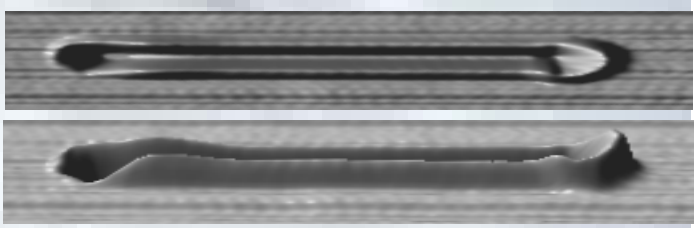
1- AFM, 2 – Surface Force Apparatus, 3 – scale of roughness and expected work of adhesion for real surfaces

Atomic Force Microscope Nanotop-207M (MPRI NASB)

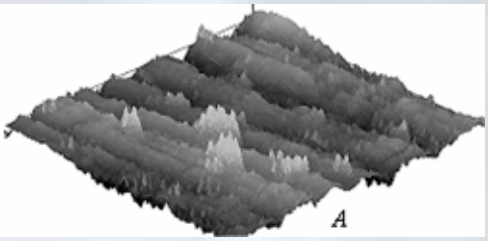


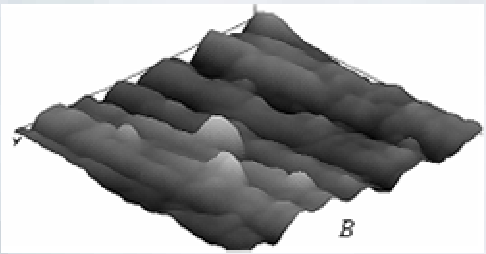
Modes	Non-contact, tapping, contact modes
Image	Topography and friction force
Scanning area	35 x 35 μm
Plane resolution	2nm on the damping table
Vertical resolution	0.1-0.2 nм
Specimen size	30/30/8 mm

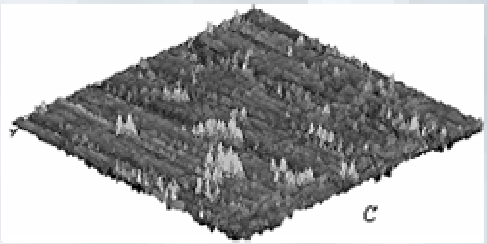




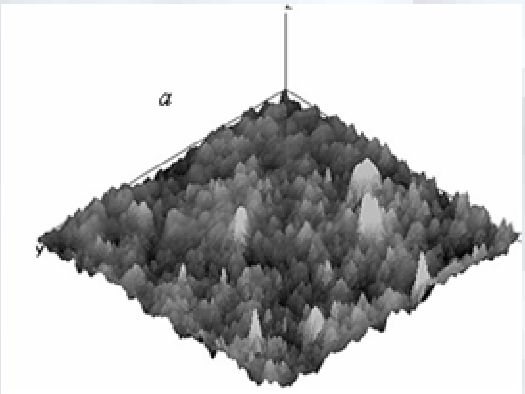
AFM applicaton for roughn contact simulation

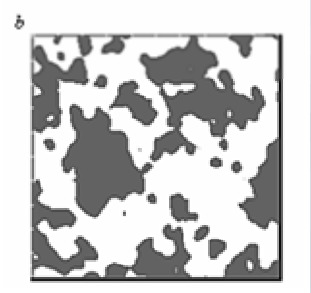


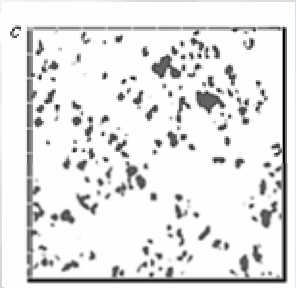




AFM image separation: A = B + C, where A – initial image, B – long-wave components of roughness, C – nanoscale roughness

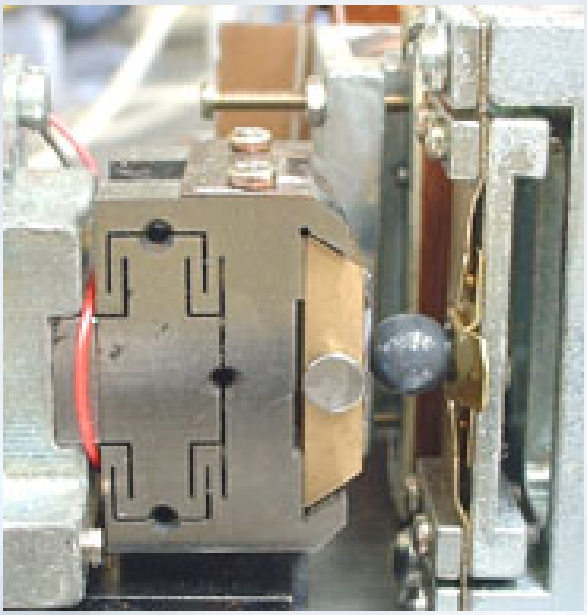


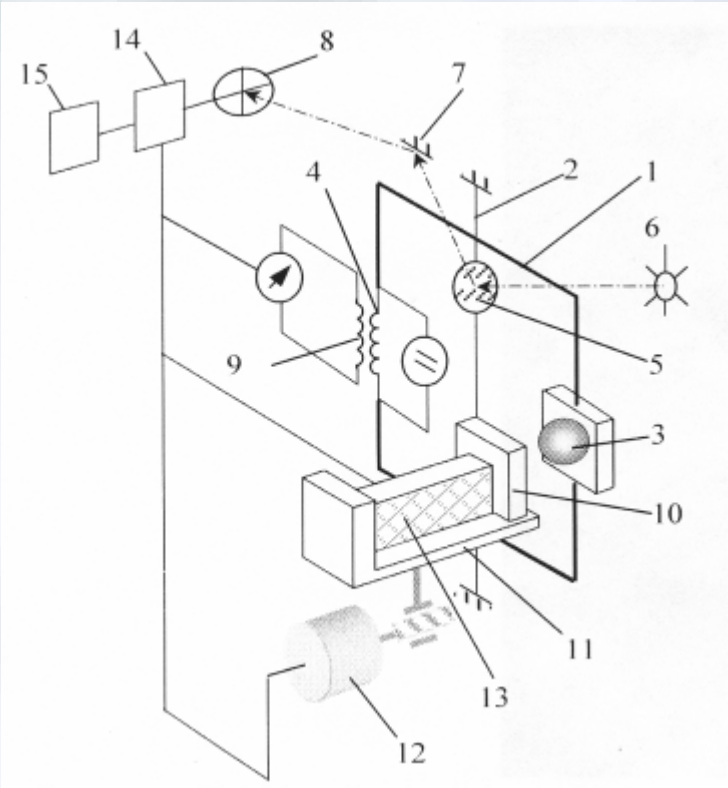




Visualization of contact spots: a – AFM image (15×15 mcm); b – microscale contact spot; c – real contact at nanoscale

Contact Adhesion Meter

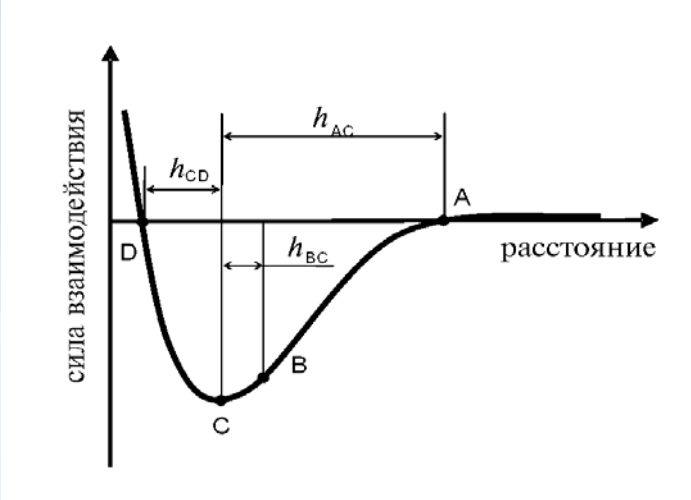




Force, mN	0.01 – 10
Distance, nm	10 -- 10000
Sample size, mm	20×20×5
Probe size, mm	0.2 -- 5

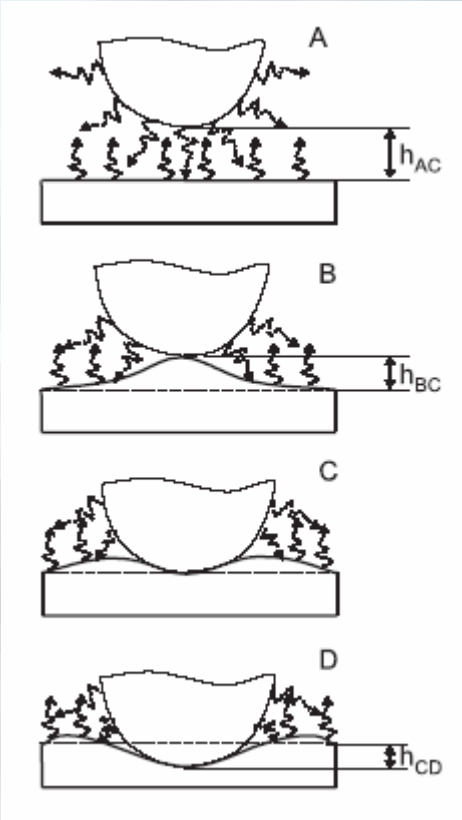
1 – rotating frame; 2 – spring suspension; 3 – ball holder; 4 – movable EM coil; 5 – mirror; 6 – laser; 7 – optical base expander; 8, 11 – photodetectors; 9 – EM coil; 10 - specimen; 12 – stepping motor; 13 – piezodrive; 14 – DS; 15 – PC.

Model of contact adhesion

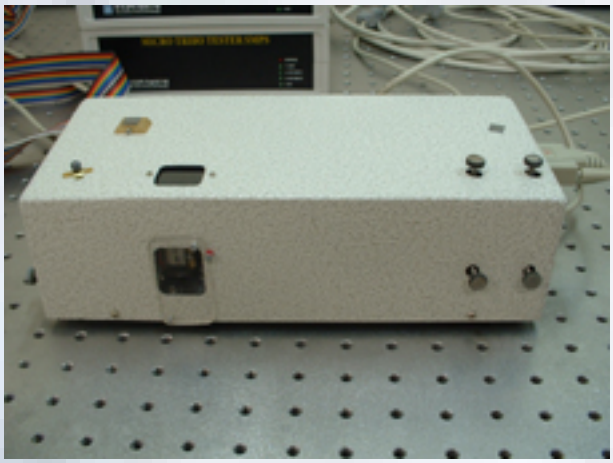


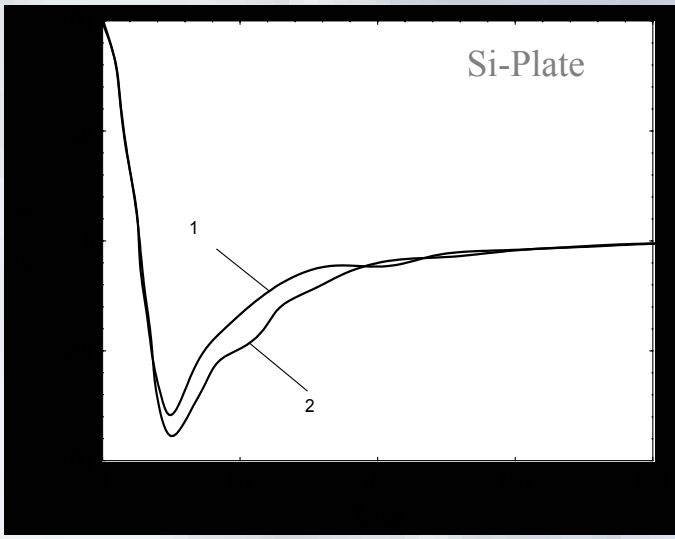
Force—distance curve: h_{AC} – effective radius of surface forces; h_{BC} – elastic deformation of surface; h_{CD} – elastic penetration with the account of adhesion

Formation of contact: A – moment of surface forces origination; B – moment of point contact formation; C – moment of sphere contact with non-deformed surface of plate; D – moment of equillibrium of attraction and elastic reaction of plate

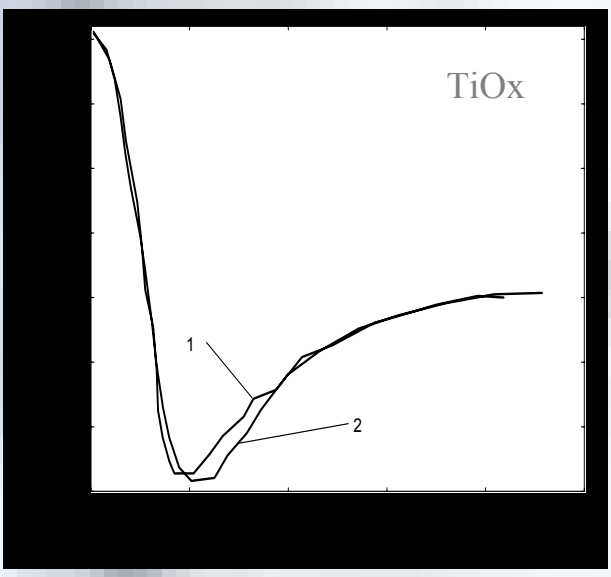


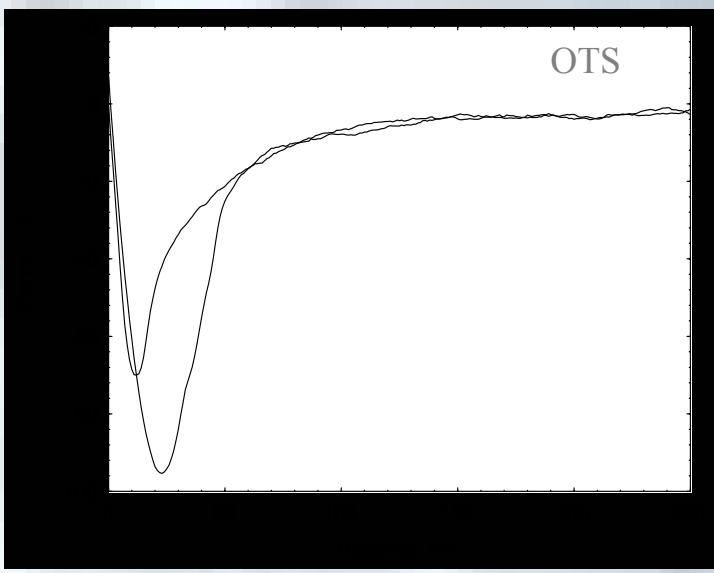
Contact Adhesion Meter ADM.



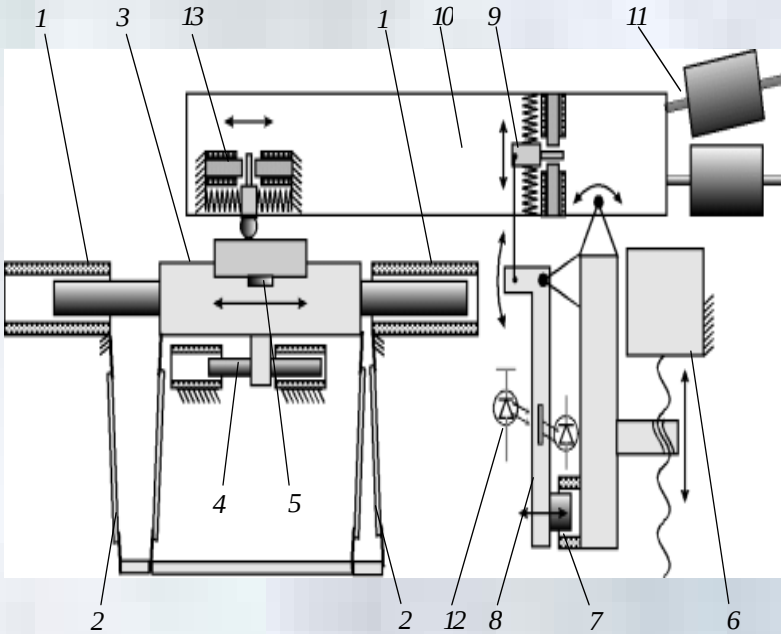


Si plate – steel sphere: 1 – approach; 2 –separation.





UNIVERSAL MICROTRIBOMETER

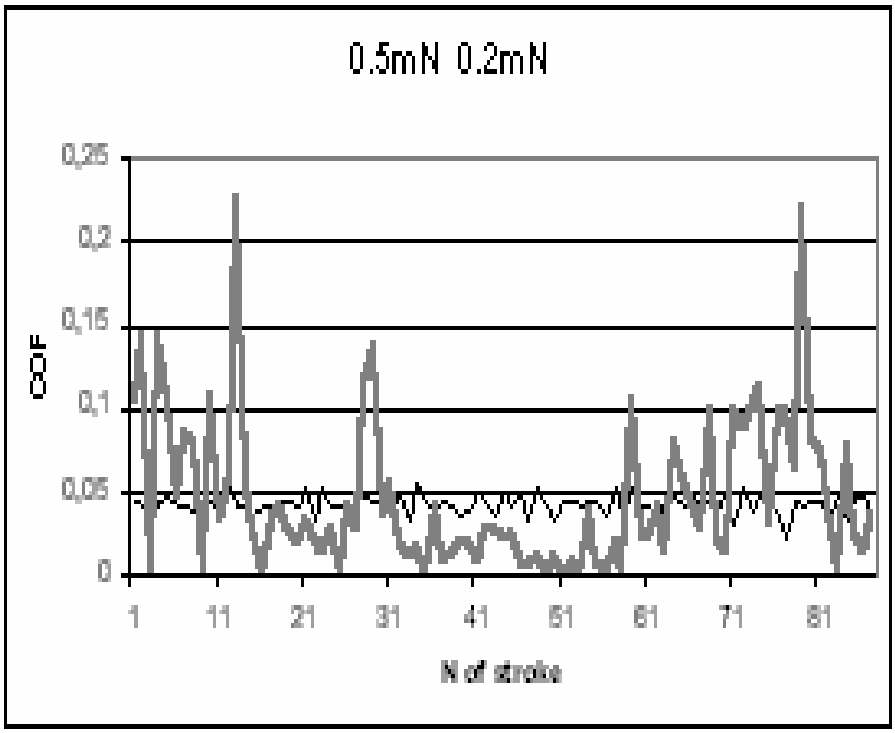


Load, mN	10 – 1000
Friction force, mN	0.01 – 2
Velocity, mm/s	0.1 -- 10
Stroke, mm	5
Ball radius, mm	1 -- 5

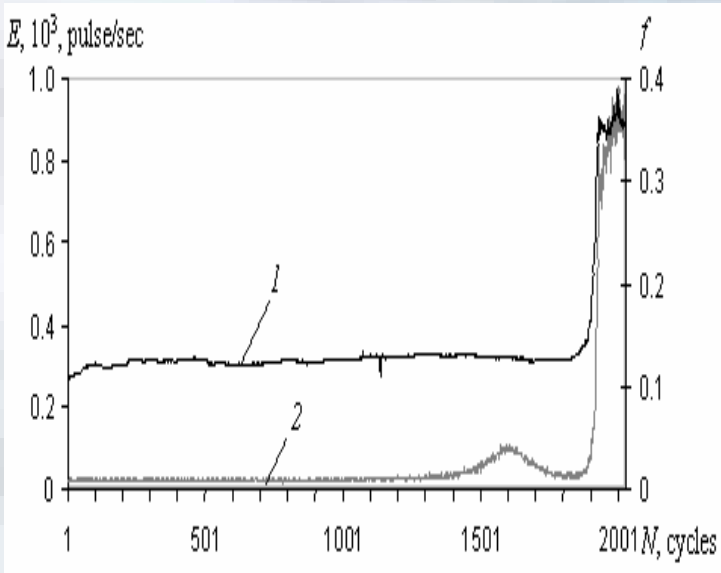
1 — drive electromagnets, 2 — flexible guides, 3 — stage for specimens, 4, 9, 13 — position, load, and friction force transducers, 5 —AE transducer, 6 — stepping drive, 7 — loading electromagnet, 8 — lever, 10 — head, 11 — balancing weights, 12 — optic coupler

Scale factor in friction

Steel ball against DLC



Coating	Thick-ness, nm	Friction coeffi-cient	Failure cycles
Si	1.2	0.12	20 000
$DDPO_4$	1.67	0.08	250
$ODPO_4$	2.2	0.09	350
OTS	2.6	0.08	20 000
SEBS	8	0.09	20 000

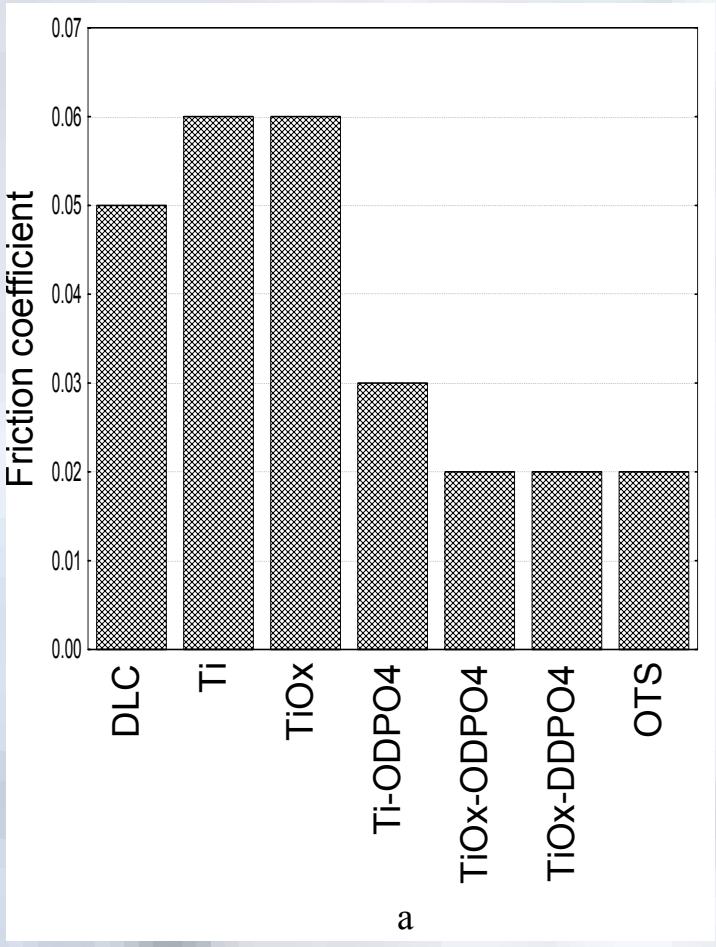


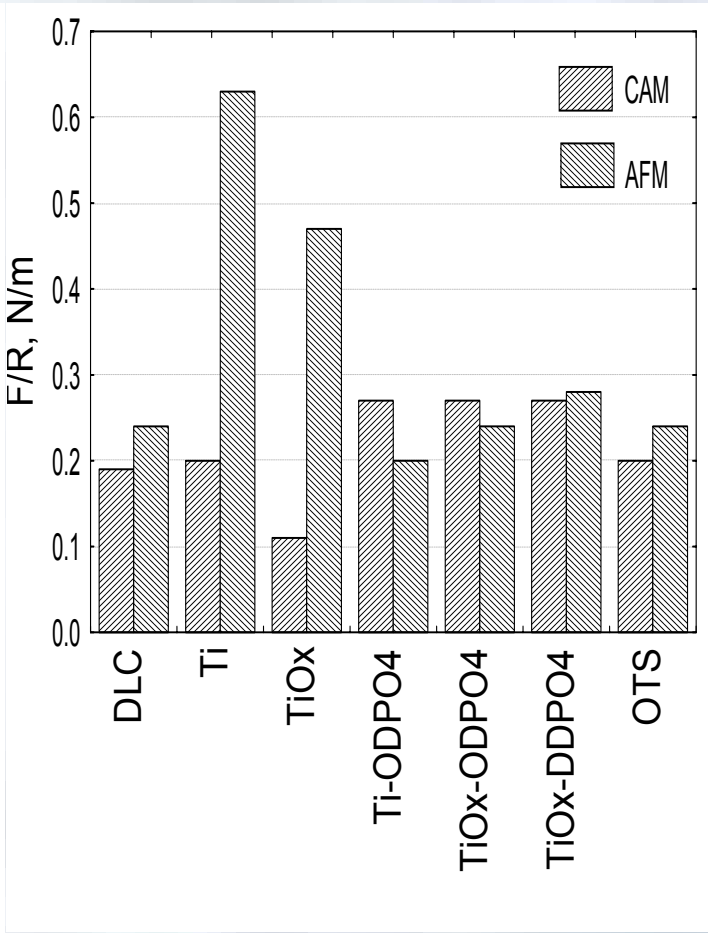
1- friction coefficient, 2- number of acoustic emission pulses

Typical objects of nanotribology

Sample	Description
Si	Substrate
Ti	Ti coating (100 nm) on Si substrate
TiO_x	TiOx coating (20 nm) on Si substrate
DLC	Diamond like carbon (~200 nm) on Si substrate
Ti-$ODPO_4$	Octadecylphosphoric acid ester (2.2 nm) on Ti covered Si substrate
TiOx-$ODPO_4$	Octadecylphosphoric acid ester on TiOx covered Si substrate
TiOx-$DDPO_4$	dodecylphosphoric acid ester on TiOx covered Si substrate
OTS	Octadecyltrichlorsilane (2.6 nm) on Si substrate
SEBS	Poly[styrene – b - (ethylene-co-butylene) - b- styrene] (1.67 nm) on Si substrate
Epoxilane	SAM (~1 nm) with epoxy surface groups on Si substrate

Friction and adhesion forces





a – friction coefficient (LFM), b – adhesion (contact adhesion meter) and separation force (AFM) normalized by tip radius

Tribology in Space Exploration

The history of space exploration started from first Sputnik has required the immediate solutions of friction, wear and lubrication problems.

Failures of tribological origin:

Soyuz-1 (1967), high friction in the bushing of parachute, death of cosmonaut.

Docking of Soyuz-10 with Salyut (1970) failed due to seizure.

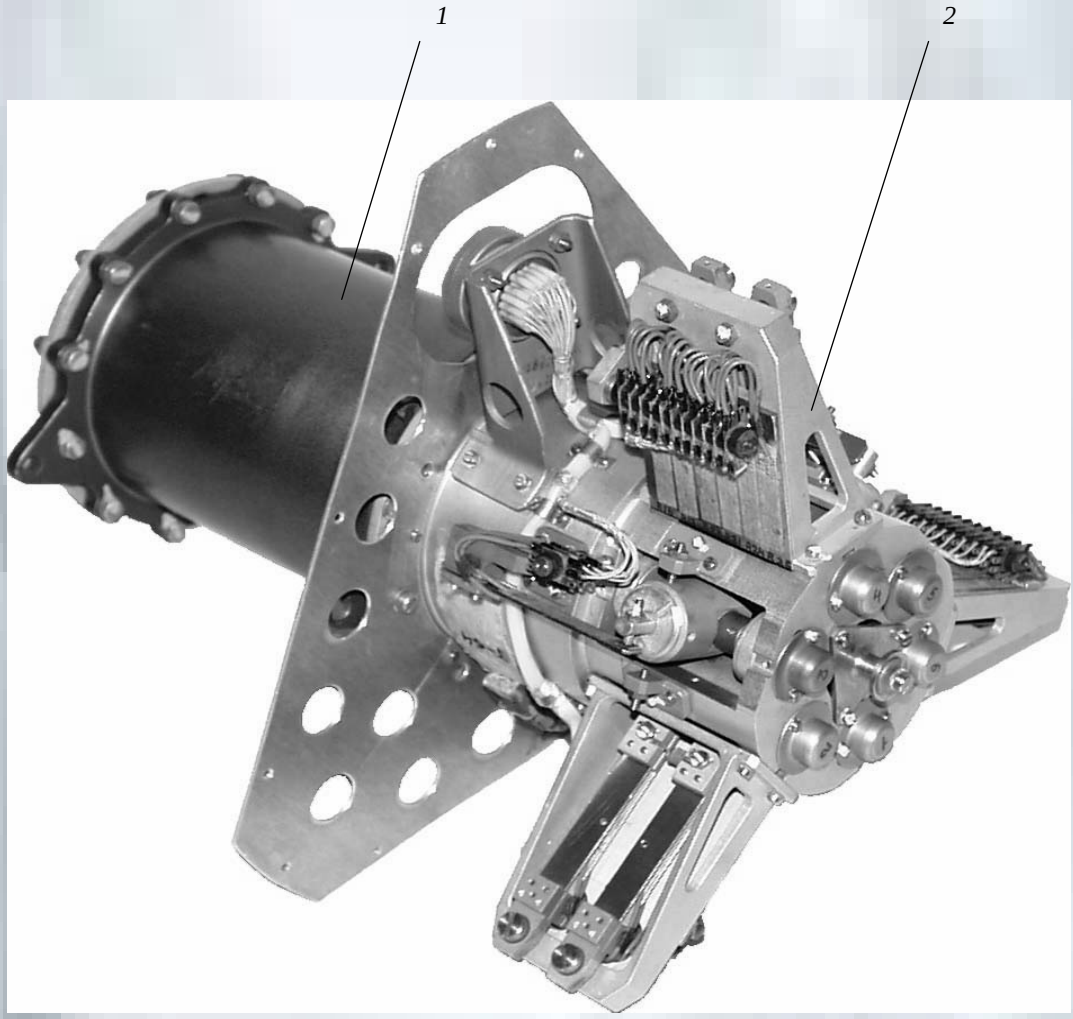
Voyager-2 (1981) - damage of self-lubricated coating in gearing. Similar failures: at satellites Insat-1 (1982), TVsat 1 (1987), TSS (1992), ETS (1995), Galileo (1989), and Magellan (1990).

Japanese lost 3 launchers – failures of ball bearings. International Space Lab (1998) – failure at locking.

EXPERIENCE OF TRIBOTEST IN SPACE

(Luna-22 spacecraft, 30 years ago)

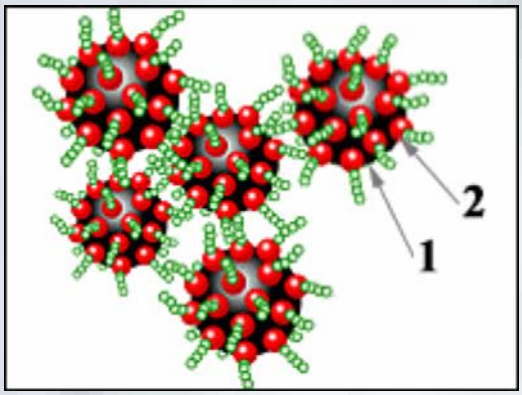
Tests were done in a ground laboratory, at the launching position,
and at the Moon orbit. There were 2 testers - ground and space ones. The latter was installed on the surface of the spacecraft. Tester consisted of three units with a total mass of 7 kg and spent in Space 1.5 years during the whole flight



Tribometer for the International Space Lab – ground protorype in MPRI NASB

Наземный прототип испытательного блока бортового трибометра

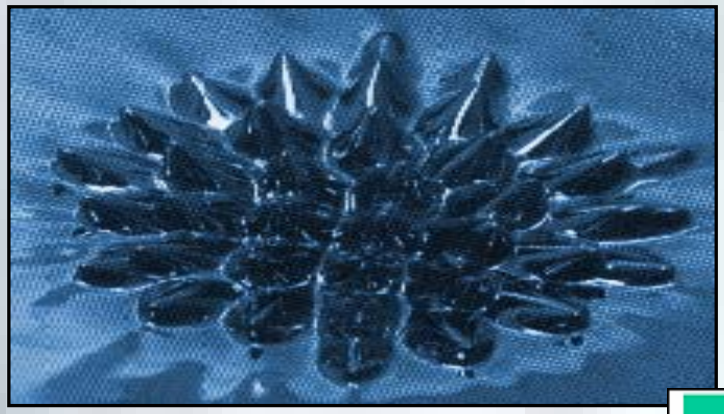
“Smart” Magnetic Nanofluid



MNF-stable magnetic colloids with particle size of about 10 nm

1 –particle

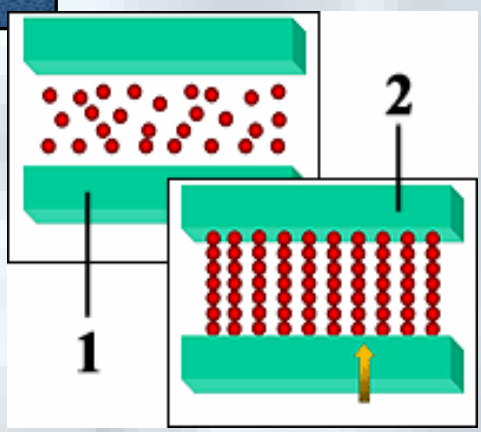
2 –SAC molecule



Free surface of MNF above the magnet

magnetic force:

$$f_m = \mu_0 m \nabla H,$$

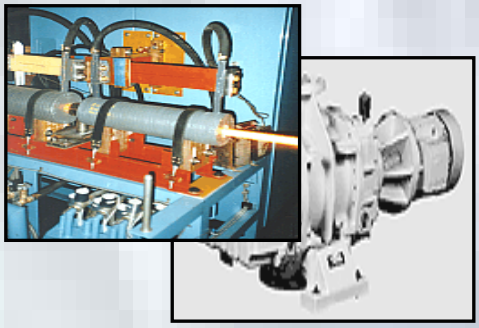


1 – no field
2 – field is present

μ_0 – magnetic constant, m – magnetic moment of particle, ∇H – field intensity gradient

MNF Applications

Space



Vacuum

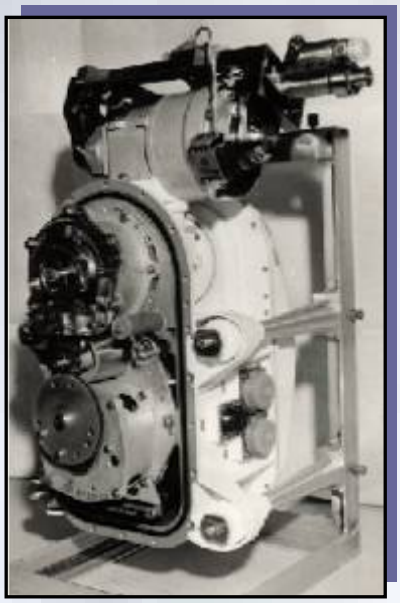
Power engineering

Biotechnology

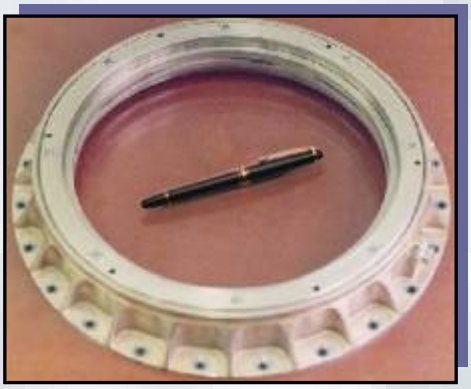
Information technologies

Chemistry

Space technologies

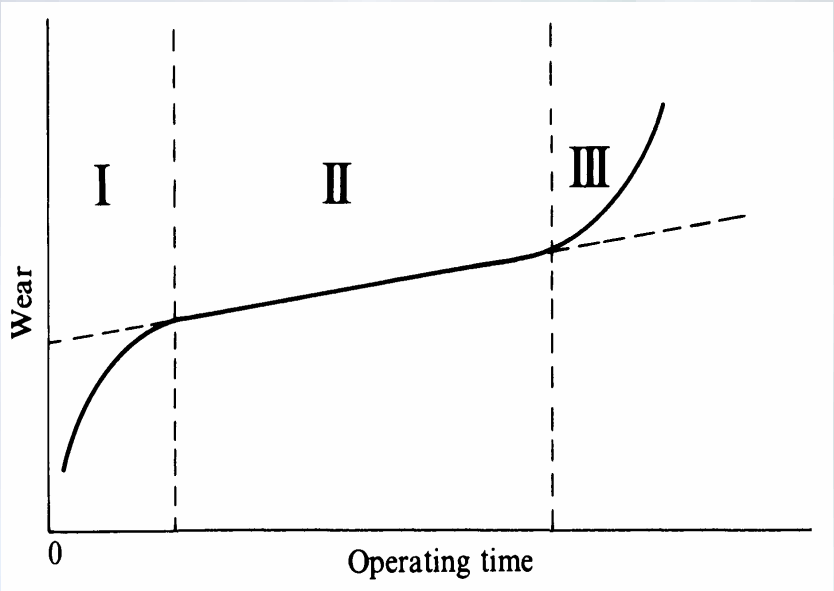


- ✦Sealing of shafts up to 250mm.
- ✦Pheriferal veloity up to 10 m/s.
- ✦Temperature -50 до +50^{0}C.
- ✦ Pressure drop to 0,2 MPa.
- ✦Leakage lower than $5 \cdot 10^{-11}$ м^{3}Па/с.
- ✦ Service life 15 years.



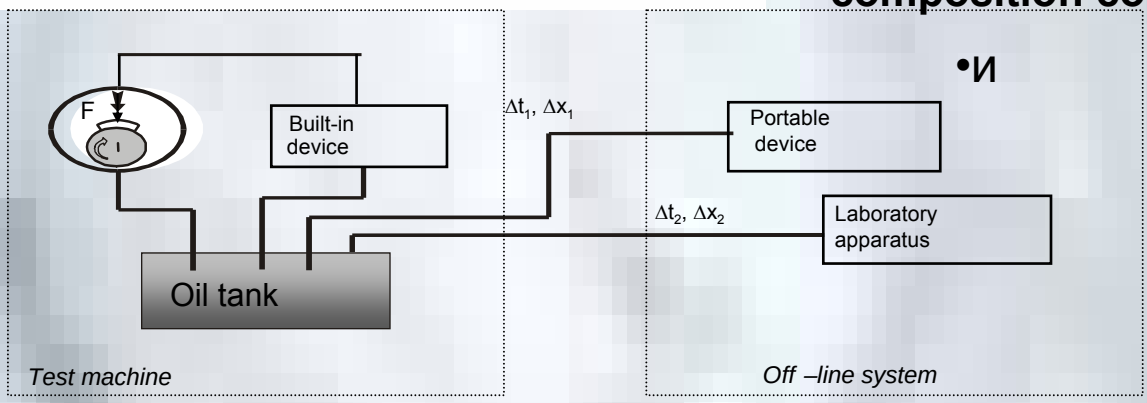
MF seals and sensors were used in spacecrafts “Buran”, Phobos”, “Mars”, “Mir” (11 years) and now at ISL.

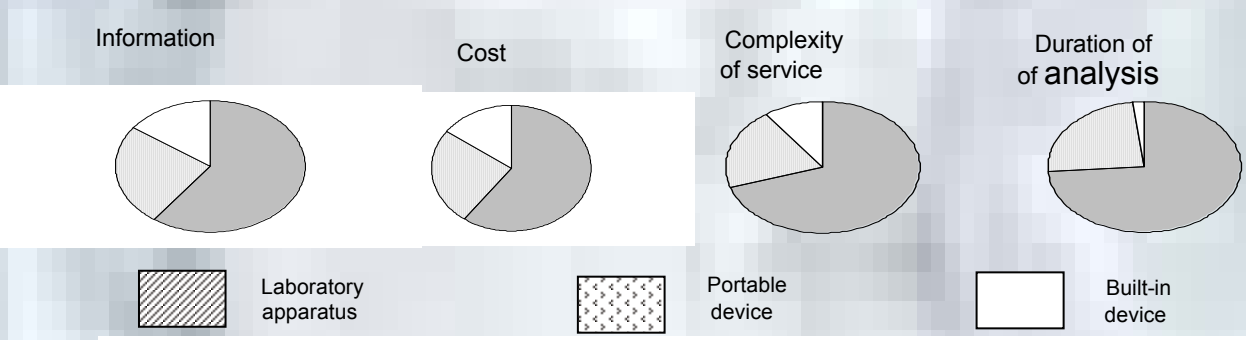
Monitoring – control and predictive maintenance in tribosystems



Typical wear curve: I - run-in, II–normal operation, III-damage

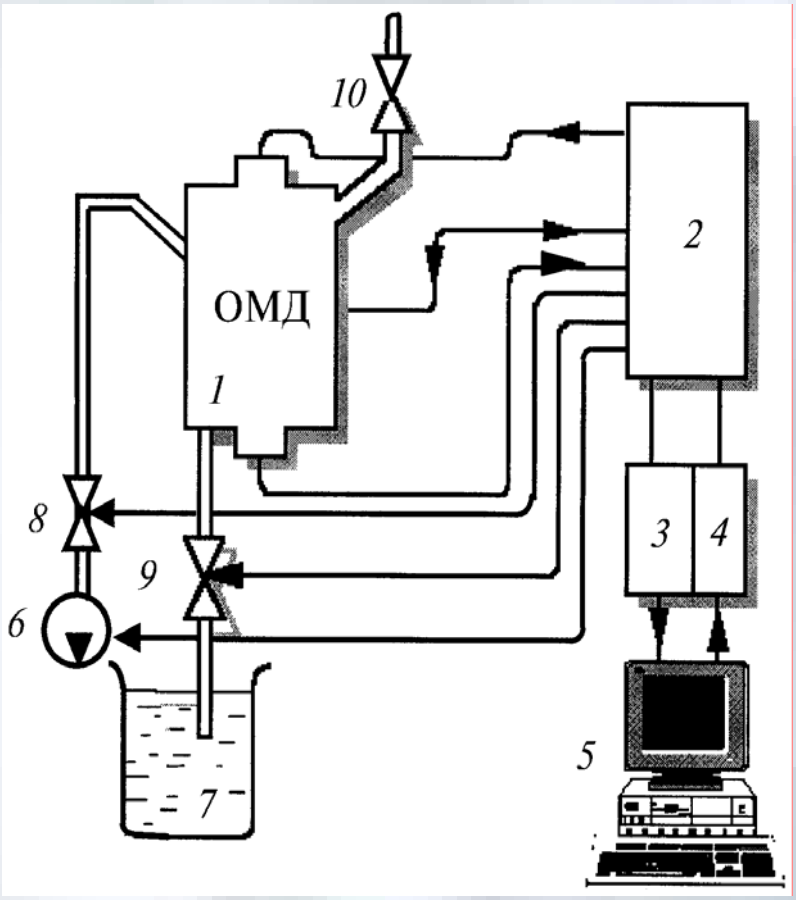
New trend in monitoring – replace of simple diagnosis by predictive maintenance, e.g. not only oil filtering but composition control.





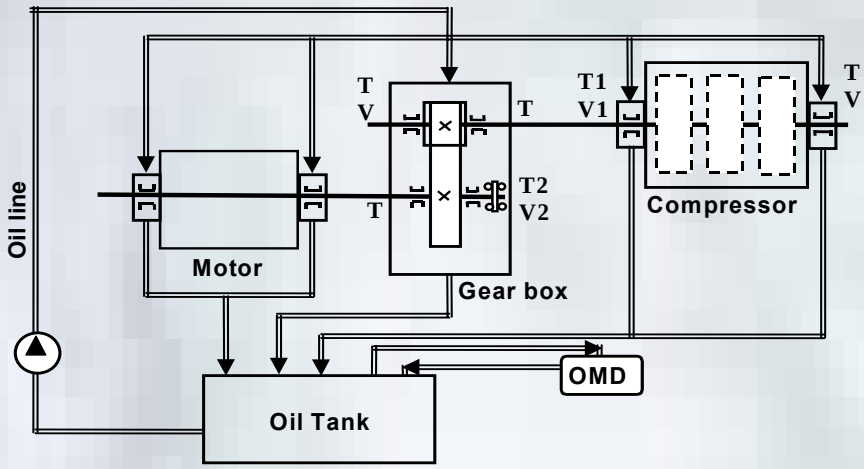
Variety of monitoring systems are available, their applications depend on task and complexity of tribosystem

Optical magnetic detector

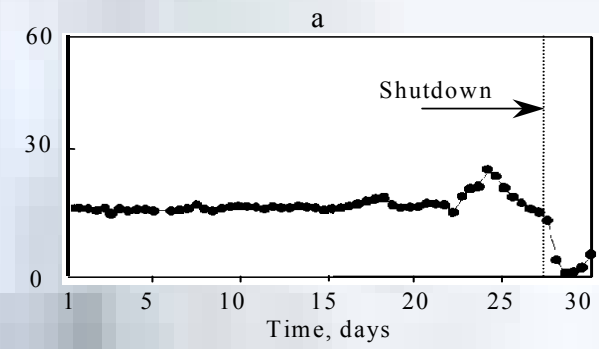


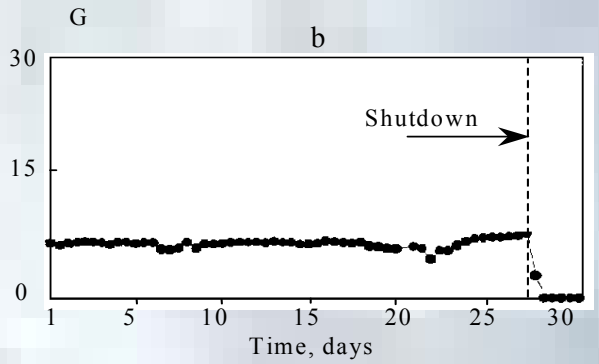
1 – detector, 2– electronic unit, 3— analog-to-digital converter, 4 – input-output unit, 5 – PC, 6 – vacuum pump, 7 – test oil

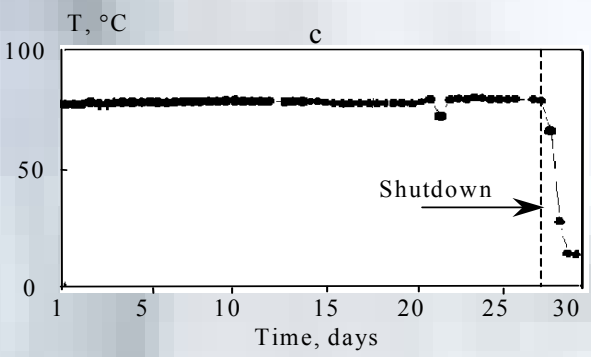
Applications of Condition Monitoring

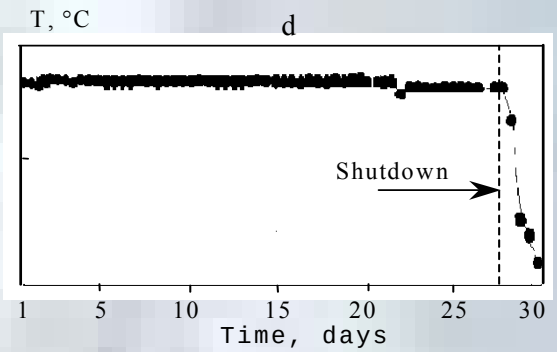


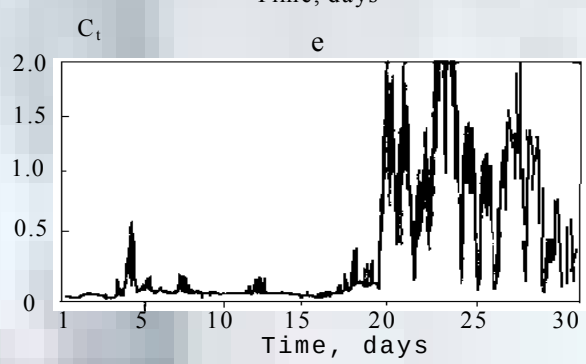
(POSCO Iron&Steel Co). OMD monitoring of gear box and bearings of large air compressor (7 tons of oil). Data for 30 days of control before failure of gear box.

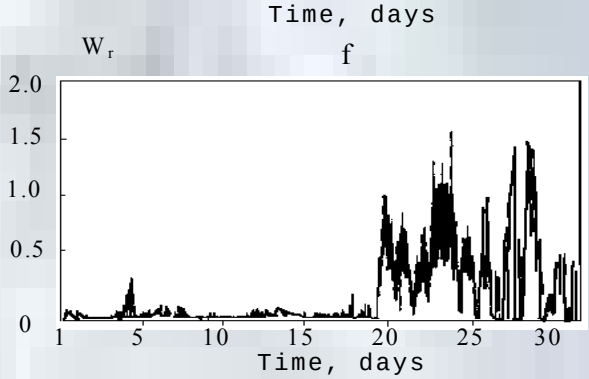




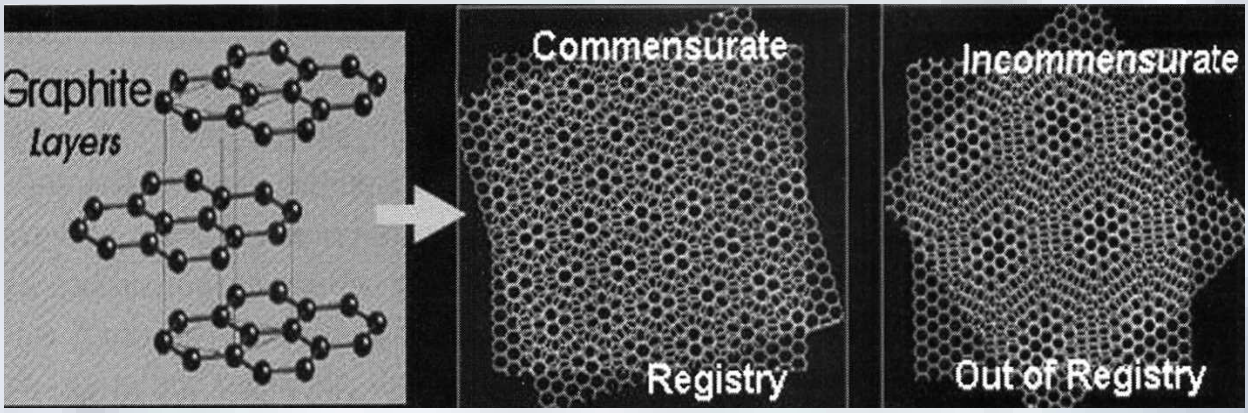




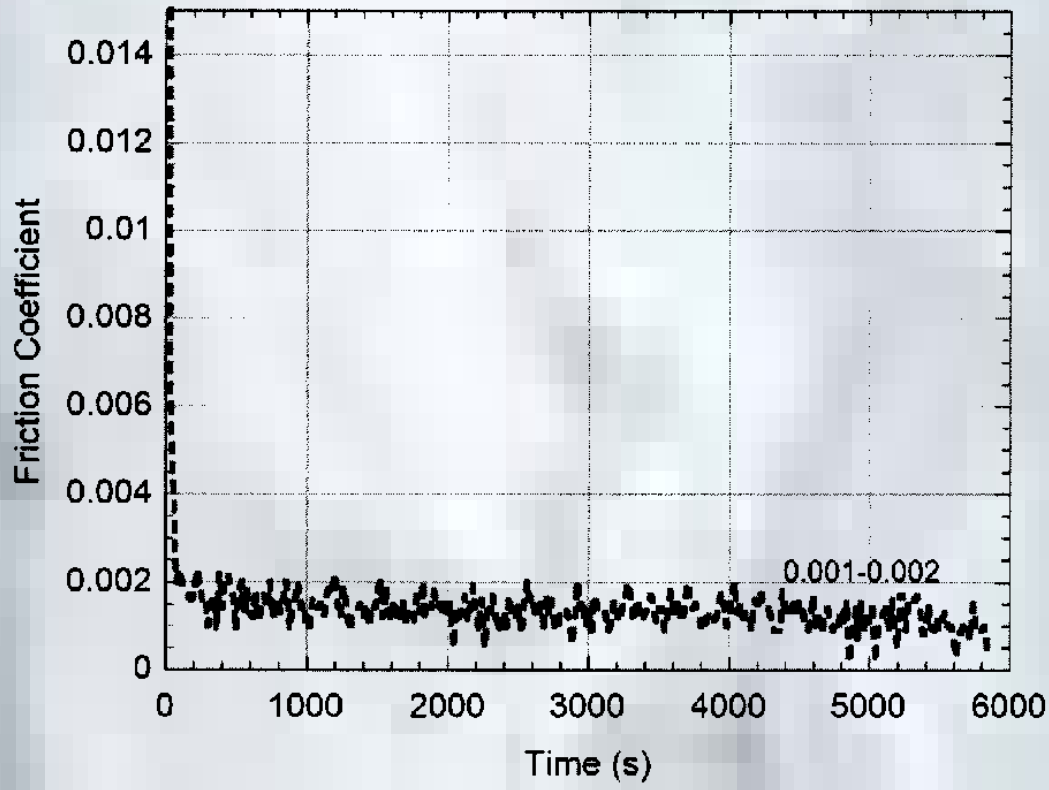




Superlubricity

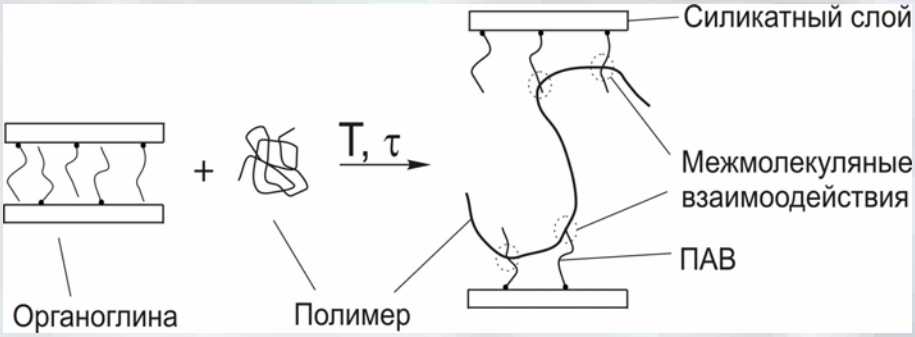


Illusteration of graphite superlubricity at dry friction

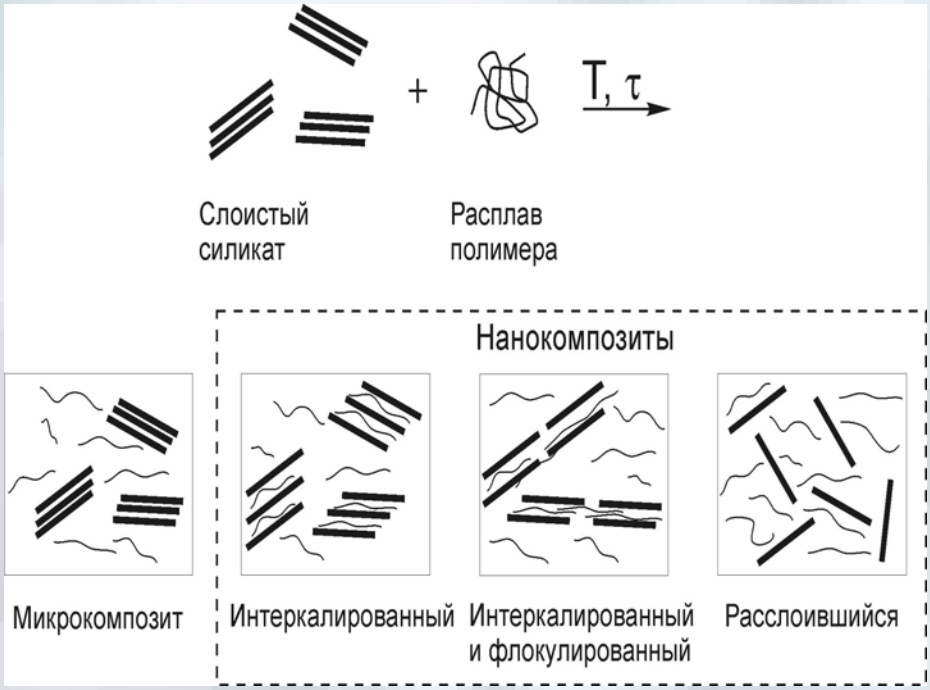


Superlubricity of DLC at 40 at.% of hydrogen iwhen rubbing in nitrogen at room tmperature

Polymer nanocomposites

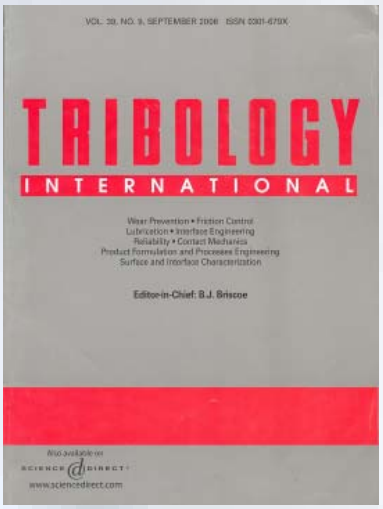


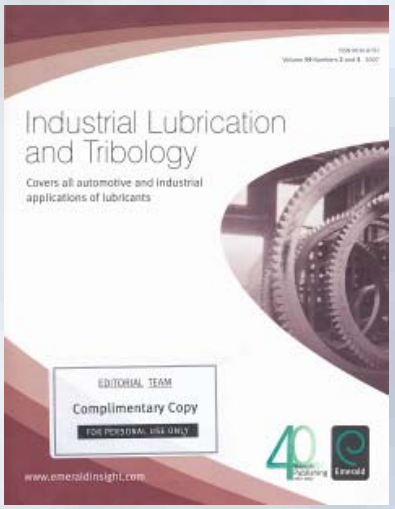
Polymer melt modified by organic clays and surface active agent

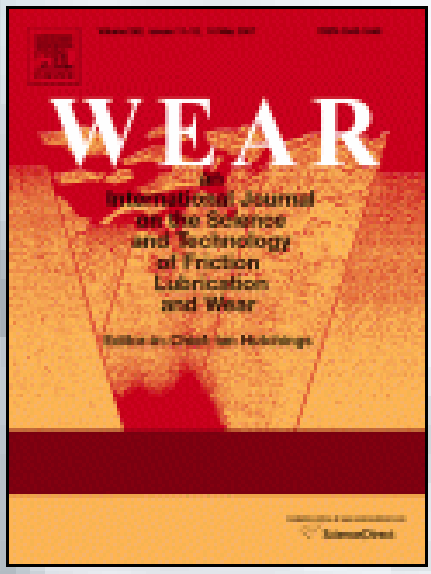


Tracktor (1–3) and automotve (4, 5) components made of nanocomposites with polyamide matrix

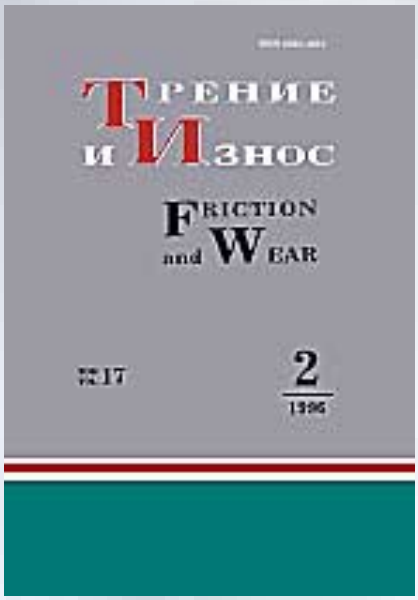
Information in tribology

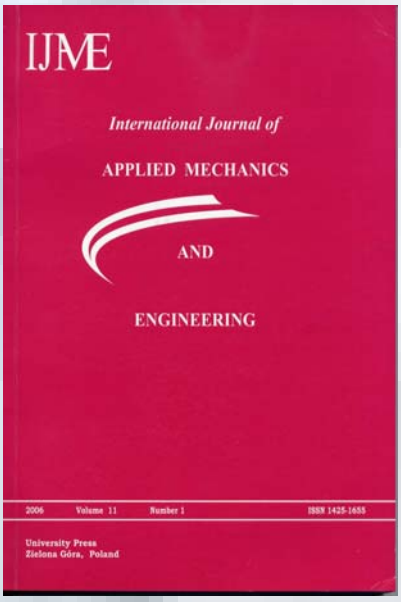






Information in tribology





Modern trends in tribology

- Contact problems solved at micro/nanolevel
- Evelopment of new tribotesting equipment
- Tribosystems for extreme conditions
- New coatings and lbricants
- Nanocomposites
- Condition monitoring and predictive maintetnance
- Global information exchange

THANKS