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RESEARCH

Nanotribometer Area of Application

Significantly important field of R&D activities during last years have been recognized as nanotechnology area, due to a fact that its impact on the future trends of the science development, in general, is taken as predominant nowadays by many scientific and research groups all over the world. Published results justify investments in this area due to generating of new knowledge that can be implemented at industrial practice.
European Commission have planned € 3,5 billion for research activities in nanosciences in scope of the 7th Framework Programme which represents the propellant key factor for European scientific community, all in order to strengthen the competitiveness of European industry.
Nanotribometer, as a device that enables researches to quantify tribological properties of observed material at nano level, represents specialized laboratory equipment for investigations in this area. There are many areas of application for such a device, some of which are very shortly presented in this paper.

Keywords: Nanotribometer, Nanotribometry

1. INTRODUCTION

Significantly important field of R&D activities during last years have been recognized as nanotechnology area, due to a fact that its impact on the future trends of the science development, in general, is taken as predominant nowadays by many scientific and research groups all over the world. According to many realized surveys, a number of research institutions aimed their programs to comprise different activities in area of nanosciences. Number of these organizations has even been established only in the last few years, thus showing the impact of nanosciences.

Published results completely justify investments in this area due to generating of new knowledge that can be implemented at industrial practice. European Commission have planned € 3,5 billion for research activities in nanosciences [1], in scope of the Seventh Framework Programme for Research and Technological Development (FP7) which represents the propellant key factor for European scientific community, all in order to more strengthen the competitiveness of European industry. A significant share of funding is assigned to development of nanosciences (Figure 1).

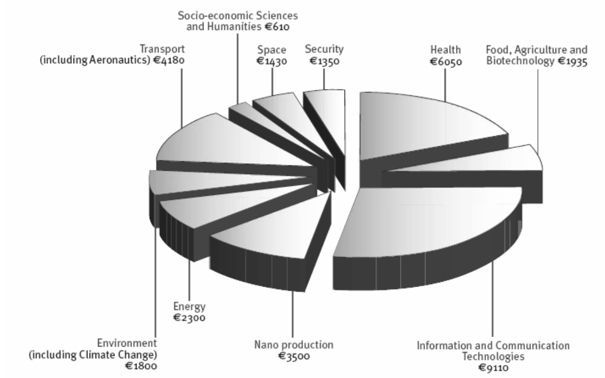

Figure 1. Thematic areas in scope of FP7 programme "Cooperation" [1]

This will benefit new industry areas, as well as existing traditional ones, because results are essentially possible to implement throughout wide range of applications, from fundamental ones to real industrial cases.

Considering the fact that nanotechnology deals with material at nano level, devices that can assist at monitoring and measuring appropriate features

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of such a system are of great importance. It is stated that era of nanotechnology started with the discovery of scanning tunneling microscope (STM) device, in 1981., for which, the Nobel Prize in Physics has been awarded to Heinrich Rohrer and Gerd K. Binning, who invented it, in 1986 [2]. Discovery of STM lead to development of different types of scanning devices, including atomic force microscope (AFM).

Nanotribometer, as a device that enables researches to quantify tribological properties of observed material at the nano level, also represents valuable specialized laboratory equipment for investigations in this area. There are many areas of possible application for such a device, some of which are very shortly presented in this paper.

2. NANOTRIBOMETRY

Tribometry, in general, represents an area of tribology that comprises means and methods of measuring: friction forces in contact zones; wear of tribosystem elements; temperature; surface roughness; contact surfaces sizes; contact strain etc. [3]. The measurement of friction force and the calculation of the coefficient of friction are of great importance for many tribosystems and for some it is even especially critical, like for brakes, clutches or similar control system, where the friction force determines the system behavior. Another major challenge is to anticipate the type of wear to which a components will be subjected and accordingly applying a specific model of testing. Surface modeling, from various aspects like contact type, temperature, lubricating modes and other case based important features, are also crucial for other types of testing.

Each tribosystem has its own set of dominant characteristics and way of working. It is impossible to select one method test that suits the needs of every possible case where tribological testing is needed. The selection of appropriate test methods to meet engineering requirements is rather complicated. Depending on the observed case, functional requirements are analyzed and after them a suitable testing procedure is adopted.

Tribological behavior of a material at nanoscale has to be studied with rather different set of observed characteristics compared to the previous traditional approach. As such, it is of a great importance to investigate phenomena and manipulation of matter at the nanoscale. Application of such a knowledge can and will lead to introduction of new forms of manufacturing, new products and services. Also, there are number of possible environment related issues that nanosciences promise to resolve in close future.

Universal friction laws can be studied at different scales (nm, μm, cm), therefore explaining various issues between macro- and nano- tribology. Friction issues at tribosystems, from aspect of energy dissipation at contact interface have been investigated by means of nanotribometry. Conducted experiments that have been realized throughout the tribological laboratories showed that tribological performance is determined by material properties of the first one hundred nanometers [2]. Nano-instruments can provide good tool to study atomic mechanisms of various lubricating characteristics, like lubricant spreading, lubricant behavior during contact etc.

Theoretical studies on atomic scale friction still need to be acknowledged from practical aspects. Nanostructures created between the surfaces in relative motion are crucial for energy dissipation mechanisms. The future trends of research in this area anticipate possibilities of engineering frictional surfaces in such a manner that they would satisfy predefined conditions regarding friction coefficients. Molecular dynamics and statistical simulations offer powerful tool for such investigations together with development of modern laboratory tribometry devices, such as nanotribometer.

There are many areas of interest to study from aspect of nanotribometry and many broadly different ranges of applications where researchers have been doing investigations through various means of testing at nanoscale. Very important part of nanosciences, in general, is research work in area of new materials and new production technologies development. There are number of already implemented new materials which greatly improve specific systems under study. Development of medicine related materials is of special importance. Soft matter, like polymers and biomaterials are studied by nanotribometry instruments and testing procedures, in order to validate theoretical findings or to study newly found effects.

It is, however, very important to connect, in more extent, existing theoretical findings with practical data obtained from some tribometry device. Information on, for instance, modeling the probing tip for realized frictional experiments is of significant importance for further advancements in understanding mechanisms of nanoscale friction.

3. NANOTRIBOMETER INSTRUMENT

There are many well established techniques for the measurement and characterization of bulk materials and their surfaces that are successfully applied in tribological investigations. A number of specialized techniques according to specific problems have also been established and applied across tribo-laboratories.

Widely applied device for performing measurements in tribology is tribometer device. Tribometer is defined as following: 1) An instrument or testing rig to measure normal and frictional forces of relatively moving surfaces; 2) Any device constructed for or capable of measuring the friction, lubrication, and wear behavior of materials or components [2].

For nano-scale testing of friction and wear, nanotribometer is applied. The nanotribometer is based on a scanning force microscope design. The cantilever is associated with two optical sensors for measurements of its normal and lateral deflection during sliding against selected specimen, according to which the friction coefficient is determined.

It is an instrument that enables low load range down to 50 μN [4]. It is equipped with a depth measuring sensor which is important in studying the time dependent wear properties (depth range 20nm-100μm; depth resolution 20nm). Furthermore, it can have various options regarding the control of environmental characteristics (high/low temperature, humidity or lubricating mode), contact pressure, speed, frequency or time. This way, real life conditions can be reproduced through laboratory simulation by this instrument.

Linear reciprocating nanotribometer is used for simulation of many real life cases, where typical reciprocating motion is present. Most contact geometries can be reproduced including Pin-on-Plate, Ball-on-Plate and Flat-on-Plate. It is equipped with appropriate software that can generate wear rates or do calculation of the Hertzian stress.

Nanotribometer device offers simple and efficient way of measurements of friction or adhesion at nano-scale. It belongs to a group of instruments for nano-scale investigations that require contact with a sample, so contact mode operation is used [5]. Figure 2. shows principle of working for CSM nanotribometer.

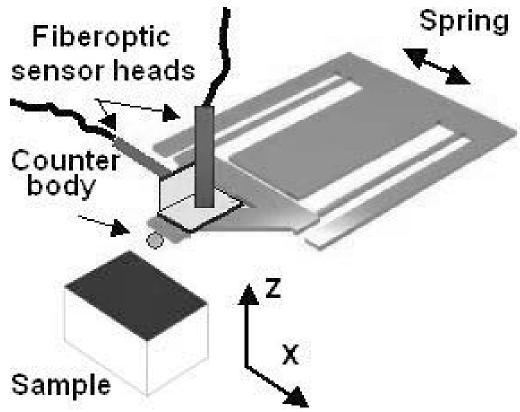

Figure 2. Schematic representation of nanotribometer contact geometry [4]

Application areas for which nanotribometer investigations can be applied varies broadly, such as: lubricants, oil additives, self-lubricating systems, semiconductor technology, protective coatings, optical scratch-resistant coatings, wear resistant coatings (TiN, TiC, DLC), paints and polymers or pharmacological (tablets, implants, biological tissue). Important information can be obtained by experiments at nano-scale in every of these areas and results that are published constantly confirm it, thus initiating series of further research projects aimed at dissemination of laboratory findings into a real world practice.

3.1. Tribological investigations of polymers

The necessity for fundamental design considerations of the macromolecular structure of polymers is becoming more prominent in view of the inability of existing polymers to fulfill all the requirements of specific purpose materials. An excellent range of polymer materials are now available with widely different properties. However, there still exists a need to measure and compare certain characteristics like, for instance, adhesion or friction properties in blended or composite polymers. Even for those polymers that are routinely fitted for use in production, there are a number of features that need to be improved or just better understood from theoretical aspects.

An important area of research is that of polymers used for manufacturing of various types of contact lenses. These newly developed materials offer series of advantages for contact lenses users, where significantly improved vision, rather good oxygen permeability and good dimensional stability are among the most important characteristics. There already exists wide range of these polymer materials for manufacturing of contact lenses, commercially available.

However, there also exists a need to further improve certain characteristics of these materials, like brittleness with breakage problem or material wear that should be minimized because it is highly undesirable from aspect of possible eye cornea injuries. New materials are still tested in order to less attract and bind other organic materials from eye environment, thus causing less staining and further damage of the lenses during their wearing. Some of these problems obviously fall into tribology area of research.

Hydrogels are synthetic or natural polymer matrices with high weight percent water, which may or may not be crosslinked [6]. They can be charged, layered or mixed together. Hydrogels are used to manufacture soft contact lenses. Mechanical properties of hydrogels are extremely sensitive to environmental conditions. Friction coefficients, for a contact between a soft contact lens and a human eye, are reported to be between μ=0.02-1.7 [7]. Tribological properties and behavior of lenses are of great importance because it determines some of their vital characteristics from aspect of the life time.

Nano-indentation can be applied to find material properties and further mathematical methods used to predict force-displacements trends. Nanotribometer can be used for investigating lens frictional characteristics through simulating contact of an eye and a lens in an environment with predefined conditions. Throughout conducted measurements and modeling a better characteristics of lenses thus can be obtained.

Tribological investigations realized in this area belong to a group of micro- and nano-scale investigations and are extremely significant because it can improve lives of millions of people who use contact lenses. They are done in close cooperation with manufacturers, that way applying knowledge and laboratory findings in industrial practice.

3.2. Tribological investigations of coatings

The mechanical properties of thin films and coatings cannot be measured accurately using techniques such as microhardness and tensile testing which were designed for bulk samples, so nanoindentation is starting to be applied more readily. Data obtained by these procedures using nanotribometer can be further applied for optimization of these properties. Investigation of coatings, in general, is area of great interest for broad range of industries. Various models for wear under nanoindenting predefined mode determine tribological characteristics useful for further application.

Very useful indicator of surface uniformity on samples is mapping of material surface characteristics, what makes it possible to reveal non-uniform areas. It can further optimize deposition conditions to produce high quality uniform thin films or can initiate further structural investigations of materials. Information regarding asperity interlocking, particle adhesion or stick-slip phenomena, can be obtained, in order to study in more details existent mechanisms of friction.

Through an enhancement of performance at the nanoscale and by seeking to extend product lifetimes and reduce energy consumption, a contribution to sustainability is achieved. Through nano-scale tribological investigation of coatings characteristics at nanotribometer instrument, friction coefficient and wear rate can be measured, therefore enabling the establishment of relations between characteristics of wear and the structures of the surface. It also makes possible to model and predict wear and accordingly to improve it to wear resistant materials.

Investigations in this area are multidisciplinary and address multisectoral applications, from metal forming and machine tools to automotive engines, wind turbines and satellite mechanics. For instance, in scope of the 5th Framework Programme (FP5) more than 40 nanotechnology-based projects were funded. One such project cluster, comprised of six separate projects, was NANOTRIB project that represented joint work of 60 partners from 16 countries, in the field of nanoscale lubrication films and low-friction surfaces [8]. Parts of this large project were devoted to the following areas: low-friction coatings; processing of structured hard coatings for microlubrication; development of nanocomposite coatings to improve competitiveness and conserve the environment; nanostructured coatings for engineering tribological applications; nanocomposite wear-resistant and self-lubricating PVD coatings for tools and components; surface layers for reduced friction and wear [1].

3.3. Biomaterials

The first funded nanotechnology programme in Europe comprised areas of biomaterials for information technology and nanobiology (Finland, 1997–1999) [9]. From those first programmes, a broad variety of investigations in area of biomaterials have been conducted. Application areas for tribological investigations such as coatings for contact lenses, mechanical properties of teeth materials, biocompatible valves, medical materials for spinal repair, or TiN coating for hip prostheses are only a few of a large spectra of possible ones [10].

Mechanical integrity and wear resistance of a biomaterial is vital for long term implantable devices, such as total joint replacements, which need to function effectively over periods of 20 years or more. Laboratory tests are necessary to help optimize the biomaterial performance, among which nanotribometer testing can be very significant for extended wear testing. Allowed wear rates for such a system are very strictly defined and are significantly more sensitive to a whole range of influences. Coating biomaterials with hard, inert coatings of diamond-like-carbon has been suggested as a mean to improve the lifetime of the femoral head in total hip replacement prostheses [11]. It is important however, to evaluate their durability, what is done through tribological testing.

Tribo testing of biomaterials are somehow different than those conducted within metal working industries, due to a fact that it is mostly done with soft materials compared to metals. Area of biomaterials investigations is yet different because research here must be done with multidisciplinary approach taking into account series of diverse data. Investigations are currently done to establish more accurate methodologies for predicting wear in complex environments of existing tribo-systems, what would greatly enhance development of more durable biomaterials for application in human related issues. Friction estimation in oscillation nano- and micro-tribometry, experimental results for controlled load, wear tests of polymer film, all can be realized at nanotribometer instrument, thus helping resolving previously mentioned questions.

Extremely complex issues of biomaterials and their application at medicine in order to improve lives of millions of people are subject to investigations at several R&D areas and can be successfully addressed only through joint acting of experts from different areas of research, where tribology is one necessary part of it. Nanotribometry is powerful tool that can offer answers to existing questions.

4. CONCLUSIONS

Under the fourth Framework Programme - FP4 (1994–1998), the EU spent approximately € 30 million per annum on nanotechnology projects [1]. Under the fifth Framework Programme – FP5 (1998–2002), the EU spent € 45 million per annum on nanotechnology projects [1]. In FP6 nanotechnology has been highlighted as a key area for European development and funding was around € 1.3 billion [1]. A further aim of FP6 funding was to promote the uptake of nanotechnology into existing industries such as health and medical systems, chemistry, energy, optics, food and the environment. This trend continues with FP7 and € 3.5 billion for research activities in nanosciences.

New, high tech industries and knowledge-based traditional industries, with application of research results from laboratory investigations at nano- and micro-scale shape the future development trends of industry in general. Integration of technologies for industrial applications with focusing on new technologies, materials and applications to address the identified needs by the different areas of human life has become a priority for researchers, among which, nanosciences have a distinguished role. Nanotribometry has become a powerful tool for helping resolving diverse issues in multidisciplinary approach.

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