NEW IDEAS OF MICRO-BEARINGS LUBRICATION

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Abstract

In this paper are presented the possibilities to attain the artificial intelligence features of slide micro-bearings taking into account:

1. *Cooperation between super thin boundary lubricant layer and thin superficial layer lying on the micro-bearing shaft and sleeve with various shapes.*
2. *Application of a novel method of depositing thin organic and inorganic layer (superficial layer) onto a metal substrate utilizing electro-spraying (electrostatic atomization) method.*

The new achievements presented in this paper are aimed at application of this technology to functional layer deposition in micro-bearings.

Electro-spraying is a low-energy process of liquid atomisation by means of electrical forces. Electro-spraying device consists of a capillary nozzle connected to a high electric potential whereas the substrate is grounded. The liquid flowing out the nozzle is subjected to an electrical stress, and fine droplets are generated from the meniscus or the jet formed at the nozzle outlet. Depending on physical properties of the liquid to be sprayed and spraying conditions, the size of the droplets can be in the submicron size range. In the electro-spraying process, a solution or a suspension of a material to be deposited is atomised into droplets, which can be targeted onto a substrate to form a condensed product, for example a thin layer after solvent evaporation. The deposition efficiency of charged droplets on a target is much higher than for uncharged ones due to electric forces, which drive the droplets along the electric filed lines towards the substrate.

Keywords: *new ideas slide micro-bearings, micro-bearings, micro-robots, memory of carrying capacity, artificial intelligence*

1. World wide research analysis

An intensive development of scientific research in the field of friction phenomena for micro pair, micro joints and especially the hydrodynamic theory of lubrication of slide or rolling micro-bearing systems, and even nano-bearings, has recently been observed outside the EU in the past seven years. Namely, it is represented by the research teams in China, Japan, South Korea, and South Vietnam [1-4, 10-13, 19-28]. The author confirms this statement by the newest scientific literature from the last seven years.

The author's knowledge development mentioned above is caused by the new constructions of friction pairs occurring in micro-and nano-motors, micro-robots, micro surgery devices, computer hard disc drivers, where the control possibility of friction and wear during the exploitation is very necessary. Most of the impairments of micro-mechanisms, micro-motors, and computer hard discs-drivers are caused by the slide micro-bearing damages regarding the disturbances of the hydrodynamic process which appear frequently in the above mentioned slide micro-bearing rather than in other roller micro-bearings [5-9].

An efficient exploitation of sidle micro-bearings require intelligent features, which include memory with a simultaneous capability to the carrying capacity, friction forces and wear control using fuzzy logic methods. The memory of micro-bearings is based on new structures and CDF programs, which are able to response to unforeseen damages during the exploitation. The actual stresses in an intelligent material can be defined by the history of their deformations and damages. The latest research in seven past years conducted in China, Japan, South Korea and the USA, and confirmed by the actual references, tends to create a new slide micro-bearing with memory through the building of the structure of various micro grooves with ca. 55 nm height on the cooperating shaft and sleeve surfaces [10-13]. To the best of the author's knowledge, it is not the only method to obtain the desired goal. After the author's initial investigations and considerations, we can obtain micro-bearing carrying capacity increases and memory capability increases simultaneously by generating the various geometries and various shapes of micro-bearing shaft and sleeve surfaces.

Many authors do not describe the above presented research problem, and are not going to obtain very important intelligent features of various friction micro-pairs, friction micro-joints, especially micro-bearing materials for example the possibilities to adaptation for environmental conditions. Such a feature of the material is very important for micro-bearings and in particular for computer hard discs drivers HDD micro-bearings. Artificial intelligence of micro-bearing denotes the creation of the mathematical and fuzzy logical models, which are not submitted to a simple algorithm to describe lubrication, friction, wear phenomena and an implementation of these models in the form of a computer program.

The artificial intelligence (AI) component of the micro-bearing is for example its adaptation capability to the environmental conditions and possibility to control the tribological parameter in micro-bearings. The AI strongly depends on the properties of bearing materials, i.e. oil properties and oil dynamic viscosity, which for a super thin layer depend on the elasticity modulus of solid micro-bearing material laying on the cooperating surfaces of the micro-bearing journal and sleeve. Classical principles of hydrodynamic theory of lubrication are not valid for hydrodynamic problems connected with slide micro-bearing lubrication and exploitation. Considerations presented in these investigations present a new non-conventional research method in the field of the hydrodynamic theory of lubrication. However, such investigations can be realized after recognizing of the main features of the superficial layer material in a nano-scale on the cooperating surfaces. At this point, investigations are necessary in the field of multifunctional organic and inorganic material production for a superficial layer lying on the micro-bearing surfaces, taking simultaneously into account intelligent properties, for example an artificial memory. The author indicates the likeness between the intelligent micro-bearing properties and the intelligent behaviour of human bio-bearings and other living joints [18].

Let us note that the real molecular nanotechnology which is observed in the biological cell is associated with considerable changes of the conformation of molecules almost in all processes. This phenomenon is so wide that cell processes can be considered rather as mechanical ones than chemical ones. For example, bacterial flagella motors are a manifestation of molecular nanotechnology in the domain of nano-bearings. Thus, we expect that investigations related to the role of the electronic structure on the resistance decrease of the motion can have an important impact on tribology for small devices. We also expect that during the realization of the project proposed we could also obtain more universal results leading to an improvement of the molecular nanotechnology.

2. New technologies, analytical or numerical description and its results regarding the thin lubricant layer

2.1. The author investigates new requirements for lubricant production with proper nano-particle saturation to be able to have artificial intelligent properties and particularly the memory features.

2.1.1. Experimental measurements of the material parameters of the non-Newtonian lubricant.

2.2. An analytical and numerical description of the non-conventional hydrodynamic lubricant flow in a super thin micro-bearing gap:

2.2.1. An estimation of the conservation of the momentum, continuity and energy equation taking into account the super thin boundary layer simplifications for the lubricant and its random properties.

2.2.2. Artificial intelligence properties, in particular case the memory features are considered at the formulation of the lubricant constitutive equation.

2.2.3. A specific feature of the super thin boundary layer lubrication demonstrated by the changes of the hydrodynamic pressure in the gap height direction.

2.3. An influence of the thin superficial layer elasticity modulus on the apparent viscosity of the lubricant.

2.4. A formulation of boundary conditions between the lubricant and the superficial layer by virtue of the measurements performed.

2.5. A numerical determination of the lubricant velocity distribution, the hydrodynamic pressure and carrying capacity, friction forces and the friction coefficient using the Matlab Program.

2.6. An experimental validation of the analytical and numerical friction force values obtained for various micro-bearing loads, various rotational speeds, and for cylindrical, conical, spherical parabolic, hyperbolical micro-bearing gap shapes.

2.7. The measurements of lubricant rheology properties, in a particular case the apparent dynamic viscosity as a function of the temperature, shear rate, normal and tangential stresses, lubricity, chemical and nano-additions, genetic code, nano-additions caused by artificial intelligence features.

Authors have gained experiences in above research during the following realization:

- Wierzcholski Krzysztof, 2001-2004 GRANT KBN–8-T10B-061-21, "Theoretical and experimental investigations of thermodynamical and magnetical bearing materials properties in the field of exploitation problems in slide journal bearings";
- Wierzcholski Krzysztof, (project coordinator), GRANT (Deutsche Luft und Raumfahrt) Bonn DLR-198-96, "Computer optimization of slide bearing parameter";
- Wierzcholski Krzysztof, (project coordinator), GRANT UNII EU. GROWTH 2001-2003 NAS., "Computer aided optimization of newly developed bioreactor for tissue engineering"; G5RD-CT-2000-00282;
- Wierzcholski Krzysztof, (project coordinator), GRANT DLR-2002-00011 (Deutsche Luft und Raumfahrt) Bonn–Berlin, "Optimierung nicht Newtonscher Flüssigkeiten mit biologischen Eigenschaften aufgrund der Analogien zwischen den Strömungen des Schmiermittels im Reibkontakt in Lagern und in der Umgebung menschlicher Gelenke";
- Wierzcholski Krzysztof, (main investigator), 2003-20062 Grant KBN 4 T-11E030-25, "Non stationary models of human joints lubrication for deformed cartilage in magnetic field and computer aided optimization during tissue cultivation in bioreactor";
- Wierzcholski Krzysztof, (coordinator Transfer of Knowledge 2005-2008), GRANT UNI EU MTKD-CT-2004-517226, "Bio and Slide Bearings, their Lubrication by Non-Newtonian Oils and Applications in Non-Conventional Systems".

3. New technologies, analytical or numerical descriptions and their results connected with the thin superficial layer

The proposal is directed towards the development of a novel technology of the production of thin organic and inorganic super thin superficial layer created by electro-spraying of droplets of controlled size from a solution of a material to be deposited of controlled concentration, with the goal for intelligent micro-bearing applications [14]. The flow rate of the electro-sprayed liquid from a single nozzle practically ranges from 0.1 to 100 mL/h that is practically sufficient for micro-deposition purposes. Higher flow rates for mass production can be accomplished by multiplying the nozzles (a multi-nozzle system).

It was determined experimentally that the deposition rate of 1 micrometer layer using electro-spray method is of the order of 1 μm/h, and it increases to about 10 μm/h for final layer thickness of 10 μm [14-17].

The density of the layer depends on the spraying conditions, particle concentration in the solvent, and the size of particles used for the suspension. It was shown experimentally that the particles can be evenly distributed over the covered surface but morphology of the layer depends on the kind of deposited material. The advantage of the process is that it proceeds in normal temperature and pressure. By this method, layer thinner than 1 μm can be readily produced. Depending on the production requirements, the inorganic surface can be produced by spraying a solution or suspension of the material to be deposited, or by spraying a liquid precursor, which will be converted into the required layer after heating the substrate (decomposition of the precursor material in high temperature) or by other chemical reactions.

Plasma methods of the precursor decomposition/conversion after the spraying process are also feasible. If necessary the layer should be sintered with the substrate at elevated temperature. All the above mentioned ways of thin layer production, formulation (including binder) used for electro-spraying, and the sheath gas composition have to be laboratory tested, after proper selection of the material of the layer and for known substrate material.

The research team has an expertise in electro-spraying applications to deposition of layers on substrate, fine powders production from a liquid phase, the electro-spinning of submicron fibres, and in application the plasma technology for chemical reaction, specifically for carbon fibres production. Layers of various morphologies from nano-particle materials, mainly metal oxides, on various substrates (metals or polymers) have been produced in our laboratory.

The proposed technology will have the following advantages:

- Droplet size is smaller than that available from conventional mechanical atomisers that allows the production of a layer of required thickness [14-17],
- The size distribution of the droplets is usually narrow, with small standard deviation that allows the production of uniform layer free of voids and flaws [14-17],
- Charged droplets are self-dispersing in the space that results in uniform spray plume, and the layer is even and uniform on the entire substrate surface [14-17],
- The process can be carried out at normal temperature and pressure [14-17],
- The layer is even and free of flows and cracks [14-17].

Analytical and numerical description of phenomena appearing during the applying a novel technology of the production of thin organic and inorganic super thin superficial layer on the journal and sleeve micro-bearing surfaces are based on the knowledge of two-phase flow, thermo-elasticity, hyper-elasticity, hypo-elasticity, non-linear elasticity theory.

Analytical and numerical description contains:

3.1. Description of two-phase flow of spray in nano-scale.

3.2. Description of strain tensor and deformation vector in super thin superficial layer by virtue of thermo-elasticity, hyper-elasticity, hypo-elasticity, non-linear elasticity theory.

  3.2.1. Estimation of conservation of momentum, energy and heat transfer equation taking into account super thin boundary layer simplifications for superficial thin layer material and its random properties.

  3.2.2. Artificial intelligence properties in particular case the memory features are considered at formulation of non-linearity in geometrical and physical sense constitutive equation for superficial thin layer material.

  3.2.3. Influence of superficial layer geometry and micro-bearing shaft geometry on the intelligent properties and memory capability of micro-bearing system.

3.3. Influence of magnetic induction vector, magnetization vector on the superficial layer material behavior by virtue Maxwell equations.
3.4. Investigation of novel functional nano-materials (e.g., polymers, piezo-electrics, metal alloys, composites) produced by electro-hydrodynamic method with respect to their applications in micro-bearings. These results will be aimed at selection of proper materials for thin layer hardening or lubricant in micro-bearings, which could adopt to variations in environment conditions.
3.5. Testing of various modification of electro-hydrodynamic technology in conjunction with other technologies such as plasma treatment, electric discharge micromachining, electroplating, chemical vapour deposition, or physical vapour deposition in order to optimise the production process and surface modification with respect to required properties of micro-bearings.
3.6. Investigations of fundamental physical processes in the developed technologies based on multiple principles.

4. Effects and anticipated results

4.1. To show pre-prototype technology for the deposition of inorganic layer (metal, metal oxides, ceramics) and biological organic layer on a various substrates which can be applied for micro-bearing cooperating surfaces production.
4.2. To obtain materials with capability for modified lubrication of micro-bearings and to gain good proper tribology properties for HDD micro-bearings.

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