Why -Bio- Hydrodynamic Lubrication Has Important Meaning in Scientific Contemporary Research

Invitation letter to the potential Authors of LIDSEN special issue entitled:

Non-Conventional Hydrodynamic Lubrication for Biological and Mechanical Surfaces

Guest Editor LIDSEN special issue
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State-of-the-art

Current international level of state-of-the-art in the field of knowledge of slide bio-bearing and bio-surfaces lubrication with phospholipids (PL) bilayer, is up today high in the field of chemistry. Unfortunately it does not contains unsteady periodic and impulsive hydrodynamic analysis under random dynamic conditions for genetic or mechanical growth deformations of hyper-elastic cartilage surfaces, as well as active control in bio-tribology aspects. Moreover, experimental bio-tribology investigation in nano-medicine and nano-technology field has not been carried out, yet. In the contemporary research of hydrodynamic lubrication problems, mainly the classical constitutive relations for Newtonian synovial fluid flow with constant viscosity in height thin layer direction, without magnetic fields and without hyper-elastic properties of joint cartilage, have been confirmed till now. Therefore not existing research will be anticipated in a new considered bio-nano-tribology and nano-medicine scientific examinations.

Purpose for contemporary research

The scientific scope of expected and now performed research is concerned in the field of non-conventional lubrication systems for living, deformed, viscoelastic and hypo or hyper-elastic biological tissues and secondarily for not living mechanical bodies. Moreover can be anticipated a new mentioned scientific domains implemented by the cooperating bio-surfaces lubrication phenomena. It will be necessary to apply the pathological or improved non-Newtonian physiological fluid properties with phospholipid (PL) bilayer in variable time-dependent magnetic induction field, under random unsteady conditions.

The main topics of intentioned and consequently realized research, are as follows:

- To indicate some new methods for analytical, numerical and experimental solving the bio-surfaces contact systems working in non-conventional conditions and environments.
- To determinate in experimental and numerical ways, the random standard deviations changes with expected values of random pressure and temperature, friction forces, friction coefficients distributions as well capacity and wear in the thin bio-fluid layer between two cooperating living bio-surfaces for various viscosity in gap height.
- To develop the active control of the tribology parameters during the bio-fluid, stochastic, laminar, lamellar, two-phase flow in the very thin gap between two living, cooperating bio-surfaces of bio-tissues restricted with the phospholipid (PL) bilayer.
- To gain the knowledge, about the devices, to determine(and examine) the velocity of moving and cooperating bio-surfaces, and to estimate results of the measurements in micro or nano time level, based on image analysis of nanotechnology.

- To gain the measurements and analytical results of the deformations phenomena occurring on the living cooperating biosurfaces in micro, nano-time and volume regions.

Core of proposed research tendencies

●The probabilistic efforts during bio-tribology and nano-medicine research tendencies will be preferred as a new recent progress of the knowledge about stochastic theory of bio-tribology and hydrodynamic parameters occurring in lubricated bio-contacts between tissues and on the real human joint surfaces restricted with a phospholipids bilayer. On the basis of experimental measurements and analytical solutions, the anticipated research are concerning to the determination of the random expectancy values of load carrying capacity, friction coefficient and lubricant bio-fluid dynamic variations for of bio- bearing, bio-surface contacts lubrication occurring in presented research for nano-medicine problems. This knowledge will be recommended to indicate the localization of expectancy values of the mentioned bio-tribology parameters for places inside the variable random, stochastic standard deviation intervals of the bio-bearing gap parameters. Moreover mentioned localization places of expected tribology parameter values included in stochastic standard deviation intervals will be assigned to the concrete probability values.

● Analytical and numerical efforts to obtain characteristics- on micro- and nano- level- of pressure, liquid velocity and friction forces, are realized by searching for the following results:

- Optimum anticipated values of hydrodynamic pressure, liquid velocity and friction forces in nano scale which are admissible to avoid excessive wear values of human joint cartilage and micro-bio surfaces,
- Desirable values of pressure, liquid velocity and friction forces in nano- scale in bio- and micro-bio-bearings for optimization of cultivation process of selected cells in bioreactor and for optimization the lubrication process,
- Real values of pressure, liquid velocity and friction forces in nano- scale between given kinds of bio-cell- surfaces, and lubricant thin layer, considered in qualitative and quantitative sense, for cartilage cells or cartilage surfaces in human joints to prepare the chondrocytes for transplantation or to prepare a good lubrication process in human joint.

● Final effects of experimental efforts- in nano- level to measure surface of cells (chondrocytes), or tissue are completed by achieving the following results:

- Geometrical structure of cooperating deformable cell and cartilage surfaces, measured by means of the atomic force microscope (AFM), and its influence on further geometrical changes during unsteady cultivation, growth and reproduction cells in bioreactors or surface lubrication in human joints and micro-bearings ;
- Velocity values inside the thin biological liquid boundary layer just near and round the cartilage cells body during the bio-surface lubrication, what follows on the bio-liquid dynamic viscosity variations across the layer thickness;
- Anisotropic properties of the cell surface and cell body material and cartilages during the human joint lubrication;
- Isotropic properties of cell body on nano –level, and its influence on the isotropic properties of the same cell body but in micro- level;

- Inequalities of roughness- on macro- and micro- level- occurring on the cartilage surface during the lubrication, what follows on the bio-liquid viscosity;
- Measurement of inequalities of roughness -in macro- and micro- level- occurring on the cartilage surface, caused by random changes during the hydrodynamic lubrication process with squeezing and weeping;

Connection with multidisciplinary scientific domains

A new considered nano-medicine and bio-tribology domain in expected and now preferred investigation, will be related to hydrodynamics, theory of elasticity, biomechanics, control systems, cybernetics, theory of vibration, tribology and theory of bio-lubrication. Additionally, it is simultaneously connected with many multidisciplinary domains of knowledge, for example: thermodynamics, bio-fluid mechanics, theory of plasticity, theory of hyper-elasticity, theory of probability, electronic engineering, electrodynamics, mechanics chemistry and mechanics biology. The random theory of conjugated fields spaces can be also applied in the nano-medicine and tribology considerations.

Many scientific research investigations in the field of nano-tribology and nano-medicine for micro-nano-bio-bearing, performed in recent years, show many new kinematics and dynamic methods and kinds of lubrication as well as many new properties of lubricants and very new interesting dependencies between lubricants and material of bio-lubricated living surfaces. Such models, features, influences on the living bio-surfaces lubrication are illustrated in Fig. 1.

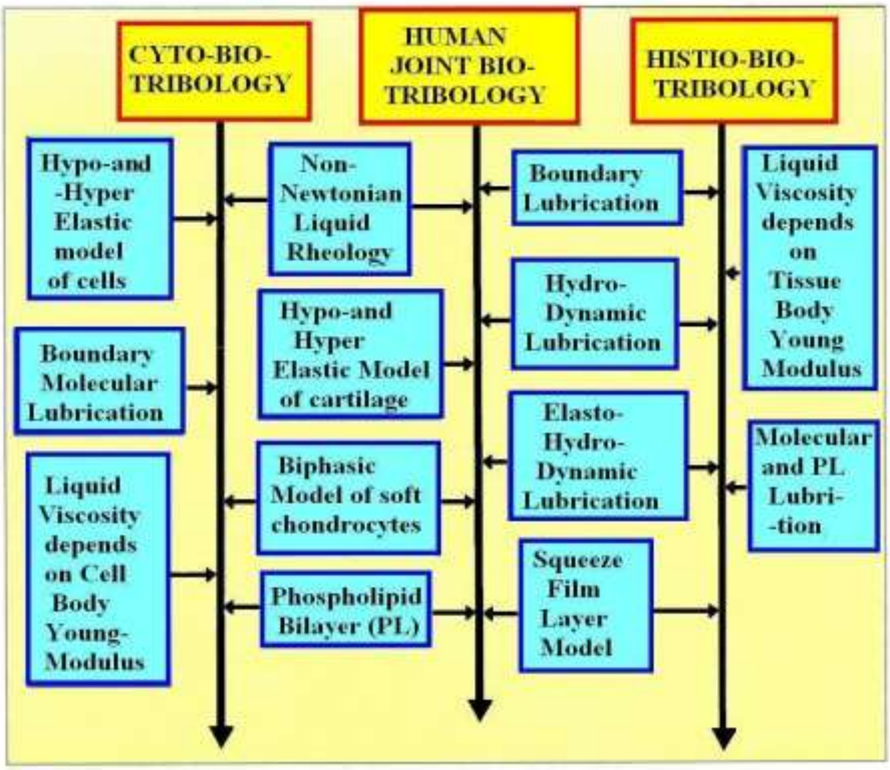


Fig.1.A new scientific research for bio-contact bio-hydrodynamic lubrication of for cooperating living biosurfaces in micro and nano level

Here are presented three research directions: cyto-bio-tribology, human joint-bio-tribology, histio-bio-tribology in nano-medicine and nano-bio-lubrication. A new research tendencies are giving an important impact to the development of the new scientific domain, which can be called for example as *cyto-tribology or cito-medicine for cells, histio-tribology or histio-*

medicine for tissue in micro-level and nano-level. According to the contemporary knowledge such scientific domains are completely new and have been not initiated so far by any scientific center and in any sphere of tribology and tissue engineering. For developing such scientific domains more knowledge is necessary not only in the field of tissue engineering but also of nano-tribology and thin layer hydrodynamics lubrication.

Preferable electronic devices

In scientific researches presented in invited papers are preferred applications of the following electronic devices:

• Pulsed Electronic Magnetic Field (PEMF)-Magcell-Arthro Device, produced in Germany, for electro-magnetic field generation,

•A new Germany Bone Dias Apparatus elaborated by the Burkhard Ziegler for acoustic waves emission with respect to the orthopedic diagnostics and ill cartilage or human skin treatments,

•Two kinds of Japan Segmental Body Compositor Analyzer (SBCA) TANITA BC-418 MA and SC 240,

•A new generated Atomic Force Microscope (AFM),

•Scanning Microscope (ACM).

Whom is addressed a new bio-tribology and nano-medicine research

This research is addressed also to such social objectives as quality of life, human health and professional safety. Intrinsic mechanism of joint cartilage or tissue usage will be also recommended here in the aspects of bio-tribology, regeneration and repair in magnetic and acoustic emission fields.

The gained experience in the field of analytical, numerical and experimental determination of either steady or unsteady distributions of bio- liquid velocity, pressure, capacities, friction forces, friction coefficients, wear of the thin boundary layer lubricating bio-surfaces, permits to apply this knowledge to determine - with the use of analogous methods - the similar parameters but occurring in mechanical devices, for example mechanical slide journal machinery bearings and micro-bearing.

The most excellent slide bearings are the biological bearings in the aspect of material and as regards their construction. Such bio-bearings are shaped by the nature over many thousand years of evolution. Lubricating liquids in bio-bearings change their viscosities under external impulses. Bio-bearings (bio-joints) can adjust themselves to the existing external conditions. These facts inspire to seek similar materials with the similar properties for the machinery bearings and to seek intelligent designs and materials for them, which could change their features during operation and adjust to external working conditions.

It very rarely happens that the experience gained during designing process of machinery bearings is transferred to the construction of bio-joints.

It can be stated that bio-joints and bio-bearings create future call for production of self-regenerating mechanisms and machinery bearings capable of adjusting themselves to the existing external and environmental working conditions.

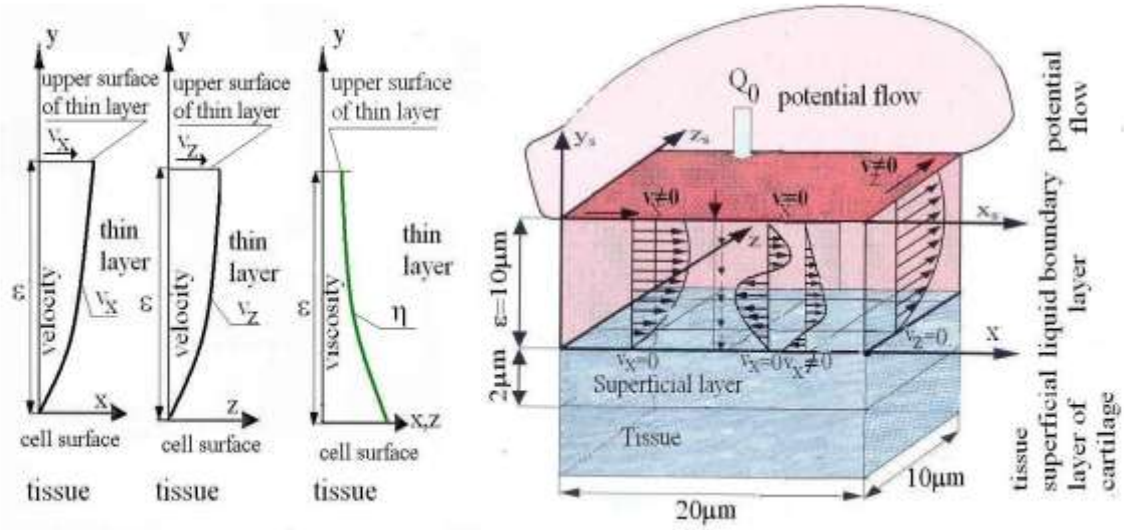
The novel scientific methods serving biotechnological applications posses characteristics to be exploited under specific circumstances as well as to enhance strength properties of endoprosthesis.

Some preliminary results

Now are presented some initial results for the further, future scientific research efforts expected in invited papers preferred in mentioned scientific domain entitled: Non-Conventional Hydrodynamic Lubrication for Biological and Mechanical Surfaces.

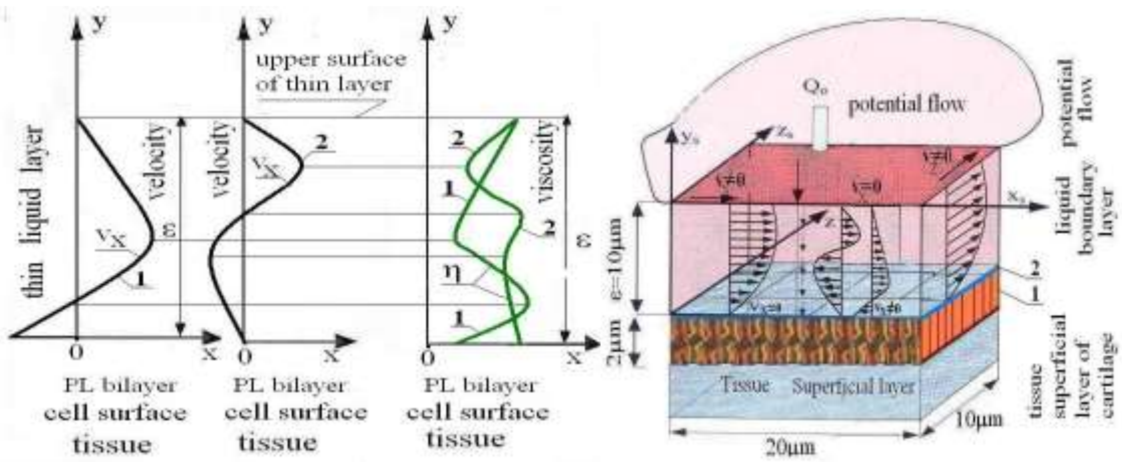
At first we show the thin gap restricted with the region of potential flow and superficial layer of cartilage tissue or cell surface in Fig.2, and with PL bilayer coated by the hydrated sodium ions in Fig.3. Mentioned gap is filled with the liquid boundary layer of non-Newtonian, synovial liquid flow. The variable velocity components v_x,v_z in two directions x and z and corresponding variable dynamic viscosity across the gap height is presented in Fig.2a.

The variable velocity components v_x, presented in two various points of gap height, and corresponding variable dynamic viscosity across the gap height are presented in Fig.3a.Results obtained in Fig.2 and Fig.3 are obtained after numerical calculations,



a) b)

Fig. 2. Bio-liquid velocity and dynamic viscosity distributions during the bio-surface pouring lubrication with flow rate Q_0: a)velocity and corresponding dynamic viscosity distributions across the thin bio-liquid boundary layer, between lower motionless cell surface and upper movable potential flow surface b) micro-level illustration of the thin liquid boundary layer between superficial cartilage layer and potential flow



a) b)

Fig. 3. Bio-liquid velocity and dynamic viscosity distributions during the PL-bio-surface pouring lubrication with flow rate Q_0: a)velocity and corresponding dynamic viscosity distributions η across the thin bio-liquid boundary layer between movable & motionless lower PL and motionless upper, potential flow surface, b) micro-level illustration of the thin liquid boundary layer, phospholipid bilayer(PL) and potential flow, 1-PL bilayer, 2-the layer of hydrated sodium ions.

Fig.4 and 5 show the gap filled by the thin (7 micrometer height) lubricant layer, restricted by the two cooperating phospholipid (PL) bilayer. After experimental measurements applying the Atomic Force Microscope and numerical calculation follows, that the flow velocity component v_x and lubricant dynamic viscosity distributions η across the gap height are not constant. We can see that the dynamic viscosity distribution in thin gap height direction, depends on the variations of velocity distribution.

Fig.4 shows, that the lubricant flow inside the thin layer between two phospholipid bilayer is generated only by the values of hydrodynamic pressure increases and decreases (variations). Upper and lower PL surfaces are motionless. Thus the velocities of the lubricant liquid particles contacting direct with the internal PL surfaces have value zero. Hence the places of maximum (minimum) values of velocity in the gap height i.e. in thin layer lubricant direction, have the minimum (maximum) values of dynamic viscosity.

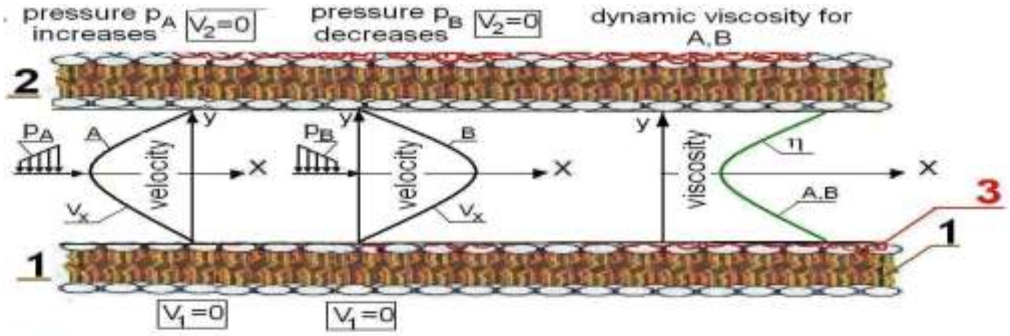


Fig. 4. Bio-liquid velocity component v_x with values V_1,V_2 on the lower and upper PL bilayer restricted the flow in point A (for pressure p_A increasing), and in point B(for pressure p_B decreasing) and corresponding dynamic viscosity distribution η across the thin bio-liquid boundary layer between motionless lower (1) and motionless upper (2) phospholipid bilayer coated with the hydrate sodium ions 3

Fig.5 shows, that the lubricant flow inside the thin layer between two PL bilayer is not generated by the constant hydrodynamic pressure, only by the motion in two opposite directions of the lower and upper PL surfaces. Thus the velocities of the lubricant liquid particles contacting direct with the internal PL surfaces, have values zero and not zero values, depended on the motion of the proper PL surface. Hence the places of maximum (minimum) values of velocity in the gap height i.e. in thin layer lubricant direction, have the minimum (maximum) values of dynamic viscosity.

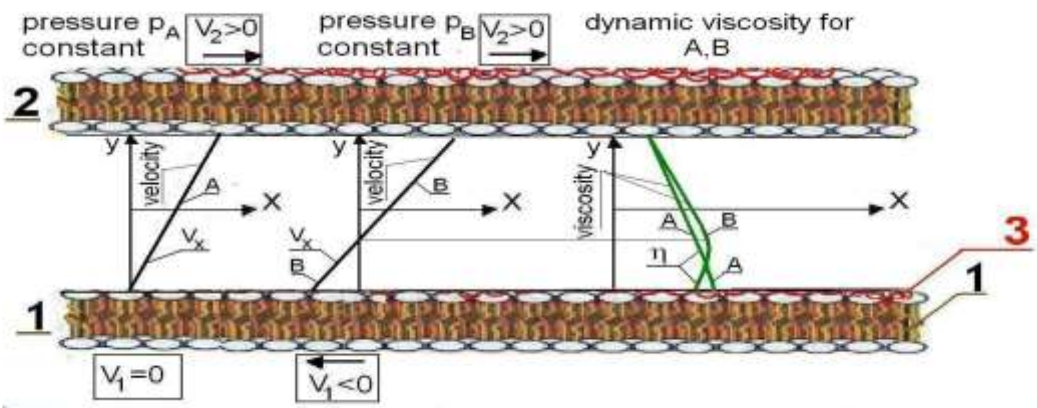


Fig. 5. Bio-liquid velocity component v_x with values V_1,V_2 on the lower and upper PL bilayer restricted the flow in point A (for constant hydrodynamic pressure p, movable upper 2, motionless lower 1 surface), and in point B(for constant hydrodynamic pressure p, movable upper 2, movable lower 1 surface with velocity in opposite directions) and corresponding dynamic viscosity distribution η across the thin bio-liquid boundary layer between two phospholipid bilayer 1,2, coated with the hydrate sodium ions 3

In Fig.4 and 5 we show that the pressure distribution and load carrying capacity of human joint, depends on the dynamic viscosity variations of biological liquid lubricant across the human joint gap. The dynamic viscosity variations of biological liquid lubricant across the human joint gap, has influence on the hydrodynamic pressure distribution.
Fig.6 illustrates the micro-elasto-hydrodynamic lubrication in human joint between two deformed cartilage in knee surfaces. Pressure distribution had been obtained after measurements using Atomic Force Microscopy and are confirmed after numerical calculations.
Fig,7a presents the element of micro-turbine bladed rotor with an operating speed up to 1 million rpm and nozzle guide vanes on the stator with dimensions less than a mm.
Fig.7b shows six-gear chain and cartilage cells where bio-liquid flow in thin boundary layer occurs.

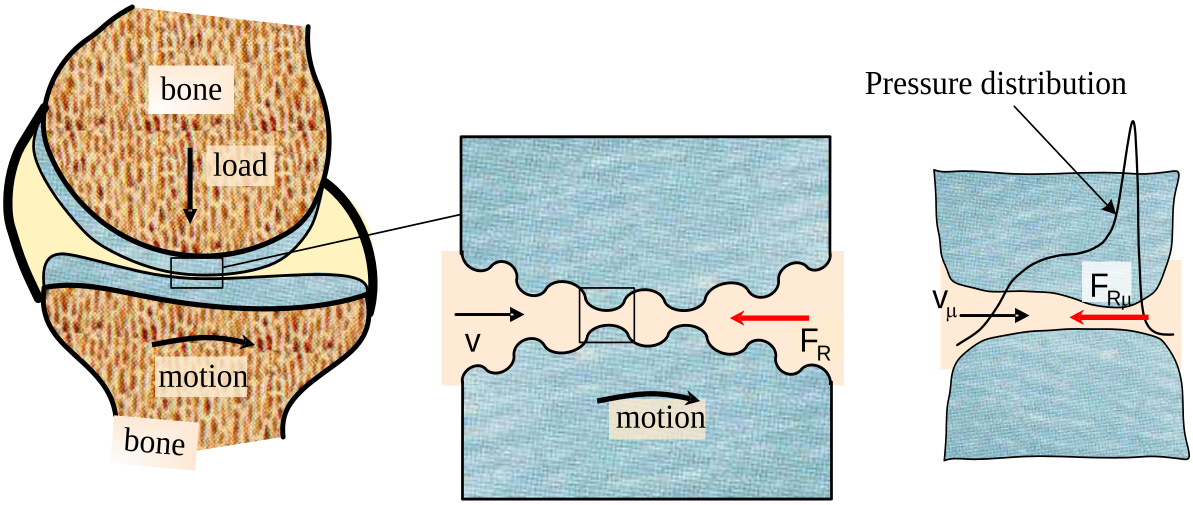


Fig.6.The model of micro-bio-elasto-hydrodynamic lubrication of human joint with enlarged gap and pressure distribution. Notations: v-bio-liquid velocity, F_R-friction force

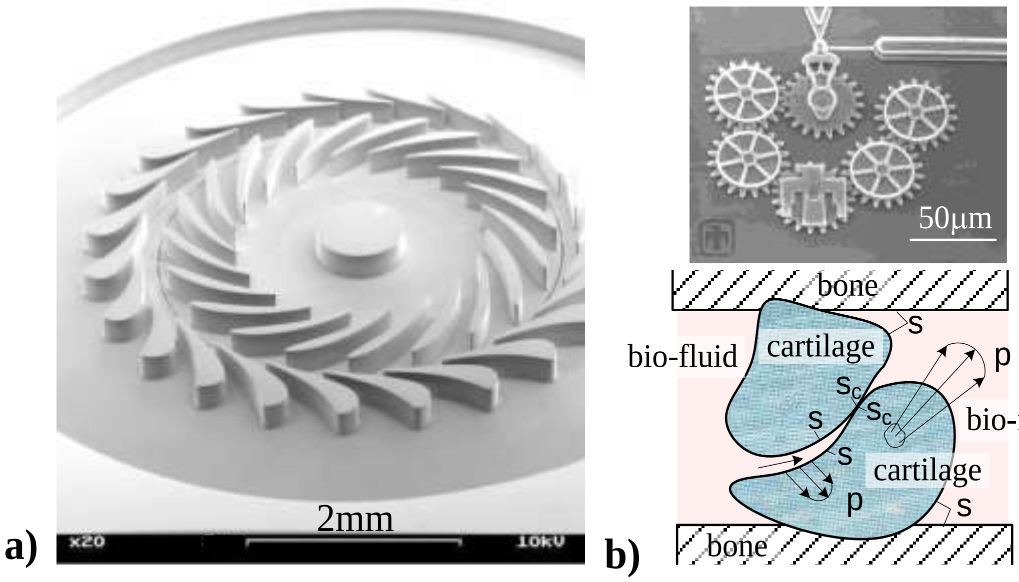


Fig. 7. Flow in super thin layers: a) around micro-turbine blades, b) in gaps between micro gear chains and between joint cartilage cells (small moments of friction of nNm but large bending stresses S, pressure p)

The distributions of the bio-liquid velocity components in the thin boundary layer across the human joints gap, and lubricant velocity components in micro-bearing gap are illustrated in Fig.8. Presented various shapes of velocity distributions in gap height direction have influence on the various shapes of lubricant dynamic viscosity distributions and finally on the values of the hydrodynamic pressure and load carrying capacity of human joints or micro-bearing devices. Mentioned results are confirmed after numerical results using Matlab 7.3 Professional Program.
Fig.9 shows the examples of hydrodynamic pressure distributions on the cylindrical and conical human elbow biosurfaces, obtained after numerical computer calculations performed in Matlab7.3 Professional Program, by virtue of the analytical solutions by means of the finite difference method. In numerical calculations are taken into account: radius of the cylindrical or conical bone R=0.026m, dimensionless joint length L=1,dynamic viscosity of the bio-liquid η=0.15Pas,angular velocity of the bone ω=1.0 1/s,dimensionless eccentricity 0.7.

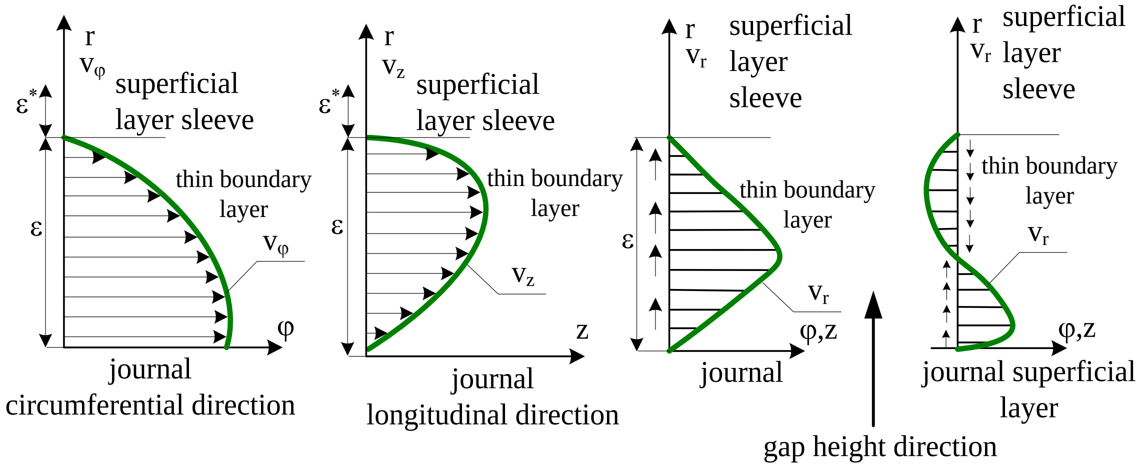


Fig. 8. Distributions of the liquid velocity components v_φ,v_r,v_z in human joint gap or thin micro bearing gap. Notations: ε-thin boundary layer, r-gap height direction,φ-circumferential direction, z-longitudinal direction

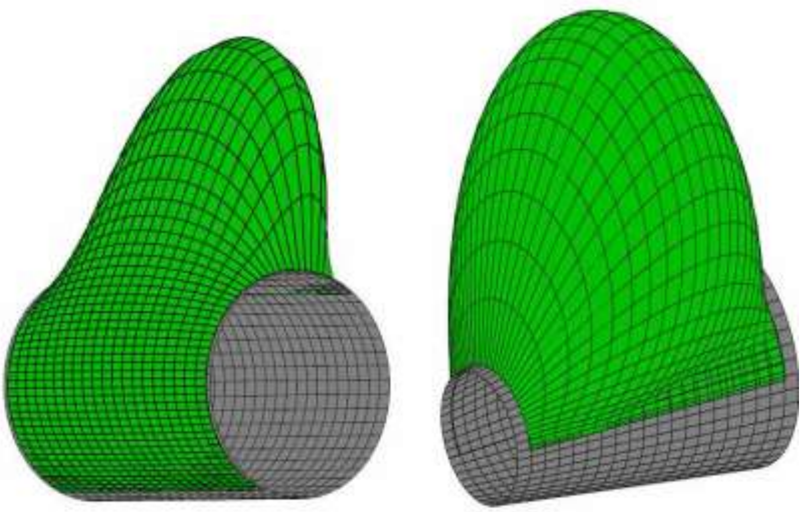


Fig.9.Hydrodynamic pressure distributions on the cylindrical and conical human elbow surface, where maximum values of hydrodynamic pressure attains values from 1 to 2 MPa. The pressure distribution on the left side of the figure presents the conical surface inclination angle 40^o.