EXPERIMENTAL MEASUREMENTS OF ARTIFICIAL HIP JOINT SURFACES AND APPLICATIONS FOR THE PRESSURE AND CAPACITY DISTRIBUTIONS

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Abstract

Taking into account the increasing need to artificial joints for in-vitro use, this paper presents the detail results of measurements of geometrical structure of cooperating surfaces in endoprothesis. The surfaces on the head and acetabulum are taking into account. Obtained results of irregularities and unevennesses of endoprosthesis cooperating surfaces are applied to the pressure simulation in artificial human hip joint. This paper has been prepared based on the objective of European Project MTKD-CT-2004-517226 to represent the methodology and goal of the idea described in and make possible wider discussion on this subject for further developments during the realization. The contour diagram of unused surface of head of Vitalium alloy of Weller's endoprosthesis, the surface of unused head of endoprosthesis made of ceramic aluminium, the sample of a new head of endoprosthesis, measured roughness of cartilage surface, vertical section of cartilage surface, Unused acetabulum of hip joint endoprosthesis as well the power spectral density distribution of the surface are presented in the paper. On the basis of performed works the author constates that the model for artificial joints lubrication without roughness of endoprothesis surfaces is incorrect and is load with a large inaccuracies.

Keywords: *artificial joints, endoprothesis, needs of measurements, geometrical structure*

1. Reason of research

It can be estimated that yearly 2.5 million joint fractures occur worldwide. Only in 2000 year in EU 414000 joint fractures was recorded. The increase in number of joint fractures in EU, anticipated on the ground of demographic development in the next 50 years, would reach about one million. Therefore the endoprosthesis will be transplanted even in a young human age [1], [2].

The determination of the hydrodynamic lubrication of artificial metal endoprosthesis and elastohydrodynamic lubrication of artificial human hip joints, is associated with the precise analysis of irregularities and uneven nesses of endoprosthesis cooperating surfaces, with the exactness of one micrometer (or even more than that) for the boundary friction.

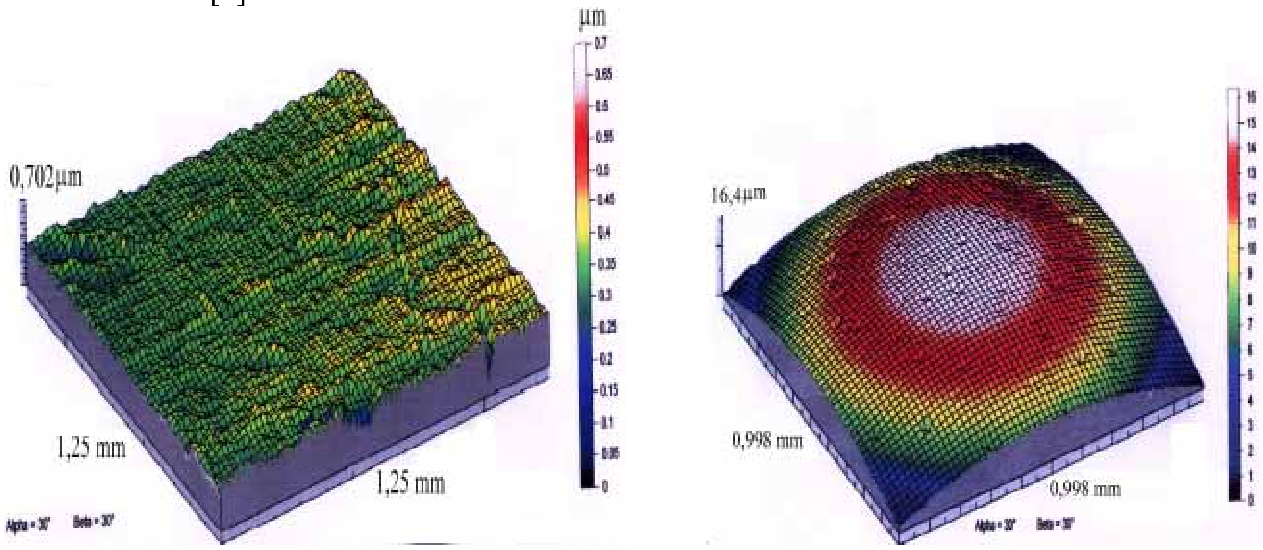
The measurements of the endoprosthesis -head surfaces are performed by using micro sensor laser installed in the Rank Taylor Hobson-Talyscan 150 Apparatus and then elaborated by means of the TALYMAP Expert and Microsoft Excel Computer Program. From many measured samples the following statistical parameters have been calculated: **St**, **Sz,** **Sa** of surface roughness expressed in micrometers. We calculate for example: **St** -differences between values of rises and deeps of bone head surfaces in human hip joint, **Sz-** arithmetic mean between values of 5 rises and 5 deeps of bone head surface, **Sa-** standard deviation of probability density function of roughness distribution of cartilage surface [3].

2. Head surfaces of artificial hip joint

The measurements of samples of artificial hip joint surfaces of endoprosthesis are performed by means of mechanical and laser sensors. The measured samples have been made of Endocast alloy, zircon and ceramic aluminium (see Fig. 1a, Fig. 1b). The samples used during the measurements, made of Vitalium or Endocast and zircon material, were either 1, 25 mm long and 1, 25 mm wide or 2, 50 mm long and 2, 50 mm wide. The samples made of ceramic aluminium were 0, 988 mm long and 0, 988 mm wide.

In the case of Weller's artificial endoprosthesis the metal surface of the head is coated with randomly shaped chaos scratches obtained due to abrasive grain treatment.

Measured values of St for metal heads of Weller's endoprosthesis barely reaches the value of 0, 702 micrometer [4].



a) b)

Fig. 1. a) The contour diagram of unused surface of head of Vitalium alloy of Weller's endoprosthesis, b)The surface of unused head of endoprosthesis made of ceramic aluminium

On the ground of the performed measurements it is easy to see that the asperities of the artificial joint surfaces are smaller than those occurring in articular bone surfaces of human hip joints.

Over the entire polished surface of aluminum ceramics, micro-cavities (micro-hollows) chaotically spread over the measuring area, can be observed.

The distribution density of such micro-cavities is within the range of 10 to 120 (and even more) elements per one mm^2 depending on a kind of ceramics and its firing process.

The depth of micro-cavities reaches the values from 4 to 8 micrometers, measured on the area from 1 to 4 square micrometers.

The occurrence of the micro-cavities on the polished ceramic surface is due to the manufacturing process of ceramic elements, which belongs to the powder metallurgy field. During the process of compacting the powder and firing the ceramic elements, natural micro-pores are produced. The pores open and convert into micro-cavities during machining when successive layers of excess material are removed, as well as in the course of the final polishing process. Influence of the micro-cavities on operational merits of ceramic heads of endoprostheses may be considered as a positive phenomenon since on the smooth surface they form a specific network of micro-ponds playing the role of the tanks which keep lubricating media. Roughness of the surface areas between micro-cavities is low as it maintains within the range of St –values from 0, 4µm to 0.8µm. In the unevenness height of 16.4µm shown a in Fig. 1b, apart from surface roughness, also a shape deviation from the ideal spherical surface is accounted for.

In Fig. 2 and in Fig. 3 are presented geometrical structure of the surface (FRANKOBAL) of a new head artificial head of human hip joint.

In the presented geometrical structure in Fig. 2 we have following amplitude parameters: Sa=0, 0604µm, St=0, 632µm and Sz=0.538µm.

In the presented geometrical structure in Fig. 4 we have following amplitude parameters: Sa=0.0582µm, St=0.602µm and Sz=0.425µm [5], [6].

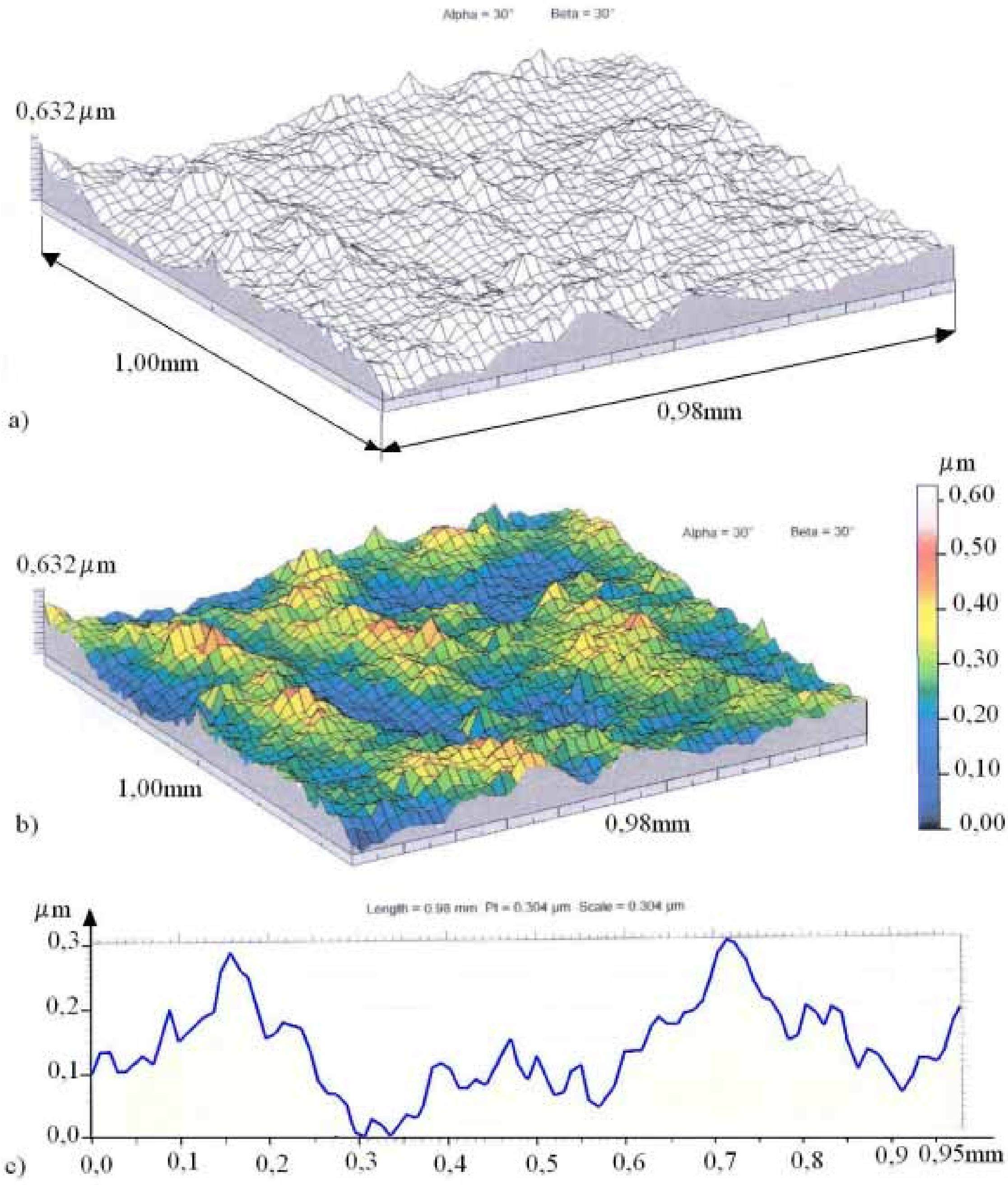


Fig. 2. Sample of a new head of endoprosthesis FRANKOBAL GL46MM: a), b)- measured roughness of cartilage surface, c) vertical section of cartilage surface

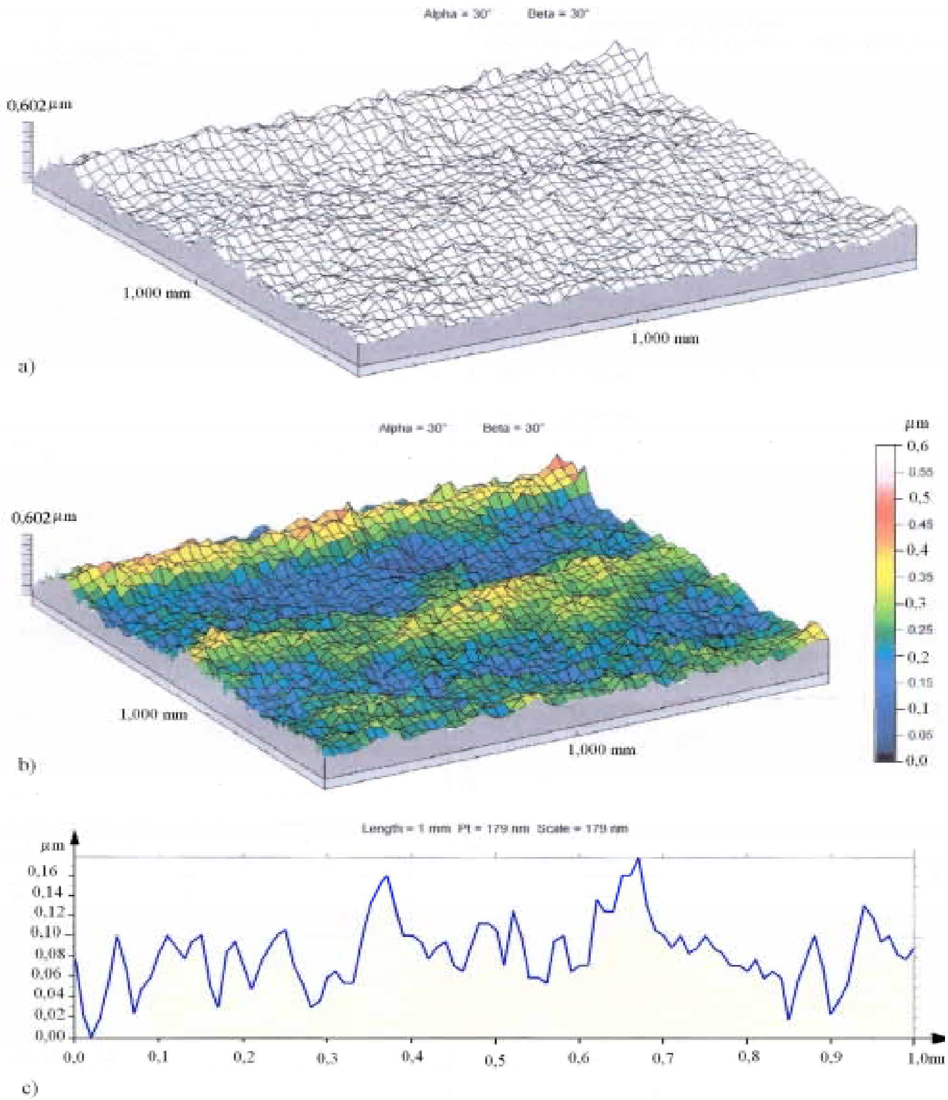


Fig. 3. Sample of a new head of endoprosthesis FRANKOBAL GL54MM: a), b)- measured roughness of cartilage surface, c) vertical section of cartilage surface

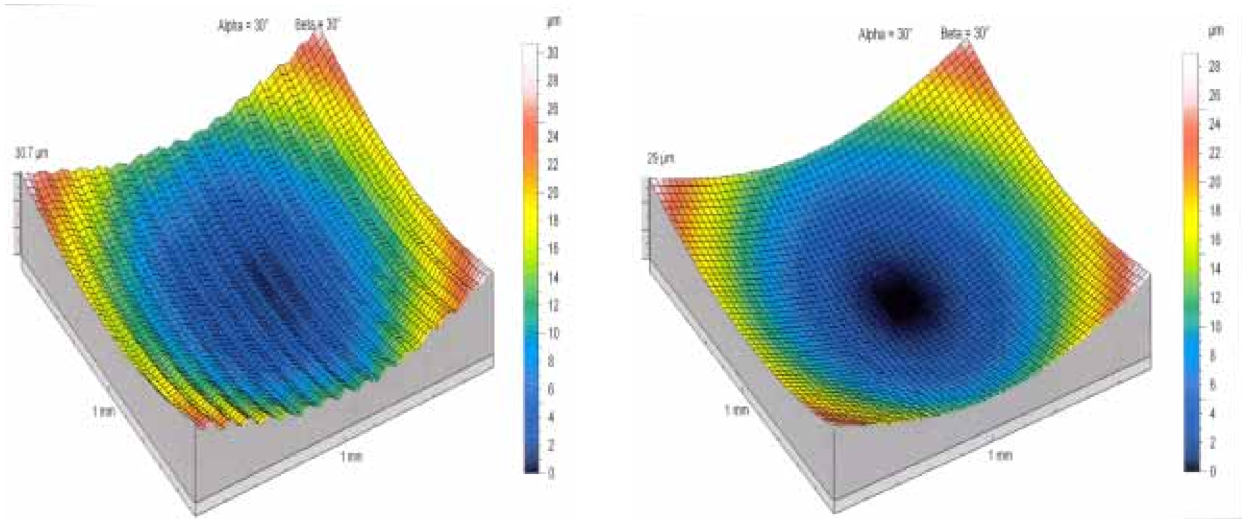
3. Acelabulum surfaces of artificial hip joint

The prevailing number of acetabula of hip joint endoprostheses is made of polyethylene by using the high-pressure compacting method in metal moulds. A typical image of surface of a new, unused polyethylene acetabulum of hip joint is shown in Fig. 4 and Fig 5.

From the presented figures it can be observed that some concentrically orientated unevennesses resulting from its manufacturing process are superimposed on the basic hollow surface of the acetabulum. Such phenomenon is also met in other manufacturing processes, and generally called *technological heritage*. In the case in question the phenomenon is charecteristic of that the unevenness of the mould has been imprinted on the acetabulum surface.

In Fig. 5a it can be observed that the acetabulum surface maintains its anisotropic and periodic character. The power spectral density distribution in function of wave length, shown in Fig. 6, confirms the above stated fact.

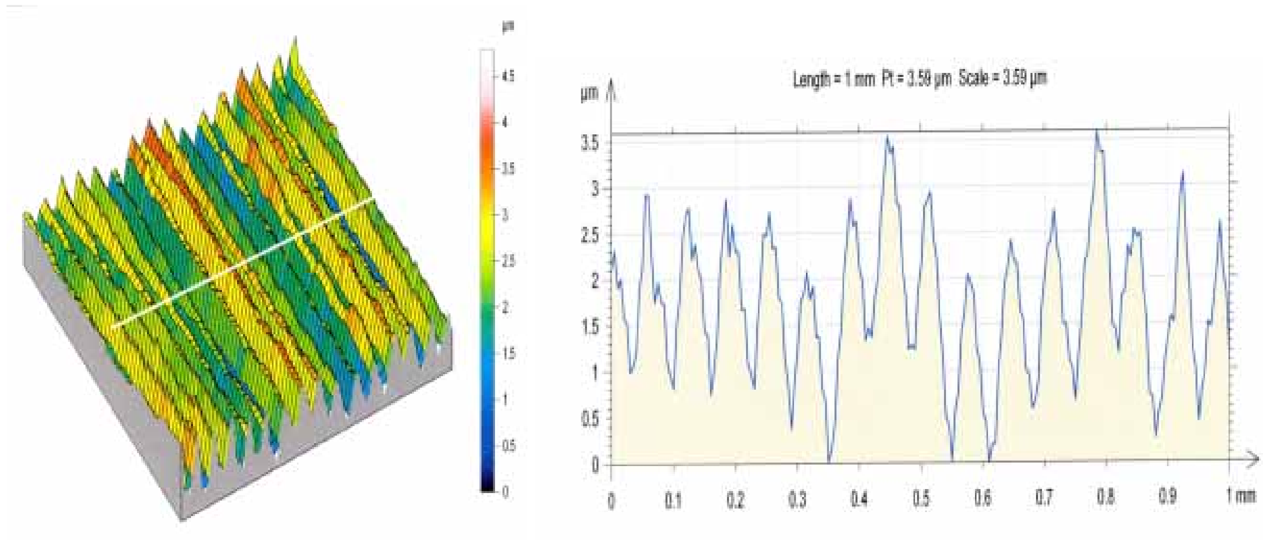
In this distribution, apart from the random components, the dominating component of 66 µm wave length as well as the surface waviness of 300 µm wave length, appear. Such character of surface may result from the applied finishing process of the mould, in which a tool of a determined geometric form is used, or it may be caused by kinematics coupling of relative motions of the tool and the machined object [5], [6].



a) b)

Fig. 4. Unused acetabulum of hip joint endoprosthesis : a) general view, b) separated initial spherical surface of the radius R=14.012 mm

It can be stated that, due to the sharp peaks of particular uneven nesses of relatively large heights reaching almost 5 micrometers, the load-carrying capacity of such surface is relatively small and may cause an accelerated wear of acetabulum during initial phase of use of artificial hip joint. On the other hand, a relatively correct, uniform volumetric distribution of the material and the voids within the roughness area of the surface, speaks in favors of the capacity of the analyzed surface. According to the performed tests the material volume can be described by the index value of 0.00241 mm^3/mm^2, and the void volume by the index value of 0.00238 mm^3/mm^2. Another factor speaking in favors of the considered surface is the large density of local peaks, Sds=1336 pks/ mm^2.



a) b)

Fig. 5. Unused acetabulum of hip joint endoprosthesis : a) surface roughness on 1 mm^2 area, b) a characteristic cross-section profile of surface

The large fractal dimension Sfd=2.43 shows that the tested surface is greatly developed. Besides, the acetabulum surface is characterized by a relatively high index of lubricant keeping ability of micro-uneven nesses, Sci=1.56 [3.17].

From the analysis of geometrical structures of the surfaces of bone heads and acetabuli of artificial hip joints the following conclusions can be drawn:

- On the basis of the friction theory it is favorable to join, as a friction pair, the endoprosthesis head of randomly variable non-directed surface and the acetabulum of directed anisotropic surface.
- Joining the acetabulum surface of a large value of lubricant keeping ability and the head surface made of alumunium ceramics of a high value of concentration of micro-ponds may create favorable conditions for boundary lubrication over the friction region of cooperating surfaces.

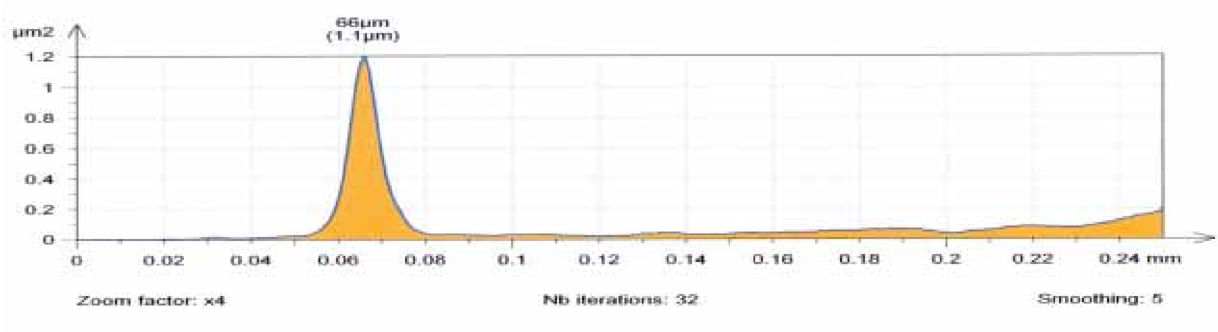


Fig. 6. Power spectral density distribution of the surface presented in Fig. 5

4. Pressure calculations for measured surfaces

The spherical dimensionless gap height ε_{T1} depends on the variable φ and ϑ and time t and consists of two parts:

$$\varepsilon_{T1}=\varepsilon_{T1s}(\varphi, \vartheta_1, t_1)+\varepsilon_{33}(t_1). \tag{1}$$

Symbol ε_{T1s} denotes the total dimensionless real- time- dependent part of the height of thin fluid layer or gap height without deformations see, ε_{33}-denotes the dimensionless gap height corrections caused by the endoprothesis head and acetabulum deformations.

The gap height corrections depend additionally on the kind and roughness of head and acetabulum geometrical structure. These corrections are determined on the basis of performed experimental measurements presented on the Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5. The experimental values of artificial surface, are measured by the micro-sensor laser.

Taking into account the roughness on the endoprothesis-surfaces, then the modified Reynolds equations in spherical coordinates φ, ϑ has the following form [7]:

$$\frac{1}{\sin\vartheta_1}\frac{\partial}{\partial\varphi}\left[\left(\varepsilon_{T1s}+\varepsilon_{33}\right)^3\frac{\partial p_1}{\partial\varphi}\right]+\frac{\partial}{\partial\vartheta_1}\left[\left(\varepsilon_{T1s}+\varepsilon_{33}\right)^3\frac{\partial p_1}{\partial\vartheta_1}\sin\vartheta_1\right]=$$

$$=\left(6\frac{\partial}{\partial\varphi}+12\,\mathrm{Str}\frac{\partial}{\partial t_1}\right)\left(\varepsilon_{T1s}+\varepsilon_{33}\right)\sin\vartheta_1=6\frac{\partial}{\partial\varphi}\left(\varepsilon_{T1s}+\varepsilon_{33}\right)\sin\vartheta_1. \tag{2}$$

We denote: $p_1=p/p_o$-dimensionless pressure, $p_o=\omega\eta R^2/\varepsilon^2$, η-fluid viscosity, R-radius of the head, ε- gap height, Str- Strouhal number, t_1-dimensionless time, φ-circumference coordinate on the head, ϑ_1-dimensionless meridian coordinate.

5. Conclusions

The model for artificial joints lubrication without roughness of endoprothesis surfaces is incorrect and is load with a large inaccuracies.

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