THE EXPERIMENTAL VERIFICATION OF EFFECT OF LUBRICATION ON COEFFICIENT OF FRICTION IN ENDOPROSTHESIS OF HIP JOINT

Andrea HARINGOVÁ[1], Karol STRAČÁR [2], Karol PRIKKEL [3]

[1] Institute of chemical and hydraulic machines and equipment, STU in Bratislava, Slovak republic, andrea.haringova@stuba.sk

[2] Institute of chemical and hydraulic machines and equipment, STU in Bratislava, Slovak republic, karol.stracar@stuba.sk

[3] Institute of chemical and hydraulic machines and equipment, STU in Bratislava, Slovak republic, karol.prikkel@stuba.sk

Abstract: *The endoprosthesis of hip joint has overall lifetime up to 20 years. After this period the patient has to submit the revision operation. The main problem of the failure of endoprosthesis of hip joint are debris that comes from direct contact of head and socket pad and so called dry friction. The paper deals with effect of additional lubricant on the value of coefficient of friction in endoprosthesis of hip joint. As the testing fluid was selected the replacement of synovial fluid: solution of hyaluronic acid.*

Keywords*: lubrication, coefficient of friction, endoprosthesis*

1. Introduction

The endoprosthesis of hip joint is composed from 3 basic parts- stem with head and socket and has overall lifetime 20 years. The lifetime is limited by debris that are caused by direct contact of head and socket with absenting lubrication layer. The dry friction continuously reflects in mostly polyethylene debris coming from the socket cup. These polyethylene debris are very harmful for human body and causes infection and loosening of the endoprosthesis followed by the failure of endoprosthesis (fig. 1).

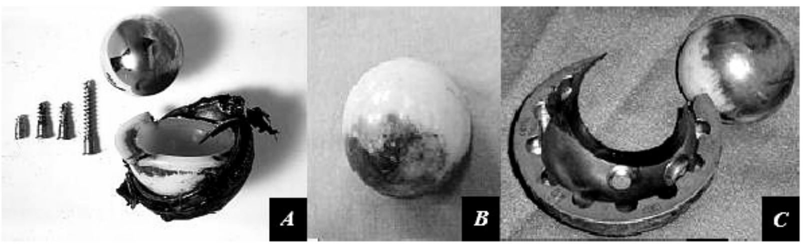


Fig.1 Failed components of endoprosthesis

According to the [5] 55% cases of failure of primary total hip joint endoprosthesis are caused by loosening of one of the components of the endoprosthesis. The amount of debris caused by dry friction is 100 - 200 µm/year for endoprothetic pair ceramics/metal- polyethylene and the polyethylene debris have irregular shape. In this article we would deal with the effect of lubrication on coefficient of friction. The average coefficient of friction in endoprosthesis is 0,3 that is more than 10 times higher as coefficient of friction in the healthy human joints ($0{,}01 < f < 0{,}1$ [2]).

2. Lubrication in hip joints

The fluid flow in endoprosthesis is described by Navier-Stokes equation that describes the equilibrium between mass, pressure and viscose forces.

$$\frac{\partial v}{\partial t} + v.gradv = -grad(U_G + \frac{p}{\rho} + \nu.\Delta v) \quad (1)$$

The viscose forces are the basic benefit of fluid in the healthy hip joint gap and effects in decrease of coefficient of friction. The lubrication fluid in hip joint is called the synovial fluid and is captured in synovial membrane around the whole joint. The elementary component of synovial fluid that is responsible for the excellent lubrication properties is hyaluronic acid. The solution of hyaluronic acid is used also for viscosuplemantation- to add the absenting lubrication layer in joint as the first solution of degenerative diseases. The solution of hyaluronic acid would be used also in our experiment as testing lubrication fluid. Thy synovial fluid behaves according to the shear rate as Newtonian or Non-Newtonian fluid.

The dynamic viscosity of synovial fluid is described:

$$\mu_p = \mu_\infty + \frac{\mu_0 - \mu_\infty}{1 + AX + BX^2} \quad (2)$$

$$X = \partial v_1 / \partial h \quad (3)$$

where μ_∞ - dynamic viscosity of synovial fluid for high shear rates, over 10^5 s^{-1};
μ_0 - dynamic viscosity of synovial fluid for low shear rates;
X – shear rate ratio;
v_1 – circumferential component of synovial velocity;
h – high of the gap;
A,B – empiric coefficients, for healthy joints A= 1,88307, B= 0,00458 and for pathological joints A= 0,03349, B= 0,00131.

The character of lubrication in human joint is changing during the motion. According to the Dowson (2001) and Medley (2001) is lubrication determined by coefficient λ that is derived from following equation [3]:

$$\lambda = \frac{h_{min}}{Ra'} \quad (4)$$

where h_{min} minimum thickness of synovial fluid;
Ra' composite roughness of endoprothetic pair.

According to the (4), it is determined the character of lubrication:
$0,1 < \lambda < 1$ critical lubrication,
$1 \leq \lambda \leq 3$ mixed lubrication,
$\lambda > 3$ thin flow lubrication or hydrodynamic.

Critical lubrication means that the layer of fluid is so thin that there is a high risk of direct contact of materials of joint. The thin layer lubrication is secured with minimum thickness of lubrication layer 0,15 – 0,25 μm [3] and in this region we obtain the lowest value of coefficient of friction as it is visible in fig.2.

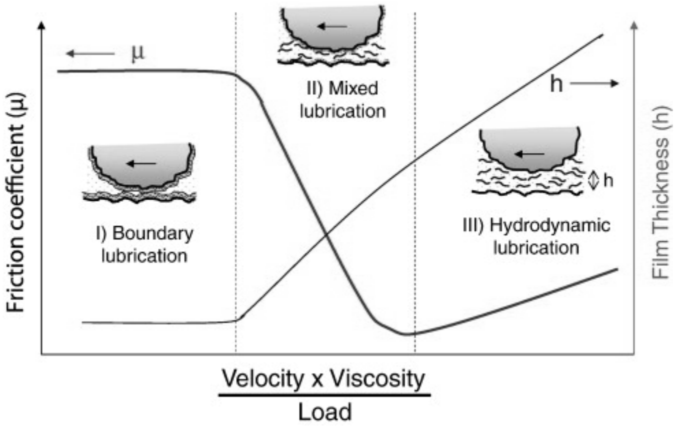


Fig.2 Stribeck´s curve of lubrication on joints[1]

3. Description of experiment

The stand for testing of endoprosthesis and their properties was designed in the laboratories of Institute of chemical and hydraulic machines and equipment of Faculty of Mechanical Engineering of STU in Bratislava. The stand is designed according to the standards ISO 142 42 for stand for testing of endoprosthesis of hip joint and secures the prescribed value of vertical load as well as the horizontak displacement value. The force and motional system is secured by hydraulic components from company FESTO Slovakia s.r.o. and demanded limits are set by the sensors: load cell, displacement sensor and magnetic sensor of position on the valve.

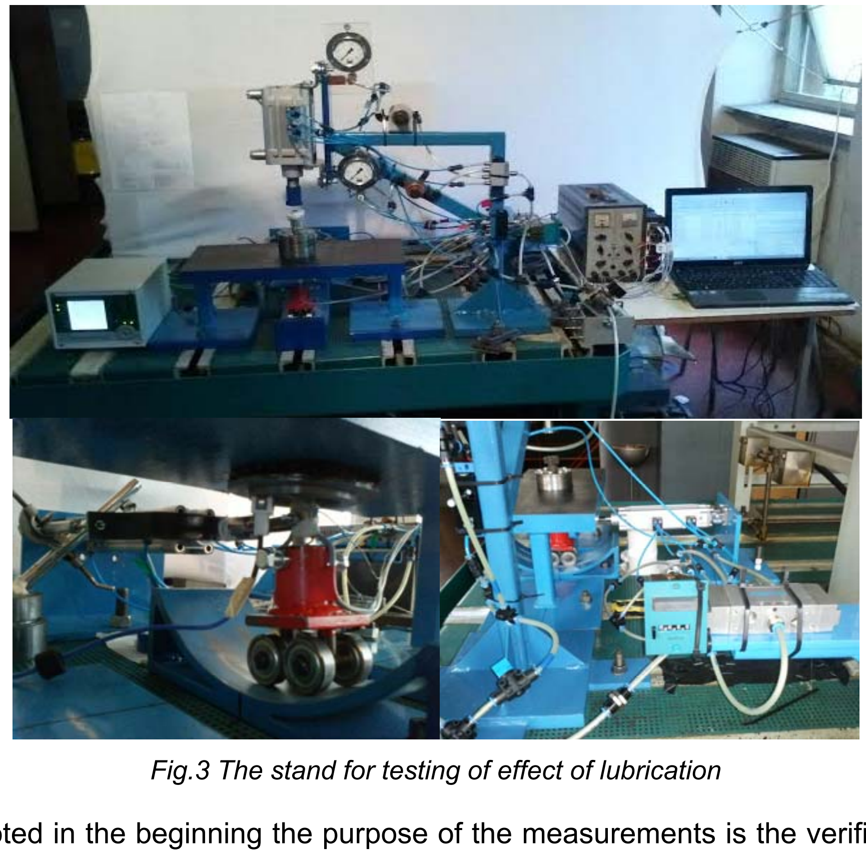
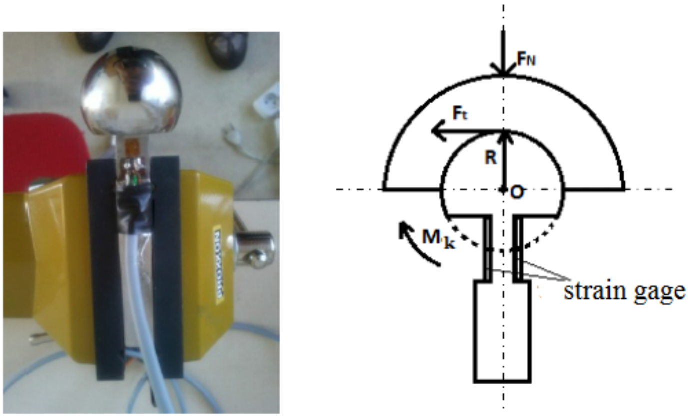


Fig.3 The stand for testing of effect of lubrication

As it was noted in the beginning the purpose of the measurements is the verification of the effect of lubrication in endoprosthesis of hip joint on coefficient of friction. The measurement is done in 2 steps-phases.

1. **Phase A** – simplified model of endoprosthesis of hip joint, with added lubrication layer
2. **Phase B -** simplified model of endoprosthesis of hip joint, dry friction, no lubrication layer



$$f = \frac{M_K}{R.F_N}$$

Fig.4 Position of strain gages on hip joint

To capture the data from measurement we have used the following sensors:
- one-axis strain gage 1-LY11-1.5/120, sensitivity0,1 %, produced by HBM;
- subminiature stainless steel compression load cell LC 302-1K, measuring range 457 kg, accuracy ± 0,5 % from range, produced by OMEGA;
- inductive displacement transducer WA100, measuring range 0-100mm, produced by HBM;
- sensor of temperature ALMEMO 5690-2.

The evaluation of measured data was made with two softwares. Software CATMAN from company HBM that help us to read the obtained data from QUANTUM MX 1615, and computational software MATLAB for next evaluation of measured data.

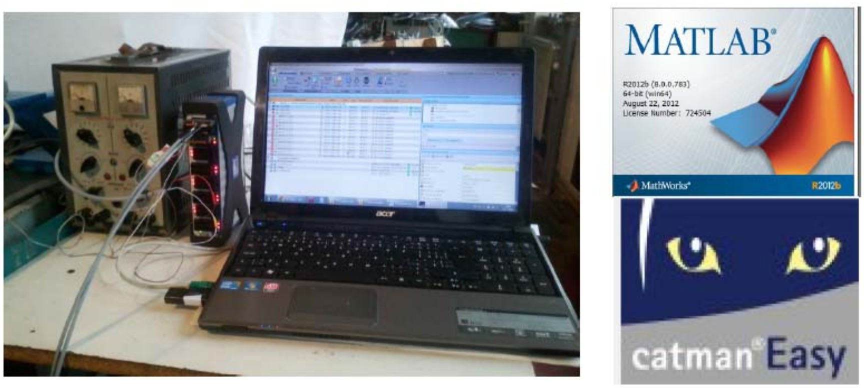


Fig.5 Software for evaluation of measured data

The measurement properties from phases A and B are following:
Date of measurement: 17.6.-10.7. 2014
Place: STU SjF Bratislava,
Length of one cycle: 1,2s
The length of loading cycle: simulation of 2 days walk
Lubricant: solution of hyaluronic acid

4. Results

The results from the experiment are on the figures 6-9. From figures follows that addition of lubrication layer causes decrease of coefficient of friction from maximum value captured in phase B - dry friction 0,2062, to the value for phase A with added lubricant 0,0502.

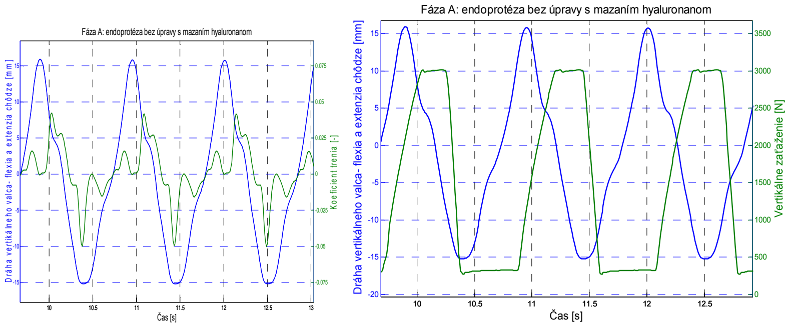


Fig.6 Phase A, Horizontal loading and coeffiecient of fricton with respect to the time, Vertical and horizontal loading with respect to time, endoprosthesis with added lubricant

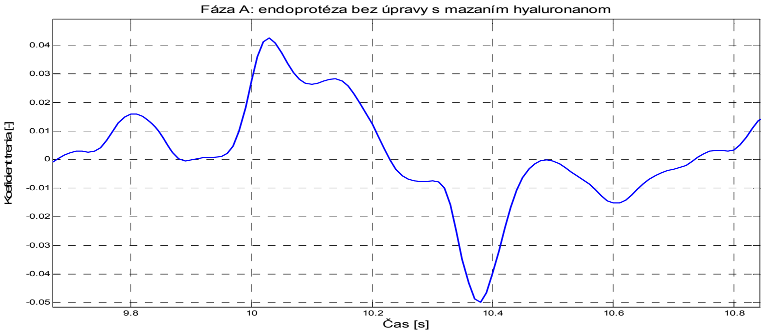


Fig.7 Phase A, Coefficient of friction, endoprosthesis with added lubricant

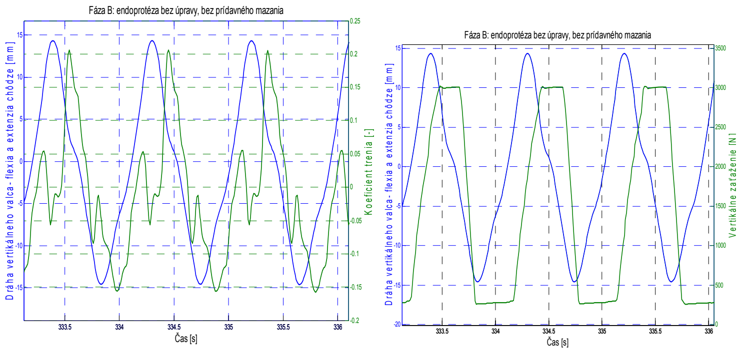


Fig.8 Phase B, S Horizontal loading and coeffiecient of fricton with respect to the time, Vertical and horizontal loading with respect to time, endoprosthesis with dry friction

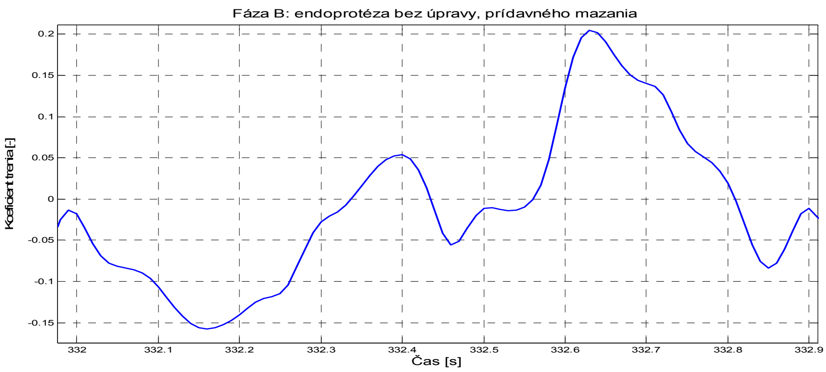


Fig.9 Phase B, Coefficient of friction, endoprosthesis with dry friction

5. Conclusions

The addition of lubricant into the endoprosthesis gap is significant step in decreasing of coefficient friction and we could derive that could also positively effect the lifetime of endoprosthesis. This results would continue to the lifetime tests of endoprosthesis with simulation of one year walking, representing 1 million of cycles.

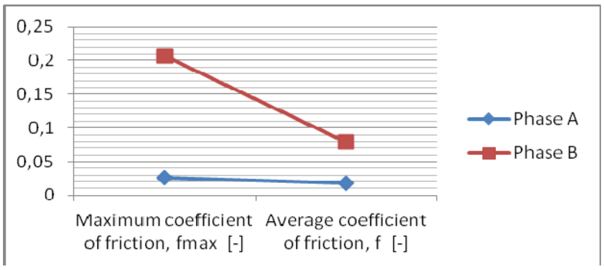


Fig. 10 Resulting coefficient of friction

REFERENCES

[1] COLES, J. M. – CHANG, D. P. – ZAUSCHER, S. 2010. Molecular mechanisms of aqueous boundary lubrication by mucinus glycoproteins . In Current Opinion in Colloid & Interface Science, 2010. Vol. 15, s. 406 – 416., ISSN 1359-0294

[2] KLEINSTREUKRER, C. 2006. Biofluid Dynamics. Boca Raton: CRC Press Taylor & Francis Group, 2006. 492 s. ISBN 0-8493-2221-9.

[3] SEEBECK, P. 2009. Clinical and Technical Review: Hyaluronic acid (Hyaluronan). TECOmedical Group, 2011. [online]. [cit.2012-02-12]. 24 s. Dostupné na: http://www.tecomedical.com/downloads/pdf/Hyaluron%20%28e%29%20%28 10%29.pdf>.

[4] MATTEI,L.-DI PUCCIO,F.-PICCIGALLO,B.-CIULLI,E., 2011, Lubrication and wear modelling of artificial hip joints: A review, In Tribology International, vol.44, 2011, s. 532-549, ISSN 0301-679X

[5] NEČAS, L. a kol. 2009. Sloveský artroplastický register. Analýza 2003 – 2008. Martin: SAR, 2009. [citovane 2011-01-24]. Dostupné na: <http://sar.mfn.sk/file/subory/SAR_analyza_2003_2008.pdf>.

[6] PRIKKEL, K.- HARINGOVA, A., 2012, Hip joint endoprosthesis. SK50222012 (U1) [citovane 2014-08-25]. Dostupné na: <http://worldwide.espacenet.com/publicationDetails/biblioDB=worldwide.espacenet.com&II=4&ND=3&adjacent=true&locale=en_EP&FT=D&date=20120903&CC=SK&NR=50222012U1&KC=U1>.

[7] PRIKKEL, K.- HARINGOVA, A., 2012, Hip joint endoprosthesis. SK50232012 (U1) [citovane 2014-08-25]. Dostupné na: <http://worldwide.espacenet.com/publicationDetails/biblioFT=D&date=20120903&DB=worldwide.espacenet.com&locale=en_EP&CC=SK&NR=50232012U1&KC=U1&ND=4>.

[8] HARINGOVÁ, A. - PRIKKEL, K. - STRACÁR, K.: The lubrication in hip joint. In: Hidraulica - ISSN 1453-7303. - No. 1 (2014), online, p. 26-31

[9] HARINGOVÁ, A. - PRIKKEL, K.: The possibilities of modification of endoprosthesis of hip joint according to the usage of hydraulic components. In: Hidraulica. - ISSN 1453-7303. - No. 3-4 (2011), p. 28-33