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SIMULATION OF SLIDING BEARING UNDER DYNAMIC LOAD CONDITIONS

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Abstract

Sliding bearings are common used in most of modern machines and mechanisms because of their very practical maintenance and very long operating life. With new simulation methods and software tools it is possible to make qualitative analysis of sliding bearing behavior under different load conditions. Previous analysis were made using only static load conditions but for real conditions it is necessary to simulate load which is changing during operating time. This paper presents a simulation of sliding bearing under dynamic load conditions using software CATIA V5 by finite elements method (FEM). Based on results of this structure analysis, parameter optimization of porous metal bearing also could be made, with taking elastic deformations of bearing shell into account.

Key words: *sliding bearing, dynamic load, CATIA V5, simulation, finite element method*

1. INTRODUCTION

Sliding bearings are so much in use today, which means they are applied to most of machines that we need and meet in whole our life. This can be understandable because of some advantages that this sort of bearing has compared with rolling bearings. Generally, their production is not so complicated, which the price makes lower, for simple mounting they can be made in parts, and in operating life they produce less noise and vibrations. In case of correct lubrication, all sorts of sliding bearings are very practical for maintenance and they have long operating life, which are probably most important reasons for their common use. Especially, selflubricating sliding bearings are very useful in the new age and their production rapidly increases.

Most of previous presented simulation and analysis of sliding bearing were made under static load. Even the static case of bearing load is not completely identical to real work, it is not so simple to simulate, but could give acceptable results for engineering practice. The real operation life conditions of sliding bearing are near to dynamic, but making such a simulation could take to much calculation time and makes the task very complicated.

Developments of well known software tools for analysis and optimization last years are additional help to reach this objective [1]. Using software CATIA V5 modules, for stress analysis by Finite elements method (FEM), it is possible to analyze static case, frequency case and finally to simulate journal sliding bearing under dynamic conditions [2].

2. STATIC CASE ANALYSIS

The main supposition for all stresses (σ, τ) and deformations (ϵ, γ) analysis is their linear dependence:

$$\sigma = E\epsilon \text{ and } \tau = G\gamma . \qquad (1)$$

Deformations in transversal direction of radial force are taken into account using Poisson coefficient (ν_p) and deformations by temperature variation is $\epsilon_t = \alpha_t \Delta T$. If we are analyzing stresses and deformations on bearing volume with known main directions, it is possible to write equations of stresses in these directions [3]:

$$\sigma_1 = \frac{E}{1-\nu_p^{\,2}}\left[\left(1-\nu_p\right)\epsilon_1 + \nu_p\left(\epsilon_2+\epsilon_3\right)\right], \quad (2)$$

$$\sigma_2 = \frac{E}{1-\nu_p^{\,2}}\left[\left(1-\nu_p\right)\epsilon_2 + \nu_p\left(\epsilon_3+\epsilon_1\right)\right], \quad (3)$$

$$\tau_{12} = \tau_{23} = \tau_{31} = 0$$

$$\sigma_3 = \frac{E}{1-\nu_p^{\,2}}\left[\left(1-\nu_p\right)\epsilon_3 + \nu_p\left(\epsilon_1+\epsilon_2\right)\right]\cdot \quad (4)$$

and equations for deformations in these main directions:

$$\epsilon_1 = \frac{1}{E}\left[\sigma_1 - \nu_p(\sigma_2+\sigma_3)\right], \quad (5)$$

$$\epsilon_2 = \frac{1}{E}\left[\sigma_2 - \nu_p(\sigma_3+\sigma_1)\right], \quad (6)$$

$$\gamma_{12} = \gamma_{23} = \gamma_{31} = 0$$

$$\epsilon_3 = \frac{1}{E}\left[\sigma_3 - \nu_p(\sigma_1+\sigma_2)\right]\cdot \quad (7)$$

These relations could not be directly used for stress and deformation calculation values of porous metal bearing because of complex bearing load. For such problems it is very useful to apply Finite element method (FEM) that could be realized using numerous software tools. In general, the (FEM) analysis consists of three main phases:

- Preprocessing or problem definition phase,
- Process or calculation phase,
- Post processing or results analysis phase.

In this phase of problem definition, the first task is to form such net of proper finite elements dimensions and form in order to cover object mass, volume or surface with satisfying accuracy. The choice of finite elements form and dimensions certainly depends of analyzed object shape and it should follow the expected stress distribution.

For this simulation the journal sliding bearing with dimensions $\varnothing 30/\varnothing 20 \times 20$ mm is taken, where linear elastic tetrahedron is chosen for finite element [4]. This four nodes isoparametric solid element has three degrees of freedom (translations) per node and the bearing volume consists of 9153 such tetrahedrons with dimensions of 1,88mm, which means there are 2208 nodes, as shown by Figure1.

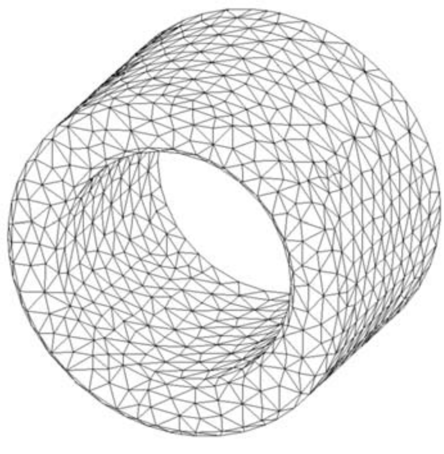

Figure 1: *The tetrahedrons net of bearing*

For sliding bearing simulation it is to be taken in account physical and properties of bearing material. In this case bearing is made of bronze alloy with mechanical and other properties given in Table 1.

Table 1. *Bearing material properties*

Properties of material CuSn10	value	dimens.
E – Young modulus	$1{,}12 \cdot 10^5$	N/mm^2
ν_p - Poisson ratio	0,341	-
ρ_l – Density	6500	kg/m^3
α_t - Therm. expans. coeff.	$17{,}8 \cdot 10^{-6}$	K^{-1}
$[\sigma_T]$ - Yield Strength (depend of alloy)	85 (80 – 120)	N/mm^2

After that, of great importance in preprocessing phase is correct definition of complex bearing load. Radial load on bearing is defined by nonuniform pressure distribution of lubricant on the inner surface of bearing. Starting from a well known Reynolds equation for sliding bearing, following hydrodynamic lubricating theory, nonuniform pressure distribution of thin oil layer (8) is calculated:

$$p = \frac{3\upsilon\eta}{rc^3}\left[\frac{\varepsilon\sin\theta}{\left(1+\varepsilon\cos\theta\right)^3 + 12\Psi}\right]\left(\frac{b^2}{4} - z^2\right)\cdot \quad (8)$$

For complete bearing load, temperature field of bearing is also to be taken in account [5]. It is done using thermics flux through elementary bearing surface (9):

$$\dot{q}_i = p\,\upsilon\,\mu = \frac{3\upsilon^2\eta}{r\,c^2}\left[\frac{\varepsilon\sin\theta}{(1+\varepsilon\cos\theta)^3 + 12\Psi}\right]\cdot$$

$$\cdot\left(\frac{b^2}{4}-z^2\right)\mu \;+p_b\,\upsilon\,\mu\cdot \quad (9)$$

To calculate correct stress values in all bearing model nodes, elastic balance equations are to be defined. Equations that connect stress and external load values in a model node (x, y, z), can be written in the matrix form:

$$[B]^T\{\sigma\}+\{F\}=0\,, \quad (10)$$

where $[B]^T$ is transponded matrix of differential operators.

Processing phase of calculation this equations could takes lot of time, depends of finite elements number and how complex is external load. Last years this problem can be solved in reasonable short time regarding new computers and software possibilities. Calculation of this problem [6] is made using structure analysis modulus of software CATIA V5 R11. In this case of complex bearing load, but relative low number of finite elements calculation process was measured in dozens of minutes.

The stress values calculation in most of FEM software are based on using Huber, Misses and Hencky hypothesis about potential energy of deformations where following Figure 2. shows the result in form of Misses stress distribution on bearing volume:

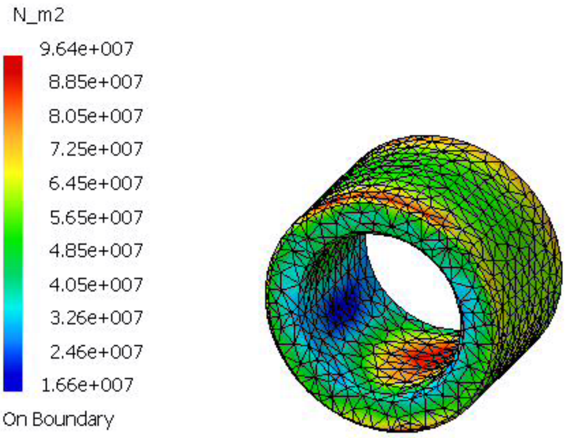

Figure 2: *Stress distribution on bearing volume*

3. FREQUENCY CASE ANALYSIS

The essential phase in a dynamic simulation is to analyze frequency case of simulated object. This means, all relevant own frequencies for defined constrains of sliding bearing as an object, are to be calculated. This phase could also take a lot of calculation time, which requires some new software tools. The bearing simulation problem in this paper is solved using CATIA V5 frequency modulus. For this kind of analysis, the restraints have main influence. As the result of such simulation and analysis, the list of main own frequencies is calculated. Such a calculation and its results give extremely high values of own frequencies for sliding bearing (from 100 to 200 kHz). This could be explained by common sliding bearing restraint in form of clamp on outer surface. Typical frequency value which represents sliding bearing behavior as a high stiffness object could be positioned around 170 kHz, as is shown on Figure 3.

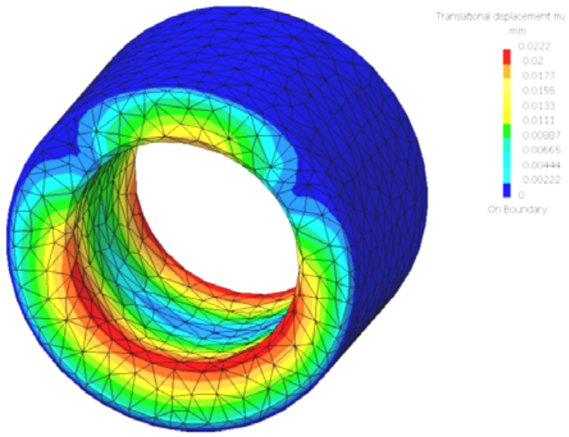

Figure 3: *Translation displacement of sliding bearing at frequency of 170 kHz*

4. DYNAMIC CASE SIMULATION

The dynamic simulation is actually based on:

- Static analysis of stress and strain,
- Frequency case solution,
- Load excitation and
- Damping (on request)

Static and frequency cases are already explained and here is to say a few words about load excitation possibilities. Excitation of load in CATIA V5 software could be defined by many different functions (such are sinusoidal and others). The load excitation in this sliding bearing simulation is used in form of white noise modulation. Damping possibilities are sometimes very important, when so big influence of load changing is to be reduced and make acceptable for further analysis.

As a result of simulation, in this case of sliding bearing analysis under dynamic load conditions, it is very interesting to present some diagrams from dynamic response solution in frequency domain. Actually, here is analyzed dependence of maximal displacement from frequency, in form of real displacement (Figure 4.) and amplitude displacement (shown on Figure 5.).

This diagrams are made in specially chosen nodes of finite elements model, where maximal stress and displacement values could be expected (nodes No.296,301, 303,.318) in high bearing load area.

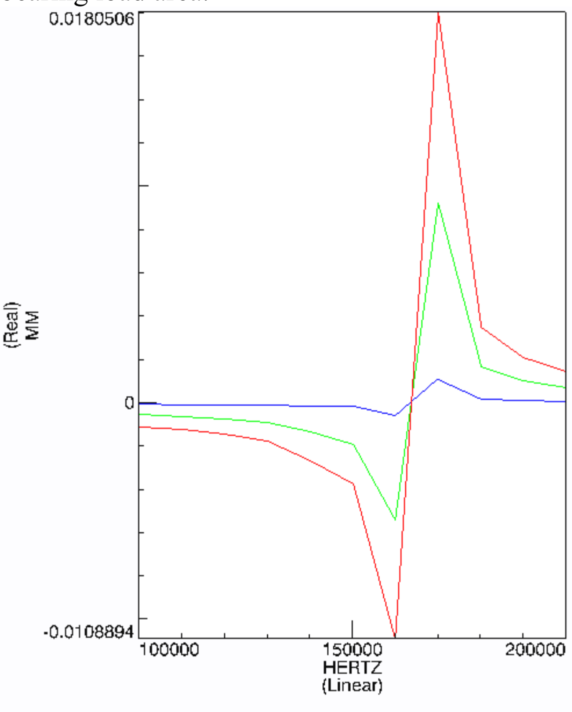

Figure 4: *Real displacement value of bearing nodes, depending on frequencies*

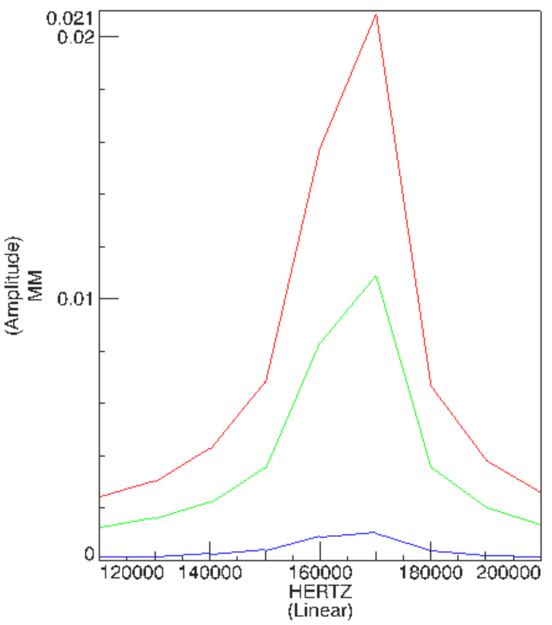

Figure 5. *Displacement amplitude value of bearing nodes, depending on frequencies*

5. CONCLUSION

After this simulation of sliding bearing and analysis under dynamic load conditions here could be concluded that relative small dimensions of bearing that are common used in micro technique and precision mechanics in combination with strong restraints in form of clamp produce very high values of own frequency response (over 150kHz). This result shows that common dynamic loads we meet using all sorts of sliding bearing are not more dangerous for bearing damage compared with static load we have most of bearing operating life.

Here is to say that using another modules of CATIA V5 software, base on dynamic load simulations and analysis results, give us a powerful tool for solving many optimization problems in structure analysis field of bearing and other engineering applications. This topic could be the next step in completing quality simulation and analysis.

REFERENCES:

[1] Rosić B., Marinković A.: Planetary gear transmission as a tribosystem: Efficiency calculation and simulation; “Zuverlaessige Tribosysteme”, *OETG International Tribology Symposium, Vienna, Austria, November 2003., Proceedings pp. 101-108, Proceedings also on CD.*

[2] Marinković A., Rosić B., Pauschitz A.: *Multicriteria optimization as a Tool for Tribology (on sliding bearing example)*; International Tribology Colloquium, Stuttgart / Ostfildern, Germany, January 2004., Proceedings, Volume II, pp. 905 - 910.

[3] Kalajdžić M.,: *Finite element method*, Institute for machine tools, Belgrade, 1978.

[4] Marinković, A.,: *Optimization of Journal Porous Metal Bearing Parameters*, Ph. D. Thesis, Faculty of Mechanical Engineering, University of Belgrade, 2004.

[5] Marinković A., Maneski T., Milosević V.,: *Porous metal bearing temperature problem*, 1st International Conference on Tribology in Environmental Design, Bournemouth UK, September 2000., Proceedings, pp.79-86.

[6] Marinković A.: *Structural optimization of Journal Porous Metal Bearing*, Transactions, 2005.