Study of hydrodynamic behaviour of large bearings depending on the viscosity of the lubricant

Sorin Barabas[1,*], *Adriana* Florescu[1] , and *Flavius* Sarbu[1]

[1]Transilvania University of Brasov, Faculty of Technological Engineering and Industrial Management, Department of Engineering and Industrial Management

Abstract. The research refers to study of hydrodynamic behavior of large bearings equipped with automatic lubrication system, where the liquid used may have a viscosity with variable values depending on the temperature or depending on the additive used. The introduction of additives with nanoparticles causes modification of viscosity and a significant reduction of friction coefficient. This study establishes a direct link between the friction, viscosity and tensions that occur in the contact area. Experimental studies confirm improving tribological properties of the contact area between the bearing rollers and raceways, through attracting nanoparticles on surfaces in contact and reducing friction coefficient. Accomplished finite element analysis showed decrease of the contact stresses, therefore decrease of the wear and increase the life of the bearing. Research has concluded that influencing viscosity and friction coefficient of lubricant can result in reducing wear of the bearing components, as well as increase the lifetime of bearing.

1 Introduction

Large bearings, used in wind energy assemblies, are mobile components that support heavy loads, in variable conditions. The rolling elements are designed to withstand at working conditions, counting on Hertz contact theory [1], lifetime theories [2], type of movements, dynamic loads and other phenomena who acts in bearings use. A decisive role in increasing bearings lifetime is owned by lubrication.

The quality of lubricants [3] and computerized methods of lubrication [4] protect the rolling elements again wear. The presence of additives with nanoparticles, or other thickener, determine the lubrication process, in terms of increasing the carrying capacity of fluid, reducing the roughness of surfaces in contact, decreasing the working temperature and modifying the viscosity of lubricant. Changes occurred at nanometric level and interactions that occur between influenced factors, have an effect that is not fully explained by elastohydrodynamic theory. Knowledge of lubrication system depends by necessity for analysis of the phenomenon, and conducting experiments that highlights the link between the viscosity of lubricant, dynamic load and contact stress appeared in rolling elements.

* Corresponding author: sorin.barabas@unitbv.ro

The influence chart of nanoparticles insertion on the hydrodynamic behaviour of bearings is presented in Fig.1.

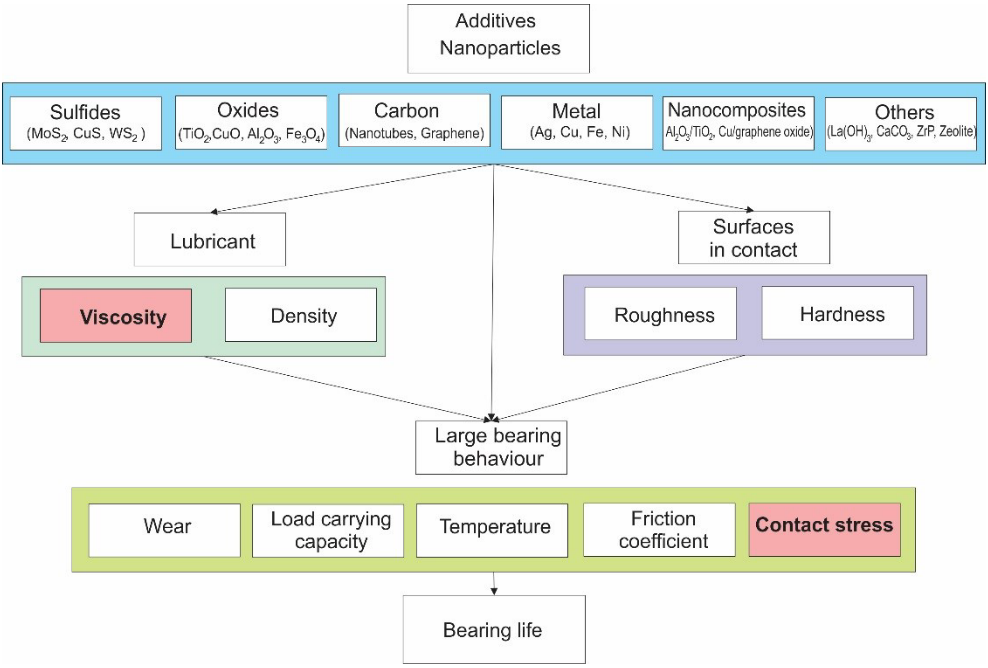

Fig. 1. The influence of nanoparticles insertion on the hydrodynamic behavior of bearings

The insertion of nanoparticles change the lubrication mechanism, improving tribological performance and decreasing the friction coefficient. Several nanoparticles like sulfides, oxides, carbon-based nanoparticles, nanocomposites (MoS_2, TiO_2, SiO_2, carbon nanotube, graphene, Al_2O_3/TiO_2), mixed in the lubricant, have multiple effects: nanoparticles penetrate the surface in contact, decreasing roughness and thus, the friction coefficient, also, grow carrying capacity of the lubricant film with raising of viscosity and decrease of temperature. Depending on the type and size of nanoparticles, friction reduction is 25% to 50% and wear reduction is aprox. 25% [5]. For metal nanoparticles (Ag, Fe, Ni, Cu, Sn) is recorded an effect of forming a protective film, raising the sliding process and the sintering effect, due to chemical absorption of nanoparticles in surfaces in contact and form a thin layer at nanometric range, having hydrodinamic properties. The multiple actions of nanoparticles insertion in lubricant on the bearing behavior, make this important subject, a matter difficult to modeling because of interdependence of considered effects.

Because the resulted viscosity depend of type, quantity and consistency of thickener, of type and viscosity of base lubricant, temperature of process, sliding speed, size of surfaces, this paper aims to establish only a relation between viscosity of lubricant (modify by nanoadditives) and contact stress occurred in contact zone with use of FEM analysis and some constraints placed to rolling elements.

Large bearings with cylindrical rollers, utilized in wind power energy, have a moderate rotational speed but the presence of large dynamic load forces require a good lubrication with monitoring the thickness of lubricant film [6]. Are usually used a grease with a mineral oil base and lithium thickener. For maintaining a lubricant film at medium speed and heavy loads, a good results was obtained with MoS_2 and carbon-based nanoparticles additives. [7].

2 Mathematical modeling

Computation of the contact stress occurred in contact zone, between roller and raceway is based on hypothesis that the surfaces in contact are separated by a lubrication film whose thickness is changing with viscosity of grease. Some constraints are made: the lubricant is incompressible, on temperature interval of bearing function, the variability of viscosity of lubricant has negligible influences on chemical composition, the curvature of thickness of lubricant film is ignored and effect of turbulence is considered null because the speed of elements in contact is reduced [8].

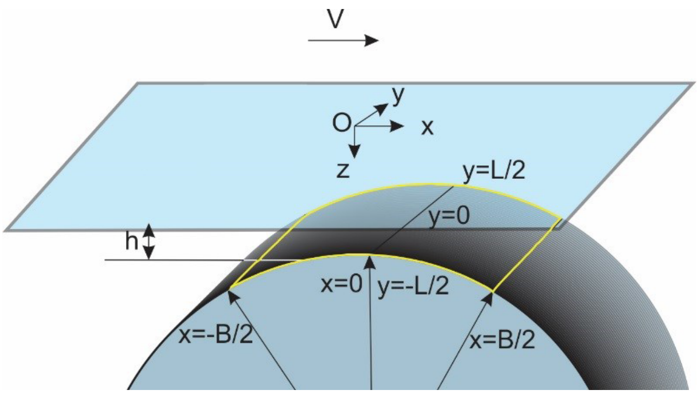

Fig. 2. The geometry of formation of lubricant film

The geometry of lubricant film is shown in Fig.2. Film formation occurs to area 2πRxL and Reynolds equation is:

$$\frac{\partial}{\partial X}\left[\frac{h^3}{\mu}\frac{(\partial p)}{(\partial X)}\right]+\frac{\partial}{\partial Y}\left[\frac{h^3}{\mu}\frac{(\partial p)}{(\partial Y)}\right]=6\mu V\frac{\partial h}{\partial X} \tag{1}$$

where: h is film thickness [mm]; μ is lubricant viscosity [Pa.s]; p is pressure of lubricant [MPa]; V is linear velocity [mm/s]; X is distance on direction parallel to sliding X=2πR [mm]; y is distance on direction normal to sliding $Y=y/L$ [mm], $\partial p/\partial X$ and $\partial p/\partial Y$ are the pressure gradients in the bearing.

Is noted integrals of thickness lubricant [9] I_1 and I_2 [mm/Pa.s]:

$$I_{1(x,y,t)}=\int_0^h\frac{1}{\mu(x,y,t,\xi)}d\xi \tag{2}$$

$$I_{2(x,y,t)}=\int_0^h\frac{\xi}{\mu(x,y,t,\xi)}d\xi \tag{3}$$

where: ξ is parameter of thickness lubricant.

By integration is obtained [5]:

$$Q=\int_0^L\int_0^{2\pi R}p(x,y)dxdy \tag{4}$$

where: Q is load capacity [daN]

The viscosity model is changed for very little particles. It was studied by Brinkman in 1952 [11], who define the relative viscosity ($\bar{\mu}$) the ratio between viscosity of normal lubricant (μ_{nl}) and viscosity of lubricant with nanoadditives (μ_{na}). In 1959 was developed Krieger-Daugherty equation [12]:

$$\bar{\mu} = \frac{\mu_{nl}}{\mu_{na}} = \left[1 - \frac{\phi}{\phi_m}\right]^{\mu_i \phi_m} \quad (4)$$

where: $\bar{\mu}$ is non dimensional relative viscosity; μ_{nl} is viscosity of normal lubricant [Pa.s]; μ_{na} is viscosity of lubricant with nanoadditives [Pa.s]; Φ is nanoparticle volume fraction; Φ_m is maxim particle volume fraction

The equation of viscosity (4) was modified by Chen in 2007, for lubricant with nanoparticle aggregate structure [13]:

$$\phi_a = \left[1 - \frac{\phi_a}{\phi_m}\right]^{-2.5\phi_m} \quad (5)$$

where:

$$\phi_a = \phi\left(\frac{a_a}{a}\right)^{3-D} \quad (6)$$

where: a is radius of primary nanoparticles [nm]; a_a is radius of aggregate of nanoparticles [nm]; D is a fractal index.

The relation [14] between shear stress given by viscous behaviour and viscosity is:

$$\overline{\tau_{ij}} = \bar{\mu}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\nabla\vec{V}\right) \quad (7)$$

where: τ_{ij} is shear stress given by viscous lubricant; $\vec{V}$ is velocity vector in nanolubricant; u_i and u_j are components of velocity on the x, y directions; δ_{ij} is function Kronecker delta.

Deformation h_0, occurred between roller and inner ring surfaces [15] can be written as:

$$h_0 = \frac{2Q}{\pi LE}\left[ln\left(\frac{2R_1}{b}\right) + 0.407\right] + \left[ln\left(\frac{2R_2}{b}\right) + 0.407\right] \quad (8)$$

where: h_o is deformation occurred to the contact between roller and inner ring [mm]; Q is load capacity [daN]; E is Young's elastic modulus [daN/mm^2]; R_1 is roller radius [mm]; R_2 is inner ring radius [mm]; B is length of solid contact between surfaces [mm].

3 FEM analysis for roller bearings with lubricant provided with nanoadditives

Using FEM analysis for study the bearing behaviour in EHD lubrication is made through discretization of equilibrium equations. Bearing chosen for finite element analysis is a large bearing with D=1600 mm, d=1100 mm, and B=440 mm. The roller have following dimensions: D=90 mm, L=180 mm. Material for rollers was SAE 3310. Other properties of used material: Rockwell Hardness – 63 HRC, E=200 kN/mm^2. For simulation, are considered 4 types of lubricant with different kinematic viscosity (ISO VG 100, ISO VG 220, ISO VG 460, ISO VG 1000)

The influence of viscosity on the contact stress and deformations are shown in (1), (7) and (8) equations. The researches done using finite element analysis are executed for 4 different load capacity: 100 kN, 150 kN, 200 kN and 250 kN.

The results of FEM analysis are show in Table 1 and Table 2.

In Fig. 3 and Fig.4 are shown graphics of Von Mises stress and deformations occurs in the roller bearing, depending on viscosity for different values of load capacity.

Table 1. Values of stress and deformation for different type of lubricant

Type of lubrifiant	Von Mises stress (N/mm^2)	Deformation (mm)	Type of lubrifiant	Von Mises stress (N/mm^2)	Deformation (mm)
Q=100 kN			Q=150 kN		
1	1028	0.0151	1	1033	0.0154
2	1016.8	0.0142	2	1026.8	0.0148
3	1005	0.0129	3	1011.7	0.0133
4	997	0.0115	4	1006.4	0.0121

1 - ISO VG 100 (μ=100 cSt) ; 2 - ISO VG 220 (μ=220 cSt) ; 3 - ISO VG 460 (μ=460 cSt) ; 4 - ISO VG 1000 (μ=1000 cSt).

Table 2. Values of stress and deformation for different type of lubricant

Type of lubrifiant	Von Mises stress (N/mm^2)	Deformation (mm)	Type of lubrifiant	Von Mises stress (N/mm^2)	Deformation (mm)
Q=200 kN			Q=250 kN		
1	1037	0.0163	1	1041	0.0175
2	1031.4	0.0154	2	1036.8	0.0170
3	1023.3	0.0143	3	1030.5	0.0163
4	1016.4	0.0130	4	1026.1	0.0148

1 - ISO VG 100 (μ=100 cSt) ; 2 - ISO VG 220 (μ=220 cSt) ; 3 - ISO VG 460 (μ=460 cSt) ; 4 - ISO VG 1000 (μ=1000 cSt).

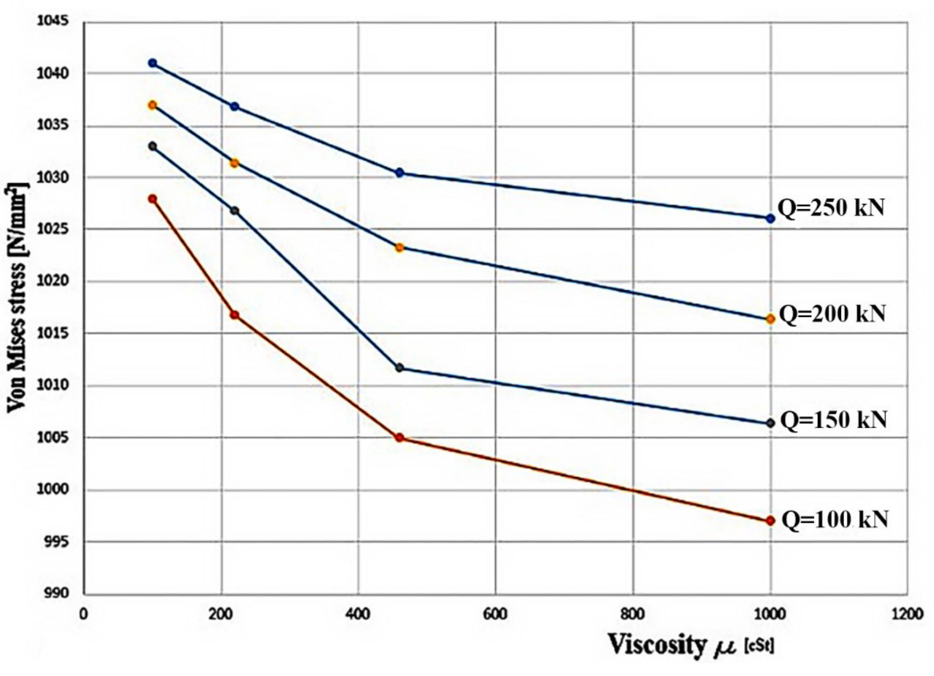

Fig. 3. The graphics of Von Mises stress occurs in the roller bearing, depending on viscosity for different values of load capacity

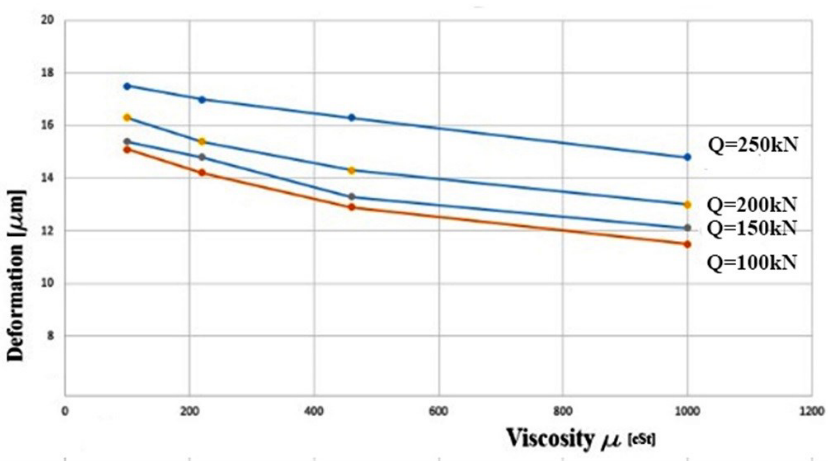

Fig. 4. The graphics of deformations occurs in the roller bearing, depending on viscosity for different values of load capacity

4 Conclusions

In the two graphics is evident influence on viscosity on stress occurs in rolling elements and on deformations of rollers. In Fig.4, adding of nanoadditives increase viscosity of lubricant and decrease Von Mises stress, with significant value. In Fig. 4 was observed a slight decrease of deformations with increasing the viscosity of lubricant.

Use of nanoadditives gives to the lubricant much better properties who confirm improving tribological properties of the contact area between the bearing rollers and raceways, through attracting nanoparticles on surfaces in contact and reducing friction coefficient.

Finite element analysis performed with Nastran program revealed a decrease of stress and deformations.

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