ON THE COMPUTATION OF ELECTRICAL RESISTANCE OF HYDRODYNAMIC JOURNAL BEARING

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Abstract: *The paper approaches the mathematical model of electrical resistance of hydrodynamic journal bearing under different parameters of operation so as to predict bearing performance and safe load carrying capacity. The currents circulating in the journal bearing of electrical machine causes reducing of lifespan by appearance of pitting on their surface and the degradation of the lubricant. In a hydrodynamic journal bearing, the zone of minimum film thickness, load-carrying oil film varies along the circumference of a bearing through its length. This has been found to form a capacitor of varying capacitance between the journal and the bearings dependent on permittivity of the lubricant used, the bearing length, the eccentricity ratio and the clearance ratio. Besides this, load-carrying on oil film offers resistance that depends on operating parameters and resistivity of the lubricant.*

1. INTRODUCTION

On the metallic surfaces of the lining and shaft of the hydrodynamic journal bearing found in dynamic functioning mode, free electric charges appear, producing an electric field in the lubricant film. This electric field causes current either by the resistance effect that occurs between the two plates and by the capacitive effect. Current through the bearings longer appears due to voltage induced in the machine shaft. The study of induced voltage in the electrical machine shaft was approached by the authors in [2] and the electric bearing capacity calculation in [3]. In this paper only electrical resistance of the hydrodynamic journal bearing will be approached. This theme was initially approached by the authors in [4].

The induced currents circulating through the bearings increase the losses of the machine, besides reducing its lifespan. The losses in asynchronous machine and the theme of decreasing losses, was approached by authors in [5].

The majority of the electric charges are found in the area where the lubricant film is at the minimum, noted with h0. The oil used for the lubrication of the bearing has an electric resistivity that depends on its physical characteristics, especially on its viscosity and its consistency. The electric resistivity of the lubricant also depends on the number and nature of the impurities found in the lubricant and on some other products, such as additives, which are used in the oil from the lubricating circuit. As a result of the fact that the metallic surfaces of the lining and of the shaft are electrically charged, and the oil used for the lubrication of the bearing has a low electric conductivity, an electric resistance appears in the bearing. The journal bearing with hydrodynamic lubrication has a variable thickness of the lubricant film along the circumference, the minimum thickness being noted with h0. As a result of the fact that the electric charges are spread unevenly on the metallic surfaces of the shaft and of the lining and that the distance between the metallic surfaces is uneven, we can speak of a specific electrical resistance which exists in the electric field tube that appears between the shaft and the lining of the bearing.

2. DETERMINATION OF THE THEORETICAL ELECTRICAL RESISTANCE OF THE BEARING

The specific electrical resistance of the journal bearing depends on the resistivity of the lubricant ρ, on the area of the metallic surfaces of the shaft and lining, on the eccentricity ratio e and on the lap c that exists between the shaft and the lining of the bearing. The specific electrical resistance of the bearing is the lowest in the point where the lubricant film has the minimum thickness h_0 and it increases once with the increase of the lubricant film. In a journal bearing, the thinner the film is, the higher the electrical conductivity gets. This means that the electric charges accumulated on the metallic surfaces of the shaft and of the lining will be passing easier through the lubricant film in the area where the film is thinner. In this area the lubricant film is also subjected to very high pressure p, due to the charging of the bearing. These external forces affect the geometry of the oil molecules, which leads to the increase of the electric conductivity of the lubricant.

The uneven distribution of the electrical charges on the metallic surfaces of the shaft and lining and the uneven thickness of the lubricant film make the calculation of the electrical resistance of a hydrodynamic journal bearing a very difficult one. In order to calculate the equivalent electrical resistance, which appears in the electric field tube existing between the metallic surfaces of the bearing shaft and lining, we started from the fact that the specific electrical resistance of the bearing is minimal in the area where the thickness of the lubricant film is minimum h_0. The calculation of the electrical resistance has been done in the area where the majority of the electrical charges are found and where the thickness of the lubricant film is at its minimum, this means the area where the position angle takes values from $+\theta$ to $-\theta$ reported to h_0. We named this value of the electrical resistance of the hydrodynamic journal bearing, the equivalent electrical capacitance of the field tube. The conducted theoretical and practical studies confirm the fact that the total electrical resistance of a hydrodynamic journal bearing is very close to the value of the equivalent electrical resistance, calculated in this mode.

The determination of the equivalent electrical resistance of the bearing is made starting from the schematic representation of the bearing illustrated in Figure 1.

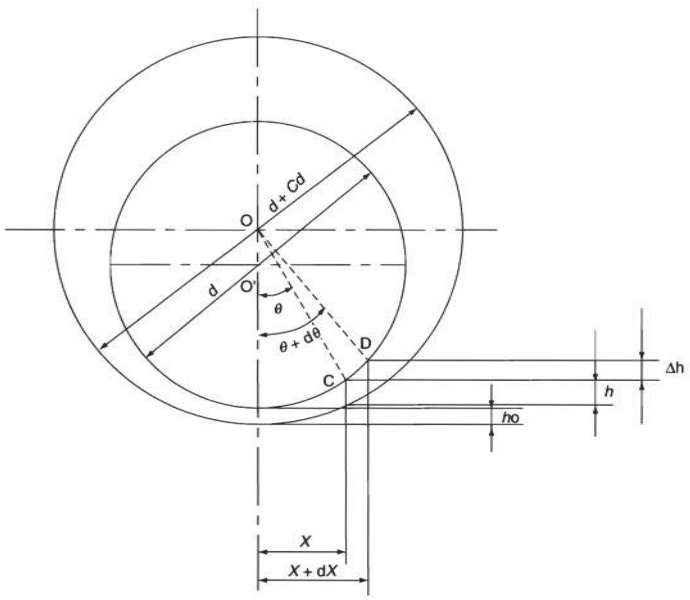


Fig. 1 - The configuration of the shaft in the hydrodynamic journal bearing [2]

The thickness h of the lubricant film in an arbitrary point C on the bearing surface, situated at an angle θ from position where the thickness of the lubricant film has the minimum value h_0, is given by the following formula:

$$h = C_r\left[1 - \varepsilon \cos\theta\right] \tag{1}$$

where

ε is the eccentricity ratio;

θ is the angle from the vertical position of the bearing;

C_r is the distance from the bearing center, O, to the h_0.

And the minimum film thickness is obtained when $\theta = 0$ and given as:

$$h_0 = C_r(1 - \varepsilon) \tag{2}$$

The change in conductance/resistance-1 (ΔF_b) between two rectangular plates of width dX situated between (X + dX) and X along X-axis (along the bearing circumference) of bearing length L (along Y-axis) located at the attitude angles varying between (θ + dθ) and θ and separated by a film thickness varying between h + Δh and h (Fig. 1), is given as:

$$\Delta F_b = \frac{dX\,L}{\rho\,h} \tag{3}$$

From relation 3, we find that the variation of the conductance depends on the thickness of the lubricant film h and the thinner h is, the higher the conductance is. Along the circumference of the bearing, the thickness of the lubricant film is minimal in point h0. The further we get from this point and the higher the angle θ becomes, the thicker the lubricant film becomes, reason for which the conductance F decreases.

In order to find the highest value for the conductance of the lubricant film for a hydrodynamic journal bearing, we'll integrate between the position angle +θ and–θ reported to the minimum thickness of the lubricant film noted with h0. In point h0 the position angle is zero, thus θ = 0. From figure 1, it is evident that

$$dX = \frac{d\theta\,d}{2} \tag{4}$$

If we substitute relations 1 and 4 in relation 3, the variation of the electrical conductance for the hydrodynamic journal bearing, represented in figure 1, is given by relation

$$F_b = \frac{1}{R_b} = \int_{-\theta}^{\theta} \frac{(L/\psi\,\rho)d\theta}{(1-\varepsilon\cos\theta)} \tag{5}$$

After the integration of this relation between the the position angle +θ and–θ reported to the minimum thickness of the lubricant film noted with h0, we obtained the following relation for the equivalent electrical resistance of the hydrodynamic journal bearing:

$$R_b = \frac{\left\lfloor \rho\psi\left(1-\varepsilon^2\right)^{1/2} \right\rfloor}{4\,L\tan^{-1}\tan 0.5\theta\left[\frac{(1+\varepsilon)}{(1-\varepsilon)}\right]^{1/2}} \tag{6}$$

The specialized publications in this field [4] confirm the fact that the variation of the specific electrical resistance of the hydrodynamic journal bearing is maximum between the limits in which the position angle takes the values +π/4 şi –π/4, reported to the area where the thickness of the lubricant film is minimal, and the position angle θ takes the value zero.

Having these conditions for the integration interval, the equivalent electrical resistance of the hydrodynamic journal bearing is determined with relation

$$R_b = \frac{\left\lfloor \rho\psi\left(1-\varepsilon^2\right)^{1/2} \right\rfloor}{4\,\delta\,d\tan^{-1} 0.41\left[\frac{(1+\varepsilon)}{(1-\varepsilon)}\right]^{1/2}} \tag{7}$$

Where:

ε is the eccentricity ratio;

δ is the bearing shaft length and diameter ratio (δ = L/d);

ρ is resistivity of lubricant

To study the variation of the equivalent electrical resistance of the bearing, we used the hydrodynamic journal bearing, which in dynamic functioning mode has 360 or 600 revolutions and 3600 rotations/minute, and the lubricant used is an oil with additives for LA32 type bearings, which has the electrical resistivity ρ=1014 Ω·cm.

2.1 The influence of the ratio ψ over the equivalent electrical resistance Rb

The study of the variation of the equivalent electrical resistance Rb for the hydrodynamic journal bearing when ratio ψ modifies, has been conducted considering that the eccentricity ratio ε and the ratio δ between the length and the diameter of the shaft are constant. The study of the variation of the equivalent electrical resistance Rb for the bearing is conducted for the situation in which the same lubricant, the LA 32, STR 5152-89 type of oil is used for the hydrodynamic journal bearing. The electrical resistivity ρ of the lubricant used for the lubrication fo the bearing has the value 1014 Ω·cm. The hydrodynamic journal bearing considered to be the experimental bearing, has:

lap c = 0,08 mm;

ratio ψ = 0,0013.

In order to determine the mode in which the variation of parameter ψ influences the variation of the equivalent electrical resistance Rb for the hydrodynamic journal bearing, we assumed that the lap c of the shaft modifies with +/-0,01 mm reported to the value obtained through calculation, which for this bearing is of 0,08 mm. In this situation, the lap c between the shaft and the lining of the bearing, which the calculation showed to be 0,08, modifies and is found in the interval 0,07 – 0,09. For a variation of lap c of the bearing, in the interval 0,07 – 0,09, ratio ψ will have a variation between 0,0011 and 0,0015. The variation of the equivalent electrical resistance for the hydrodynamic journal bearing, for the three values of ratio ψ: 0,0011, 0,0013 and 0,0015 are presented in table 1.

Table 1. The variation of the equivalent electrical resistance with the ψ ratio

Ratio ψ [mm]	ε	0,0011	0,0013	0,0015
The bearing resistance [10^9 Ω]	0,9	2.27	2.67	3.088
The bearing resistance [10^9 Ω]	0,72	2.30	2.71	3.14
The bearing resistance [10^9 Ω]	0.58	2.32	2.74	3.17

The next graphs show the variation of the echivalent electrical resistance of the bearing

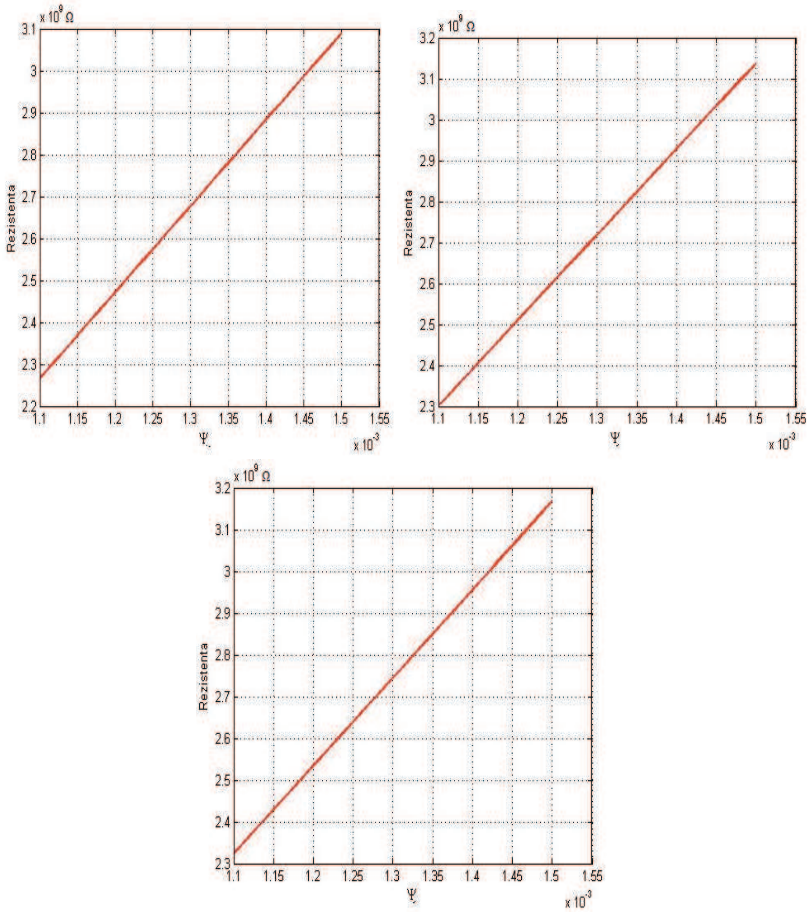


Fig. 2 - The variation of the equivalent electrical resistance of the bearing with ψ ratio

2.2 The influence of the eccentricity ratio ε over the equivalent electrical resistance

The study on the influence of the eccentricity ratio ε over the equivalent electrical resistance of the bearing, Rb, is made keeping constant the values of ψ ratio and δ ratio. The resulted values are presented in Table 2.

Table 2. The variation of the equivalent electrical resistance with the ε ratio.

The eccentricity ratio ε	ψ	0,58	0,72	0,9
The bearing resistance [10^9 Ω]	0,0015	1,52	1,10	0,51
The bearing resistance [10^9 Ω]	0.0013	1,31	0,94	0,44
The bearing resistance [10^9 Ω]	0,0011	1,11	0,80	0,37

The next graphs show the variation of the equivalent electrical resistance of the bearing.

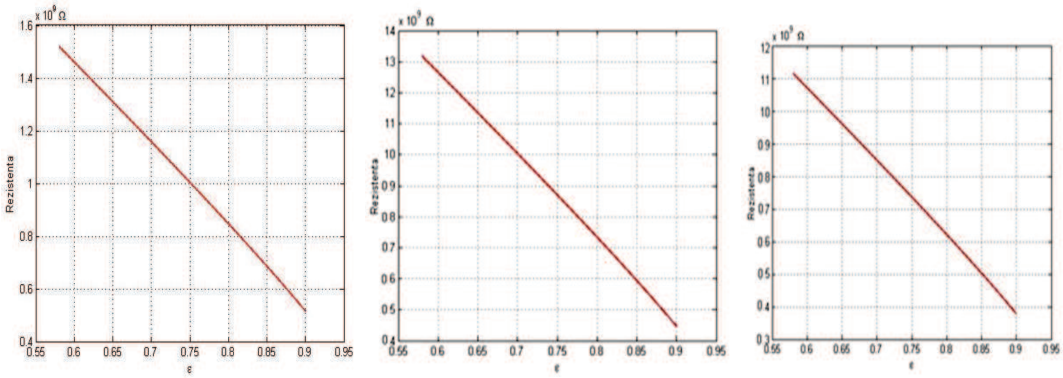


Fig. 3 - The variation of the equivalent electrical resistance of the bearing with ε ratio

Table 3 The variation of the equivalent electrical resistance with the ε ratio.

The eccentricity ratio ε	δ	0,58	0,72	0,9
The bearing resistance [10^9 Ω]	1/2	1,31	0,95	0,44
The bearing resistance [10^9 Ω]	1	0,65	0,47	0,22

The next graphs show the variation of the equivalent electrical resistance of the bearing.

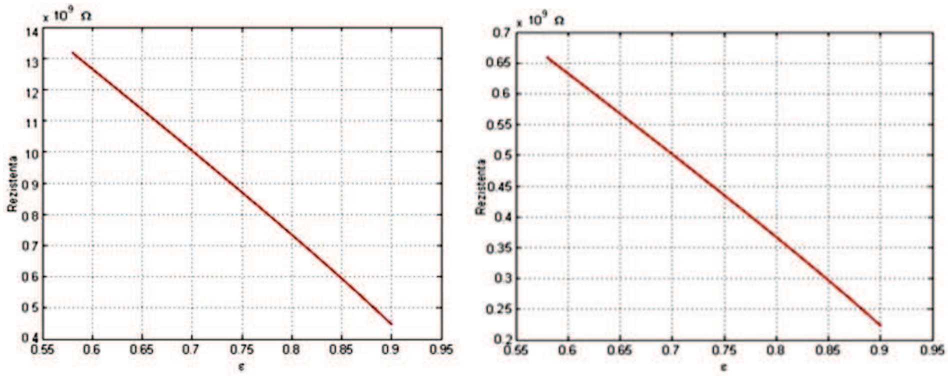
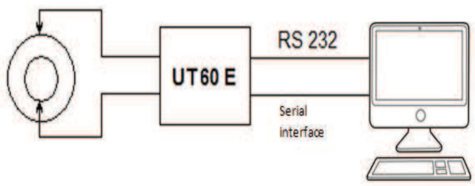


Fig. 4 - The variation of the equivalent electrical resistance of the bearing with δ ratio

Experimental study of electrical resistance of hydrodynamic journal bearings was carried out using the stand presented in fig. 5.



a) Stand scheme

b) Stand foto

Fig. 5 – Stand for determination electrical resistance

Data are acquired with a frequency of three samples per second and transmitted to a personal computer via the standard RS232 serial interface. Transfer rate is 2400 bps.

The studied radial bearing has a nominal diameter D = 60 mm and the width L = 30 mm, bronze material in the composition 88% Sn, 8% Sb, 4% Cu, and the journal material is 18MoCr10.

Effective diameters of the journal and liner are d_e= 59.85 mm, D_e=59.93 mm and bearing width is L = 30 mm. Input speed variation is achieved by means of a gearbox, which provides speeds of 120, 360, 600 and 960 rev / min.

The measured value of the electrical resistance of the hydrodynamic journal bearings at the speed of 120 rev / min, after having been filtered through the sliding average method, are shown in Fig. 6.

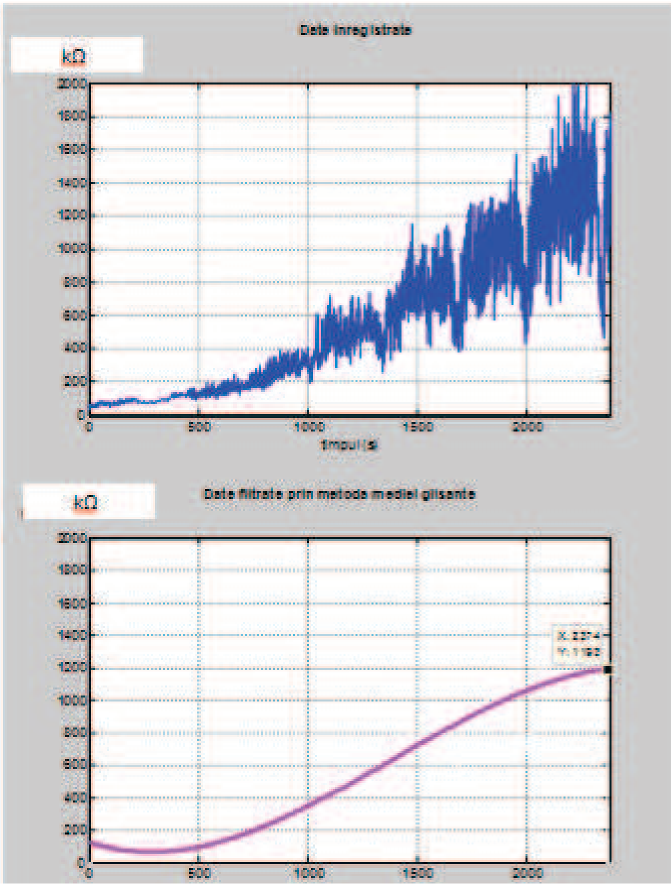


Fig. 6 – Electrical resistance variation with time(s)

3. CONCLUSIONS

The theoretical values of the equivalent electrical resistance Rb of the experimental bearing, presented in three tables and three figures, lead to the following conclusions:

The value of the equivalent electrical resistance Rb of the bearing increases if the ψ ratio increases. The increase of the value of the equivalent electrical resistance once with the increase of ratio ψ is justified, because the lubricant film thickens. Once with the increase of the lubricant film thickness, the conductivity of the oil used to lubricate the bearing decreases, which leads to the increase of the equivalent electrical resistance of the bearing.

The value of the equivalent electrical resistance Rb of the bearing decreases if the eccentricity ratio ε increases. The increase of the eccentricity leads to the decrease of the lubricant film. The decrease of the lubricant film between the shaft and the lining results in the decrease of the equivalent electrical resistance of the bearing.

The value of the equivalent electrical resistance Rb of the bearing decreases if the bearing length and diameter ratio increases. The increase of ratio δ, between the length and the diameter of the tree shaft, from value ½ to 1, is equivalent to the increase of the surface of the bearings shaft and liner. The increase of the metallic surfaces of the shaft and liner, which are electrically charged, leads to the increase of the lubricant film conductivity, which means the decrease of the electrical resistance of the bearing.

Experimentally it was observed that the electrical resistance is not constant over time. At the beginning of operation it grows and then tending to stabilize at a maximum value.

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