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DIAGNOSIS OF THE BEARINGS DURING OPERATION

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Abstract: *In order to prevent aggressive damage, vibration control is required and also monitoring during operation, the easiest method being the one with acoustic probe placed as close as possible to the bearing which is to be controlled. The analysis concerning the field of time requires simple equipment, providing the possibility of fault detection through the apexes positioned at regular intervals in time, for the faults from the internal or external ring, and quasi-regular for the faults on the rolling bodies.*
Keywords: *bearings, moment of friction in bearings, high speed bearings.*

1. INTRODUCTION

The frictions due to the contact deformations are manifested in two aspects:
- internal frictions occured into the material of the bodies in contact;
- frictions obtained by increased resistance at the rolling moment due to the contact deformations.

The first category refers to the energy loss due to internal frictions from the material of the bodies in contact, caused by the fact that the energy needed for bodies' deformation is higher than the one obtained after the action stop of the external load and, consequently, material's relaxation. This povokes a resistance against the rolling motion. Mechanical deformation work is directly proportional to the bearing's rotational speed.
The moment in the bearing generated by the elastic hysteresis is:

$$M_H = \sum M_{Hi} = 5{,}8 \cdot 10^{-7} \cdot d_m \cdot D_w^{-\frac{2}{3}} \sum Q_i^{\frac{4}{3}} \, [\mathrm{Nm}] \tag{1}$$

where D_w is the ball's diameter in [mm]; d_m is the medium diameter of the bearing in [mm]; Q_i is the load requiring a certain body „i" in [N].
While functioning, the rolling bodies are required by the forces perpendicular on the contact surface, coming into contact with the bearing race.
Due to these forces, the bodies in contact are deformed, the dimensions of the deformed surface being based on Hertz's relations.

2. THEORETICAL AND EXPERIMENTAL ASPECTS

To overcome the resistance in the rolling moment, caused by these deformations, a tangential T_i force (Figure 1) is needed. The size of the T_i force will be determined also by the necessity of overcoming the resistance of prominent material occuring before the rolling body, in the same time with a negative pressure generated behind this body, phenomenon caused by the roling motion [1].

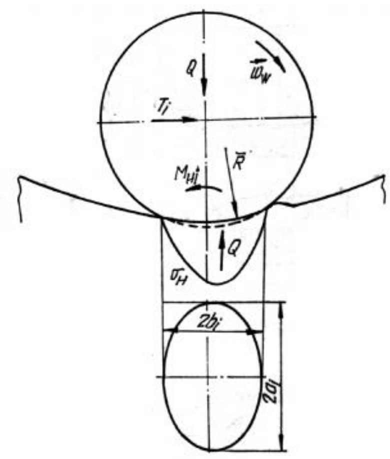

Figure 1

The moment of friction in a bearing may be considered as made up of two components: the friction moment at the idle running M_o independent of the load, and the friction moment M_1 dependent of the load. M_o depends on the bearing's size, the kinematic viscosity of the lubricant ν at the temperature during operation, speed and the coefficient f_o dependent on the constructive type of the bearing and lubrication system.

$$M_0 = f_0 \cdot (\nu n)^{2/3} \cdot d_m^3 \quad (2)$$

where M_o is expressed in [Nmm]; the medium diameter d_m in [mm]; the kinematic viscosity ν in [mm^2/s] and the speed n in [min^{-1}]. The values of the coefficient f_o are given in the catalogues of various companies.

Table 1

The type of the bearing construction:	Type	F_0 FAG	F_0 SKF	F_0 INA
Ball bearings	Grease	$(0,7\text{-}1)\cdot10^{-7}$	$(1,5\text{-}2\cdot10^{-7}$	-
	Oil pan	$(1,5\text{-}2)\cdot10^{-7}$	$(1,5\text{-}2)\cdot10^{-7}$	-
Cylindrical roller bearing with cage	Grease	$(1,5\text{-}2)\cdot10^{-7}$	$(2\text{-}3)\cdot10^{-7}$	-
	Oil pan	$(2\text{-}3)\cdot10^{-7}$	$(2\text{-}3)\cdot10^{-7}$	-
Cylindrical roller bearing without cage	Grease	$(2\text{-}2,5)\cdot10^{-7}$	$(2,5\text{-}4)\cdot10^{-7}$	$(0,2\text{-}1)\cdot10^{-6}$
	Oil pan	$(2,5\text{-}3,5)\cdot10^{-7}$	$(2,5\text{-}4)\cdot10^{-7}$	$(0,4\text{-}1,2)\cdot10^{-6}$
Needle bearings	Grease	$(3\text{-}6)\cdot10^{-7}$	$(1\text{-}10)\cdot10^{-7}$	$(0,1\text{-}1)\cdot10^{-6}$
	Oil pan	$(6\text{-}12)\cdot10^{-7}$	$(3\text{-}9)\cdot10^{-7}$	$(0,3\text{-}0,9)\cdot10^{-6}$

In Table 1 are presented the values of the coefficient f_o to calculate the friction moment at the idle running of M_o bearing. Analysing the values from the chart, it is found that, beside the large dispersions from one catalogue to another, there are also dispersions of the coefficient f_o even within the same catalogue (Chart 1). At the same time, the indicated values for f_o don't take into account a series of particularities related to the lubricant quantity from the bearing, the heat exchange, etc. In case of oil lubrication, M_o depends on the oil quantity offered to the bearing. In case of greasing, if the quantity is too much, M_o increases, because the excess must be removed from the bearing's components. And in case of oil mist lubrication (minimum quantity), the value of f_o may decrease until the half value of the oil pan.

The friction moment M_1 dependent on the load can be calculated, according to Palmgren:

$$M_1 = f_1 \cdot g_1 \cdot P_0 \cdot d_m \quad (3)$$

where: - f_1 is a coefficient depending on the construction and relative load of the bearing
- g_1 is a coefficient dependent on the direction of the load
- P_o represents a static load equivalent of the bearing
- d_m is the medium diameter.

The coefficient f_1 is a constant dependent on the equivalent static load, radial or axial load provoking in the bearing the same deformation as the real load.

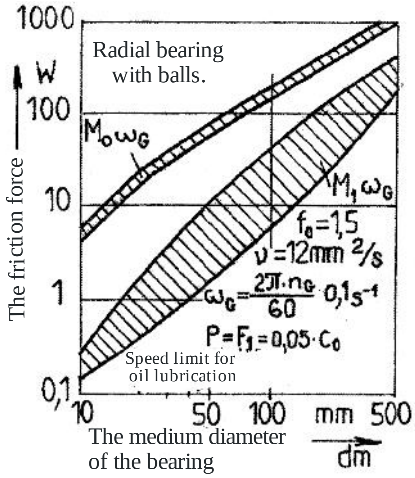

Figure 2: Variation of the rolling power for the ball bearing.

In Figure 2 are presented the force of the idling rolling, independent of the load ($M_o\omega_G$) and the friction force dependent on the load ($M_1\omega_G$), for a ball bearing at the limit value of the speed and the corresponding load at $0.05C_o$. For a given viscosity of the lubricant and a constant speed, $M_o\omega_G$ depends on the value of the coefficient f_o [2- Bolfa thesis]. The values of the friction moment M_o, obtained when the bearing functioned without radial load, together with the product (ν n) have been represented in the diagram of Figure 3.

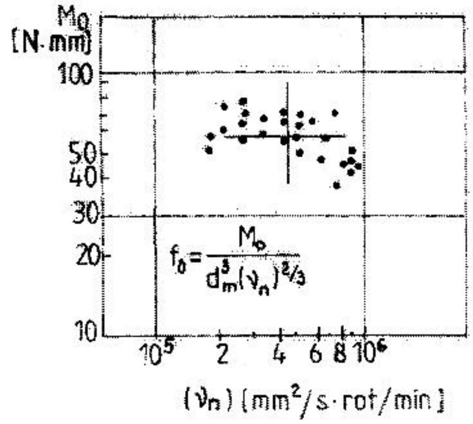

Figure. 3: Value representation of the friction moment M_0

Taking into consideration the medium values for M_o and the product (ν n), the coefficient f_o was determined from the relation (2), whose value resulted to be $1.4 \cdot 10^7$.

Compared to the recommendations of different catalogues, the value determined experimentally approaches to the inferior limits, due to the decrease of the frictions with the lubricant, in the case of using the drop lubrication. In conclusion, also for high speed, the calculus relation of the moment M_o is usable.

Loading the bearing with radial forces, under the same speed and lubrication conditions, are determined the values of the total moment (M_o+M_1). Knowing the values of M_o, previously determined, can be found the values of M_1, represented graphically as loading function (Figure 4), in a logarithmic coordinate system.

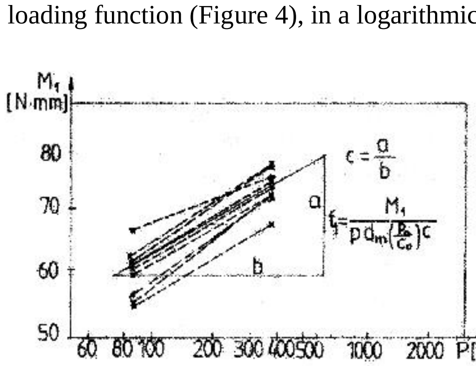

Figure 4: Value representation of the friction moment M_1.

For the drawn lines, it has been calculated and drawn the regression line, whose slope *c* represents the exponent of the relation (P_o/ C_o), which has the value of 0.55, in the given situation. This value is consistent with the indications given in the catalogues.
It can be concluded that for the standard bearings, when are drop lubricated, the catalogue relations can be used also at high speed, using the minimum values from the catalogue for the factor f_o. Using oil mist lubrication, but especially making constructive changes related to the decrease of the friction from the bearing, the factor f_o may be reduced considerably (until values of 1/10 from the ones from the catalogue).

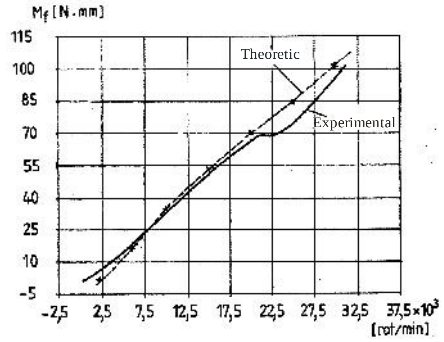

Figure 5

In Figure 5 is presented the graphic representation of the variation for the friction moment depending on the speed. Some perturbations occur when the speed is high of (18.000- 23.000) rpm, because of the loss of cage's stability.

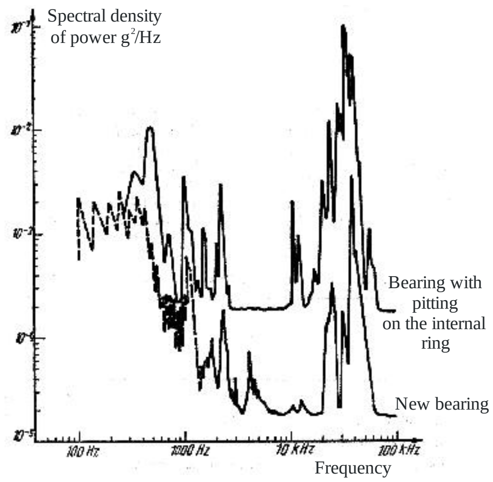

Figure 6

In Figure 6 are presented the outcomes of the analysis for a faulty bearing, compared to a faultless bearing. It can be corelated the size of the fault with the occurence of a distinct "shock" frequency, as a counter-value of the time needed for a rolling body to go through the length of the fault. The faults' sizes and their number lead to changes in the frequency spectrum, as the deformations expand, the damaged areas from the spectrum amplify in the field of frequencies (1- 100) kHz. (Fig.6). The contamination particles lead to spectrum changes both in the fields of excitation frequencies, and also in the entire frequency spectrum, this way creating the microshock conditions.
The analysis in the amplitude field through probability density can bring important specifications, compared to the simple counting of some apexes. If it is marked as p(x) the probability density for a given distribution of the signal, the following values can be defined:

- medium value $M_1 = \int_{-\infty}^{+\infty} p(x)x\,dx = \overline{x};$
- the dispersion $M_2 = \int_{-\infty}^{+\infty} p(x)x^2 dx = D^2 = \sigma^2;$

➢ the asymmetry coefficient $\sqrt{\beta_1} = \frac{M_3}{\sigma^3} = \left(\int_{-\infty}^{+\infty} p(x)(x - \bar{x})^3 dx \right) / \sigma^3$

➢ the influence coefficient of the apex $\beta_2 = \frac{M_4}{\sigma^4} = \left(\int_{-\infty}^{+\infty} p(x)(x - \bar{x})^4 dx \right) / \sigma^4$

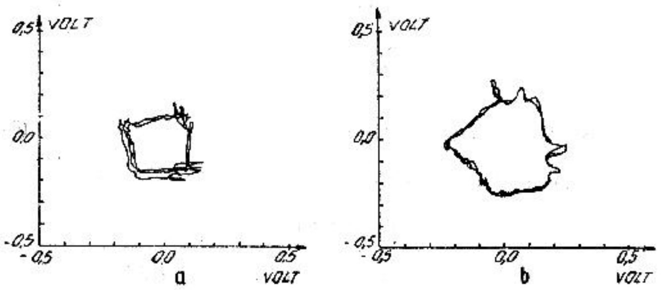

Figure 7

In Figure 7 are presented the results of the measurements for the position of the shaft center if settled on a sealed bearing in case *a*, and on a bearing with removable cage in case *b*, for which the displacements of the shaft centre are higher.

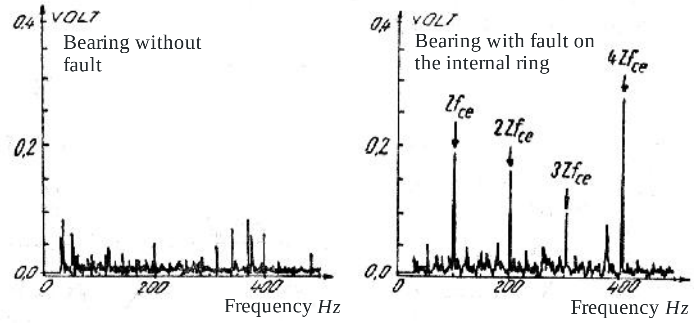

Figure 8

The faults on one of the rings occur as much as obvious in the frequency spectrum (Figure 8), either for the first harmonic of the excitation corresponding to balls' passing over the faulty area, or for the second or third harmonic.

3. CONCLUSION

An important issue for a structure is the early determination of some faults during operation, that could lead to serious demage during operation. For the bearings, the level of vibrations and noise is a global quality indicator, showing off the product's competitivity, correlating it with the failure, indicating the occurence and size of the faults, acting either through direct effects as acoustic radiation, or through indirect effects at the level of other elements (shafts, shells).
The vibration and noise provide a significant sensitivity to the analysis, developing the processing techniques of the signal.

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