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USE OF DIFFERENTIAL EQUATIONS TO MEASURE THE POWER LOSS IN SLIDING BEARINGS WITH DIFFERENT LUBRICATING OILS

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Abstract. *The loss of energy occurs in any type of equipment. In the bearings, the insertion of a lubricant into the gap between shaft and bearing reduces the friction of metal-to-metal contact, thus, the energy dissipation being mainly represented by the dissipation of viscous energy from the fluid. The objective of the present work is to study the loss of power in electric motor bearings for different lubricating oils in order to find the most suitable lubricating oil to minimize the loss of energy due to heat dissipation. The power's loss reduces proportionally according the reduction of viscosity and rotation of work. Was noted a reduction of energy loss of 53% by changing the lubricant specified in the study by ISO VG 32.*

Keywords: *dissipation, heat, electric motor, lubricating oils.*

1. INTRODUCTION

In any type of transmission, power loss is inevitable. A transmission system includes axles, bearings, friction wheels, drive belts, chains, and gears that must be properly installed and subjected to regular maintenance operations. The losses are caused by the friction between the surfaces, agitation of the lubricating oil, slipping between belts and pulley, among other situations. Bearings are devices used to support loads and provide adequate and necessary support to the axles and general components of a transmission. The life of the sliding bearings may be prolonged if some construction parameters are observed, one of which includes the lubrication system used.

For lubricating oils the viscosity is among the main factors for the selection. If the viscosity is too low, the formation of the oil film will be insufficient, becoming the cause of abnormal wear and overheating. Conversely, if the viscosity is too high, the shear strength of the oil may cause heating or increase power loss. In general, low viscosity oils are used the higher the speed of rotation; and the higher the load and the bearing, the higher viscosity oils should be used (NSK, 2013).

Simple or sliding bearings are those in which the sliding represents the principal relative movement between the shaft and the bearing, and can be classified as flat, guide and anchor (Carreteiro and Belmiro, 2006). In order to allow free rotation of the shaft and compensate for possible expansion and misalignment, the bearings are designed with small clearances, also used for the lubricant distribution (Lima, 2003).

According to Niemann (2000), the operation of modern machines depends mainly on the perfect functioning of the bearings in them. The failure of the bearings, be they sliding or rolling, is reason enough to make the machines stop working, causing damages to the production.

The operation of a sliding bearing depends on the formation of a lubricant film, which will only be formed from the relative sliding movement between the parts. These are generally represented by cylindrical surfaces, housing an axis in its interior. The main function of the sliding bearings, existing in machines and equipment, is to provide support and

guidance for the rotating shafts (Shigley and Mischke, 2001). According to the second law of thermodynamics, a viscous flow always tends to lose its available energy because of the dissipation, viscous fluids lose mechanical energy irreversibly (White, 2011).

Based on this, the loss of power for different lubricating oils used in induction electric motors was analyzed in order to find a lubricant with less dissipated power value.

2. MATERIALS AND METHODS

The objective of the present work is to study the loss of power in a sliding bearing in a three-phase induction electric motor used in the petroleum industry for different lubricating oils in order to find the most suitable lubricating oil to minimize energy loss through dissipation of the heat. The Table 1 shows the bearing specification.

Table 1. Data used to calculate heat transfer.

Measure	Value	Comments
D1	79.756 mm	Shaft diameter
D2	79.883 mm	Bearing diameter
H	61.7 mm	Length of fluid contact
N	300 – 5000 rpm	Rated rotations
L	0.0635 mm	Space between D1 and D2 (gap)

According to Çengel (2011), the bearing oil flow can be approached by a flow between two parallel plates, one being in motion and the other stationary, like shows the Fig.1.

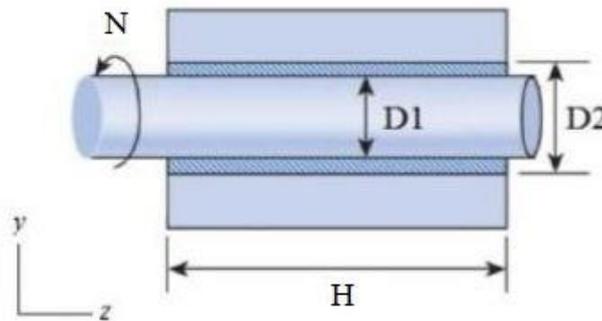


Figure 1. Schematic drawing of the bearing.

The lubricant specified by the manufacturer is the MOBIL VACTRA N° 2 (MV2). For the study, three ISO VG industrial lubricating oils were chose for lubrication of machines in general.

Besides these, three other industrial lubricants (SAE) applied to the lubrication of machines in general were evaluated.

Table 2 shows the properties of interest of each oil at the temperature closest to the working temperature for simplification of the calculations.

Table 2. Technical data of lubricants oils.

Lubricant	Viscosity 40 °C [Pa.s]
1) Vactra MV2 (recommended)	0.060
2) ISO VG 32	0.032
3) ISO VG 46	0.046
4) ISO VG 68	0.068
5) SAE 5W20	0.045
6) SAE 5W30	0.074
7) SAE 5W40	0.084

The viscosity values of ISO VG and SAE lubricants were obtained from the Technicals Informations Catalogs from Tecém (2018) and Texaco (2018).

Considering that the manufacturer does not report the thermal conductivity, the value k is 0.148 W/mK, found in literature was adopted.

For calculation purposes, it's considered that, bearing contact area and the tangential velocity showed in Eq. (1) and Eq. (2) respectively.

$$A = \pi D_1 L \quad (1)$$

$$V = \frac{\pi N D_1}{60} \quad (2)$$

The flow of the lubricating fluid inside the slide bearing can be idealized as a Couette flow, this flow occurring between two flat plates, where one is moving and the other is stationary (Incropera *et al.*, 2014). With this, a linear speed profile can be adopted between the bearings when the gaps between the shaft and the bearing are small compared to the bearing radius.

For the development of the problem analysis, the following equations were used are continuity, moment and energy, represented by Eq. (3), Eq. (4) and Eq. (5) respectively.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (3)$$

$$\rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (4)$$

$$\rho c_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) + \mu \Phi \quad (5)$$

Where Φ corresponds to viscous dissipation showed in the Eq. (6).

$$\Phi = 2 \left[\left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial v}{\partial y} \right)^2 \right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)^2 \quad (6)$$

In high velocity flows, viscous dissipation occurs in a dominant manner, causing a significant increase in fluid temperature, resulting from the conversion of the kinetic energy of the fluid into thermal energy (Çengel, 2011).

Solving the system of equations and applying the necessary boundary conditions gives the temperature distribution is given by Eq (7).

$$T(y) = \frac{\mu U^2}{2k} \left(\frac{y}{L} - \frac{y^2}{L^2} \right) + T_0 \quad (7)$$

From the definition of the heat flow, the heat flux in the two plates is determined by the Fourier's Law shows in the Eq. (8).

$$\dot{q} = -k \frac{dT}{dy} \quad (8)$$

To solve the differential equations, some considerations and boundary conditions were necessary like shown below:

- Steady state flow;
- Newtonian Fluid;
- Stable Properties;
- Two-dimensional analysis;
- Isothermal plates $\rightarrow \{T(0) = T(L) = T_0\}$;
- $T = T(y)$.

3. RESULTS

Solving the differential equations by analytical method with the above-mentioned conditions yields Eq. 9. This expression allows to estimate and to compare the loss of power based on the geometric characteristics of the system and the viscosity of the lubricant.

$$\dot{Q} = \frac{\pi DH\mu U^2}{L} \tag{9}$$

where D is the shaft diameter, H is length of sliding, μ is the oil viscosity, U is the linear speed of the shaft and L is the average gap. It's observed that the only parameter that does not favor the heat dissipation with the increase is slack, being a factor inversely proportional the loss of power of the system.

The Figure 2 shows the comparison of the power loss of the recommended lubricating oil with class ISO VG with the aid of Eq. 9.

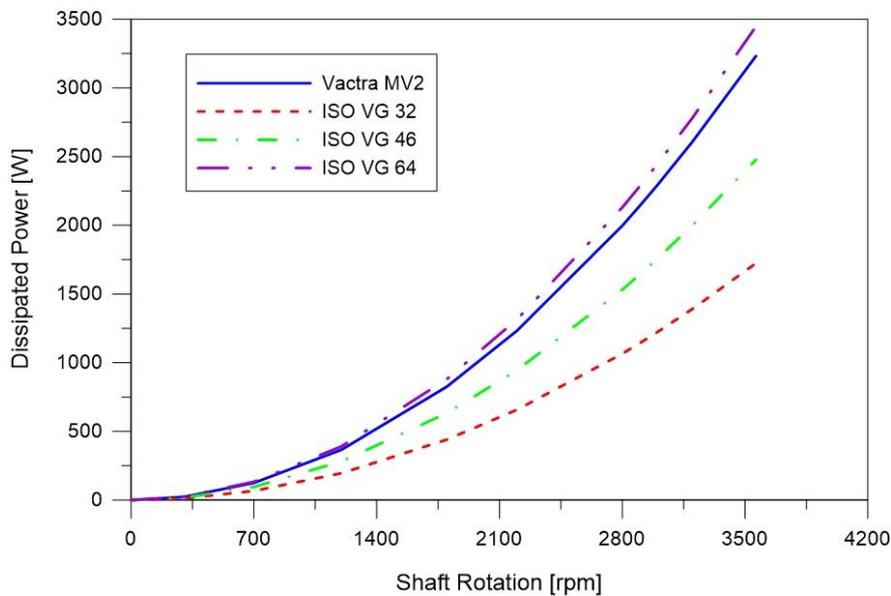


Figure 2. Results of the power's loss for class ISO VG.

Already the Fig. 3 shows the comparison of the recommended lubricating oil with class SAE using the Eq. 9.

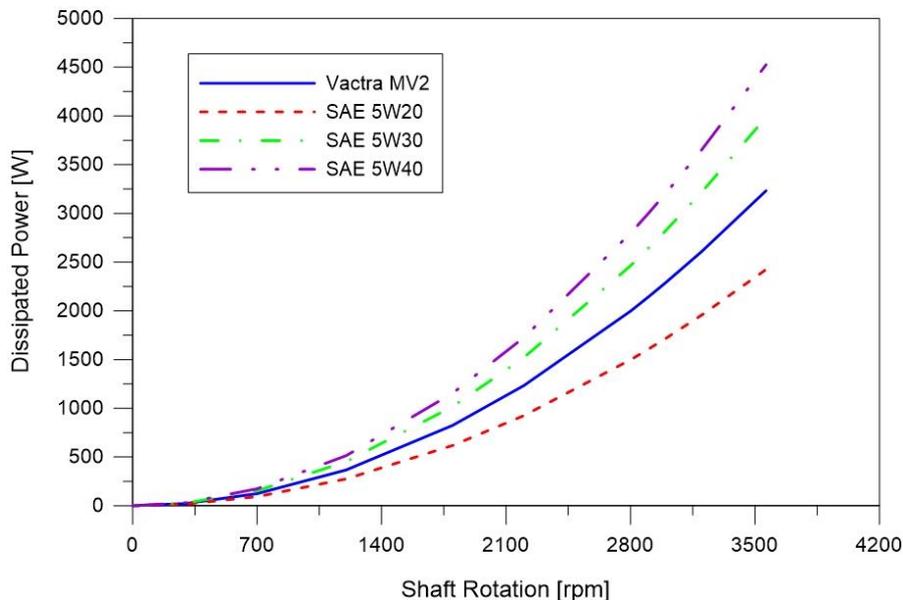


Figure 3. Results of the power's loss for class SAE.

It's noted that the heat dissipation is proportional to the viscosity of the lubricant and shaft rotation. For the high rotations, the lubricants that presented reduction in power loss are ISO VG 32, 46 and SAE 5W20 oil with the most significant reductions in ISO VG 32, about 53% of loss reduction. Therefore, the feasibility of replacing the lubricant oil recommended by the manufacturer with any of the ISO VG 32 oils must be checked.

The most dissipation is observed in SAE 5W40 it showed the increase about 40% of the power's loss. For low rotations, the difference in heat dissipation is very small. Like this, the power loss is proportional to the axis rotation and viscosity of the oil, and according to the manipulation of the equations, proportional to the length of the bearing, the diameter of the shaft and inversely proportional to the gap.

Gabriel *et al.* (2015) proposed replacing MOBIL VACTRA N° 2 (MV2) whit SAE 5W20 for the application in sliding bearing on a milling machine, reducing about 30% of power's loss. The replacing by ISO VG 32 should be analyzed to minimize losses.

Also, it's possible to obtain the distribution of temperature for the various oils analyzed according to the various rotations available. The temperature of the system is also an important parameter to be evaluated, as well as tests to see if lubricants with lower viscosities will leak through the gaps. The Figure 4 and 5 shows the temperature distribution.

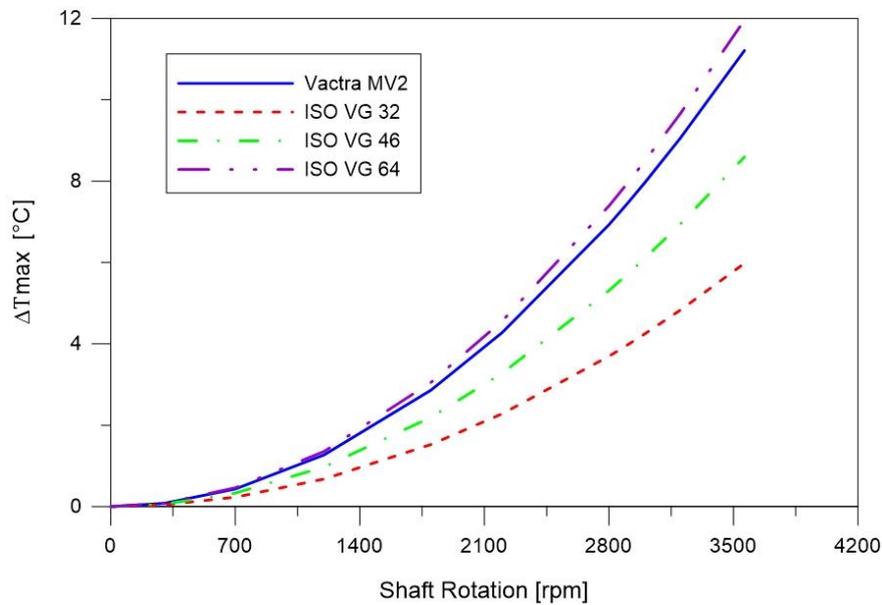


Figure 4. Results of the temperature distribution for class ISO VG.

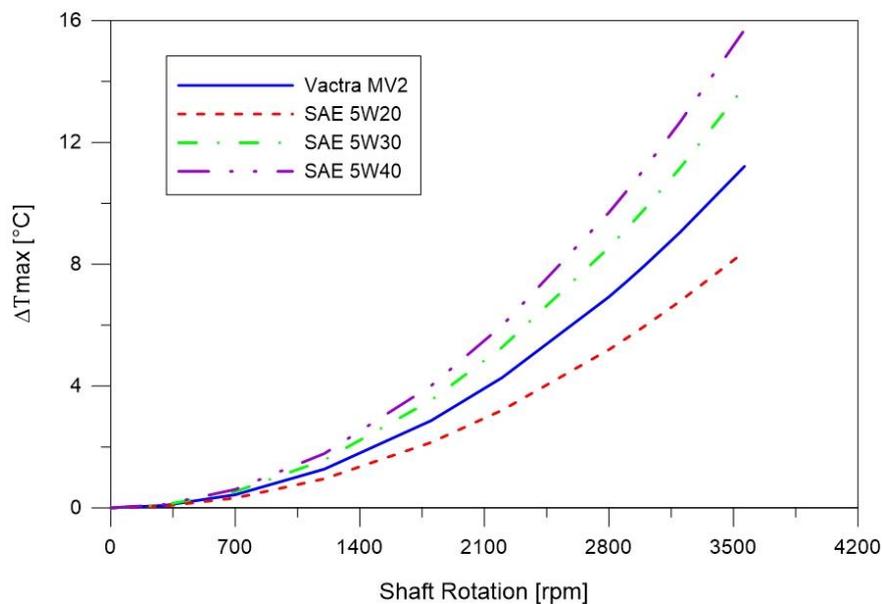


Figure 5. Results of the temperature distribution for class SAE.

For the temperature distribution, behavior similar to that obtained for the loss of power is verified. Lubricants with lower viscosity have, in addition to lower power loss, lower temperature gradients, thus representing lower heating of the system like proposed in NSK (2013). This is important conclusion to ensure a longer life for the equipment or to choose a system, according to the dimensions of the bearing and lubricant required, which has fewer rotational losses and ensure a higher acquisition cost over time.

However, other criteria exist to ensure the correct replacement, such as existing clearances, lubricating oil components, service time, the behavior of the viscosity of the oil with the increase temperature and the costs with the power loss. In order to avoid leakage of oil by gaps and estimate costs for system selection which ensures greater cost benefit.

4. CONCLUSION

By approximating the flow of the lubricating fluid inside the sliding bearing through a Couette flow, it was possible to apply the differential equations of conservation of mass, moment and energy to model the heat transfer of the same, in order to analyze the loss of power and temperature distribution to the recommended lubricating fluid and to analyze the viability of substitution by one which has the best thermal performance.

According to the obtained results, it is understood that, among all, the lubricant that presented a lower power dissipation in function of the evaluated parameters was the ISO VG 32, reducing in approximately 53% the loss of power. Other lubricants have also provided a good alternative for replacement, such as ISO VG 46 and SAE 5W20, as they dissipate less heat compared to the recommended (Vactra MV2)

From this analysis, it becomes very important to verify the possibility and feasibility of replacing the oil recommended by some ISO VG and SAE, since these showed a lower power dissipated.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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