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Analysis of electrical motor mechanical failures due to bearings

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Abstract. Regardless of the high operational reliability of modern ball and roller bearings and advanced methods for their selection and durability calculation, a significant proportion of the failures in the electric motors, about 51% [1], are of mechanical nature. Often, mechanical damage leads to irreversible engine states and costly replacement. Careful theoretical analysis of bearing failures may indicate the root causes of their defects mainly from external for the bearings surface factors and to recommend proper preventive actions. Damage cause can undoubtedly refer to the way in which significant mechanical energy generated in the rotor is transmitted, most often through belt drives or elastic couplings, while the bearings themselves withstand the significant reaction forces that have occurred. A model analysis will be performed to reveal the interconnection of the mechanical power output of an electric motor via belt drive or an elastic coupling to the internal loads and friction of supporting ball or roller bearings. In addition, a suitable lubrication regime for bearings will be examined according to different types of bearings, shaft speed and temperatures.

1. Introduction

Traditionally, the bearing life is predicted by the calculation of subsurface fatigue with a ratio of C [kN]/P [kN] according to ISO 281 [2], but most of the motor bearings fail in the field due to surface defects, although they are calculated for a ratio of 15-20 and more. Failure investigations in more than 90% of the cases show predominantly surface defects like smearing, abrasive and adhesive wear resulting in micropitting, and subsequent ring cracks, etc. [8]. Lubrication conditions also have major influence on this, so proper selection for grease, based on the applications parameters, has to be made.

This study researches the working conditions on the bearings from a 75 kW motor which rotates at 2995 rpm and is loaded with a belt drive or a flexible coupling. As a main criterion for the functionality of the particular bearing type the Frictional Model [3] which considers the comparison between sliding friction Msl and rolling friction Mrr is used.

2. Frictional Model research

2.1 Lubrication selection based on working conditions in electrical motor

The research is based on the specific bearings with temperature (55°C), speed (2995 rpm), and loads ratio (C/P=15 and more) - typically light load conditions for electrical motors [4]. The improper lubrication is one of the biggest reason for mechanical failures of motors bearings. That is why a special web-based application program for a grease selection is used - "LubSelect" [5]. It selects the

right grease based on many working conditions like as temperature, speed, load, position, cleanliness, etc. Table 1 below shows different types of greases that are analysed.

It can be concluded that the speed factor is critical for some greases and it makes them even useless. Nevertheless, improper greases could be sometimes used by mechanics by mistake and thus lead to a failure of the bearings by creating higher friction and additional sliding motion inside them. The best choice for the current case with the given working conditions is the first one from the list LGHP 2 - a special grease designed for an electrical motor usage. It is adequate for ball and roller bearings.

And one additional conclusion - roller bearings are more sensitive to grease speed factor than ball bearings due to the need of more oil in their larger contact zone, especially in lower temperatures.

Table 1. Grease selection ratings for 6217 ball / NU 217 roller bearings.

Grease	Total Rating	Temp.	Speed Ball/Roller	Load
LGHP2	100%	100%	100% / 100%	100%
LGLT2	100%	100%	100% / 100%	100%
LGMT2	100%	100%	99% / 63%	100%
LGMT3	100%	100%	99% / 63%	100%
LGWA2	90%	100%	65% / 24%	100%
LGEP2	90%	100%	65% / 24%	100%

2.2 Motor with a belt drive - wrapped classical V-belt, 17/B profile (PHG B120)
The next step in the research is to check performance of bearings when motor is mechanically connected with a belt drive which parameters are shown in Table 2.

Table 2. Parameters of the belt drive.

Parameter	Value
Rated power [kW]	75
Rated torque [Nm]	239.13
Service factor	1.3
Driver speed [r/min]	2995
Driven speed [r/min]	2096.04
Pulley center distance [mm]	1068.79

Calculated dynamic driver shaft radial load F_r, by set of 6 pcs. with 17/V-belts is around 5000 N and this value is used for the model calculations as a load to the motor drive end - Figure 1.
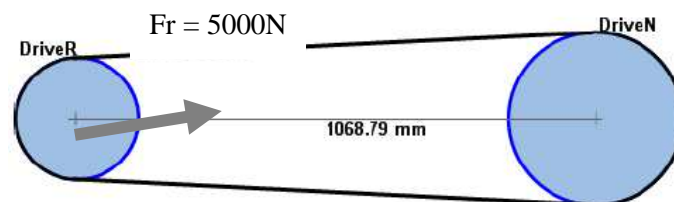

Figure 1. Belt drive layout.

2.2.1 Variant 1. Motor with ball bearings in both sides
Both motor bearings at the drive and non-drive ends are SKF 6217/C3. It is obvious that the drive-end bearing is the most loaded one, so the analysis is focused on it. For the calculations is used a specialized software for bearings analysis named "SimPro Expert" made by SKF [6].

It can be noticed that DE bearing 2 (and system) has a quite low basic rating life - around 16 000 h which is below than recommended duration of 20-40 000 h for electrical motors.
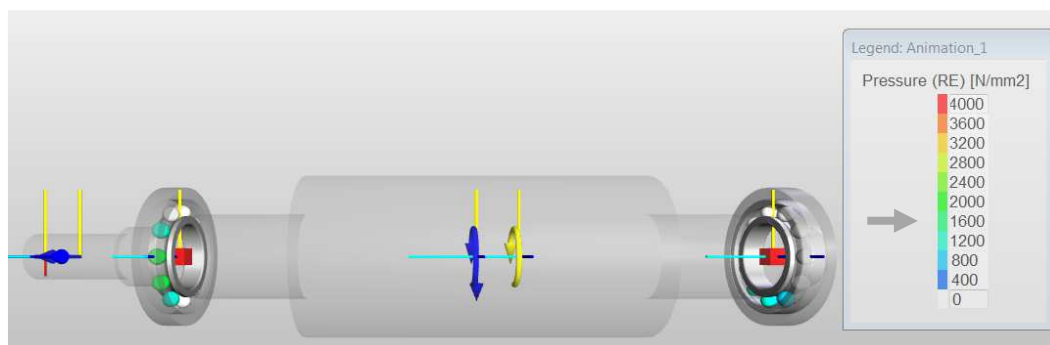
Table 3. Friction torque calculation.

Bearing	Bearing type	C/P	Basic rating life [h]	Speed [rpm]	Temp. [°C]	Starting friction torque [Nmm]	Friction Torque Total [Nmm]	Rolling friction [Nmm] Mrr	Sliding friction [Nmm] Msl	Sliding-to-Rolling ratio
Bearing_1	DGBB **6217/C3**	50	684910	2995	52.5	61.8	288.3	267.7	20.6	0.077
Bearing_2	DGBB **6217/C3**	14.4	16581	2995	57.5	282.1	437.1	343.1	94.0	0.274
	~L_system		**16345h**							

Additional calculations are made for this bearing according to the latest standard for bearing life calculation ISO 16281 [7]. The standard takes into account factors like misalignment, clearance, internal load distribution, lubrication and cleanliness. Result shows an increasing of lifetime until 181 000 hrs. - almost 11 time. For the calculation is used motor LGHP 2 grease. This proves that lubrication has a vital role for the bearing performance and might increase the service life of a motor.

But for the current study the analysis is performed only with a *basic rating life* according to ISO 281 [2] in order to reveal the relationship between rolling, sliding and fatigue. Sliding movements (with Msl) destroy lubrication film between rolling elements and raceways, so it is not relevant to use the *modified rating life* calculations in which lubrication regime has a major role.

On the other hand, the ISO standards do not consider and provide methodology to predict failure mechanisms like wear or microspalling. In order to find a clear indication of possible wearing in bearings the investigation will continue with a comparison of *sliding-to-rolling* ratio which can be a critical key feature. In the Table 3 for bearing 2 the value is 0.274. At the same time internal contact pressures in the loaded zones are in acceptable range - around 2000 MPa - Figure 2.

Figure 2. Roller elements contact loads - max. contact pressure is normal and within 1600-2400 MPa.

2.2.2 Variant 2.Motor with a combination of ball and roller bearings
Bearing: at Drive end is SKF NU 217 ECP and at Non-drive end - SKF 6217/C3.

Table 4. Friction torque calculation.

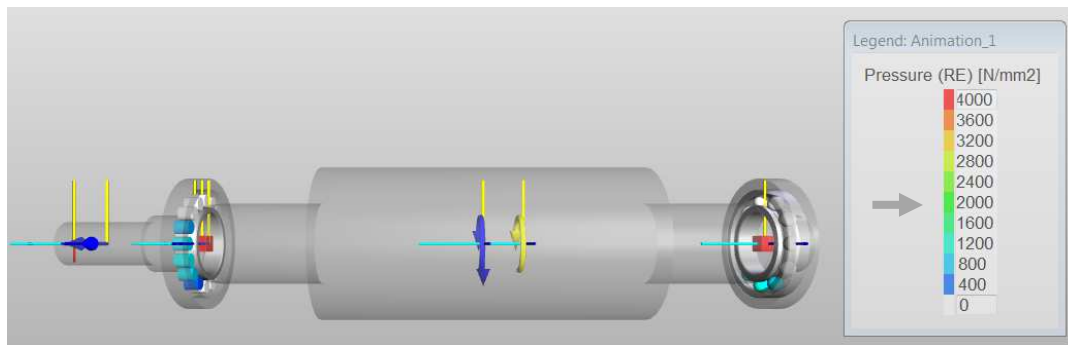| Bearing	Bearing type	C/P	Basic rating life [h]	Speed [rpm]	Temp. [°C]	Starting friction torque [Nmm]	Friction Torque Total [Nmm]	Rolling friction [Nmm] Mrr	Sliding friction [Nmm] Msl	Sliding-to-Rolling ratio
Bearing_1	DGBB **6217/C3**	50	685014	2995	52.5	61.8	288.7	268.1	20.6	0.077
Bearing_2	CRB **NU217**	31	543468	2995	63.5	160	999.3	978	21.3	0.022
	~L_system		**324552h**							

Figure 3. Roller elements contact loads - contact pressures are quite low, around 1200 MPa.

Here in the Table 4 *sliding-to-rolling* ratio for bearing 2 is about 10 times smaller than this in Table 3 and basic rating life of a system with NU217 is increased to 324 552h which is quite satisfied.

2.3 Variant 3. Motor with an elastic FRC coupling on it's drive end
In this part the belt drive is replaced with an elastic coupling which is popular machine part in many motor-pumps or fan applications. In Figure 4 and Table 5 are shown parameters for a relevant coupling type for the 75 kW electrical motor.
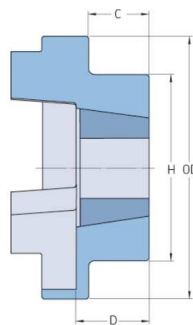

Figure 4. Elastic coupling PHE FRC130FTB, one half of it.

Table 5. Parameters of elastic coupling.

Parameter	Value
Power rating [kW]	98.95
Nominal torque [Nm]	315
Service factor	1.26
Catalogue speed [r/min]	3000
Mass of 2 hubs and rubber element	5.46 kg
Pulley center distance [mm]	1068.79

Table 6. Friction torque calculation.

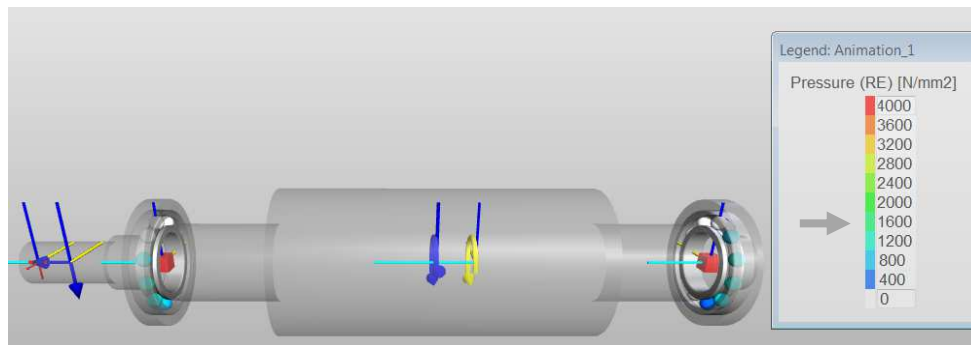| Bearing	Bearing type	C/P	Basic rating life [h]	Speed [rpm]	Temp. [°C]	Starting friction torque [Nmm]	Friction Torque Total [Nmm]	Rolling friction [Nmm] M_{rr}	Sliding friction [Nmm] M_{sl}	Sliding-to-Rolling ratio
Bearing_1	DGBB 6217/C3	56	> 1e06	2995	52.5	49.9	275.8	259.2	16.6	0.064
Bearing_2	DGBB 6217/C3	52	786763	2995	52.5	33	187.6	176.6	11	0.062
	~L_system		473615							

Figure 5. Roller elements contact loads - low contact pressures, around 1200 MPa

In the results from Table 6 sliding friction and *sliding-to-rolling ratio* are small and satisfied. Figure 5 shows that rolling elements contact pressures are within the low values range and should not rise any performance concerns.

3. Conclusions

The sliding friction torque Msl has a destructive nature and creates wear for both roller elements and the raceways of the bearings. In this study in Variant 2 the sliding was reduced 4.4 times than that in Variant 1 (from 94 Nmm to 21 Nmm) just by changing the drive-end bearing type from ball to cylindrical roller one, with the same boundary dimensions. It is fair to mention that the rolling friction has increased 3 times from 343 Nmm to 978 Nmm, but it has also increased drastically the system basic lifetime by 20 times - from 16 000 hrs to 352 000 hrs.

The second important criterion to understand better the bearings functionality (whether rolling elements rotate more than slide) is the *sliding-to-rolling* ratio. Again, a positive result is achieved with a reduction of the above ratio by 12.5 times - from 0.274 to 0.022, when replacing ball with cylindrical roller bearing.

A well balanced and compact solution is a motor connected via an elastic coupling - Variant 3. From the results in Table 6 it can be seen that the value of Msl and Mrr is less than that of the others in the two cases above with a belt drive. Sliding friction Msl is the least in value - only 11 Nmm for bearing 2. *Sliding-to-rolling* ratio is also quite satisfying - 0.062. And the System life has the maximum value compared to the other variants such as L system = 473 615 hrs.

In all three cases the internal contact pressures and loads are within the acceptable limit - below 2500 MPa, far away from heavy contact pressures of 3600-4000 MPa. But this is not enough to make conclusions whether bearings will rotate reliably based only on the internal contact loads. More comprehensive approach is needed to investigate Frictional Model and lubrication regimes.

In Table 7 there are compared values between *sliding-to-rolling ratio* of the most critical bearing 2 from one motor shaft system to the *system basic rating life*. In such a way it is quite illustrative to estimate bearings performance from wearing point of view. The combination of 6217 plus NU217 (Variant 2) with belt drive has an excellent result. Motor drive with the flex coupling (Variant 3) is close to it. But the Variant 1 - a motor with 2x6217 bearings and a belt drive is quite risky and the only

Table 7. Relation between Sliding-to-Rolling and System Basic Rating Life.

	2 x 6217 with Belt Drive	6217 + NU217 with Belt Drive	2 x 6217 with Flex Coupling
(1) Sliding-to-rolling ratio for DE bearing 2 x 0.001	274	22	62
(2) System Basic Rating Life x1000h	16.3	324.5	473.6
Kwear = (1) / (2) ratio	**16.8**	**0.068**	**0.13**

way to mitigate the risk is to grease bearings with high quality grease and to replenish it regularly. It could be said also that the **Kwear** is a sensitive key indicator when it is needed to estimate bearings performance in addition to the comprehensive calculations from ISO 281 and ISO 16281 standards.

Finally, the research proves that the practice of motor producers to recommend when a user needs to buy a motor which has to be modified with a proper bearing types (ball or roller) depending on the mechanical connection for a certain application (through belts or directly via coupling), is correct.

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