Analysis of defects arising during exploitating of elements of rolling bearings

A Gwiazda¹, S Topolska² and W Rakowska³
¹ Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems
Konarskiego 18A, 44-100 Gliwice, Poland
² Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Materials and Biomaterials
Konarskiego 18A, 44-100 Gliwice, Poland
³ Łukasiewicz – Welding Institute, Department of Non-Destructive Testing
Bł. Czesława 16-18, 44-100 Gliwice, Poland
E-mail: aleksander.gwiazda@polsl.pl

Abstract. Bearings are damaged most often as a result of operation under improper lubrication conditions (no correlation between lubricant parameters and operating conditions). This often leads to the operating temperature of the grease being exceeded. Such operating conditions are either the result of the bearing operating under overload conditions (too high load causing the dropping point to be exceeded, leading to lubricant leakage and deterioration of the bearing operating conditions), or the result of improper lubrication of the bearings (application of too little grease and lack of re-lubrication of the bearing or the application of improper grease). The article presents an exemplar analysis of the influence of the exploitation process on their slow degradation.

1. Introduction
Designing heavy-duty engineering systems has always been problematic. One of the elements that were a variable of such projects is the time of failure-free operation and the frequency of servicing. In the case of engines exposed to severe operating conditions, one of the most important structural nodes, in terms of reliability, are the bearings assemblies. Rolling element bearings are the most important part of the bearings assemblies’ components to be found in industrial rotating equipment. They are found in machinery used in different industries. Particularly important is the selection the rolling element bearings in the case of heavy duty machinery systems [1-3].

A bearing itself is a mechanical device designed to reduce friction. It is a part of a machine allowing cooperating elements turns or slides. There are generally two types of bearings: plain (journal) ones and rolling ones. They may come in many sub-varieties. Because of friction reduction they are the most important components of many technical systems. Hence it is very important to have the factors like: carrying capacity and reliability, at high level of sureness. Bearings used in heavy duty machinery must be able to support: the outer loads imposed on the shaft, the momentum generated by the engine, and the loads of the driven machinery. The other task of bearings is to keep the axial movement as well as the lateral deflection of the shaft within acceptable ranges. It helps to maximize the durability of the whole technical system. One must say that bearings operation acts, in a significant
way, on the operation and efficiency of the whole system. On the other hand, the signals in the form of bearing faults main indicator of decreasing performance of the system being monitored within the life-cycle management system. It can be detected on the basis of increasing the bearings vibration [4-6].

Rolling bearing operation is affected by a number of different factors. To them one can include: friction, wear and lubrication mechanisms, fluid dynamics and lubricant rheology, material properties, and contact mechanics. Hence the changes in rolling bearings states occur because of three factors: bearing elements plastic deformation (static), bearing elements contact wear (dynamic), and bearing elements interaction (fatigue). The most common is the contact wear. In this process the particles are torn from the base material and mixed into the lubricant. This converts the lubricant into an abrasive and accelerates the wear of the bearing. The level of wear could be monitored by analyzing the levels of vibrations being the result of surface degradation. Rolling contact wear and occurring at a later stage of bearing operation the rolling contact fatigue can be diagnosed by combining measured monitoring data. It also allows drawing conclusions that could support the day-to-day operation of the bearings to extend their life. One of the basic problems related to the construction of bearing nodes is just their durability. If bearings nodes are designed and used correctly, rolling bearings will last for their intended life. Bearings, however, often fail prematurely due to avoidable errors. Reasons for such premature failure include poor bearing assembly design, poor assembly, or poor bearing performance. This results in insufficient lubrication, the ingress of foreign bodies or excessive heating. The characteristics of a defective wear process in bearings can be defined by these wear symptoms [7-8].

2. Analysis of motor bearings operation conditions. Case study

Induction asynchronous motors (IAM) have a basic role in many industrial branches. They create a very sophisticated system that contains of three main elements: stator, rotor and bearings. Though any working IAM is subjected to faults related with these components. Between the possible faults of bearings one should say that nearly 40% of faults is detected in systems with IAM [9]. In the systems with IAM, bearings are subjected to large stress caused by switching the converter. This is why bearings are more frequent subjected to degradation and to lowering their efficiency. Wear, in such a class of systems, is one of the common causes of faults in bearings. It could be improved by proper control system [10-11].

A case study was carried out because there was a failure of the technical system (heavy duty presses), individually designed press with very high pressure. It turned out that the high-powered motor bearings had failed. In order to determine the cause of the failure, these bearings were tested. Two bearing sets were provided for the tests, as each bearing node was designed as a two-bearing one (figure 1 and 2). Each set of the bearing arrangement included a ball bearing with dimensions of Ø 80 mm / Ø 140 mm SLF 6216 C3 J20A1 142N and a cylindrical roller bearing with dimensions of Ø 80 mm / Ø 140 mm NSK NU2216E JAPAN Z as well as a pressure disk.

Figure 1. First set of bearings and a pressure disk.
The individuality of the project consisted in replacing the hydraulic drive with an electromechanical drive in which a high-power motor was applied. However, after one year of operation, in accordance with the documentation, the system failed. One must say the bearings nodes, in this system was designed as maintenance-free. Therefore, the bearing failure was surprising. Hence the research devoted to explaining this situation.

Figure 3 shows traces of charred grease observed after disassembling the bearings. As the permissible operating temperature of the grease was 180°C, it means that this temperature was exceeded in the bearing nodes.

In order to determine other forms of destruction of bearing elements, they were inspected. As a result, discoloration of the working surfaces of the bearings was found under normal conditions (figure 4, two top photos.). It should be noted that discoloration of the cage, rolling elements and raceways of the rings occurs due to the reaction with the lubricant and high temperature. Its causes are: insufficient
lubrication, oil stains due to reactions with the lubricant, or high temperature. In addition, on both races of the roller bearings, transverse stripes are visible, corresponding to damage such as false Brinell imprints of low intensity (figure 4, two bottom photos). These imprints appear as recessed areas due to vibration and sway wear at the points of contact between the raceway and the rolling elements. This is one type of fretting corrosion [12-14]. The causes are: oscillation and vibration of a non-operating bearing at times such as transport, low-amplitude oscillating motion, or insufficient lubrication.

**Figure 4.** Discoloration of the working surfaces of bearing elements and false Brinell impressions.

Microscopic examination of the working surfaces of the bearings was also carried out (figure 5). The green color was chosen as it best reflects the details of the surface.

**Figure 5.** Microscopic photo of the bearing streak abrasion.
Analyzing the photos taken at various magnification levels, the following defects of the tested bearings are listed; smear rubbing, scratches and the material applied as a result of charring of the grease (figure 6). All of the detected defects in the working surfaces of the bearings are the result of poor lubrication of these surfaces. Additionally, the deposited carbonization products of the lubricant indicate that the faulty lubrication was the result of exceeding its operating temperature. It is worth noting that in one photo you can see the bright blue color of iron oxide bloom [15]. This means that in this place the temperature reached values of 310-315 °C. As the limit temperature of the grease was 180 °C, it should be assumed that the local exceedances of this temperature were even 135 °C.

Taking into account the identified damage to the working surfaces of the bearings, it turned out to be essential to find the cause of this state of affairs, as the metallographic tests themselves did not indicate the primary cause, only confirming that the limit temperature of the grease was exceeded.

![Bearing streak abrasion and scratch (mag. 28x)](image1)

![Bearing streak abrasion and blue deposition (mag. 28x)](image2)

![Scratches and deposited material (mag. 28x)](image3)

![Scratches and deposited material (mag 500x)](image4)

**Figure 6.** Microscopic photos of the bearing damages.

A qualitative analysis in the form of a weighted Ishikawa diagram (figure 7) was used to analyze the cause of failure of the tested technical system operating in difficult conditions [16-17]. Classical 6M + E graph was drawn up. During the analysis, the influence of six internal factors and the environment were taken into account. The first internal factor was men. In this regard, it was found that the operators had no knowledge of the system in use. They have been advised that it is maintenance free. In terms of material, it was found that the design of the bearing nodes was based on
standard bearings closed in non-opening bushings. In terms of the factor machine it was found to be an innovative solution with elements that had never been verified in operation. Additionally, the factor determining the system operation was its performance. In terms of the method, it was found that the system was not monitored at all, due to the information about its unattended operation. In addition, the motor shaft bearings were subjected to a periodic load (continuous cycles of starting and stopping the motor with a power of 200 kW lasting for a few minutes alternately). In terms of measurement, it turned out that the safety system temperature sensors were mounted on the stator of the motor and not near the bearing nodes. The number of sensors was 2, which was too few to monitor the operation of such a large engine. Finally, in terms of management (of system maintenance), it was found that the maintenance department also relied on a record of maintenance-free system operation. The last element was the environment. It turned out that the ambient temperature (in the production hall) was about 50 °C or even a little more, which already caused the system to operate at an elevated temperature. Additionally, there was a lot of dust.

![Ishikawa Diagram](image)

**Figure 7.** Weighted Ishikawa diagram of the analyzed problem.

The identified causes were subject to quantitative analysis in order to determine the structure of their impact. As shown in figure 7, the main cause of the failure should be seen in an improperly designed motor safety subsystem, which only monitored the problem of stator overheating. However, the monitoring of bearing overheating was not included. In addition, the selection of bearings itself and the failure to take into account the operating conditions in the design and the impact of the ambient temperature on the reduction of the safety margin in the scope of the bearing operating temperature were found to be incorrect.

### 3. Conclusions

The presented results of research on the cause of bearing failure in a 200 kW electric motor have shown that even experienced design teams may not analyze all possible aspects of the operation of complex technical systems, especially in the case of unit designs. In the described case, high-power electromechanical drives replaced hydraulic cylinders for driving heavy industrial presses. However, the specificity of the operation of these devices contributed to a significant deterioration of the operating conditions of electric motors, including their bearing nodes. Additionally, the project did not take into account the influence of the temperature in the production hall in the summer, which exceeded 50 °C (sometimes reaching almost 60 °C - own measurements). Dust also deteriorated the operating conditions of the system. However, it did not directly affect the operating conditions of the bearings, as they were in non-dismountable bushings. Generally, therefore, the general causes of
failure should be looked for in poorly prepared design assumptions of the analyzed system. This resulted in the adoption of design assumptions with a much lower load on the system with the forces generated by the system operation process. This resulted in an excessive minimization of the size of individual structural nodes and an erroneous assumption about the possible, maintenance-free operation of the bearing nodes.

However, wrong design of the work monitoring system should be considered a special cause of the system failure. It was developed on the basis of two temperature sensors which, however, measured the operating temperature of the stator and rotor of the motor, and not the operating temperature of the bearings. This is strange because in the standard designs of such electric motors, the number of temperature sensors is at least 4, and two of them are located near the bearing nodes [18-19].

The presented analysis shows how important it is to study the functionality of various components in different environments, to create a methodology for designing such systems and build a knowledge base in this area [20-22].

4. References

[1] Saruhan H, Sandemir S, Çiçek A and Uygur I 2014 J. App. Res. Tech. 12(3) 384-395 (doi: 10.1016/S1665-6423(14)71820-7).
[2] Kumaran S S, Velmurugan P and Tilahun S 2020 J. Crit. Rev. 7(9) 492-501 (doi: 10.3183/jcr.07.09.99).
[3] Muzakkir S M and Hirani H 2015 Int. J. Eng. Res. 4(3) 133-136 (doi: 10.17950/ijer/v4s3/311)
[4] Reddy M R and Srinivas J 2016 Procedia Eng. 144 825-832 (doi: 10.1016/j.proeng.2016.05.093).
[5] Abu-Zeid M A. and Abdel-Rahman S. M. 2013 Alex. Eng. J. 52 241–248 (doi: 10.1016/j.aej.2013.02.002).
[6] Patel V N, Tandon N and Pandey R K 2014 Procedia Tech. 14 312-319 (doi: 10.1016/j.protcy.2014.08.041).
[7] Shrivastava A and Wadhwani S 2013 Int. J. Sci. Res. 2(5) 256-259 (doi: 10.36163/ijsr).
[8] Kim Y-H, Tan A C C, Mathew J and Yang B-S 2016 Engineering Asset Management. (London: Springer) (doi: 10.1007/978-1-84628-814-2_21).
[9] Önel I and Benbouzid M 2008 IEEE ASME Trans. Mechatron. 13(2) 257-262 (doi: 10.1109/TMECH.2008.918555).
[10] Lyse k K, Gwiazda A and Herbuś K 2019 IOP Conf. Ser.: Mat. Sci. Eng. 591 1-6 (doi: 10.1088/1757-899X/591/1/012055).
[11] Nalepa B and Gwiazda A 2020 IOP Conf. Ser.: Mat. Sci. Eng. 916 1-6 (doi: 10.1088/1757-899X/916/1/012072).
[12] Topolska S and Łabanowski J 2017 Arch. Metall. Mater. 62(4) 2107 (doi: 10.1515/ammt-2017-0312).
[13] Topolska S and Łabanowski J 2017 IOP Conf. Ser.: Mat. Sci. Eng. 227 1-6 (doi: 10.1088/1757-899X/227/1/012131).
[14] Adamiak M, Czupryński A, Kopyść A, Monica Z, Olender M and Gwiazda A 2018 Metals 8(2) 1-7 (doi: 10.3390/met8020142).
[15] Djilali K-A and Hebbar A 2020 Scienced 22(4) 1247-1260 (doi: 0.2478/mme-2018-0096).
[16] Malinowska E 2010 Equilibrium. Q. J. Econ. Econ. Pol. 5(2) 165–177 (doi: 10.12775/EQUIL.2010.033).
[17] Fabiś-Domagała J 2017 Scienced 114(8) 193 – 198 (doi: 10.4467/2353737XCT.17.141.6892.
[18] Hryniewicz P, Banaś W, Gwiazda A, Foit K, Sękala A and Kost G 2015 IOP Conf. Ser.: Mat. Sci. Eng. 95 1-8 (doi: 10.1088/1757-899X/95/1/012086).
[19] Hryniewicz P, Banaś W, Foit K, Gwiazda A and Sękala A 2017 IOP Conf. Ser.: Mat. Sci. Eng. 227 1-7 (doi: 10.1088/1757-899X/227/1/012061).
[20] Gwiazda A, Sękala A, Banaś W, Topolska S, Foit K and Monica Z 2017 *IOP Conf. Ser.: Mat. Sci. Eng.* **227** 1-6 (doi: 10.1088/1757-899X/227/1/012054).

[21] Michalec M, Svoboda P, Krupka I and Hartl M 2021 *Eng. Sci. Technol., Int. J.* **2** 1-23 (doi: 10.1016/j.jestch.2021.01.010).

[22] Wasilczuk M and Wasilczuk F 2020 *Eng. Fail. Anal.* **115** 1-10 (doi: 10.1016/j.engfailanal.2020.104651).