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DIAGNOSTICS AND FAILURE OF PLAIN BEARINGS

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Abstract Plain bearings have wide application in heavy mechanical engineering like mills, turbines, crushers, rolling mills and forging machines, presses and similar. Early detection of plain bearing failures is necessary in terms of systems maintenance and reliability as well as from the aspect of economy and protection of these production facilities. Failure and damage of plain bearings are most commonly manifested as wear, tear and plastic deformation of the material. Fracture and plastic deformation are damages related to strength, while wear, with all their manifestations, is associated with tribological processes. The research in this paper has shown that, in a reliable way, these problems can be detected at the very stage of their formation by vibration analysis and thermal analysis of bearing condition. This paper presents a part of the research done in the Laboratory for Applied Mechanics and Constructions at the Faculty of Mechanical Engineering in East Sarajevo. In this paper, the selection of plain bearing failures was performed, diagnostic models whose reliability was investigated in above mentioned Laboratory as well as on real industrial machines during their expulsion were developed..

Keywords: Diagnostic models; failure; plain bearing; technical diagnostics.

1. INTRODUCTION

Under the concept of technical diagnostics it means scientific and technical discipline which includes the theory, methods and tools for recognizing the condition of technical systems. The main aim of technical diagnostics is to detect and prevent potential failure of technical systems. This is achieved by measuring characteristic or diagnostic parameters and on the basis of certain criteria it concludes if they are within acceptable limits or not. The usage of sliding bearings is very present in practice, because of very long lifetime. Small problem in process oriented complex production system, as sliding bearing failure, can often cause long deadlocks during plant working, which results to huge financial costs in company business [1]. Monitoring and diagnostics sliding bearings failure are given in the literature [2]. Plain or sliding bearings are lubricated by the formation of a hydrodynamic film of lubricant, where the wedge formed lifts the shaft or journal off the bearing [3].

Research has shown that two most important indicators for the prediction of plain bearing failures are vibration analysis and bearing temperature analysis [4, 15].

Although the sliding bearing price is relatively low, any damage to the bearing that reduces the functional correctness of the system or failure occurence can cause significant indirect costs. On tehe basis of previous, the sliding bearings are considered as high-risk elements [2].

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Basic causes that cause damage and failure of sliding bearings include many aspects of construction, material selection, materials mistakes, production and processing, assembly, control, testing, storage, transportation, maintenance, unforeseen exposure to overload, direct mechanical or chemical damage during operation [4]. Often, multiple causers contribute to the sliding bearing failure. The frequency of the individual causers given in Table 1 was obtained by monitoring 530 cases of sliding bearing leakage [5].

Table 1. Causers and frequency of sliding bearing failures.

Failure causer	Failure frequency, %
Errors during production: • inadequate budgeting, • material mistakes, • irregularities during production and installation.	23,4 9,1 3,6 10,7
Errors during exploitation	39,1
Wear during long-term operation	30,5
Other	7,0

Failures and damages caused by said groups of causers are manifested, most often, as wear, breakage and plastic deformation of the material. These are, at the same time, the basic types of failures that can be divided into two categories, relative to material properties. One that is connected and dependent, above all, on the strength of the material and the other which is the function of tribological processes on the bearing-sleeve ground surfaces. Fracture and plastic deformation are damages in the function of strength, while wear and tear with all their manifestations are related to tribological processes

2.SELECTION OF PLAIN BEARINGS FAILURE

There is general agreement that wear is the most frequent manifestation of failure in sliding bearings, as confirmed by the authors [6, 7]. The results show that abrasive and adhesive wear is the most present, then wear due to surface fatigue, while other types of wear are considerably less represented. These are, also, indicators that need to be taken into account when defining the bearing condition monitoring program during exploitation. Table 2 shows few plain bearings failure mechanisms.

Table 2. Plain bearings failure mechanisms.

Failure type	Appearance	Cause	Manifest	Solution
Abrasion	 	Presence of solid impurities	Visible rolling of the bearing surface	The bearing damaged by abrasive wear should be dismantled and a new one installed
Wear and tear		Inadequate gap Inadequate supply of lubricants or inadequate supplies characteristics of lubricants	Frequent color surface change due to heating	The bearing can be used again if the causes are removed

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Surface fatigue		Dynamic loading of plain bearings	Cracks occurrence	Eliminate the cause of surface fatigue
Cavitation erosion		Fluctuation of pressure in the bearing, vibration of the sleeve, inadequate flow lubricants through holes and channels	The occurrence of material destruction is always at the same or similar bearing location	Improving the bearing construction by increasing the oil pressure in the lubrication system
Corrosion		Corrosive action of the material	Visible corroded surfaces of materials	Changes in lubricant characteristics
Plastic deformation		Irregularities in the lubrication system, inadequate lubricant layer	Roofing of the bearing material on the surface and plastic streaming	Changes in lubrication system or lubricant characteristics
Fracture		Overload, impact load	Loss of bearing material from larger surfaces	Removing possible overloads or expressive impact loads

3.DIAGNOSTIC MODELS OF PLAIN BEARING

In order to correctly understand the diagnostic indicators of vibration and temperature measurements for damage of the plain bearing, a mathematical model of vibration and heating or cooling of the sliding bearing has been developed, which was confirmed by experimental tests [16, 17, 18].

3.1.Dynamic model of plain bearing

The dynamic model of the sleeve in the plain bearing is shown in Fig.1.

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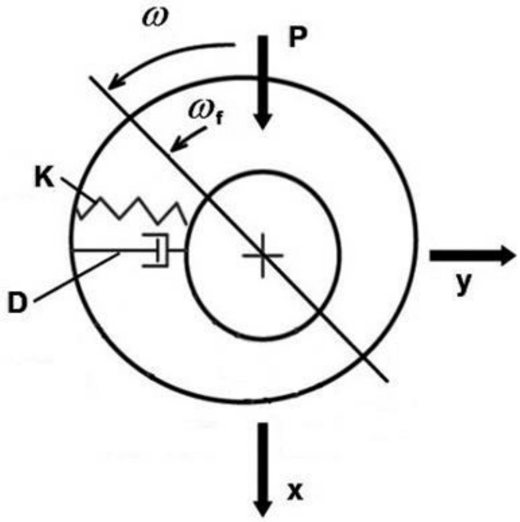

Figure 1. The dynamic model of the sleeve in the plain bearing.

By introducing relations $z_r(t) = x_r(t) + jy_r(t)$, ie $z_r = z \cdot e^{-j\lambda_0\omega}$ the differential equation of movement of the sleeve in the bearing is obtained (Eq. 1):

$$M \cdot \ddot{z} + D \cdot \dot{z} + (K - j \cdot \lambda_0 \cdot \omega \cdot D) \cdot z = F \cdot e^{j(\omega t+\delta)} \tag{1}$$

The parameters of the model are: M - modal mass, K - modular rigidity and D - damping of the environment.The proportionality coefficient λo is one of the key factors affecting the stability of the rotor system, since the lubricant in the bearing acts as a spring. The proportionality coefficient depends on the dimensions of the bearing.

Damping in the lubricant is determined by the damping coefficient D corresponding to the dynamic viscosity of the lubricant. The bearing force of the fluid film (wedge) is equal in intensity and the opposite is in the direction of the radial force and is determined, according to the model, by the form (Eq. 2):

$$F_f = D \cdot \lambda_0 \cdot \omega \cdot z \tag{2}$$

Problems that occur in sliding bearings lead to high levels of vibration and noise. These problems mainly arise as a result of an inadequate gap in the bearing (oil gap) or the appearance of oil instability. An excessive gap in the bearing results in looseness and irregular lubrication, which in the vibration response of the system produces a characteristic vibration shown in Fig. 2.

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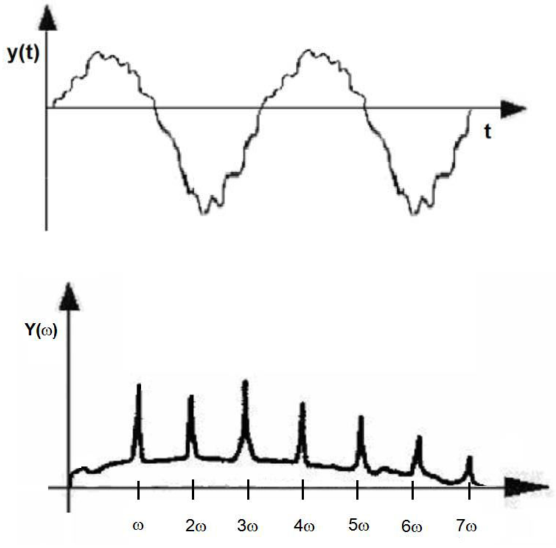

Figure 2. Time recording and vibration spectral display due to excessive plain bearing gap.

Oil instability is manifested in the appearance of oil vortex and oil whip. The oil vortex occurs as a result of the orbital motion of the rotor and occurs at a frequency that is proportional to the rotation frequency and amounts usually 0.4 to 0.5 Ω with the growing amplitude as the number of rotations rises.

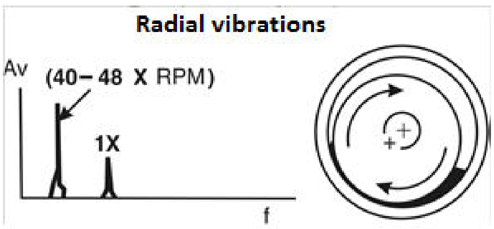

Figure 3. Spectral display of oil instability.

In machines that operate above the first critical speed, the oil vortex usually passes into an oil whip which frequency is equal to the frequency in the formation of the same.

3.2.Temperature model of plain bearing

It is clear that the bearing heating or cooling process may be described by the differential equation of the first order. By solving this equation, with the condition for dynamic model of the first order (Eq. 4).

$$\frac{d\theta}{dt} + \frac{1}{T} \cdot \theta = 0 \quad (3)$$

The formula is obtained which models the cooling of the bearing, which may happen, for example, during the decline in rpm, according to the Newton's law of cooling [18]:

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$$\theta(t) = \theta p \cdot \exp(-t/T) \tag{4}$$

The expression (4) may be corrected by introducing Θk, the final temperature measured when the steady-state is reached:

$$\theta(t) = (\theta p - \theta k) \cdot \exp(-t/T) + \theta k \tag{5}$$

On the contrary, when the heating process occurs, for example as a result of increased rpm, this process is described by the equation:

$$\theta(t) = (\theta k - \theta p) \cdot (1 - \exp(-t/T)) + \theta p \tag{5}$$

Figure 3. presents time diagrams of the cooling and heating of the journal bearing according to the equations (5) and (6).

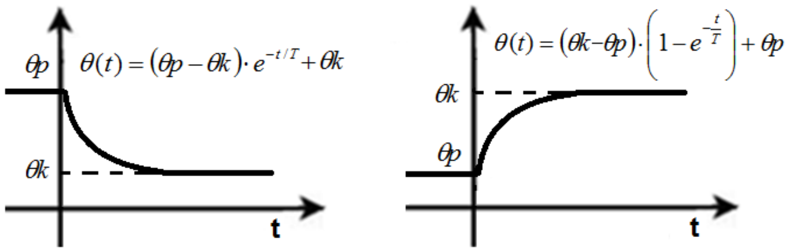

Figure 4. Time diagram of cooling (left) and heating (right) of the journal bearing.

3.3.Vibration-thermal indicator of the plain bearing malfunction

In order to reliably determine the condition and prediction of plain bearing failure, it is necessary to observe and analyze simultaneously several parameters of the condition. One such method is based on the fuzzy logic and enables the diagnostics of the state of the element and determining the urgency of the need for intervention on the machine element. Thus, by applying the disjunctive probabilistic fuzzy operator, a vibration-thermal indicator of malfunction of the plain bearings (defect factor DFJB) can be defined which contains information about both the temperature and the vibration of the bearing defined as [17]:

DFJB= (x(q) +w(v))- x(q)×w(v) (7)

If the temperature and vibrations are within the allowed limits, i.e. below the warning limit, then the value of the DFJB indicator = 0, and if at least one of the parameters (temperature or vibration) is above the limit, then the value of the DFJB indicator = 1 in accordance with the rules for disjunction. If any of the parameters are in the fuzzy warning area, then the indicator of the malfunction in the fuzzy area. It should be noted that in this factor of malfunction, besides the level of absolute and rotor vibrations in the analysis, other parameters such as the vibration spectrum or the thickness of the oil film can be included, which depends on the need for diagnosis.

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4. CASE STUDY

4.1.Analysis of the turboaggregate plain bearing failure in thermal power plant Gacko

Turbine No. 1 and 3 bearing vibrations intensity were directly dependent on the load on the block. With a decrease in the block power, vibrations were dropped from a speed of about 7-8 mm/s to a value of 6-7 mm/s, with the component vibration on the semicircons 1/2X, 3/2X, 5/2X visible in Fig. 5 appears.

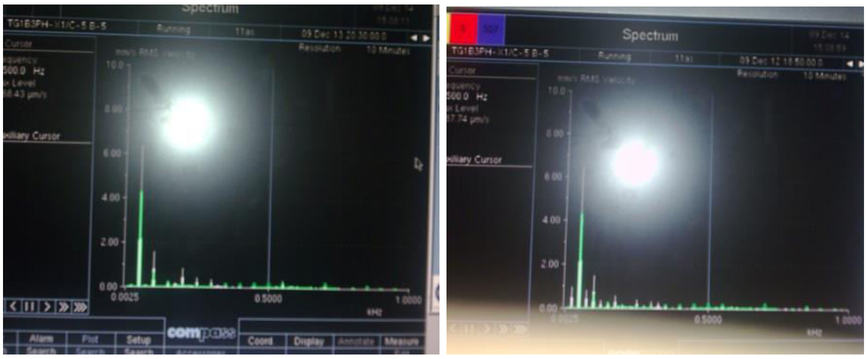

Figure 5. Spectral Vibration view from bearing No.1.

On the first bearing traces of damage to the part of the white metal surface on the lower half are visible (Fig. 6). According to the character of the damage it is clear that it is an electro-corrosion corrosion that occurs due to the breakdown of the vortex currents from the rotor to the stator part. The restoration of the bearing consists of showering the bearing surface, adjustment to the caliber and re-assembly.

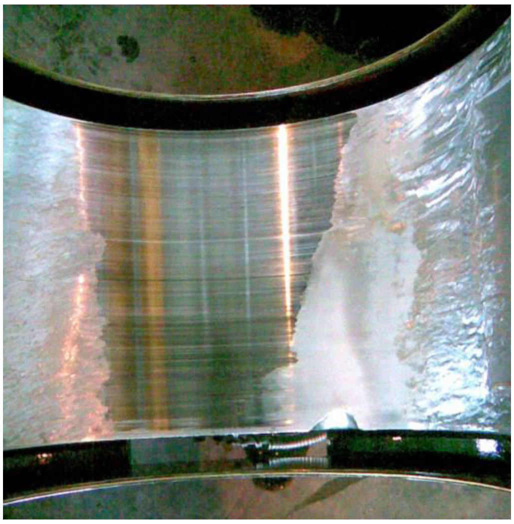

Figure 6. Damage to the lower half of the bearing cup due to electro-erosion corrosion.

The removal of white metal on the lower half of the surface of the sliding bearing due to the failure of the rotor of 0.16 mm is visible.

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4.2.Analysis of the turbo pump plain bearing failure in thermal power plant Gacko

The main vibration stimulus originates from the oil vortex and is dominant on bearing No. 1 in the horizontal radial direction. The presence of semi-harmonics in the spectral display of vibrations indicates problems with the lubrication of the bearing and the rotor-stator contact, Fig.7.

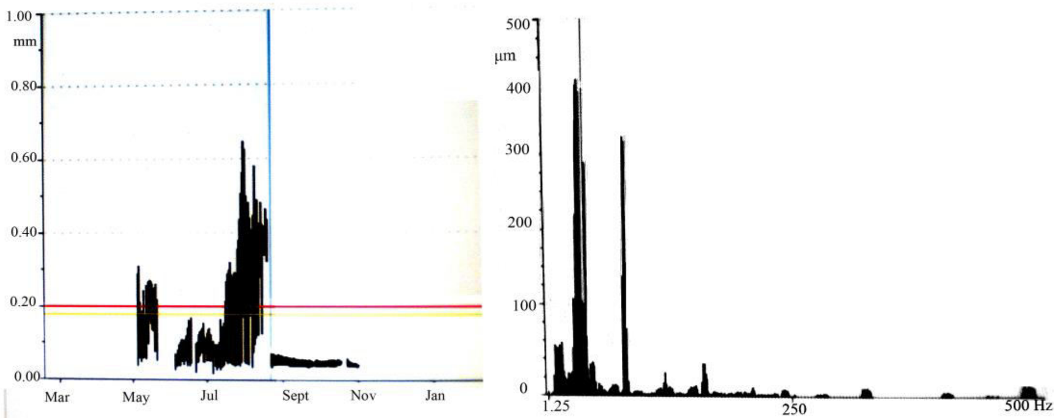

Figure7. Vibration level and spectral display from the pump bearing no.1.

After the bearing was revised, damage was clearly detected and a new "lemon" bearing was developed which proved to be a good solution.

Figure 8. Damage to the plain bearing (left) and the appearance of the new "lemon" bearing (right).

4.3. Analysis of the electric motor plain bearing failure in Kakanj cement factory

By measuring the temperature and absolute vibration velocity on the housing of plain bearings, on one bearing housing absolute vibrations $v = 9.3$ mm / s and temperature $\Theta = 66$ ºC were measured.

For the concrete application of the bearing, the vibration limits were $v_a = 4$ mm / s and $v_d = 12$ mm / s, and the temperature limits $\Theta_a = 60$ ºC and $\Theta_d = 90$ ºC. After the fuzzification of the measured values of the vibration and temperature velocity is carried out, we obtain: $x(\Theta)=(66-60)/(90-60)=0.20$ and $w(v)=(9.3-4)/(12-4)=0.66$. By calculating the vibration-thermal indicator of malfunction, the $DFJB=(0.20+0.66)-0.20\cdot 0.66=0.73$ is obtained. It can be noted that the value of the vibration-thermal indicator is greater than the two-fuzzy variables x and w. After the bearing was dismantled, significant damage was observed on the bottom half of the bearing bed, which is visible in Fig. 9.

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Thus, this example demonstrates the applicability and reliability of the vibration-thermal indicator of the plain bearing defect.

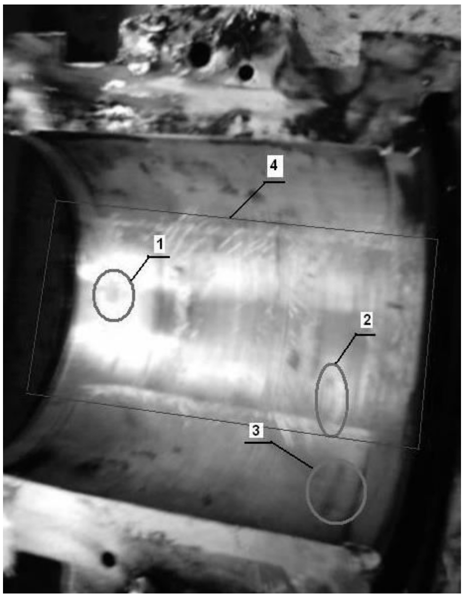

Figure 9. Damage of the bottom half of the plain bearing bed.

The frequency spectrum of absolute vibrations on the housing of the bearing is shown in Fig. 10, from which one the shape of the frequency spectrum characteristic of wear of the bearing can be noticed.

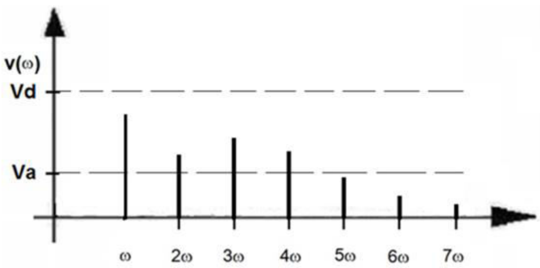

Figure 10. Frequency spectrum of absolute vibrations measured on the housing.

5.DISCUSION AND CONCLUSION

Failures and damages caused by said groups of causers are manifested, most often, as wear, breakage and plastic deformation of the material. These are, at the same time, the basic types of failures that can be divided into two categories, relative to material properties. One that is connected and dependent, above all, on the strength of the material and the other which is the function of tribological processes on the bearing-sleeve ground surfaces.

Problems that occur with plain bearings lead to high levels of vibration and noise. These problems are mainly due to an inadequate gap in the oil spill or the occurrence of oil instability. Excessive gap in the bearing leads to looseness and irregular lubrication. Oil instability is manifested in the appearance of oil vortex and oil whip. Vibration-thermal malfunction indicator of the plain bearing (failure factor

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DFJB) contains processed temperature information and bearing vibration, but in some applications, other than temperature and vibration, other parameters can be included, such as, for example, the thickness of the oil bearing film or the strength of the ultrasonic bearing emission, and can be integrated in this plain bearing DFJB failure factor.

Further research can be carried out in this regard. Further research can be carried out for the function of belonging choice, because in this research the linear function of belonging was used, and other functions of belonging can also be used. Further research can be done in general with regard to the application of the fuzzy logic in technical diagnostics.

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