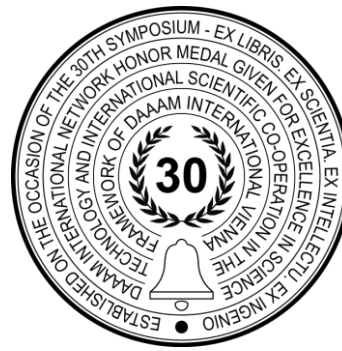


APPLICATION OF VIBRATION ANALYSIS IN JOURNAL BEARING PROBLEMS DIAGNOSTICS

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Abstract

Journal bearings are machine elements that enable relative movement of working parts while simultaneously loading the load between them while maintaining the stability of their position. As part of overall diagnostics of the technical state of the plant, vibrational diagnostics or analysis of vibrational parameters is becoming one of the most important methods. Previous research has shown that over 40% of machine failure results in problems with bearings. For this reason, not only are the new methods of detecting the damaged bearing being developed, but the identification of the causes that lead to them as well. Methods for determining the technical condition of journal bearings are divided into those used to test the bearings while they are still and those that are driven while the bearings are in operation, i.e. while they are under workloads. This paper presents a modern method of testing the condition of journal bearings in operation by means of vibration analysis, and the identifying indicators of the biggest problems. The purpose of this paper is to demonstrate the importance of this method by changing the parameters related to two different structures of journal bearings that are grouped in the so-called Sommerfeld number.

Keywords: vibration; diagnostics; journal bearings; defects; Sommerfeld number

1. Introduction

The key point in maintaining the plant is determining the need of repair before any breakdowns occur with all the costs that come with them. Determining maintenance needs is carried out by one or more methods:

- Status check - from detected changes of the observed state or performance;
- Effectively corrective maintenance - by turning attention to the problem;
- Scheduled preventive maintenance - by routine or periodic examination;
- Maintenance by condition - from measured state or performance changes.

These processes contribute to increased plant reliability when maintaining the application in combination with precision skills. Every machine must be maintained properly to work reliably during its intended lifetime. For all the large and expensive equipment, to which vibrational diagnostics generally relate, lifetime plays a great role. Preventive maintenance by vibration analysis is based on two basic facts:

1. Each type of fault has a characteristic component of vibrational frequencies that can be filtered and defined;

2. The amplitude of each vibration component will remain constant if the dynamics of the technical system remain unchanged [1].

Vibration analysis has recently been used as the primary preventive maintenance method because most plants have more mechanical components in their system. It represents the best tool for monitoring and identifying startup problems, making vibration measurement and analysis the most important plant status monitoring method for several reasons [2]:

- It is very effective in detecting a large number of defects on the machine;
- It detects failures early enough in order to take corrective actions;
- As a diagnostic tool it can be used to identify specific machine malfunctions;
- The method is non-destructive and can be performed while the plant is in operation;
- Different stages of instrument- and technique sophistication can be applied;
- Relatively low price of measuring devices compared to the repair costs of damage caused by damaged components (experiences show that in simpler machines 20% of the cost of equipment, skills and knowledge in using this method is used to detect 80% of possible failures);
- It is quickly applied for in-situ balancing.

The main purpose of this paper is to show the application of vibration analysis when diagnosing problems with journal bearings. In doing so, the criterion based on different construction and working parameters of the cylindrical and elliptical journal bearing would be used. Parameters affect the so-called Sommerfeld number that influences the critical rotor speed which determines the stable area and indicates the failures of journal bearings.

Journal bearings are the most used elements in high-speed rotary machines and therefore there is a great need for their proper performance and high-quality lubrication to achieve normal rotary operation. For these reasons there is a need for constant research and analysis of irregularities in the operation of journal bearings. Oil whirl and oil whip are common failures of journal bearings and are caused by instability of oil film, especially when the rotating speed of the shaft exceeds the critical speed of the rotor system.

2. Journal bearings, types, purpose and characteristics

The bearings are machine elements for the mobile connection of machine parts, and their basic function is to transfer loads from the moving parts of the machine to the stationary parts. They are primarily used with circular motion moving joints, eg. in shaft supports, where they enable rotation of the pin with respect to the stationary support, while simultaneously carrying the corresponding load. They are also used with straight and curved joints, such as for guides and threaded pairs. Bearings are considered the main "culprits" for machine failures, although they are designed to operate for a long time, but only under the proper conditions of their exploitation. However, some tests have proved that 10% of bearings reach their lifespan according to the instructions.

The bearing shapes are primarily adapted to the forces in need of transmitting, so the basic bearing division is on the radial and axial ones, although they can be divided into rolling element bearings and journal bearings [3].

Rolling element bearings consist of rings directly connected to the stationary and moveable parts of the machine and from rolling bodies (rollers, balls, needles, etc.), which lie between them and the cage. The main part of each journal bearing, by which the sliding is done directly, is made of the bearing shell and it is the basin in the narrow sense the shell can be one-piece, two-piece or multiple, and one-layer or multilayer. Depending on the purpose and the working conditions, journal bearings with dry, mixed and fluid friction are used in the application. In all operating conditions, except for the vacuum, fluid-static bearings can be used. For high temperatures, the best results come with aerostatic bearings, but for increased vibration – the hydrostatic ones. It is best to apply bearings of non-lubricated plastic materials in vacuum conditions.



Fig. 1. Examples of Journal Bearings

Under certain conditions, hydrostatic bearings allow fluid friction with high specific load and low speed of relative displacement on the friction surface, as well as with non-stationary working regimes during starting and stopping times.

Such bearings allow precise guiding of the pin in the bearing shell and stable work at high speeds and have a long lifetime. Their great advantage is reflected in the choice of the required thickness of the lubricating film between friction surfaces, good lubrication stability and vibration damping. On Fig.1. some types of journal bearings are shown in modern application.

Cylindrical journal bearings are the simplest types of journal bearings. The holes in the bearing are circular and their diameter is larger than the radial clearance. In the position when the bearing does not work, when the pin is at the bottom of the shell, the side clearance is equal to half the vertical clearance. In actual constructions, it is about 1.5 to 2 per mille diameter. Fig. 2 shows the movement of the center of the pin in the bearing clearance under the increase of the running speed and loads that cause stress on the touch surface [4].

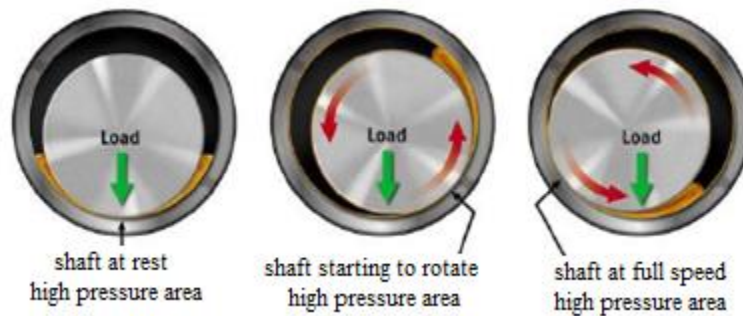


Fig. 2. Moving the center pin in the bearing clearance with an increase in running speed

Theoretically, infinite high running speed would move the center of the pin to the hole on the bearing at its circumference. In order to reduce friction loss, the length of the cylindrical bearings of older constructions is usually larger than their diameter. Specific pressure in such bearings is estimated at about 0.8 MPa (calculated as the ratio of the reaction force of the rotor weight to the projection of the bearing area). The bearing must be properly fixed in the housing and must ensure the force transmission and allow the alignment with the axis, taking the deformation of the rotor bending into account.

Due to different operating conditions, loads and stresses, they result in the development of defects within the bearings. Most defects on the bearings are gradually developed, leaving the user enough time to carry out well-timed maintenance activities, thus avoiding damage to the production process due to the sudden failure of the bearing. Due the high percentage of prematurely demolished bearings, several detection methods have been developed, not only for their damage, but also for identifying the types of failure. One of the detection methods, such as the failure of the bearing, as well as failure of other elements of the mechanical systems, are measurement, monitoring and analysis of vibration, which one calls vibrating diagnostics.

3. Vibrational diagnostics

Maintenance by applying vibration analysis is a tool that is applied in the industry across three levels: monitoring of the state of damage, diagnosis and prognosis of the future technical condition. Recorded vibration signals are the result of vibration superposition of different causes or different machine elements, which makes it difficult to interpret the degree of damage of a particular element. Separating the frequency signals of individual elements is achieved, not only by locating faults on the elements, but also by tracking the damage estimation on each one of them [5],[6].

3.1. Measurement of vibro-parameters

The observation of the state of damage by vibration analysis cannot be performed without the vibration parameter measurement procedure, after which a time signal is formed and the frequency analysis for generating a frequency spectrum, so that the vibration components from the (overall) vibration signal are distinguished, which disturbs the signal that comes from certain damages [7].

Increased vibrations measured on the bearing housing can be caused by a defect on the bearing itself, although it may be damaged due to increased vibration coming from other sources. For this reason, vibration measurements are performed on characteristic positions to check whether they are within the allowed limits for a particular type of machine. One of the most important ways of measuring vibration is to track and form the trend of vibration parameters change that point out a potential defect. Thus, the vibration measurement method represents the measurement of a vibration parameter (displacement, velocity or acceleration), and the recording a time diagram from which the components that point to the

problem cannot be distinguished, unlike the frequency analysis by which the time signal forms its FFT spectrum (Fig. 3) [8],[9],[13].

By obtaining the FFT spectrum of vibration signals, characteristic spectral components pointing to the defect of the bearing can be detected. The only deficiency of this method is that in the initial stages these components are of less intensity and are more difficult to detect due to the structural vibration of the machine itself [10]. An example of vibration measurement using a precision instrument is shown in Fig. 4.

Instrument on Fig. 4. represents a very specific equipment for the measurement of vibro-parameters that determine the vibration level and that does not only measure but also performs the frequency analysis of the measured data. Such equipment includes sensors - whether transferable or built-in, data collectors, and Data collector firmware (software in a hardware device).

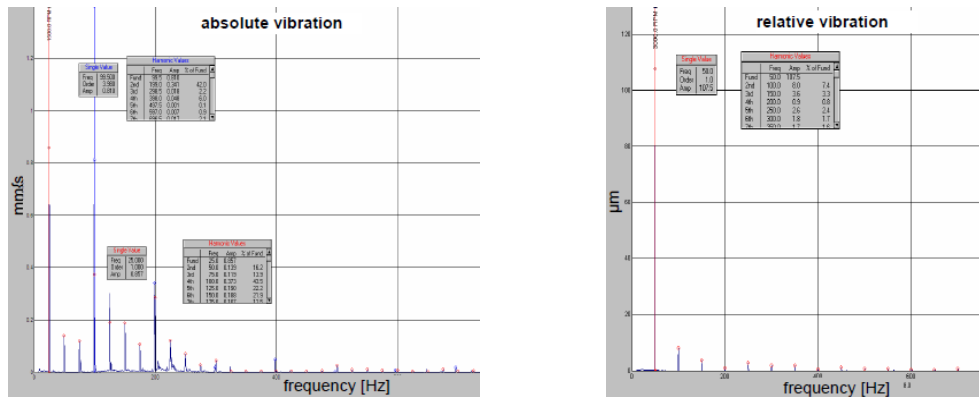


Fig. 3. FFT Spectrums (vibration velocity and relative displacement) of a journal bearing with excessive clearance

The choice of software systems depends on the complexity of the machines being tested, the skill of the operator and the degree of risk. Data collectors are frequency analyzers, providing the ability of collecting and the analysis of time and FFT domains from any sensor that sends a dynamic signal. Measurements are performed under normal operating conditions, at working temperature and at nominal speeds in both radial and axial directions. The sensors are mounted by magnet, screws, glue or another way, and for this reason mounting the sensor is the weakest link of the entire measurement system. If the sensor is badly mounted, even the most complex and expensive devices of data collectors and softwares will not produce accurate results. Depending on which size you are working with, there are different types of sensors.

Therefore, the analyzer with its functions and with the appropriate sensor is used as the most important instrument for vibration measurement and analysis (Fig. 4).

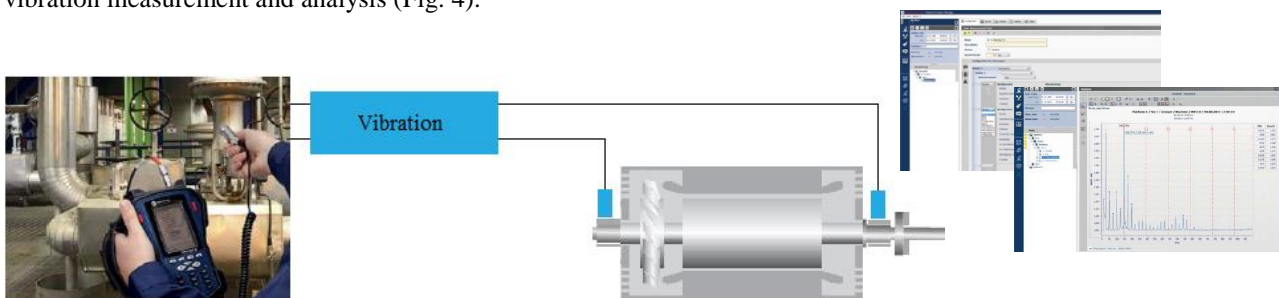


Fig. 4. VIBROTEST 80-efficient machine faults management via route-based measured vibration with the Report & Route Manager host software [11]

3.2. Problems in working with journal bearings

Practical research on work problems due to vibration on journal bearing machines has shown that less than 10% of all bearings work within the intended duration. About 40% of defects on the bearings occur because of improper lubrication, about 30% are caused by improper assembly or machine alignment, and about 20% of the defects occur due to other reasons such as overloading, irregularities in design, inappropriate oil temperature and viscosity, etc. Some extreme operating vibration-modes can have loads of bearing to the limit of their stability, even overcome these limits.

For these reasons wear occurs, which causes excessive clearance inside the bearing, which is identified by the occurrence of the rotation frequency harmonics, especially in the absolute vibration spectrum (Fig. 3. left). Symptoms of

excessive clearance in the bearing are similar to those in the mechanical clearance. A bearing with a proper clearance, but with loose contact on the support, acts vibrationally similar to a bearing with excessive clearance. For this reason, these two cases are difficult to distinguish. The appearance of oil whirl and oil whip or instability of the oil film between the shaft and the pin in the journal bearings is the result of rotation of the shaft inside the journal bearing, and this phenomenon causes a very high vibration amplitude in the radial direction in the range of 0,42 to 0,48 rpm [7],[12]. Due to this phenomenon, because of the excessive clearance within the journal bearing, the so-called 'surfing' of the shafts in the oil foam that is being formed occurs, and that way it forms an oil spin in the form of a wedge that opposes rotation and affects the pushing of the shaft towards the pin. At the shaft barrier, the oil film has the same speed as the shaft, and at the frontier of the pin the oil film is immovable. Therefore, instability occurs, i.e. an unevenly distributed oil film around the shaft. When the rotor speed is near twice (2x) the critical speed, and the oil film speed is also at its critical level, and high vibration amplitudes prevent stable shaft rotation from the oil film (oil whirl), this leads to the so-called 'slamming' of the journal bearing. If, in this case, the rotor speed continues to increase, the speed oil film remains the same, i.e. even though the rotor speed increases, the oil film instability frequency will not increase. Some bearing designs may develop oil instability with certain characteristics of oil viscosity and specific bearing loads. In such cases, the oil film is pumped around the shaft, and the speed of such oil pumping usually occurs at 42% to 48% of the rotational speed, so instability occurs in this already mentioned and very precise frequency range. Instability of the oil film is a very serious problem and needs to be accurately identified, because it results in direct contact between the surfaces inside the journal bearing, which can cause even greater defects in the machine [13],[14],[15].

3.3. Diagnosis and recommendations for problem solving

As long as rotary machines work at speeds below critical, cylindrical sliding bearings serve very well. Since machines were being designed at significantly higher speeds (to increase production efficiency, reduce size, etc.), it became apparent that speeding at twice the critical level is no longer possible - a large increase in vibration leads to failures machines. Research and theoretical analysis of this phenomenon resulted in recommendations. An important criterion for solving the problem is a broadly accepted criterion that combines machine design and parts and their mode of operation.

The design and operating parameters are grouped in the so-called Sommerfeld number S_0 , calculated according to formula (1):

$$S_0 = \frac{F_{stat} \cdot \psi^2}{B \cdot D \cdot \eta_{oil} \cdot \omega} \quad (1)$$

where: F_{stat} - bearing static load, B - bearing width, D - bearing diameter, $d = 2r$ - diameter of the rotor pin, ΔR = bearing clearance, $\psi = \frac{(D-d)}{d}$ - relative bearing clearance, η_{oil} - dynamic viscosity of oil, ω - angular rotation speed (rpm).

The formula takes the ratio of the reaction force F_{stat} (force of the rotor weight) to the geometrical bearing dimensions (B and D) into account, which is the specific bearing pressure (the characteristic value for the cylindrical bearings is about 0.8 MPa), the relative clearance in the bearing (the ratio of the actual clearance to the diameter ranging from 0.15 to 0.2% of diameter, which is important because it is quadrated in the formula), oil viscosity, which not only depends on the type of oil but also on its temperature and angular velocity of the rotor (rpm, for most machines is constant). In the function of the Sommerfel number, a graph for determining the rotor speed limits (as a non-dimensional size) is shown in Fig.5. which is based on a series of measurements that determine two areas: the area of stable work (below limit curve) and the area of unstable work (above limit curve) [16].

On the Fig. 5. graph there are two functions relating to cylindrical and elliptical journal bearings. For cylindrical bearings a stable area below the graph is indicated, on the basis of which it can be concluded: in order to achieve stable operation at a given speed without vibration, it is necessary that the point, which is the combination of the Sommerfeld number and velocity, lies in a stable area below limit curve, which means that the Sommerfeld number should be large enough. In order to achieve this, it is advisable to use a higher specific pressure in the bearing (usually about 1.5 MPa, but can also be up to 3 MPa in extreme cases). In this way, steady work is achieved to reduce loss caused by friction. Since the diameter of the pin depends on the design of the entire rotor, such a bearing is usually detected by shortness - its length is smaller than the diameter. In reality it happens that the weight of the rotor is the same, and the reaction force as well, while the bearing area is determined by its construction. As there are usually four bearings in the machine, which is a statically unstable system, and if the coupling is not properly centered, some of the bearings will not be loaded because the rotor is lifted by a coupling from one of the bearings and the other will be overloaded. In this case, the driving forces and pressure will increase which leads the machine near or above the stability limit.

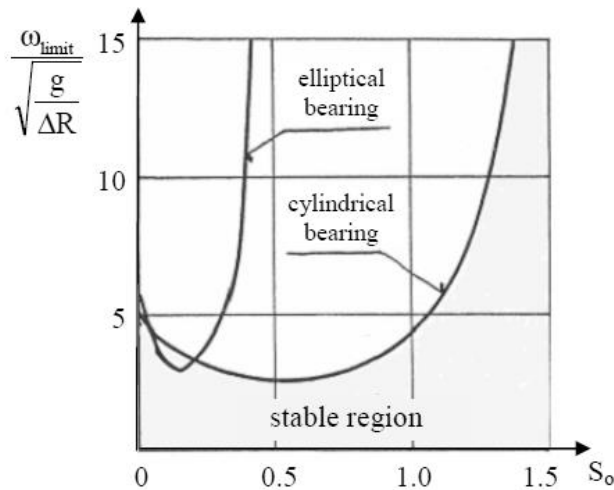


Fig. 5. Limit rotor speed vs. Sommerfeld number

Practice has shown, that it is advisable to use larger clearances, although oil leak problems occur then, so newer bearing types do not have different clearances than older ones. As the oil viscosity coefficient is found in the denominator of the Sommerfeld number, it is concluded that the more viscous, i.e. thicker oil is, the more harmful to the stability of the work it is. If the correct oil is used, the only danger is the lower temperature, so it is more practical that the machine does not start until a temperature of about 36° is reached (outside conditions are sometimes lower), while modern bearings also have heating equipment oils.

The second function on the graph shows a significant increase in the stability of the elliptical bearings, which is a completely different bearing construction. Its construction affects the increase of the working speed of the machine above the critical speed.

The critical velocity stability which directly affects the vibration reduction is achieved with respect to the cylindrical bearing so that the pin is stabilized not only with the oil whirl from the lower part, but also with the upper part used in the cylinder to seal both the gasket and the oil supply. This is achieved by changing the geometry, the inner shape changes, it is not circular, but elliptical, and the relationship between the lateral and vertical clearances changes as well. This ratio, e.g. 2:1, means that in rest position, clearances on both sides of the pin are as large as the vertical clearance.

Another factor for increasing stability and reducing vibration is the increase in specific pressure in the bearing because the elliptical bearing is visibly shorter than the cylindrical relative to the diameter.

Thus, an important recommendation for determining the stability of journal bearings is the determination of critical velocity in the function of the Sommerfeld number. For further testing, it is recommended that the theoretical results are compared to the results on an experimental model that simulates the errors caused on two types of journal bearings. In this way, it would be possible to select the optimal journal bearings that would function at different loads. It is best to interpret test results by measuring vibroparameters and frequency analysis with the help of the appropriate vibration analyzer in laboratory conditions, so it is best for the research to continue in that direction.

4. Conclusion

Journal bearings have been used in the industry because of their characteristics that represent ideal support that allows stable operation of machines at high speeds, as well as machine shafts that require precise movement of the pin in the shell. Also, the constructional design of journal bearings makes it easier to operate in non-stationary regimes during starting and stopping of machines. However, because of improper maintenance and lubrication of bearings various irregularities in the operation of the machine occur, the most significant of which are the vibrations that are generated in the bearing itself and are still transmitted to other parts and machine assemblies. This affects the overall operation and condition of the machine, increases maintenance costs and causes irregularities in other parts of the machine.

To avoid such irregularities, vibration diagnostics are performed on the basis of measurement, monitoring and analysis of vibro-parameters by measuring instruments and tools whose complexity depends on the degree of importance of certain parameters for the technical state as a whole.

This paper has shown that different construction and working parameters that are compared on two types of journal bearings determine their (non)stability. It would be good to demonstrate theoretically calculated results in an experiment

to determine the unstable area. The results of the research would be checked by an adequate vibrating device for measurement of one of the relevant vibro-parameters.

The most important step in the vibrational diagnostics of journal bearings is the choice of measuring points, as well as the choice and mounting of sensors, most of which depend on the accuracy of the test and the results obtained. Sometimes, certain irregularities of the journal bearings need to be performed by some other analysis, in order to obtain a more accurate diagnosis of irregularities. Given that the oil film is applied between the pin and the shell of the journal bearing, it is necessary to examine the quality and properties of the oil itself.

The vibration analysis performed in order to diagnose the problem of journal bearings, gives information on their condition in the best possible way, by which taking the appropriate measures after diagnosis can prevent what is being done by the diagnostic itself, which is the goal of the preventive maintenance mode: prevention of breakdown and failures of expensive machine parts and reduction total maintenance costs.

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