VIBRATION MEASUREMENT TRENDS IN THE BEARING INDUSTRY

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Abstract: *Industrial rolling bearing vibration measurement systems are one of the most important quality control devices in bearings factories. Larger factories have up to several dozen devices of this type. Mostly, companies based on large experience, have sufficient production facilities to create self-devices for vibration control of their products. The world's leading bearing companies such as SKF, ZYS or LDI not only have their own measuring equipment for their purposes, but also sell them to other companies, presenting a specific offer. Small bearing plants that do not have sufficient resources or experience in this matter are need to buy measuring instruments. Due to the continued drive to increase measurement accuracy in order to increase overall customer satisfaction, it is useful to analyse trends in industrial measurement systems. The conducted analysis allows scientists not related to the bearing industry to get to know with the measurement techniques used on production lines in bearings factories.*

Key words: *rolling bearings, vibrations, industrial measurement, quality control*

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1. Introduction

One of the greatest inventions in human history was the invention of the wheel. Its history dates back to 3500 BC. The sliding motion was then changed into rolling motion, which facilitated transport. This invention also initiated tribology, i.e. the science of the phenomenon of friction and its related processes. The combination of wheel and rolling friction led to another invention, which was the invention of the bearing (Morhain & Mba, 2003), (Tong et al. 2017), (Serrano et al., 2010), (Kankar et al., 2011), (Nassif et al., 2005). Rolling bearings are the basic components of many machines and devices. Their correct operation largely determines the reliability of the machines produced. The main elements of the rolling bearing are the outer ring (mounted in the housing), the inner ring (the rotating shaft is fixed in the bore), rolling elements (balls, rollers) and a basket supporting the rolling elements (Rodriguez et al., 2002), (Aye, 2012), (Tallian & Gustafsson, 2008), (Adamczak & Zmarzły, 2017), (Nassif et al., 2005). The basic criteria for selecting a bearing are:

- dimensional limitations of bearings,
- the size and direction of the load,
- bearing stiffness,
- rotation speed,
- static and dynamic load capacity,
- radial and axial clearances,
- surface roughness,
- accuracy of manufacturing,
- level of generated vibrations (low noise level).

The level of vibrations generated by bearings, is currently one of the most important parameters determining the quality of a bearing. By measuring the vibrations generated by the bearing, we are able to determine the degree of its wear, indicate the elements that have been damaged, determine cleanliness or properties of the lubricant (SUGAWARA), (Adamczak et al., 2016), (Lacey, 2008), (Standard ISO 15242-1:2015), (Standard ISO 15242-2:2015), (SKF company), (*).

More and more customers are paying attention to the level of vibration generated by bearings. Maybe the bearings for the agricultural industry are not yet subjected to such requirements regarding the level of vibration, but otherwise other customers have some requirements. The highest requirements for the level of vibrations are reported by manufacturers of electric drives and manufacturers from the automotive industry group (**), (Adamczak & Wrzochal, 2018), (Inoue, 2014), (Wrzochal et al., 2018). Recently, there we see tendency for science and industry to cooperate more and more widely. This is evidenced by a joint project of the Kielce University of Technology and the Fabryka Łożysk Tocznych Kraśnik S.A. (Polish Bearings Factory) concerning the construction of a research and development center on the factory premises. As part of the project, eight innovative bearing measuring devices were created, i.e. four devices for measuring the durability of rolling bearings, one device for measuring the thrust torque of tapered roller bearings, two devices for measuring vibrations and a device for measuring the geometric structure of the surface of rolling elements.

During the project, in order to verify the newly developed vibration measurement devices, a need arose to apply a mathematical model of rolling bearing vibrations that could be applied in industrial conditions to newly manufactured bearings and would take into account factors relevant to quality control. The undertaken review of the latest mathematical models of rolling bearing vibrations (Wrzochal & Adamczak, 2020) showed that none of the newest models is able to meet the expectations from the point of view of the problem presented above. The theoretical recognition of the mathematical models of rolling bearings shows that they are constructed with far-reaching simplifications and refer only to a few factors influencing the vibrations of the bearing. There is no mathematical model that would take into account the majority of real factors, and in addition contamination of bearings and in grease are the most overlooked factor in vibration analysis. In addition, most of the analytical models focus on a bearing with an obvious defect that may appear only as a result of long operation or bad conditions of use. Therefore, the models proposed in the latest world literature are not universal and it is not possible to apply them in industrial practice (e.g. to predict vibrations of manufactured bearings undergoing quality control or calibration of industrial vibration measuring instruments).

The authors of mathematical models of bearing vibrations focus in most cases that taking into account the roundness deviation, waviness of the raceways of rolling bearings and rolling elements or the properties of the lubricant, i.e. factors that are constantly monitored during their production and can be corrected to a certain extent even before assembling the finished bearing. Meanwhile, the highest number of rejects on the production line when measuring vibrations concerns the problem of bearing cleanliness, i.e. a parameter that is not checked at any other stage of the inspection. The main reason for taking up the topic proposed in the paper is the conclusion that the authors of mathematical models develop them in without thinking of industrial practice. For this reason, the authors of this article decided to describe the trends that related to the measurement of vibrations during quality control in industrial plants.

2. Industrial measurement of bearing vibrations

Two types of measuring devices are used to measure the level of vibrations generated by bearings in industrial conditions: semi-automatic and automatic measuring devices. Automatic measuring devices are used in automatic assembly lines, while semi-automatic devices are used to control small series of folded bearings. The main components of such devices are: a measuring unit with a vibration sensor, a measuring spindle (hydrodynamic, hydrostatic or pneumatic) with a drive, a bearing pressure unit, a bearing feeder mechanism to a measuring station (manual or automatic), a supporting structure with shock absorbers and a controlling.

The above measuring devices allow to assess the vibration level in three frequency bands: Low (50 - 300 Hz), Medium (300 - 1800 Hz) and High (1800 - 10,000 Hz). The vibration level is measured in various units, depending on the recipient's requirements: dB, $\mu\text{m/s}$, $\mu\text{m/s}^2$, A (androns) or % (the conventional unit of one of the recipients). The bearing rotational speed during the measurement is constant and amounts to 1800 min⁻¹.

During the measurement, the average value of the vibration velocity (RMS) and the maximum value are determined for each frequency band. The maximum value of the vibration velocity is sometimes called the size of the "peak".

The RMS value is displayed numerically on the screen of the device and additionally visualized in the form of bar graphs. For the bearing being measured, the RMS and "peak" limits for each strand are entered before starting the measurements. Correct measurement of vibrations of the measured bearing, i.e. below the limit sets, makes the graphs glow green. Each RMS violation of the set limit value is signaled by the color of the appropriate bar on the diagram changing to red.

Fig. 1. a) Bar chart of the vibration level measurement of a good bearing on both sides in three frequency bands, b) bar chart of vibration level measurement of a damaged bearing on both sides in three frequency bands.

In the automatic cycle, the bearing is measured twice, measurement on both sides of the bearing. However, in the semi-automatic / manual cycle, the bearing is measured four times, on each side of the bearing two measurements every 90° in relation to the bearing measurement axis. With semi-automatic / manual measurement, the bearing is additionally checked noise. The bearing should be characterized by operation with noise appropriate for the operation of the bearing. Noise disturbances, such as rattling, whistling, temporary crackling noises caused by contaminations, damage to the raceway of the inner and outer rings, as well as the rolling element, are unacceptable.

Additionally, oscilloscopes are used for such measurements (if there is no vibration spectrum analyzer). The image of the vibration amplitude observed on the oscilloscope should be uniform, should not show peaks and irregularities of waves higher than $\frac{1}{2}$ of the baseband width for standard bearings and $\frac{1}{3}$ of the baseband width for bearings with reduced vibration level, i.e. electric bearings (C66).

Electric bearings (C66) are 100% vibration controlled, while for standard bearings, the measurement frequency is 3% for each assembly batch, but not less than 10 pieces.

3. Organization of bearing vibration control

The vibration level generated by the bearings is measured on exposed bearings (without lubricant and seals). Such bearings are protected only with a thin oil filter. If the exposed bearing meets the quality requirements regarding the vibration level, then the covered bearing, i.e. lubricated and sealed, will meet such conditions all the more (the grease dampens the vibration level in the bearing). The customer may wish to measure the vibration level in a covered bearing. In this case, the drive of the measuring device must have more power, and the pressure must have a greater force. The increase of these parameters (higher motor power and higher bearing pressure force) may cause the danger of accelerated wear of the measuring device. This risk increases with increasing diameter and weight of the tested bearing.

Fig. 2.a) Automatic device on the assembly line for measuring the vibration level generated by rolling bearings, b) Semi-automatic (manual) FAG device for measuring the vibration level of bearings

Each bearing manufacturer has devices for measuring the level of vibrations generated by bearings. Such devices are used in automatic assembly lines and in stands for semi-automatic / manual vibration measurement. FŁT Kraśnik S.A. factory equipped there are newly designed (by local constructors and scientists from the Kielce University of Technology) semi-automatic devices for measuring the vibration level. These devices are the equipment of the newly established Research and Development Center at FŁT Kraśnik S.A.

Each bearing produced is subjected to vibration level control. The result of the vibration level proves its technical level. By making this measurement, we obtain information about potential defects of individual bearing components (outer ring, inner ring, ball / roller, cage) and possibly about contamination in the bearing. The results of the vibration level measurement are subject to continuous check and depending on the result, the quality services respond appropriately according to the procedures.

It should be checked that the defective bearings with exceeded vibration levels are individual cases (one time issue) or whether there has been an error in the production process. Dirty bearings are directed to be washed again. Bearings with exceeded vibration levels, but not showing symptoms of production defects, are reclassified to lower class bearings and offered for sale. As for bearings with exceeded vibration levels and showing symptoms of production defects, these bearings are subject to the disassembly process. Disassembled bearing components: inner rings, outer rings and rolling elements are subject to microscopic inspection. The results of this control have an impact on the next procedure steps. If the issues are individual, the production procedures should be traced, and if the issues are serial, then the cause of the issue should be found and removed. Defective bearing components are subject to regeneration if possible, and if not, they are scrapped. The detected deficiencies have an impact on the improvement of the technological process. Each improvement in the technological process improves the parameters of the manufactured bearings. This automatically influences the design and production of new, more and more accurate devices for measuring the vibration level.

Fig. 3. Newly designed automatic assembly line device for measuring the vibration level generated by rolling bearings

4. Contaminations - the most common issue

Although a rolling bearing may be rejected from the production line during vibration control for a variety of reasons, the contamination inside the bearing is by far the most common cause. Such bearings, in accordance with the company's procedure, are directed to the repeated washing process.

Bearing samples, both contaminated and clean, are sent to the laboratory. There, the degree of pollution and its structure are determined. The test is performed by the weight method. The delivered bearings are washed in extraction gasoline and filtered through a nylon membrane with a mesh side of 0.8 μm . Then the washing bath is filtered on an MN 640w paper filter. After weight analysis, the filters are visually inspected under a microscope. Examples of analyzes are given in the reports in figures 4 and 5.

Bearing number	Bearing type, quantity	Mass of contaminants (mg / kg)		Contaminants above 300 μm Quantity (max. Dimension)	
		Requirements	Result	Requirements	Result
1.	513-716 A (2 pieces)	max 5,0 mg/kg	3,8	max 300 μm (above unacceptable)	2(450)
2.	513-716 A (2 pieces)		3,8		1(360)
3.	513-716 A (2 pieces)		5,0		1(340)

Tab. 1. Contamination weight analysis results

Fig. 4. Filters for the tested bearings type 513-716A (tests 1 - 3).

The appearance of the filters and the contaminants on them are shown in photo on fig. 4. All filters contain a few fibers, small amounts of dried preservative and metallic dust. There are single unacceptable impurities on the filters, exceeding the maximum allowable dimension of 300 μm . These bearings do not meet the cleanliness standards and, in accordance with the procedure, they are sent for repeated washing.

In order to ensure the appropriate cleanliness class of bearings, more and more modern devices with extensive filtration systems are designed for washing individual bearing elements, as well as already assembled bearings. Thus, thanks to accurate systems for assessing the level of vibration generated by bearings, we are able to determine the cause of increased vibrations. We can also determine what is the reason for this and which stages of the technological process of bearing production can be improved.

5. Conclusions

Contamination of the lubricating layer with solid particles is an important parameter reducing the durability of rolling bearings. The degree of service life reduction caused by solid particles in the lubricant layer depends on the type, size, hardness and quantity of particles, the thickness of the lubricant film (viscosity) and the bearing size. Durability tests, however, are destructive and very time-consuming. The level of vibration generated by a rolling bearing is a superior parameter which is inversely proportional to service life.

Bearing vibration tests are much less time-consuming and do not damage the bearing. However, both in theoretical models of bearing vibrations and in experimental tests, the cleanliness of bearings is largely ignored. This is due to the fact that, firstly, the contamination is very difficult to simulate mathematically and, secondly, the emphasis in the experimental studies is on the high-amplitude components in the low and medium frequency range due to damage or the geometric structure of the surface.

The most important conclusion from the description presented in this article is that bearing contamination is an important factor determining the positive assessment of the manufactured bearing during the final vibration control. Therefore, ignoring this factor in mathematical models is unjustified.

In the future, the authors plan to conduct detailed studies on the analysis of the impact of the level of contamination of the rolling bearing on its vibrations, and research on the degree of detection of this type of non-compliance by instruments and measurement methods used in the bearing industry (as a result of the planned tests, it will be possible to predict the importance of bearing vibrations for its purity). In turn, these studies will be part of the preliminary research for a wider research work related to an attempt to develop a model based on multi-criteria statistics, which can be used to forecast vibrations of a newly manufactured bearing in industrial plants.

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