 

# MONITORING THE TECHNICAL CONDITION OF THE BALL BEARING BY METHODS OF VIBRATION AND THERMAL IMAGING DIAGNOSTICS

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ABSTRACT: Bearings are now part of most small or large rotary machines. Maintenance of rotary machines is an essential part of preventing a bearing seizure, which can cause extensive damage to the machine or injury to the machine operators. Early replacement of a broken bearing can preserve the machine, avoiding long-term downtime and saving considerable amounts of money. This paper is concerned with the measurement of two vibration parameters (velocity and acceleration of vibrations) on the bearing housing of a laboratory model using a worn and unworn bearing. The measurement also focuses on monitoring the temperature change in the bearings using a thermal imager. Subsequent analysis of the vibrodiagnostic signal and thermal imaging pictures from the bearing is critical in terms of early identification of an upcoming failure, which can result in the failure of the production equipment.
KEYWORDS: Diagnostics, laboratory model, measurement, evaluation, bearing, temperature, vibrations

## 1. INTRODUCTION

In the industrial field, measuring and evaluating the amplitude of vibrations is an essential part of monitoring the operating condition of machinery. Vibration measurement is critical not just for ensuring operational safety, but also for cost-effective operation. Improving measuring methods requires an effort not only on the part of diagnostic meter manufacturers but also on the part of equipment operators [1]. The use of modern techniques leads to the acquisition of timely and accurate information that speaks of the current technical condition of the measured object. Machine repairs are arranged using vibration diagnostics based on their current state [2,3]. This reduces the costs associated with equipment maintenance. Despite the indisputable advantages of vibrodiagnostics and monitoring of the technical condition of bearings, in certain cases, it is necessary to supplement their possibilities with means of thermodiagnostics [4]. This is especially true if the bearing housing or bearing mounting does not allow for reliable and safe vibration sensor positioning or if a quick and cost-effective preventive examination of the bearing's technical condition is required [5].

Thermodiagnostics of bearings is based on infrared thermal imaging technology, which can measure the surface temperature of the monitored object with a very high-temperature resolution (usually less than 0.1° C) without contact. The surface temperature is shown in thermograms, with information from the measuring point detector as input. The color resolution of the individual measuring points allows for the detection of local temperature changes, which can indicate qualitative changes in the grease or rolling surface (resistance) even at a difference of 3 - 4 ° C, such as when forming a pit [6,7]. In conclusion, thermodiagnostics can be used to detect the quality and suitability of greasing of rolling bearings, as well as surface damage that causes an increase in rolling resistance.

## 2. OBJECT AND MEANS OF DIAGNOSTICS

The experiments were conducted in the laboratory of diagnostics of operating states of production systems at the Faculty of Technologies of the Technical University in Košice with its establishment in Prešov at the Department of Design and Monitoring of Technical Systems.

A double-row ball bearing type 2205 was used to measure the magnitude of vibrations and temperature changes on the bearing housing of a laboratory model (Figure 1). During the measurement, the magnitudes of the vibrations and the temperature change were examined using the unworn and worn selected bearing (Figure 2) [8,9].

The model on which the measurements were performed is used to generate, measure, analyze, evaluate, and present a vibrodiagnostic signal. The SIEMENS 1LA7063 electric motor with a 0.25 kW output and the PowerFlex 40 frequency converter, which was utilized to manage the motor speed, are the two main components. The changing input values were set as 600 rpm, 1200 rpm, 1800 rpm, 2400 rpm, and 3000 rpm engine speeds.

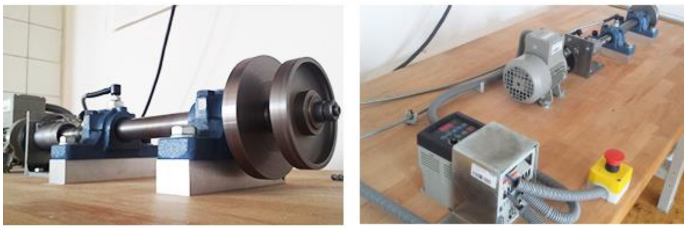

**Figure 1.** Laboratory model for measuring and evaluating the magnitude of vibrations

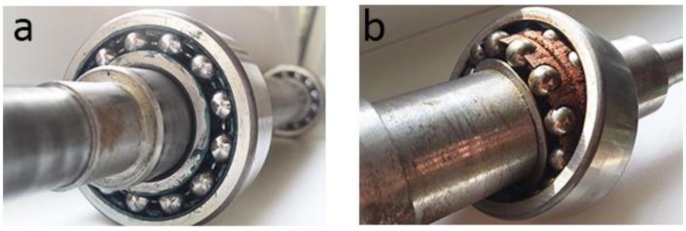


**Figure 2.** Unworn and worn ball bearing type 2205

The magnitude of vibrations was measured using an Oktalon measuring system with a piezoelectric sensor type PCB 607A11. Table 1 lists the technical parameters of the calibrated sensor. Oktalon is a modular multiparametric measuring system designed for continuous monitoring of mechanical vibrations. Measurement, evaluation, and storage of measured values are performed automatically. These values are compared with the set alarm level. The status of each measured node is displayed on the front panel of the instrument using three-color LEDs (green, yellow, red). Numerically measured values for individual measuring points can be displayed using numerical displays and a button for selecting the measuring point. The signal from vibration measurements was processed using software called Promotic 2000, which is a development tool that lets you create applications for visualization, monitoring, and control of technological processes in a wide range of industries [8].

**Table 1.** Basic technical parameters of the sensor PCB 607A11

| PARAMETERS | VALUE |
|---|---|
| measuring range [m.s$^2$] | ±490 |
| frequency [±3dB] | 32 |
| sensor sensitivity (±15 %) [mV/m/s$^2$] | 10.2 |
| working temperature [°C] | 20 |

A Testo 875-2i thermal imager was used to capture the thermal images. Its basic technical parameters are listed in Table 2. The Testo - IRSoft tool was used to process data from thermal imaging measurements, allowing infrared images to be processed and accurately analyzed in a convenient and accurate method. Extensive analysis functions are available for professional thermal image processing. Using thermographic analysis software, critical temperatures, exceedances, and undershoots of limit values, as well as pixels in a specific temperature range, can be highlighted in the image.

Also, an infinite number of measuring points can be determined, hot and cold points can be identified, and comments on the thermographic application can be made. The results from both measurement parameters are recorded in the form of graphical dependencies for predetermined input values.

**Table 2.** Basic technical parameters of the Testo 875-2i thermal imager

| PARAMETERS | VALUE |
|---|---|
| infrared resolution [px] | 160x120 |
| focal point | manual |
| refresh rate [Hz] | 33 |
| measuring range [°C] | -30 to +100; 0 to +350 |
| measurement accuracy | ±2 °C, ±2 % of m.v. (±3 °C of m.v. at -30 to -22 °C) |

## 3. CONDUCTING THE MEASURING

Before beginning the measurement, the placement for mounting the piezoelectric sensor had to be determined. The sensor was attached with a two-component adhesive to the bearing housing of the laboratory model. The position of the sensor with the mounting detail is shown in Figure 3 [8].

**Figure 3.** Position of sensor type PCB 607A11 with mounting detail on the bearing housing

## 4. MEASUREMENT EVALUATION OF THE UNWORN BEARING

The evaluation of the measurement using a worn bearing consists of creating vibration and thermal imaging analysis, which are described in more detail below.

### 4.1 Vibration Analysis

Vibration analysis consists of evaluating two basic parameters of vibration - velocity, and acceleration of vibrations. For the selected measuring point - bearing housing - and predetermined engine speeds 600 rpm, 1200 rpm, 1800 rpm, 2400 rpm, and 3000 rpm, the data are evaluated in tabular and graphical form. Table 3 shows the measured values of velocity and vibration acceleration for the unworn bearing.

**Table 3.** Measured values of the two observed vibration parameters for an unworn bearing

| | Analyzed vibration parameters | |
|---|---|---|
| Engine speed [rpm] | v [mm/s] | a [g] |
| 600 | 0,26 | 0,11 |
| 1200 | 0,6 | 0,33 |
| 1800 | 1,43 | 0,54 |
| 2400 | 6,68 | 0,82 |
| 3000 | 14,89 | 1,14 |

The graph in Figure 4 shows a graphical dependence of the vibration velocity on the engine speed. It can be argued from this dependence, that when the engine speed increases, the value of the vibration velocity also increases. The highest value of the vibration velocity was 14.89 mm/s reached at an engine speed of 3000 rpm. The lowest value of the vibration velocity was 600 rpm when a value of 0.26 mm/s was reached. The difference between the minimum and maximum values represents an increase of up to 98.25%.

Next, the acceleration of vibrations at engine speed, shown in the graphical dependence of Figure 5, was evaluated. It can also be observed from the curve that an increasing trend of values is recorded with increasing engine speed. The highest value of the amplitude of the vibration acceleration was 1.14 g also at the engine speed of 3000 rpm. As with the vibration velocity, the lowest acceleration value was reached at an engine speed of 600 rpm, where a value of 0.11 g was reached. The difference between the measured values can be as much as 90.35%.

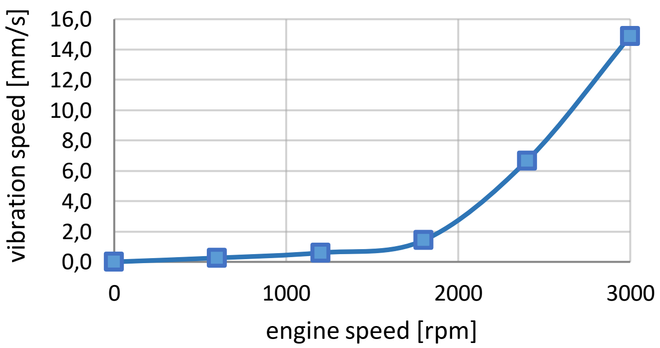


**Figure 4.** Graphical dependence of vibration velocity on engine speed for unworn bearing

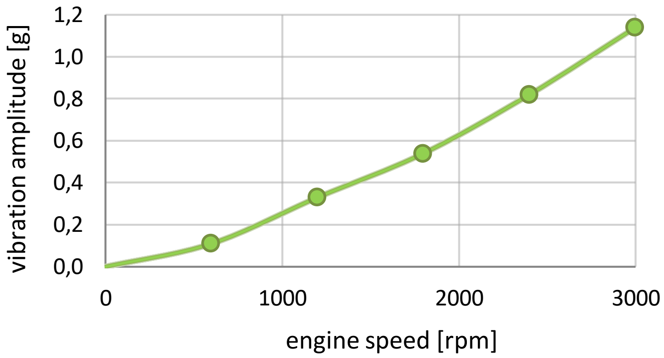


**Figure 5.** Graphical dependence of vibration acceleration on engine speed for unworn bearing

## 4.2 Thermovision analysis

Thermovision analysis consists of evaluating the temperature when performing measurements using an unworn bearing. Thermal images and temperature histograms are evaluated separately from the measurements in Figure 6 for the specified engine speeds of 600 rpm, 1200 rpm, 1800 rpm, 2400 rpm, and 3000 rpm.

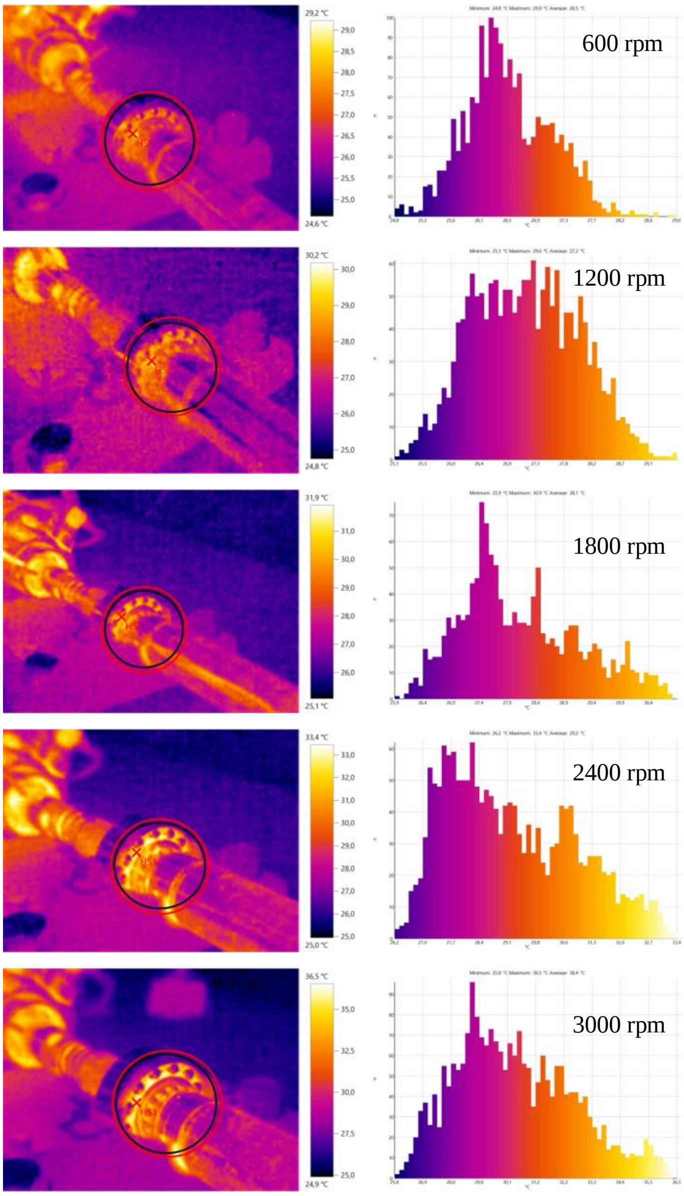


**Figure 6.** Thermographs and temperature histograms for unworn bearing

From the thermal images taken in Fig. 6, the dominant temperature values at all engine speeds used have been achieved on the inner ring of the bearing. The dominant temperature at 600 rpm reached 29°C and the average temperature of the whole bearing is 26.5°C.

From the evaluation of the thermal image using the engine speed of 1200 rpm, the highest temperature value is 29.6°C and the average temperature on the whole bearing was 27.2°C. The highest temperature when using a speed of 1800 rpm reached a temperature of 30.9°C and the average temperature on the whole bearing was 28.1°C. At an engine speed of 2400 rpm, the highest temperature reached was 33.4°C and the average temperature on the whole bearing was 29.2°C. Subsequently, using an engine speed of 3000 rpm, the dominant value reached 36.5°C and the average temperature on the whole bearing was 30.4°C.

## 5. MEASUREMENT EVALUATION OF THE WORN BEARING

The evaluation of the measurement using a worn bearing consists of creating vibration and thermal imaging analysis, which are described in more detail below.

### 5.1 Vibration Analysis

Vibration analysis, like the previous case, includes evaluating two basic vibration parameters: the velocity and acceleration of vibrations. The results are evaluated in tabular and graphical form for the selected measuring point-bearing housing and predetermined engine speeds 600 rpm, 1200 rpm, 1800 rpm, 2400 rpm, and 3000 rpm. Table 4 shows the measured values of velocity and vibration acceleration for a worn bearing.

**Table 4.** Measured values of the two observed vibration parameters for a worn bearing

| | Analyzed vibration parameters | |
|---|---|---|
| Engine speed [rpm] | v [mm/s] | a [g] |
| 600 | 0,43 | 0,31 |
| 1200 | 0,85 | 0,9 |
| 1800 | 1,79 | 2,09 |
| 2400 | 7,61 | 3,09 |
| 3000 | 16,78 | 4,13 |

The graph in Figure 7 shows a graphical dependence of the vibration velocity on the engine speed. It can be determined from this dependence that when the engine speed increases, the value of the vibration velocity also increases. It can also be observed from the curve that with increasing engine speed, an increasing trend of values is recorded. The highest value of the vibration velocity was 16.78 mm/s achieved at an engine speed of 3000 rpm. The lowest value of the vibration velocity was recorded at a speed of 600 rpm, where a value of 0.43 mm/s was reached. The difference between the measured values was up to 97.44% greater. After that, the acceleration of vibrations at engine speed, as shown in Figure 8 is graphical dependence. It can be concluded from this relationship that when the engine speed increases, the value of the vibration velocity also increases. At the same engine speed of 3000 rpm, the highest value of the amplitude of the vibration acceleration was 4.13g. The lowest acceleration value, 0.31g, was reached at an engine speed of 600 rpm, as was the case with the vibration velocity. The difference between the minimum and highest value corresponds to a 92.50% increase.

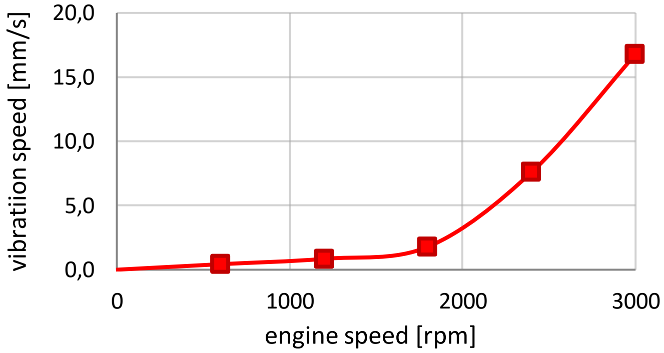


**Figure 7.** Graphical dependence of vibration velocity on engine speed for the worn bearing

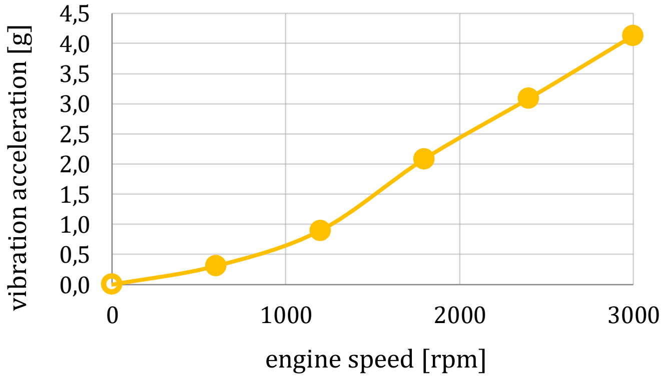


**Figure 8.** Graphical dependence of vibration acceleration on engine speed for the worn bearing

### 5.2 Thermovision analysis

Thermovision analysis consists of evaluating the temperature when performing measurements using a worn bearing. Thermal pictures and temperature histograms are analyzed individually from the measurements in Figure 9 for the selected engine speeds of 600 rpm, 1200 rpm, 1800 rpm, 2400 rpm, and 3000 rpm. The dominant temperature values on the inner ring of the bearing were achieved at all engine speeds used, as seen in the thermal images in Figure 9. The dominant temperature at 600 rpm reached 30.1°C and the average temperature of the entire bearing is 27.1°C. From the evaluation of the thermal image using the engine speed of 1200 rpm, the highest temperature is 33.2°C and the average temperature on the whole bearing reached 28.7°C. The highest temperature when using a speed of 1800 rpm reached 36.8°C and the average temperature on the whole bearing is 30.5°C.

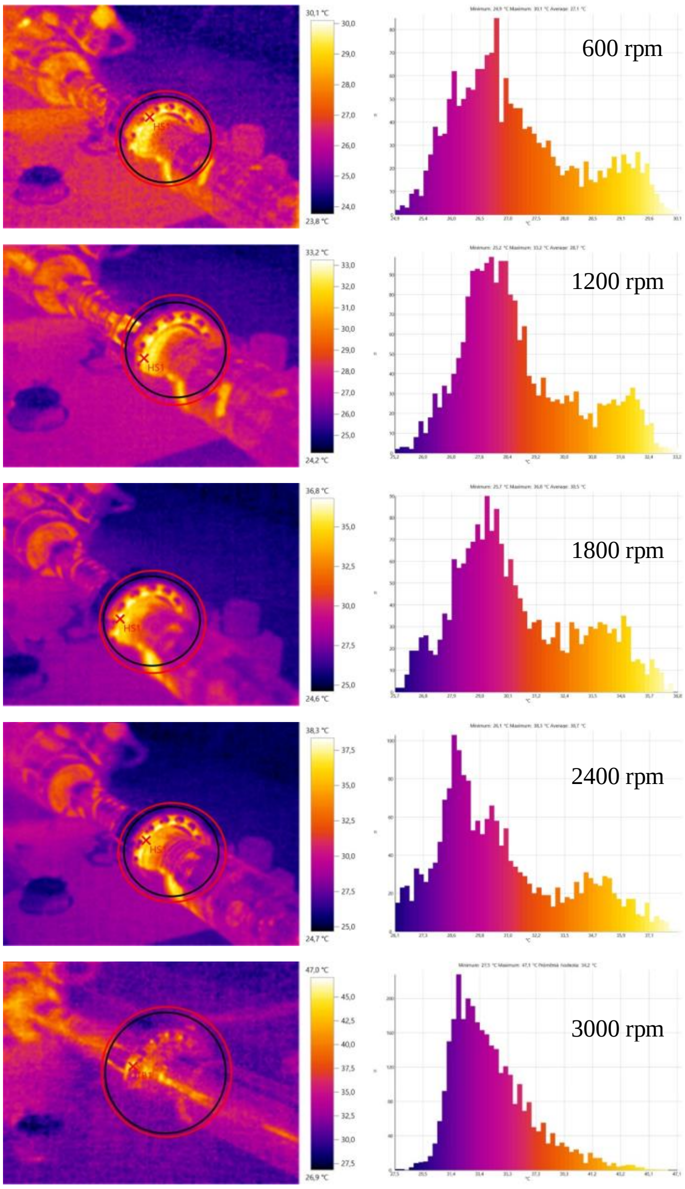


**Figure 9.** Thermal images and temperature histograms for the worn bearing

Another level of evaluation is the comparison of the results of the measured values of vibrations and temperatures in the form of comparative graphs, as shown in the graphical dependencies below. A comparison graph of vibration velocity versus engine speed for worn and non-worn bearings is shown in Figure 10. This graphical dependency of vibration speed on engine speed in comparison to a worn with an unworn bearing shows that increasing engine speed from 600 rpm to 1800 rpm resulted in about the same vibration velocity values with a negligible difference. A visible difference between the measured values of the vibration velocity can be seen when at the engine speed of 3000 rpm, where dominant values were achieved at both used speeds. With a worn bearing, the vibration values are higher compared to an unworn bearing, which represents an increase of 11.27%.

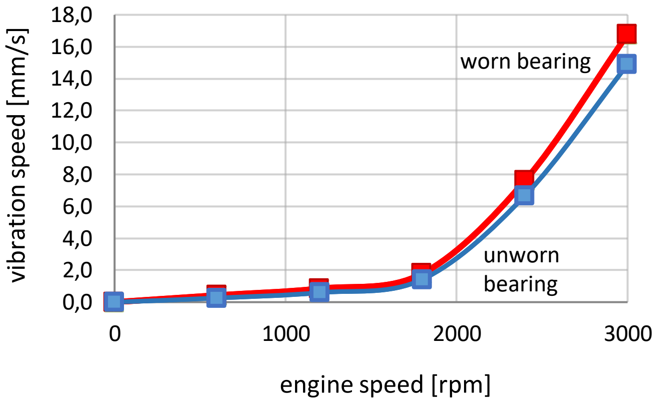


**Figure 10.** Comparative graph of vibration velocity for worn and unworn bearings

A comparative graph of vibration acceleration at engine speed for worn and non-worn bearings can be seen in Figure 11. The graphical dependency of the vibration acceleration on engine speed in comparison to a worn bearing with an unworn bearing shows that with increasing engine speed values, an increasing trend of values is recorded. A visible difference between the highest achieved values of vibration acceleration can be seen when setting the engine speed from 1200 rpm up to an engine speed of 3000 rpm. The biggest difference can be seen at the engine speed setting of 3000 rpm, where dominant values were reached at both speeds used. With a worn bearing, the vibration values are higher compared to an unworn bearing, which represents an increase of up to 72.4%.

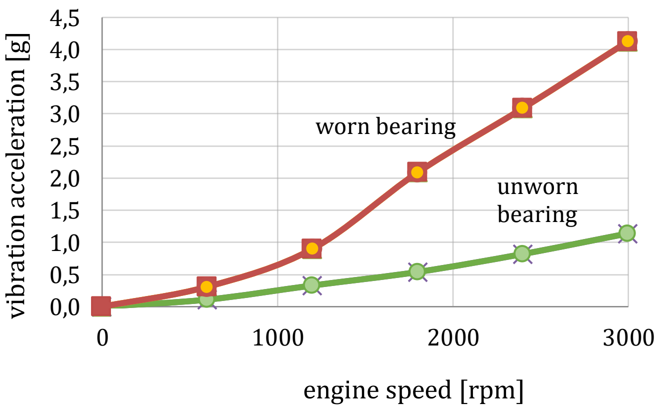


**Figure 11.** Comparative graph of vibration acceleration for worn and unworn bearings

A comparative graph of temperatures for worn and unworn bearings is given in the graphical dependence of temperature on engine speed shown in fig. 12. At a speed of 600 rpm, about the same temperature values were reached. The first visible difference in the values may be observed at a speed of 1200 rpm, and as the speed value increases, so does the temperature value on the bearing. Dominant values were reached at a speed setting of 3000 rpm in both cases. The temperature of the worn bearing was considerably greater than the temperature of the unworn bearing, representing a 22.51% increase.

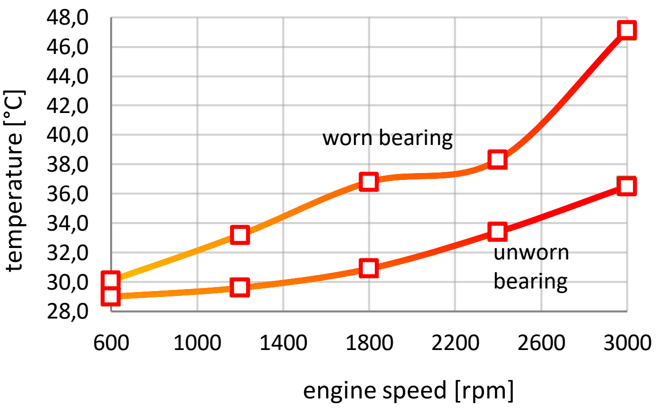


**Figure 12.** Temperature comparison chart for worn and unworn bearings

## 6. CONCLUSION

The highest values of the magnitude of vibrations and temperatures were observed at engine speeds of 2400 and 3000 rpm using worn and unworn bearings, according to the measured values. Thus, we can say that with increasing speed, the values of speed and vibration acceleration increased, as well as the temperature on the bearing.

The vibration velocity measurements were analyzed using the ISO 10816 standard, which indicates that values more than 7.10 mm/s indicate a condition that is unsuitable for future use unless repaired or replaced. Such a value was achieved using a worn bearing at a 3000-rpm engine speed setting - 14.89 mm/s. A value of 6.68 mm/s was reported at 2400 rpm, which is still considered the limit. Engine speeds of 2400 and 3000 rpm are not recommended for worn bearings, as both have reached values that indicate a condition that is unsuitable for further use until repair or replacement.

The amplitude of the vibration acceleration, in addition to the velocity of vibration, is used to describe the machine's condition. The values measured with the unworn bearing correspond to almost new operation. The values obtained with the unworn bearing are close to those obtained when the bearing is new. The highest amplitude of 1.14 g was observed at 3000 rpm. Acceleration amplitude values measured on a worn bearing were higher, in some cases almost four times, compared to an unworn bearing at all measured speeds. Only the acceleration amplitude at 3000 rpm, which is 4.13 g, presents a threat.


## 7. ACKNOWLEDGEMENTS

This work was supported by the Slovak Ministry of Education within project VEGA No. 1/0823/21 and by the Slovak Research and Development Agency under contract No. APVV-18-0316.


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