Effect of Vibration on Machine Tool Accuracy and Lifetime

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Abstract. The article deals with the influence of vibrations for the accuracy and durability of machine tools. Main content involves the use of technical diagnostics, which includes vibrodiagnostics. Vibrodiagnostics is applied directly in the technological manufacturing process. Technological manufacturing process of machining is the rough grinding of steel balls. Using vibrodiagnostics, information is recorded, which are further evaluated. The evaluation of the obtained information has several parts. The first part deals with the influence of vibrations on the service life of the machine assembly. And it examines the current state of the machine. The second part consists of from finding a connection between the vibrations and the workpiece. Several geometric measurements of the samples were used to find the connection, for example primary profile, undulation surface, profile amplitude and other are compared with the recorded vibrations.

1 Introduction

Technical diagnostics deals with various machine maintenance systems. Thanks to them, it is possible to prevent situations that would cause problematic damage to functional parts of the machine. One of the main systems of technical diagnostics is vibrodiagnostics. Its main advantage is that it is one of the diagnostic methods that does not require dis-assembly. Thanks to it, it is possible to determine the exact cause and location of the failure. It also deals with the analysis of vibrations at individual connections such as motor, gearbox, spindles, etc. They record the condition of bearings, check mechanical looseness, misalignment of bearings, clutches and gears.

2 Design of the experiment

The solution of the experiment was located in a production plant dealing with precise engineering production. It includes the production of rolling elements used in rolling bearings. The rolling elements are made of bearing steel 100Cr6.

The manufacturing process consisted of a rough grinding operation during which a number of balls are machined by a grinding process. The grinding is performed with the help of two grinding wheels; from a rotating wheel and a fixed wheel. Both wheels contain grooves with a given shape of the element that ensure, together with the speed of the wheel, the

rotation of the elements during the grinding process. The process does not deal with the balls individually, but hundreds of balls run simultaneously through the process. The grinding process consists of three phases. In the first, the start-up phase, a lower pressure is used, this is in order not to damage the grinding wheels, as the balls differ significantly from the previous operations. Subsequently, the pressure is set for the required material removal for the given process. The last phase is to reduce the pressure to equalize the difference to enter the next operation. After the end of the process, the balls travel further where the last process in their finishing phase takes place – the so-called lapping or super-finishing. This will ensure that irregularities are eliminated as little as technologically possible.
The machining process is performed on a JGS 813 V device. The device consists of three main parts:

– engine,
– transmission,
– system for performing the grinding process.

Each of these machine parts includes rolling bearings and rotating parts that cause vibrations. These are the object of the investigation monitored on the device (see Fig. 1).

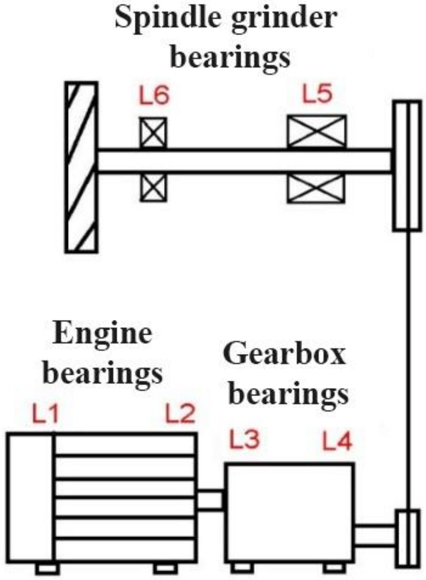

Fig. 1. Bearing scheme of the machine tool [2].

2.1 Measuring devices

An SKF MicrologAnalyzer GX – CMXA 75 device (Fig. 2) was used to record vibrations. It evaluated the vibrations recorded by the CMSS2111 vibration sensor. The SKF @plitude analyst software was used to evaluate the records.

Fig. 2. SKF Microlog Analyzer GX CMXA 75 and vibration acceleration sensor CMSS2111.

2.2 The course of vibration recordings

Vibration measurements within the first part of the experiment were performed on a machine tool that performs a rough grinding operation. It is a run-in process, which means that a stable production process is monitored. During this process, a number of balls placed in the container are repeatedly being ground many times throughout the cycle. In the experiment, the measurement of vibrations is performed on the above mentioned machine tool in clock cycles during the whole grinding process. The first measurement was performed at the beginning of the grinding process. Then, another measurement was performed every hour until the end of the process. The grinding process lasted 6.5 hours. It follows that a total of seven measurements were performed on the device. For each measurement, samples of five balls were selected on which the actual profile of the shape and waviness of the balls was subsequently monitored.

The measured vibrations were recorded at the designated point Fig. 1. This point directly transmits the dynamic forces from the rotating element from the bearing location and characterizes the total vibrations on the element.

To process the second part of the experiment, vibration measurements were performed at other locations in order to determine the overall condition of the equipment. These are in accordance with ISO 10816. In order to determine the vibration process, it is necessary to perform recordings for each measurement from three mutually perpendicular directions. In measurements being accomplished during the production process, the monitoring is accomplished by performing one or two measurements in the radial direction, usually in the horizontal and/or vertical direction.[3, 4, 6].

Fig. 3. Measurement report – vertical. horizontal, axial direction [2].

3 Processing and evaluation of experiments

3.1 Processing of results for the overall condition of the device

From the performed vibration measurements on the monitored device, the measurements are selected to determine the overall condition of the device (Table 1). The stated measured values are measured after two hours of the grinding process.
It follows that the measured values are not affected by the running-in factors. The evaluation of the total absolute vibrations was performed in accordance with ISO 10816-3, point A.2, where medium-sized electric motors and turbines are classified in group 1, in the group for flexible foundations[1, 3].
It has specified band boundaries: A/B = 2.3 mm/s, B/C = 4.5 mm/s, C/D = 7.1 mm/s.

Table 1. Measured values of total vibrations.

Bearing	RMS mm.s-1		
	Horizontal	Vertikal	Axial
L1	7,001	-	-
L2	2,492	3,483	2,609
L3	3,022	3,073	4,418
L4	2,546	6,041	4,479
L5	0,712	-	-
L6	-	-	-

3.2 Processing of spindle vibration results

The recorded measurement results on the grinder spindle bearing marked L5 are shown in the graphic record. The recorded values represent the vibrations captured by the HFD filter Fig. 4.

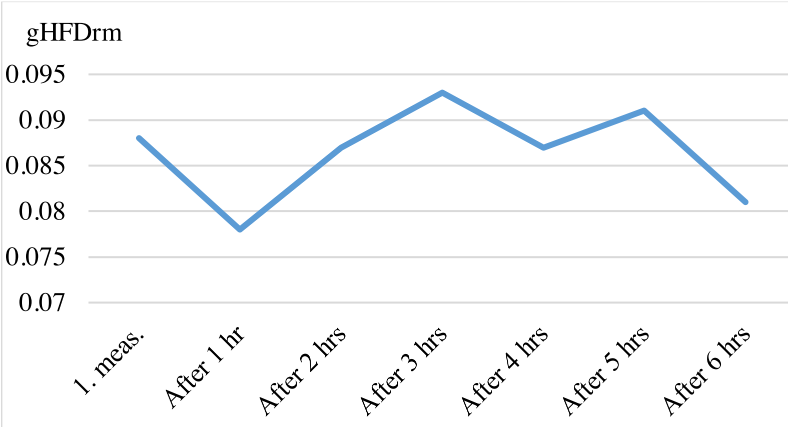

Fig. 4. Graphic display of measured vibration values using an HFD filter.

3.3 Dimensional and shape measurements of samples

In the experiment, various measurements are performed using measuring and microscopic devices on the selected steel balls. The balls (hereinafter referred to as samples) are numbered with the appropriate number from 1 to 5. The primary profile of the samples was measured with the Talyrond 73 ring meter. The Gaussian filters were used to obtain the primary profile of the samples. The Gauss 2 – 50 filter was used to obtain roundness values. The Gauss 15 – 500 filter was used to evaluate the waviness. Harmonic components were determined using the above measuring instrument. These cause vibrations, noise and wear in the bearings and consequently reduce the bearing lifetime. Behind each harmonic component being created there is a certain cause responsible for its creation. Examples of the most common harmonic components are as follows: The harmonic component No. 1 is induced by the eccentricity of the measured object to the axis of the zero point. The harmonic component No. 2: The measured object is oval but it can also be created with a poorly aligned object during the measurement. The harmonic component No. 3: Most of the harmonic components of the lower series are caused by the force of the fastening. The harmonic component No. 4 is inaccessible for objects such as spheres because this component speaks of an emerging shape of a square on the object.

Fig. 5. AliconaInfiniteFocus G5 measuring device and program output.

An AliconaInfiniteFocus G5 was used to perform the detailed waviness of the selected samples from each performed vibration measurement. The device uses an optical system for measuring shape and roughness.

3.4 Processing of measured sample values

On the graphic displays it is possible to see the process of creation of the primary profile of the samples. The effect of grinding is reflected not only on the dimensional values of the samples, but also on the measured values, such as on the graphic course of the waviness (see Fig. 8) where it is possible to see the shape transformation that occurs during the machining process. The values measured on the samples from the first measurement contain the waveform spectrum belonging to the heat treatment and previous operations; it is removed by successive machining process.

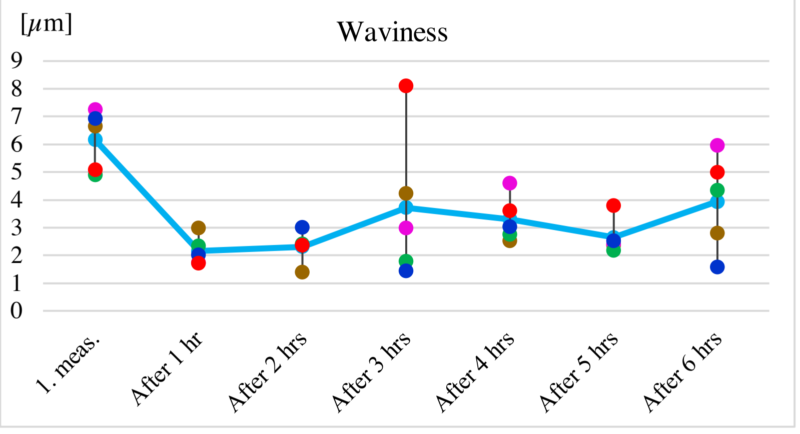

Fig. 6. Graphic display of measured waviness values.

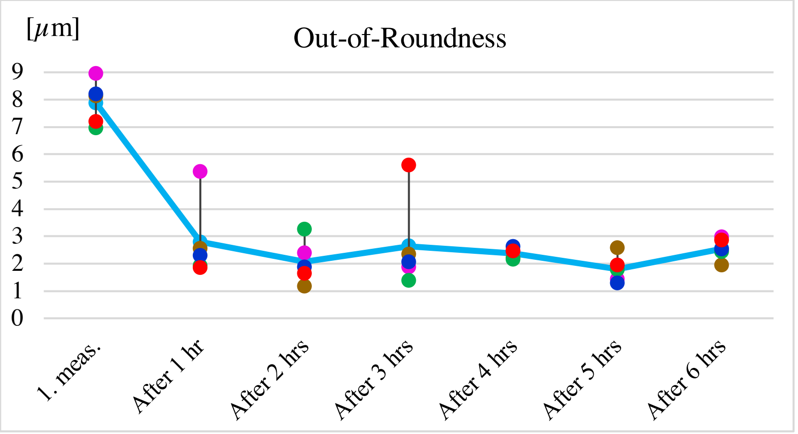

Fig. 7. Graphic display of measured values the standard deviation of the profile.

A detailed record of the waviness of the balls can be seen in Figure 10, which represents the actual profile made by mapping the surface of the balls with a microscope. These so-called surface maps show us in detail where a protrusion or depression is located on the given sample. It is also possible to see on the samples how the shape of a sphere is formed. After 4 hours of grinding, the profile of the samples is circular and further hours of grinding improve their waviness.

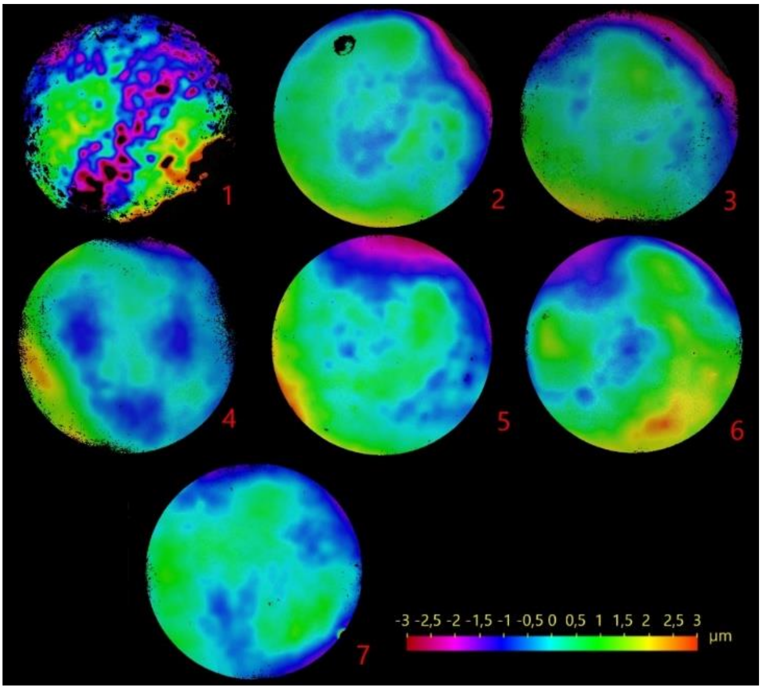

Fig. 8. Detailed influence of waviness of selected cases.

In the following graph (see Fig. 9) of the roundness deviations, it is possible toobserve the ongoing shaping of the primary profile. The measured roundness values on the sample after one measurement are in the range of 7 – 9 [μm]. This is due to previous operations, so in

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order to obtain the perfect shape of the spheres, it is necessary to repeat the machining process several times to obtain the perfect shape. Furthermore, it is possible to see a decreasing and increasing course of roundness on the graph which is directly influenced by the changes performed during the grinding process.

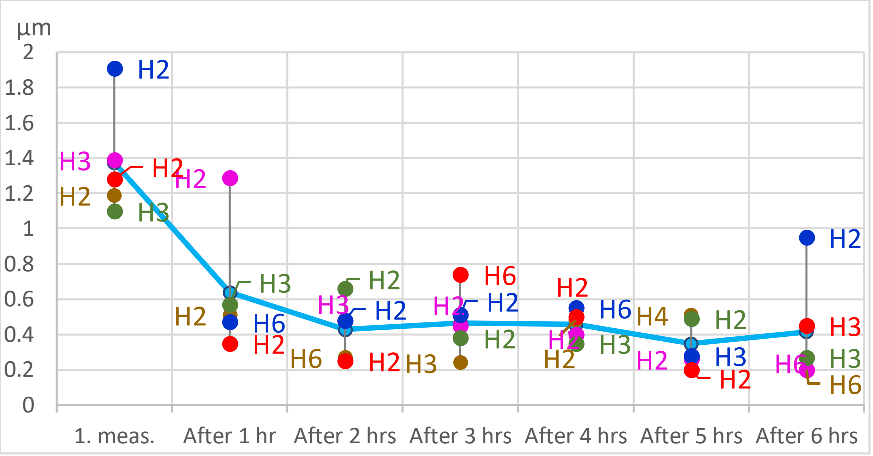

Fig. 9. Graphical record of prevailing harmonic criteria on estimated samples.

A further graphical record is a graph of the load-bearing amplitudes of the profile which defines which component of the harmonic waveform prevails (Fig.9 – represented harmonic waveform by the letter H with the relevant number).
This is used to determine the load-bearing capacity. The higher measured harmonic component guarantees a higher load-bearing capacity of the ball. In practice, this means that the bearing used in a high load system must contain elements with the highest possible harmonic component. After six hours of the grinding process, it can be seen that the harmonic components No. 3 and No. 6 predominate, indicating that the machining process is producing the desired shape.

3.5 Evaluation of experiments

From the performed measurements of the overall condition of the device, it is possible to evaluate that the values measured at most bearings indicate the fulfilment of the operating criteria for operation for an indefinite period of time. However, since values have been recorded even close to the D-area, which indicates that vibrations in that area are considered dangerous, it would be appropriate to make further measurements in order to determine whether the vibrations on the device will manifest themselves again.
During the measurement, increased vibrations in the vertical direction were recorded on the L4 bearing. This recorded value is in the C-area. From the record in Fig. 12 there is a visible spectrum of the vibration velocity ranging from a frequency of 5,000 to a frequency of 9,900. This spectrum is also on the record in the axial plane (see Fig. 13) and the amplitude values are even higher.

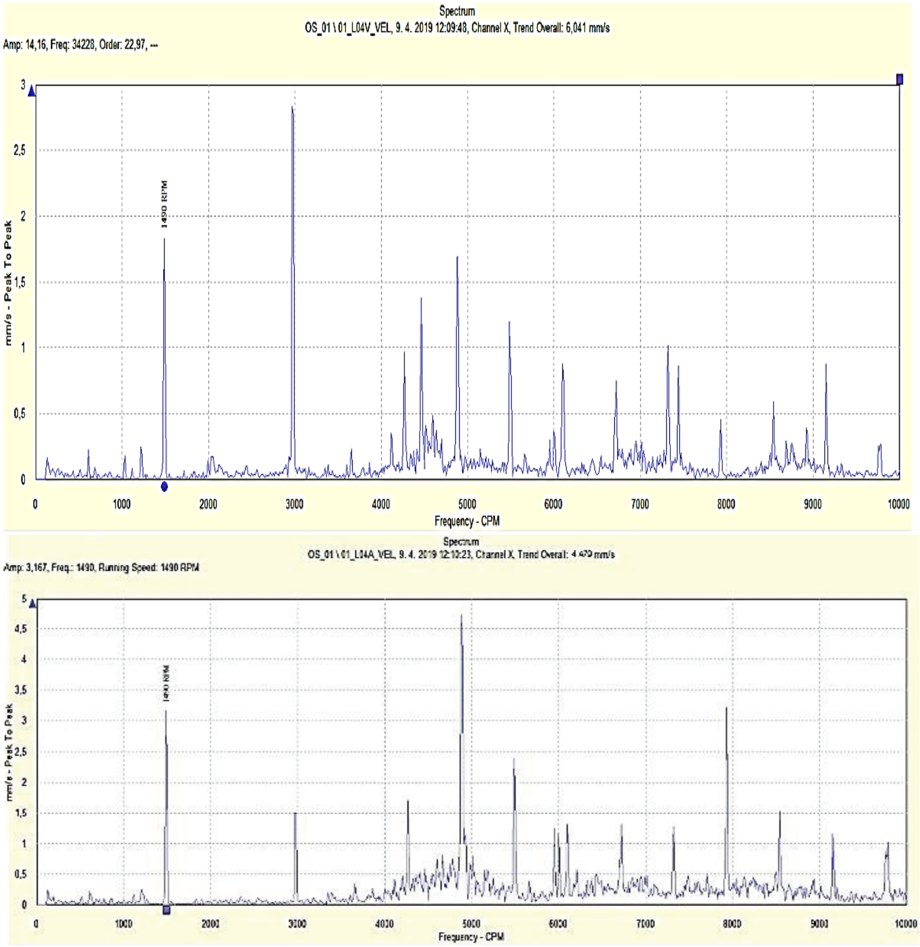

Fig. 10. Vibration speed recording L4 (up) vertical direction, (down) axial direction.

In practice, it has been found that under ideal conditions, vibrations in the axial direction should be recorded as a minimum, since most of the forces are generated perpendicular to the shaft. However, vibrations in the axial direction are attributed to misalignment and bent shaft. From these records, it is possible to evaluate that it would be appropriate to perform re-measurements of vibrations and, depending on their results, to perform other actions to prevent the formation of vibrations. One of the actions required to prevent vibrations may be to check the alignment on the transmission output shaft.

The next part of the evaluation is focused on an experiment that deals with the study of the influence of vibrations on the machining process. This effect was determined between the vibrations on the L5 bearing of the grinding wheel spindle and the samples as seen in Fig. 10 which are machined by this grinding wheel. Practice says that the effect of vibrations in the work process can be observed on the given objects. From the measurements performed on the samples, it is possible to monitor the variable course of the measured values. It can be presumed that this variable course occurs due to the influence of vibrations. In order to

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determine the result of the evaluation, a graphical record is compiled which consists of the waviness and the measured values of the vibrations captured by the HFD filter.

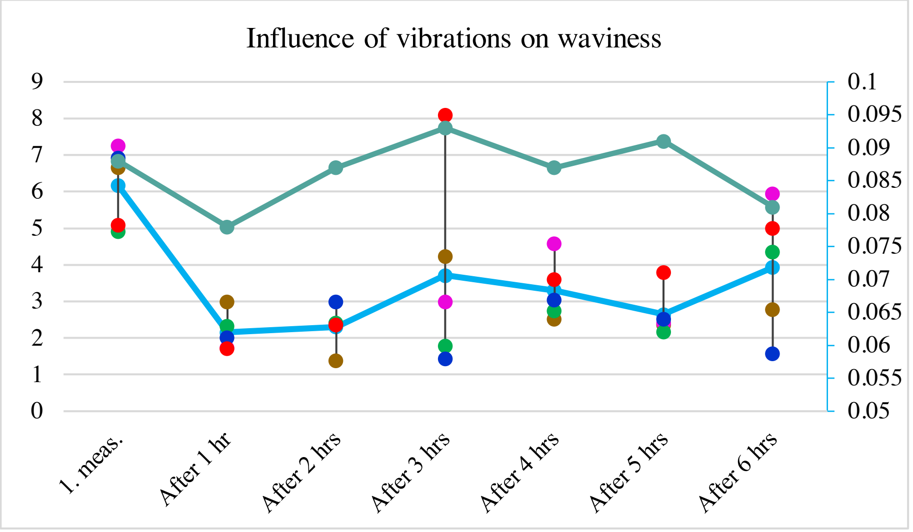

Fig. 11. Interaction between vibrations and waviness of samples.

It is possible to observe the waviness of individual samples on the graphic record which is represented by a light blue line. The captured vibrations are shown in purple. By combining these two elements, a record is obtained on which the relationship between the two elements is visible. For samples after one hour, a decrease in vibration is recorded, as well as a decrease in the waviness. In the following two measurements, an increase in vibrations was recorded and again the waviness of the ground objects increased. The waviness of the samples corresponds to the created curve from the vibration measurement. In the measurement No. 5 the working conditions changed due to which an increase in vibrations was caused and at the given time the curves do not correspond to the waviness.
Since the product of the machining is the rolling element for the bearing, and the primary profile of this product plays an important role in the service life of the bearing, it would be appropriate to keep the manifestation of vibrations to a minimum. This would prevent the subsequent transmission of these vibrations to the balls being machined. This would help to improve their resulting waviness after the rough grinding process.

4 Conclusion

The experiment includes the analysis of vibrodiagnostic data on the machine tool and the subsequent evaluation of this data. Vibrodiagnostics falls under the area of technical diagnostics which is one of the main applications to ensure the correct operation of the equipment nowadays. Therefore, the evaluation of the obtained data consisted of two parts. The first part focuses on the device as a whole which has a fixed lifetime. High demands are placed on the control of the service life of similar machine tools which guarantee the early detection of the machine failure which could cause interruption of production on the machine tool, and paralyze the long-term operation of the machine. The evaluation of the vibration records measured on the device provided information on the current state of the device. The second part of the experiment consists of the determination of the effect of vibrations on the product of production, which are balls in rolling bearings. From the

evaluation of this part, it was found that the vibrations captured on the spindle of the machine affect the geometric specifications of the machined samples. Deteriorated geometric specifications and the primary profile of the samples were recorded when increased machine vibrations were detected. The evaluation of the experiments is of benefit to the company in which the examination was accomplished. Thanks to them, the company obtained information about the current state of the device that can be implemented into the actual system of the diagnostics of the device.
The processing of diagnostic signals used, specifically based on RMS velocity of vibration and HFD values, was based on the requirement to use measurable values in a simple and fast way to predict the occurrence of deviations in production.However, their simplicity does not always cover the complex problem of predicting and taking into account the specific properties of the signal.It is therefore appropriate to focus in the following work, for example, on the use of integral transformations, such as the wavelet transform [6,7,8] and its advantages in the analysis of signals from diagnostic measurements.

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