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THE SPINDLE DEFECT EVALUATION USING A THREE-DIMENSIONAL VIBRATION ANALYSIS

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Abstract: *In this paper, accelerometers transducer are used to check the spindle vibration. Once the spindle is out of balance, the transducer gives a dialog response to computerized numerical controller (CNC) which is set with a control level. This paper aims at analyzing the state of the machine tools and data detection due to vibration-shaft electric motor assembly (Fig. 2). A series of measurements are performed in order to determine the cause of the vibration generator and highlighting effects. To determine the source of vibration is used a number of tools and techniques based on signal processing. Such vibration analysis in this paper is based on a number of methods, such as spectrum frequency, harmonic order, and trend signal. The linking part between the transmission belt and the main spindle was measured and as a result, it was observed that the elastic part doesn't work accordingly and that it represents the cause of the 4th order harmonic.*

Key words: *vibration, main spindle, order analysis, frequency spectrum.*

1. INTRODUCTION

The spindle system is one of the coomoly used mechanical devices in machine tool industry. The dimensions of the spindle shaft, as well as the location and the stiffness of the bearings and the load of workpiece, affect the deformation of the spindle. The bearing stiffness is dependent on the pressure and thickness of the lubrication film, which is also affected by the deformation of the spindle system [1]. Machining and measuring operations are invariably accompanied by relative vibration between workpiece and tool. These vibrations are due to one or more of the following causes: in homogeneities in the workpiece material; variation of chip cross section; disturbances in the workpiece or tool drives; dynamic loads generated by acceleration/deceleration of massive moving components; vibration transmitted from the environment; self-excited vibration generated by the cutting process or by friction (machine-tool chatter) [2, 3]. Diagnosis spindle defects, such as unbalance, misalignement, bearings defects, nonuniforn elctrical parameters, and crack plays a very important role in reducing operation and mainetance costs [9]. Considerable research related to bearings and spindles has been published. The proposed that vibration caused by mass imbalance is an important factor affecting the machining accuracy, limiting the performance and fatigue life of the rotating system [4].

Machine troubles are almost always characterized by an increase in vibration level which can be measured on some external surface of the machine and thus act as an indicator. The frequency spectrum of a machine in a normal running condition can therefore be used as a reference "signature" for that machine. Subsequent analyses can be compared to this reference so that not only the need for action is indicated but also the source of the fault is diagnosed. Vibration analysis is the most common technique used in machine tools maintenance.

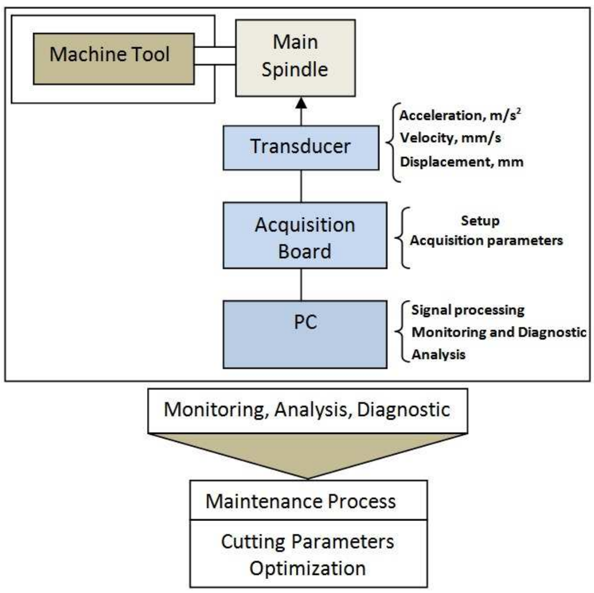

Fig. 1. Research synopsis.

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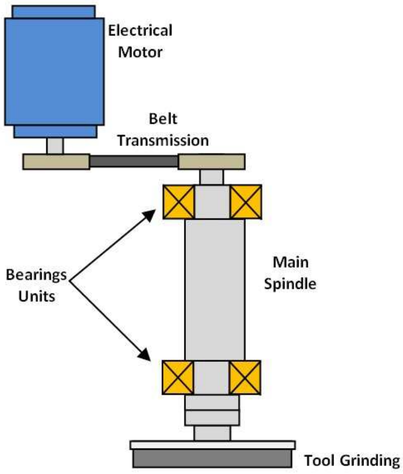

Fig. 2. Kinematics elements.

This technique allows monitoring of machine tools operating condition, identification of mechanical defects in gears, bearings, couplings etc. In this study, the main interest is represented by main spindle – bearings assembly (Fig. 1). Unexpected failure of a spindle can cause severe part damage and costly machine downtime, affecting overall production logistics and productivity.

Vibrations caused are affecting the machining accuracy, limiting the performance and fatigue life of the rotating system. Those failures could results in a poor surface finish, vibration or excessive heat build-up within the spindle or a seizure of the spindle under extreme condition. In any event the exact cause of the failure is usually difficult to be detected and will induce undue friction between the manufacturer and the end user [5, 6, 7, 8]. This paper aims at analyzing the state of the machine tools and data detection due to vibration-shaft electric motor assembly (Fig. 2). A series of measurements are performed in order to determine the cause of the vibration generator and highlighting effects. To determine the source of vibration is used a number of tools and techniques based on signal processing. Such vibration analysis in this paper is based on a number of methods, such as spectrum frequency, harmonic order, and signal or trend polar diagram.

2. OBJECTIVE

The objective of this paper is represented by characterization of the malfunctioning of a grinding machine tool. When monitoring the vibration level of the machine, it has been observed that when the rotational speed reaches 1 500 rpm, the vibration level increases with increasing rotational speed. When reaching speeds of 2 000 – 2 500 rpm, the amplitude of vibrations is very high, a fact that makes impossible the obtaining the appropriate surface quality for the machined pieces.

3. EXPERIMENTAL SETUP

For the dynamic analysis, it was developed an experimental protocol [9] consisting of (Fig. 3): the grinding machine tool, the vibration measuring equipment – DSA 550 and the acquisition board NI 4432 from National Instruments, a triaxial (3D) accelerometer, which was fixed on the main spindle (on the bearings in proximity of the tool) and an uniaxial (1D) accelerometer mounted on the back bearing of the spindle, both used for measuring the accelerations for the vibration signal, and a laser tachometer for direct measuring of the spindle rotational speed, by converting the speed in an electrical signal.

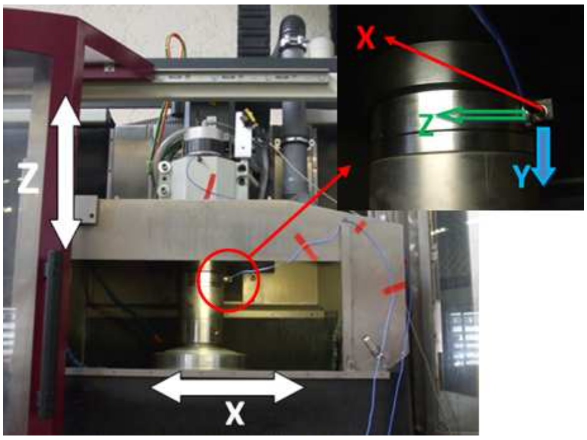

Fig. 3. Experimental setup for vibration measurements (axes of the machine tool and of the 3D accelerometer).

The tests were conducted on a 2 axes CNC-controlled grinding machine, used in pre-, fine and finest grinding of optics plane, for workpieces having diameters less than 500 mm. The main spindle speed reaches 3000 rpm.

The two axes (*X* and *Z*) are represented in Fig. 3, as well as the axes of the 3D accelerometer.

The experimental procedure consists in measuring the vibrations of the machine tool during functioning in a speed range of 1 000...2 500 rpm, for different levels of speed and for two different configurations: with and without the tool. The amplitudes of vibrations at each speed, on all three axes, for the two configurations are represented in Figs. 4 and 5, and the values are centralized in Table 1.

Table 1

Global vibration measurement

Speed [rpm]	With tool [m/s^2]			Without tool [m/s^2]		
	X	Y	Z	X	Y	Z
1000	0.007	0.003	0.006	0.012	0.005	0.006
1500	0.018	0.050	0.047	0.030	0.047	0.043
2000	0.030	0.037	0.139	0.063	0.037	0.128
2500	0.026	0.067	0.107	0.050	0.066	0.096

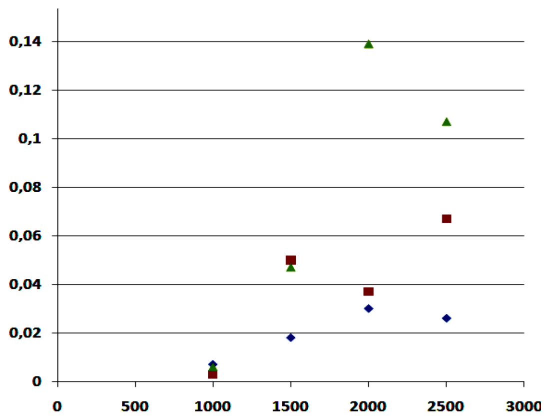

Fig. 4. Vibration level vs. rotational speed, with tool: X axis; Y axis; Z axis.

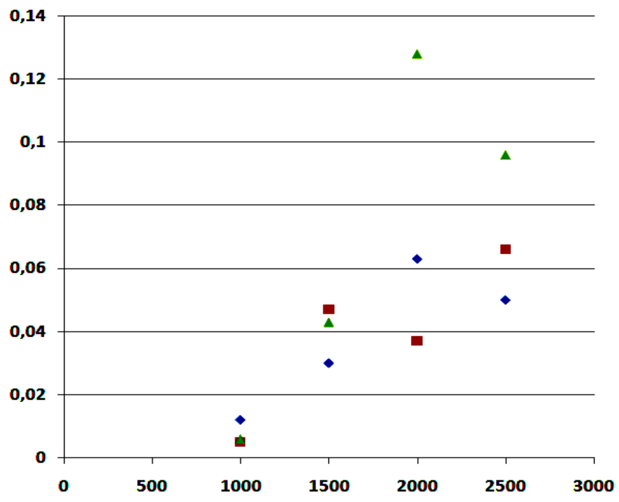

Fig. 5. Vibration level vs. rotational speed, without tool: X axis; Y axis; Z axis.

In Fig. 5 one can observe that the vibration level for the machine tool configuration without tool is greater than in the case of the configuration with tool. Therefore, as the level of vibrations increases, it is safe to say that the tool cannot be the cause of vibrations. Further analysis will concentrate on the configuration grinding machine without tool.

4. RESULTS AND ANALYSIS

Knowing that the grinding machine must work in the domain of 2 000 – 2 500 rpm, the dynamic analysis focuses on this speed range. In order to achieve the objective of the study, it is necessary to do a more thorough vibration analysis looking for the necessary information to identify the cause of vibration.

The measurement protocol presents the following analyses: waveform of vibration signal, frequency spectra and harmonic spectra.

In Fig. 6 the waveform of the vibration signal is represented. The first free signals come from the tri-axial accelerometer on the three axes (*X*, *Y* and *Z*), the forth signal is registered from the laser tachometer and the last signal represents the uni-axial accelerometer.

Figure 7 represents the increase of vibration amplitude with the increase of the main spindle rotational speed. The increase of rotational speed is registered by the laser tachometer as an electrical impulse, as shown in figure. Above it, the increasing vibrations are registered with the two mentioned accelerometers (3D and 1D).

By applying the Fast Fourier Transform the frequency spectra of vibration was obtained (Fig. 8). The first peek on the diagram shows the rotational frequency. As the measurements were conducted at a speed of 2 000 rpm and considering the formula below (1), the value of the rotational frequency is 33.3 Hz.

$$f = \frac{n}{60} \text{ [Hz].} \qquad (1)$$

As shown in Fig. 8, the amplitude increases a lot at the frequency of 133.8 Hz, corresponding to the 4^{th} order harmonic.

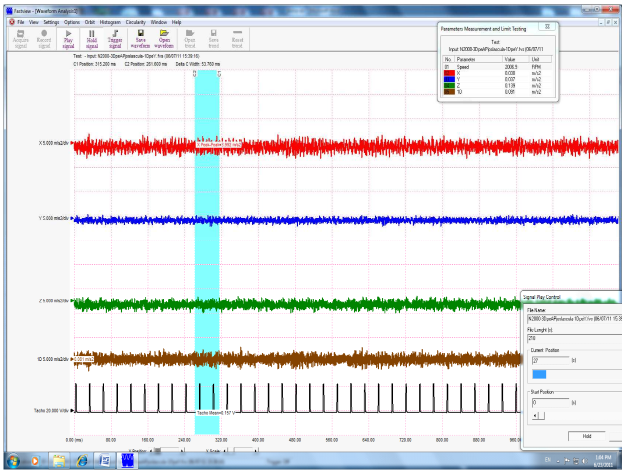

Fig. 6. Time signal for rotational speed n = 2 000 rpm.

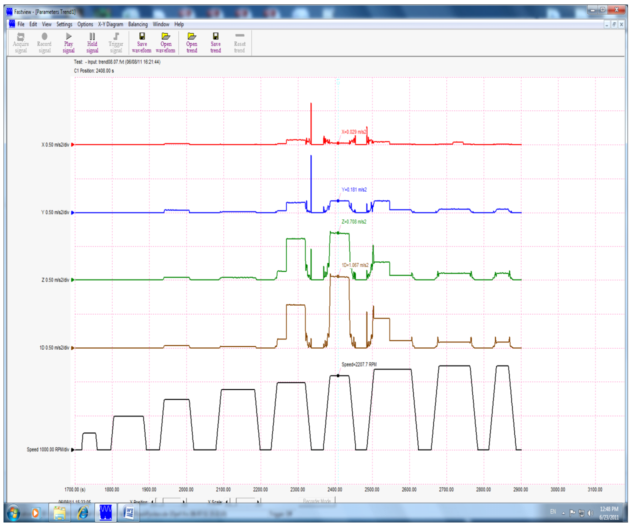

Fig. 7. Evolution of vibrations with rotational speed of main spindle.

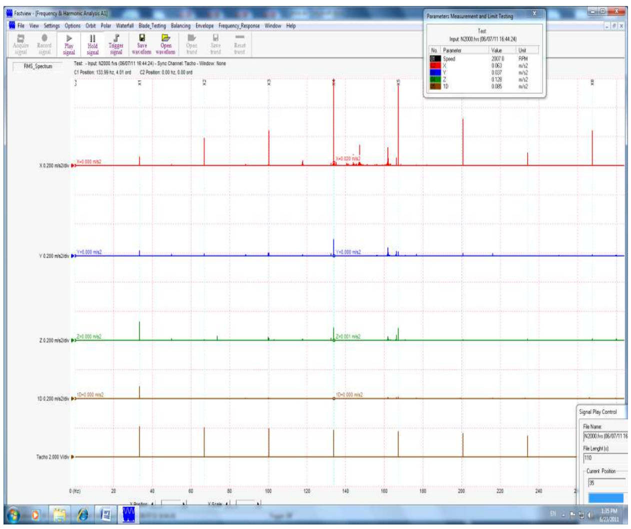

Fig. 8. Frequency spectra for spindle speed n = 2 000 rpm.

For a thorough result, an order analysis is used for verification (Fig. 9). As it can be seen, the 4^{th} harmonic points out itself, with obvious high amplitude.

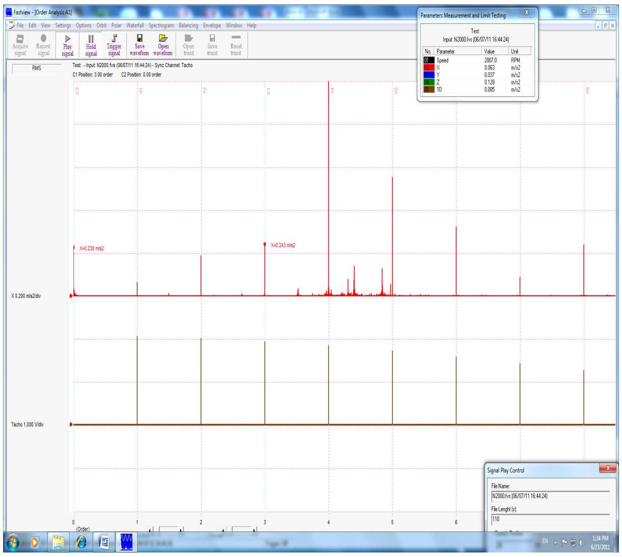

Fig. 9. Order analysis for spindle speed n = 2 000 rpm.

Figures 8 and 9 also indicate, with lot smaller amplitudes, an unbalance by the presence of the first order frequency (rotational frequency) and a misalignment materialized by 2nd and 3rd harmonic orders.

The result of the conducted analysis is that the vibration problem is caused by the 4th order harmonic. This 4th order harmonic is rarely present in vibration spectra and it could be considered as a misalignment.

Because the mechanical design of the main spindle assembly does not provide a mechanical part with such a geometry equivalent to the 4th order harmonic, the analysis was oriented towards the transmission part. In conclusion, a decision of disassembling the transmission pulley from the main spindle was made.

5. DEFECT IDENTIFICATION

Circularity measurements were effectuated on the main spindle axis and on the transmission pulley, using a comparator device. The values show no defect on either of these components: 0.002 mm circularity for the main spindle axis and 0.004 mm circularity for the pulley.

The electric motor/transmission belt/pulley/main spindle assembly revealed also the presence of an elastic mechanical part (Figs. 10 and 11).

Considering the functionality of the assembling part, circularity measurements were made for it also (Fig. 12). The measurements were done at the exterior, as at the interior of the part, for both rings. The values obtained from the measurement are centralized in Table 2. It is easy to observe that the circularities are very high.

As conclusion following the measurements, a clamping defect was discovered for the assembling part, respectively a four points contact defect.

Figs. 13 and 14 represent the assembly of the elastic mechanical part with the transmission pulley and with the main spindle and shows the defect at montage. At the exterior of the part, only one ring is in contact with the transmission pulley, and at the interior, one of the rings doesn't have the correct angle for assembling, thus the high level of vibrations that occurs during functioning are higher speeds.

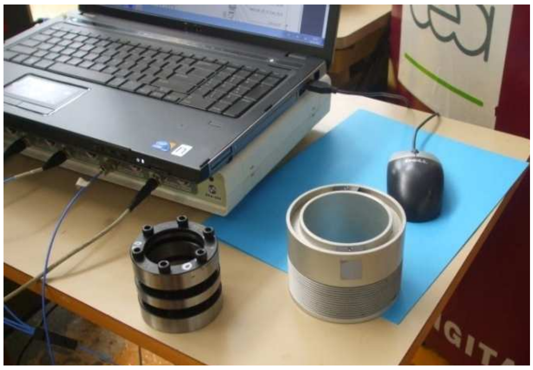

Fig. 10. The assembling part and the transmission pulley.

Fig. 11. The assembling elastic part.

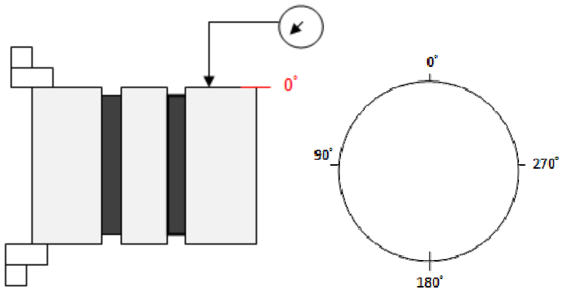

Fig. 12. Circularity measurements.

Table 2

Circularity values for the elastic assembling part

	Exterior		**Interior**	
	Ring 1	Ring 2	Ring 1	Ring 2
0º	0	0	0	0
90º	+0.12	+0.05	+0.27	+0.29
180º	+0.1	+0.07	+0.28	+0.029
270º	+0.09	+0.06	+0.28	-0.01

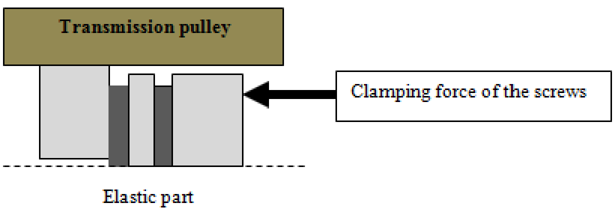

Fig. 13. Inappropriate assembly of elastic part and transmission pulley.

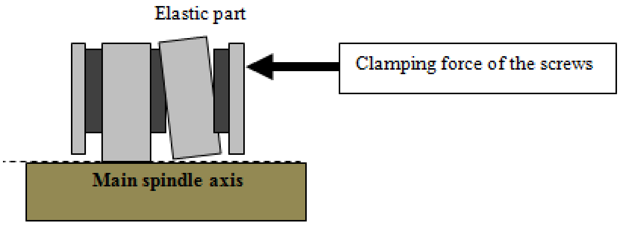

Fig. 14. Inappropriate assembly of elastic part and main spindle.

6. CONCLUSIONS

The definition of the problem is highlighted by the objective of the study. An experimental protocol in order to obtain the results and solutions for the proposed issue was designed [9]. It was conducted a campaign of tests in different configurations for measuring the vibration time signals. By applying the FFT transform, the result was the frequency spectra. For more accurate results, a dynamic analysis was imposed. Therefore, by using the order analysis diagrams, the vibrations are characterized by their order of harmonics.

The result of the analysis was identifying the vibration generating frequency and localizing its cause.

The linking part between the transmission belt and the main spindle was measured and as a result, it was observed that the elastic part doesn't work accordingly and that it represents the cause of the 4th order harmonic. As recommendation, the linking part should be replaced, or better, the transmission belt/main spindle assembling solution should be changed.

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