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Vibrations in the Machining System of the Vertical Machining Center

Edward Miko\textsuperscript{a}, Łukasz Nowakowski\textsuperscript{b}, a*

\textsuperscript{a\textsuperscript{b}Kielce University of Technology, Chair of Mechanical Engineering and Metrology, Aleja Tysiąclecia Państwa Polskiego 7, PL- 25314 Kielce, Poland

Abstract

The paper discusses the equipment and method for measuring vibrations in the tool-workpiece system during face milling. The experimental results show that the vibrations in the tool-workpiece system are dependent on the feed rate. The relationships between vibrations and time, as well as the standard deviation of the displacements and feed are presented graphically. The tests conducted on an AVIA VMC-800 with a built-in measuring system involved milling C45 steel samples with a Sandvik Coromant CoroMill 490 cutter. The process of surface roughness formation in face milling with a CoroMill 390 is difficult to define, as there are a number of factors to be taken into consideration. The work analyzes the influence of the vibrations in the tool-workpiece system on surface roughness. The simulations were conducted basing on the mathematical model for predicting surface roughness discussed in Ref. [1].

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Keywords: Face milling; feed; vibrations in the tool-workpiece system; measurement; milling machine.

1. Introduction

Face milling is considered to be one of the most efficient methods of surface formation. However, the process is very costly and requires determining the most optimal conditions. Thorough research is necessary to make further improvements in its efficiency, and accordingly the quality of the outer layer [1], [2]. Face milling is one of the basic dimension- and surface-formation operations used in the
Vibrations that occur in the tool-workpiece system during Face milling are an undesirable phenomenon. They cause a decrease in the process output, cost efficiency and quality, and shorten the service life of the tools and subassemblies [1], [2], [3], [5]. As the displacements have been found to considerably affect surface texture, they should be taken into consideration when it is vital to improve the efficiency of the cutting process. The study described in ref. [1] confirms that there exists a significant relationship between relative displacements in the tool-workpiece system and the roughness of the machined surface.

This paper discusses the method, equipment and results of measurement of relative displacements in the tool-workpiece system during face milling for different values of the feed and analyzes the influence of the vibrations in the tool-workpiece system on surface roughness.

2. Equipment for measuring vibrations in the tool-workpiece system

The measuring system was built using a Renishaw laser interferometer and a rolling guideway. Such equipment is frequently employed for comprehensive assessment of the accuracy of machine tools, coordinate measuring machines (CMMs) and other mechanical systems. The laser interferometer applied to construct the system for measuring the relative displacements in the tool-workpiece system ensures a linear measurement accuracy of ±0.5 ppm. The laser system produces a highly stable laser beam. The system is equipped with an environmental compactor and sensors. The data can be registered with a frequency of up to 50 kHz at a maximum linear measurement speed of 4 m/s and a linear resolution of 1 nm [6, 9].

The system enables immediate and very accurate measurement of vibrations in the tool-workpiece system for a wide range of positions of the spindle in relation to the machine tool table. It is possible to apply different tools and workpieces of different sizes without calibration. As the measuring system is versatile, it can be used on most milling machines; no additional accessories are required.

The measuring system was mounted on an AVIA VMC 800 vertical machining centre. The centre consists of a cross table moving in the X- and Y-axes and a single-sided headstock moving along the column guideways in the Z-axis. It is equipped with a numerically controlled rotary table, which provides a fourth axis. This four-axis vertical machining centre uses a HEIDENHAIN iTNC 530 controller with a direct-axis drive system [8,10].
3. Laboratory tests

The tests involved face milling cuboid-shaped samples made of C45 steel, which is a common engineering material characterized by repeatable properties and good machinability. The samples were milled without coolant on a VMC 800 vertical machining centre shown in Fig. 2.

The tool applied for the tests was a CoroMill 490 milling cutter with 490R-08T308M-PL 1030 inserts (see Fig. 3) [7], [11].
The milling was performed with a CoroMill 490 cutter under the conditions listed in Table 1.

Table 1. Machining conditions during measurements

| Machining parameters | \( f_z \) [mm/tooth] | \( v_c \) [m/min] | \( n \) [rev/min] | \( a_p \) [mm] | \( d \) [mm] | \( r_e \) [mm] | \( z \) [inserts] |
|----------------------|----------------------|------------------|------------------|--------------|-----------|------------|-------------|
| 1                    | 0.02                 | 300              | 1911             | 0.2          | 50        | 0.8        | 5           |
| 2                    | 0.04                 |                  |                  |              |           |            |             |
| 3                    | 0.06                 |                  |                  |              |           |            |             |
| 4                    | 0.08                 |                  |                  |              |           |            |             |
| 5                    | 0.10                 |                  |                  |              |           |            |             |
| 6                    | 0.12                 |                  |                  |              |           |            |             |
| 7                    | 0.14                 |                  |                  |              |           |            |             |
| 8                    | 0.16                 |                  |                  |              |           |            |             |
| 9                    | 0.18                 |                  |                  |              |           |            |             |
| 10                   | 0.20                 |                  |                  |              |           |            |             |

Fig. 2. VMC 800 vertical machining centre

Fig. 3. Tool used in the tests: (a) a CoroMill 490 milling cutter; (b) (c) a 490R-08T308M-PL 1030 insert
The tests involved registering signals of relative displacements in the tool-workpiece system during face milling and calculating their standard deviation. Fig. 4 illustrates signals of the relative displacements in the tool-workpiece system for a sampling period of 0.2s. Ten signals were registered for ten values of the feed ranging from 0.02 to 0.2 mm/tooth. The diagrams above were used to calculate the displacement amplitude, frequency, standard deviation, etc.

4. Results and discussion

As can be seen from the graphical representation of the measurement data, the relative displacements in the tool-workpiece system are dependent on the feed rate and time. Example diagrams are presented in figs. 4,5,6 and 7.

![Vibrations](image)

Figure 4 shows vibrations in the tool-workpiece system after filtering the guideway errors. Several characteristic zones can be distinguished in this diagram. In the time range from 1s to 1.84 s, the tool travels towards the workpiece in the X-axis. From 1.84 s to 2.04 s, the tool approaches the workpiece in the Z-axis, and from 2.04 s to 2.15 s, the tool reaches the workpiece edge in the X-axis. The tool is then fed into the workpiece, which takes place from 2.15 s to 2.45 s. The actual cutting lasts from 2.45 s to 3.65 s. Between 3.65 s and 3.95, the tool is fed out of the workpiece and then, from 3.95 s to 5 s, it moves away along the X-axis.

The diagram in fig. 4 shows the calculated standard deviations of the vibrations in the tool-workpiece system. The blue curve illustrates the standard deviation calculated for the whole range of machining, while the red one shows the values calculated for the vibrations measured for 0.2 s.

As can be seen from fig. 5, an increase in the feed led to an increase in the relative displacements. The optimal range of the feed from the viewpoint of efficiency and the magnitude of displacements is 0.12-0.15 mm/tooth. Figures 5 show segments of signals of relative displacements in the tool-workpiece system during machining, with measuring time being 0.2 s.
Fig. 5. Standard deviations of the vibrations in the tool-workpiece system, $D(\xi)$, versus feed $f_z$.

Fig. 6. Vibrations in the tool-workpiece system for $f_z=0.2$ mm/tooth.

The fig. 7 presents the diagram of the fast Fourier transform analysis of vibrations in the tool-workpiece system show spectral lines with a frequency corresponding to the value of the tool rotation per minute.
5. Predicting influence of the vibrations in the tool-workpiece system on roughness of surfaces face milled with a CoroMill 390

The metal cutting process is generally accompanied by vibrations. These are mainly due to changeable forces produced by the tool, unbalance of rotating masses, performance of bearings, shafts, and toothed wheels, nonhomogenity of the stock. The mathematical model presented in ref. [1] was used to develop a Mathcad application, perform simulation calculations, and finally, create graphs for predicting the values of surface roughness $Ra$ during a face milling operation with a CoroMill 390 equipped with rounded corner inserts. The milling was conducted under the conditions recommended by the producer.

The simulation was carried out to analyze the effect of:
- the feed,
- the vibrations in the tool-workpiece system.
The simulations to determine the effect of vibrations were conducted assuming that $D(\rho) = 1 \mu m$ and $D(\xi) = 0, 1, 2, 3, 4 \mu m$. The calculations were performed assuming that the tool corner radius, $r_e$, was 0.4 mm, and the minimum undeformed chip thickness, $h_{min}$, was 1 $\mu m$. The calculation results are represented graphically in fig. 8.

As can be seen from fig. 8, the higher the value of the feed $f_z$, the less effect the vibrations $D(\xi)$ have on the roughness $R_a$. When feed ranges 0.25 to 0.35 mm/tooth, the influence of the vibrations on the process of microhardness formation becomes negligible.

6. Conclusion

The system for registering vibrations in the tool-workpiece system can be used to assess the efficiency of a tool and a cutting process. The signals representing the displacements of the tool in relation to the workpiece are distorted periodic signals. They are dependent on the tool rotation and the successive entrances and exits of the cutting edges. It is possible to distinguish between some characteristic zones, i.e. the particular stages of the process: positioning, start of cutting, and cutting. The simulations and analysis confirms that the vibrations in the tool-workpiece system are dependent on the feed and affects on surface roughness. If the feed rate increases, there is an increase in the standard deviation of the relative vibrations. The standard deviation of relative displacements $D(\xi)$ can be reduced by decreasing the amplitude of relative displacements $A_{\xi}$ which makes the machining system more rigid and causes the attenuation of vibrations acting on the system. Moreover, it is crucial that the machining conditions be selected properly avoiding the occurrence of self-excited vibrations.
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