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The influence of vibrations on surface roughness formed during precision boring

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ABSTRACT

In this paper, the analysis of vibrations on surface roughness generated during boring with the application of the conventional boring tool and one with the damper is presented. The experiments included the measurement of vibration accelerations carried out with the piezoelectric sensor, as well as the evaluation of surface roughness parameters after each machining pass. The obtained results reveal that in the investigated range, no stability loss was found. Furthermore, the growth of the rotational speed induces the increase of vibration level, as well as the growth of the differences between the vibration values generated during boring with the conventional tool and one equipped with damper. Vibrations have also the direct influence on the machined surface roughness. In case of the tool equipped with the damper, the tool's overhang *L* had more intense influence than rotational speed *n*. However, for the conventional boring tool this dependency was unequivocal.

1. INTRODUCTION

In the case of high requirements towards the surface quality of machine parts manufactured by means of the modern technology, the application of special machining methods and conditions is necessary.

During the precision machining, the mechanical vibrations have the significant meaning, because of their influence on the machined surface accuracy and dimensional errors. In case of boring process, the effect of vibrations emerges by the reduction of the hole accuracy and the deterioration of surface roughness. Therefore, the precision boring is recently more often carried out with the tools equipped with vibration dampers, because of the improvement of machining process' technological effects in comparison to those obtained after the conventional machining. The role of precision machining is to maintain the narrow dimensional tolerances and low surface roughness of the manufactured parts. This kind of process is usually carried out with the low depth of cut $a_p < 0.5$ mm, which consequently allows the obtainment of accuracy corresponding to 8–6 class and surface roughness Ra = 0.63–0.32 μm [1].

Figure 1 presents the boring process scheme [2]. During the boring of the accurate holes, the process stability is an influential factor. Having the appropriate stability model, one can analyze many different variants and configurations of boring system, and consequently select the optimal one.

The boring process is very often carried out with the slender tools, i.e. with the high overhang to diameter ratio L/D. In this kind of applications, the risk of stability loss increases. Consequently, the generation of chatter is very often characterized by excessive displacements of tool's working part, which can lead to formation of unacceptable shape errors. Machining instability appears usually when the overall rigidity of the machine-tool-work material system is low. Therefore, the cutting tools are often designed with the focus on the growth of their static rigidity and damping. However, independently of tool's construction, the slenderness boundary which limits the process stability can be found [3]. This phenomenon has been described in many papers, e.g. in [4 - 9].

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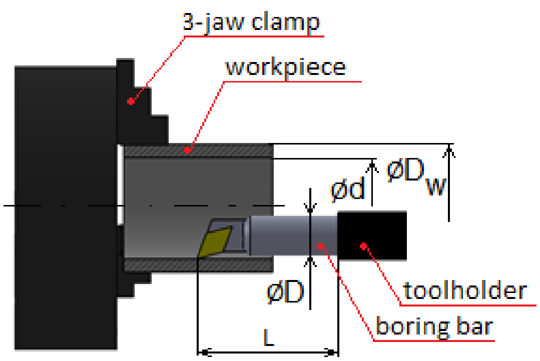

Fig. 1.The general scheme of boring process [2]

From the work [8], it can be seen that cutting process stability mainly depends on the ratio of boring bar overhang *L* to bar external diameter *D*. Accordingly the critical ratio (*L/D*) can be defined as the maximum *L/D* ratio assuring process stability for most cutting parameters combinations. In this case the stability loss was found for *L/D*=6. This consequently led to the rapid growth of the vibration amplitudes, and the generation of shape errors.

Moreover, chatter can induce an excessive tool wear, and even catastrophic failure of the tool, or spindle bearings. Thus, the avoiding of chatter is a key issue.

One of the solutions, which have to prevent the stability loss is application of boring tools with vibration dampers. The cause of excessive vibration during cutting is the occurrence of time-varying components of the total force, which induce dynamic bending of tools with large slenderness. However, using the tools with the damper significantly reduces this phenomenon. The characteristic feature of these tools is a construction which is characterized by a high level of damping. Therefore, they can be applied to the cutting with higher overhang values.

2. EXPERIMENTAL DETAILS

2.1. Research objective and range

The primary objective of the work is analysis of vibrations' effect on surface roughness generation during boring with the application of the conventional boring tool and one with the damper.

The work material's sample (with the dimensions presented in Figure 2) was made of low alloy chromium-molybdenum13CrMo4-5 (15HM) steel, intended to work in an elevated temperature.

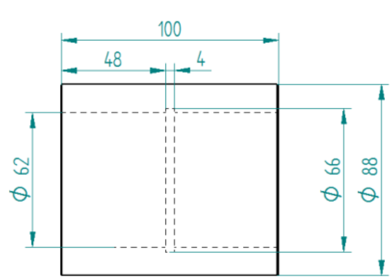

Fig.2. The view of sample

The applied boring tools (Figs. 3 and 4) were equipped with the trigonal inserts made of coated sintered carbide (Fig. 5).

Fig.3. Conventional boring tool: SANDVIK CoroTurn 107, A10K–STFCR 09-R (4xD)

Fig.4. Boring tool with damper made by SANDVIK CoroTurn 107, F10M–STFCR 09-R (10xD)

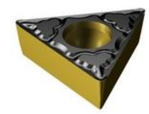

Fig.5. The applied cutting insert TCMT 090204 – PM 4325

The experiments were carried out on conventional lathe TUR 560E , within the range presented in table 1.

Tab.1. Research range

Lp.	Rotational speed ***n*** [rev/min]	Cutting speed v_c [m/min]	Overhang ***L*** [mm]	Feed ***f*** [mm/rev]	Depth of cut a_p [mm]
1	335	70	55	0,1	0,2
2	530	110	55		
3	900	186	55		
4	335	70	60		
5	530	110	60		
6	900	186	60		
7	335	70	65		
8	530	110	65		
9	900	186	65		

For each combination of the input parameters, the 3 repetitions of machining tests were carried out, which consequently resulted in 54 machining passes.

The boring parameters were selected in accordance to the lathe's capabilities, i.e. cutting speed recommended by the tool company was v_c = 450 m/min, which corresponded to rotational speed: *n* = 2171 rev/min. Nevertheless, the selection of these parameters resulted in the generation of chatter during machining. Thus the rotational speed was reduced. The remaining parameters were kept in the range recommended by the Sandvik company:

- feed per tooth *f*= 0,1 mm/rev.
- depth of cut a_p= 0,2 mm

2.2. Research method

The applied overhangs were selected in order to assure machining process stability, and the comparison of the research results for the same combinations of the input parameters. The overhang *L* was specified with respect to the scheme depicted in Figure 6. Consequently, the boring tests were carried out with the following overhangs: *4xD*, *6xD*, *8xD*.

The vibrations were measured by a standard track measuring. The composition of this track consisted of the following devices: vibration sensor, amplifier, A/C converter, computer.

The surface roughness was evaluated with stylus profile meter HommelWerke T500 (Fig. 7). The measurements were made on the measuring range *Lt* equaled to 4,8 mm, in 3 areas located on the circumference of the sample.

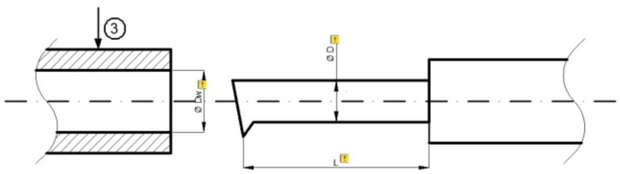

Fig. 6.The designation of tool's overhang L, where: D – boring tool's diameter, D_w – internal diameter of the hole

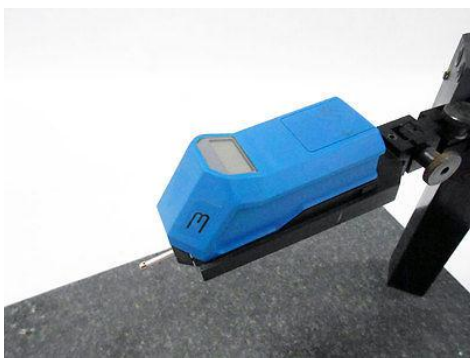

Fig. 7. Stylus profile meter T500 HommelWerke

3. RESULTS AND DISCUSSION

In the range of the carried out research (see – tab. 1) no stability loss was found. This can be observed on the representative vibration spectra charts (Fig. 8), which show that during cutting process, the boring tool's natural frequencies are dominant.

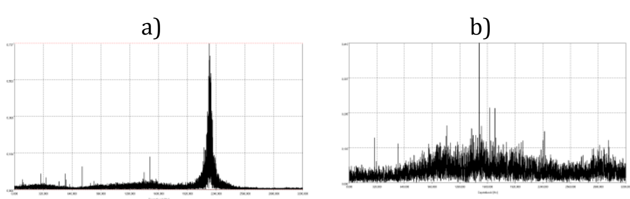

Fig. 8. The representative vibration spectra charts for: a) conventional tool; b) tool with the vibration damper (n=900 rev/min, L=60 mm)

Figures 9 and 10 show vibration time domain charts, measured in the thrust direction for the investigated tools. From the both charts it can be clearly seen that for the same input parameters, vibration amplitudes generated during boring with the conventional tool are significantly higher than that obtained during boring with the tool equipped with damper. The 3-fold differences between the peak values can be observed.

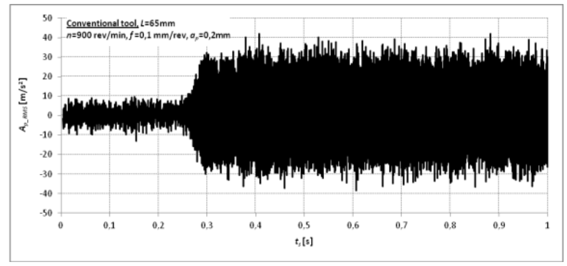

Fig. 9. The representative vibration time domain chart for the conventional boring tool

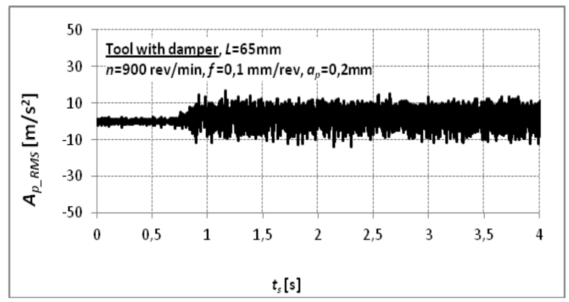

Fig. 10. The representative vibration time domain chart for the boring tool equipped with damper

In the next part of the paper, the influence of the rotational speed *n* and tool's overhang *L* on the vibrations (Figs. 11 and 12) and surface roughness (Figs. 13 and 14) is presented. It seems obvious that the growth of the rotational speed induces the growth of vibrations level (Fig. 11). However, the increase of the rotational speed causes the growth of differences between the vibration amplitudes generated during cutting with the conventional boring tool and one equipped with damper. For the *n*=335 rev/min, the vibration amplitudes are comparable, however during cutting with *n*=900 rev/min, differences are almost 10-fold.

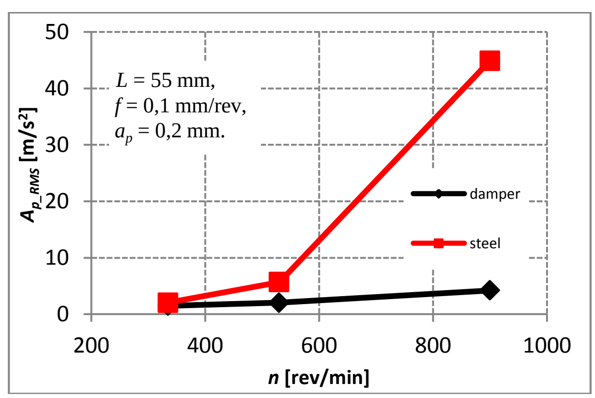

Fig. 11. The influence of n on the vibrations in the thrust direction

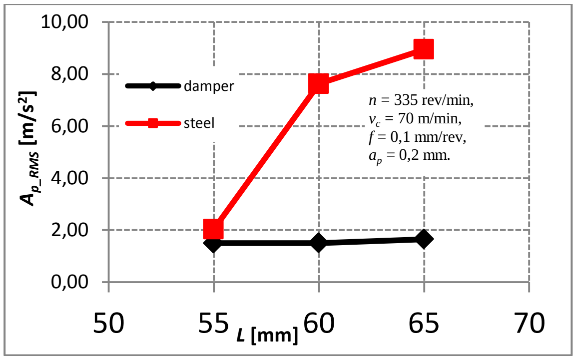

Fig. 12. The influence of L on the vibrations in the thrust direction

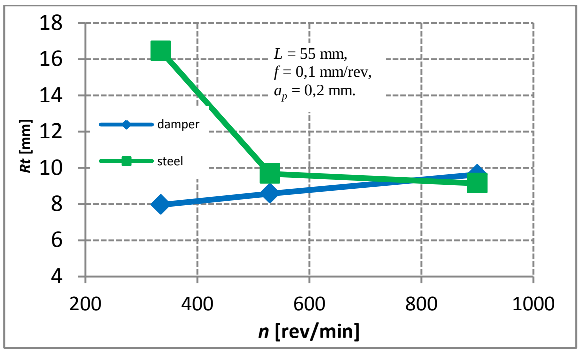

Fig. 13. The influence of n on the surface roughness

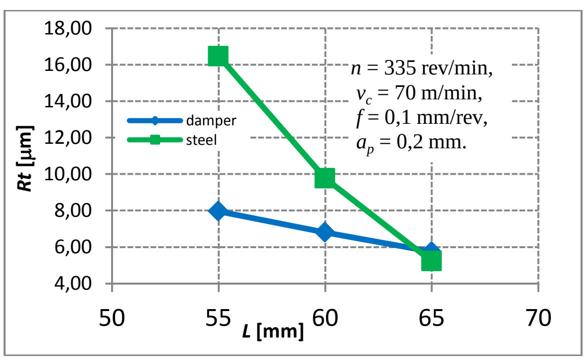

Fig. 14. The influence of L on the surface roughness

The similar dependencies were observed for the *L* factor. In case of surface roughness the opposite tendency is seen (Fig. 13 and 14), i.e. the highest differences were observed for the lowest rotational speeds and overhangs. Figures 15 – 17 depict the cumulative data obtained for the investigated range. Figure 15 shows the significant differences in vibration level in favor of the boring tool with damper. This difference is almost 10-fold, which indicates the high damping properties of this kind of tool. The vibration amplitude correlates directly to the surface roughness (Figs. 16, 17). The differences in *Rz* and *Rt* parameters are not as large as in case of vibrations, nevertheless the lower values of these parameters were obtained for the boring tool with damper. Moreover, the alterations of the surface roughness parameters' values in function of *n* and *L* are completely different. In case of the tool with damper, the overhang has the higher influence on *Rz* and *Rt* parameters in comparison to the effect of the rotational speed *n*. However, in case of conventional tool this dependency is unequivocal.

The application of the tool with damper enables the reduction of surface roughness parameters, in relation to the application of conventional tool. However, the differences can be found only in the range of lower investigated cutting speeds.

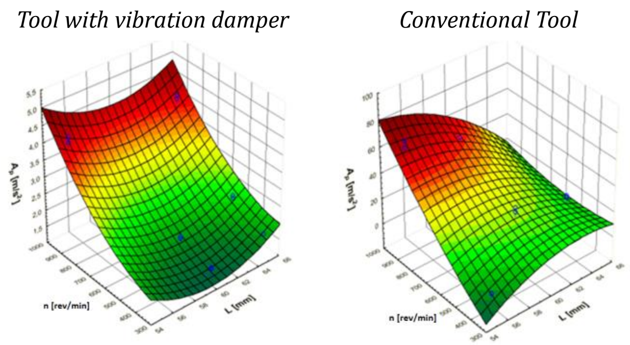

Fig. 15. Vibrations in the thrust direction in function of rotational speed and overhang

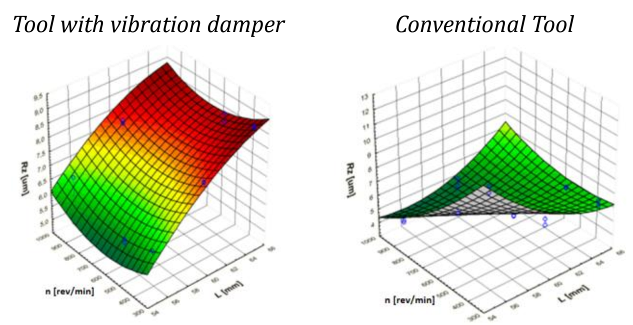

Fig. 16. Surface roughness Rz in function of rotational speed and overhang

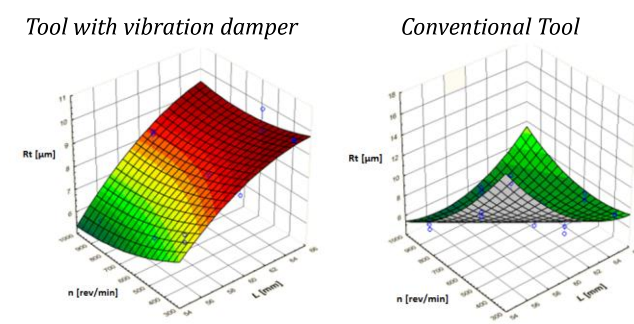

Fig. 17. Surface roughness Rt in function of rotational speed and overhang

4. CONCLUSIONS

On the basis of the obtained results, the following conclusions are formulated:

- In range of the carried out research no stability loss was found.
- Growth of the rotational speed induces the growth of vibrations level and moreover the increase of the rotational speed causes the growth of differences between the vibration amplitudes generated during cutting with the conventional boring tool and one equipped with damper.
- The study shows that from the point of view of surface roughness' minimization the n = 900 rev/min and L = 65 mm are the recommended cutting parameters during cutting with the application of the tool with damper.
- The almost 10-fold difference can be found between the vibration amplitudes generated during cutting with the conventional boring tool and tool equipped with damper.
- Vibrations have direct influence on the machined surface roughness.
- The lower *Rz* and *Rt* values were obtained during machining with the tool equipped with damper.
- In case of the tool with damper, the overhang has the higher influence on *Rz* and *Rt* parameters than rotational speed n. However, in case of conventional tool this dependency is unequivocal.
- The application of tools with vibration damper enables the reduction of surface roughness and vibration amplitudes. However these advantages can be found only in the specified range of cutting parameters.

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