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DETERMINATION OF VIBRATION DURING LONGITUDINAL MILLING OF WOOD-BASED MATERIALS

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ABSTRACT

The study of vibrations during the operation of the cutting mechanism in a woodworking shaper is presented in the paper. Wood-based details used in the furniture manufacturing like plywood and medium-density fibreboard (*MDF*) were milled. The experiments were performed using the universal milling machine with lower spindle position *FD-3* located in a laboratory at the Department of Woodworking Machines, University of Forestry – Sofia.Vibration velocity was measured using a specialized device model Bruel & Kjaer Vibrotest 60 at 6000 min^{-1} rotation frequency. The exact vibration state measurements were made in two mutually perpendicular directions ($A_x$andA_y). On the basis of the experiment, regression equations were developed. Determination of the influence of feed speed U (from 2$m·min^{-1}$to 10$m·min^{-1}$) and milling area A (from 48 mm^2 to 144 mm^2) at the vibration velocity V $mm·s^{-1}$ (r·m·s) was performed by conducting planned two-factor regression analysis. The vibration velocity values at the point A_x were from 1.85 $mm·s^{-1}$ to 2.76 $mm·s^{-1}$, and at the point A_y were from 1.75 $mm·s^{-1}$ to 2.97 $mm·s^{-1}$. The measured roughness Rz of the test specimens was from 20 µm to 157 µm. The investigation results can be used as a base for making some recommendations concerning an increase in reliability of the wood shapers as well as the accuracy and quality of their production.

Key words: MDF, plywood, milling, cutting mechanism, vibrations.

INTRODUCTION

Wood shapers are widespread in practice. Their universality allows them to be used in diverse industries in the woodworking and furniture manufacturing industry. Their main use is in the manufacture of furniture, windows, doors, construction products and many other items used in everyday life. Wood shapers allow different devices to be attached to them, Their technological capabilities are increased this way. Contemporary wood shapers should be able to work at different cutting speed. Most often the speed ranges between 30–60 m/s (GOCHEV 2005, OBRESHKOV 1997). This inevitably is associated with the machinery resources to work at different rotational speed. They are a precondition for the emergence of different cutting forces that create conditions for loads in the mechanisms which lead to errors during operation (VUKOV *et al.* 2012*)*. Dynamic effects are constantly changing, which is a premise for permanent shifting loads in the bearings.

Not just the milling machines, but the rest of the woodworking machines operate at high cutting speeds. This is certainly a precondition for an increase in overall vibration throughout the mechanical system. Important attention should be paid to the preparation of the cutting tools. The use of cutting tools exceeding the required imbalance is also a reason to increase the vibration intensity of the particular mechanical system (GOCHEV *et al.* 2017, ORLOWSKI *et al.* 2007, VITCHEV*et al.* 2020). Also, increased levels of mechanical oscillations have an influence on the production noise and the quality of finished products (BREZIN *et al.* 2015, ROUSEK *et al.* 2010, VITCHEV *et al.* 2019). Clearing the wood cutting tool after work and correct installation are factors greatly affecting the ability of each cutting tool to process the wood quality. The choice of the technological operation mode depends on the processed tree species and wood-based materials, type and preparation of the cutting tool, the complexity of machining, the quality of the milling, etc. This set of factors during cutting creates forced oscillations throughout the mechanical system.These vibrations directly affect the quality of each milling wood detail.

The aim of this work is the measurement and analysis of vibration velocity at working tread by universal wood shaper with bottom location of the working shaft. The load on the bearings is researched while milling different wood-based materials and changing some technological factors. The study is aimed at improving the reliability and efficiency of a wood shaper machine to ensure the accuracy and quality of products.

MATERIAL AND METHODS

To conduct the experiment, a universal wood shaper with bottom location of the working shaft was selected Fig.1. The cutting mechanism of the selected machine is of relatively simple construction, which helps the more accurate execution of the experiment. The cutting mechanism is driven by an asynchronous electric motor at 3 kW of power and rotation frequency of 2880 min^{-1}.The rotation frequency used for the experiments was 6000 min^{-1}. This is one of the most commonly used frequency in milling machines.The selected rotational speed wass performed by pulleys mounted on the electric motor shaft and the machine shaft.

Fig. 1 Wood shaper general view.

Fig. 2 Groove cutter D=140 mm.

A cutter with a diameter D = 140 mm was used Fig 2. The technical data of the cutting tool are shown in Table 1. The inscriptions in the table are: *D* - diameter of the milling cutter,*d* – diameter of the bore, *B* – milling width, α – back angle of cutting, β – angle of sharpening, γ – front angle of cutting, *z* – number of teeth.

Tab. 1 Technical data of the cutting tool.

Type of instrument	***D*** mm	***d*** mm	***B*** mm	α °	β °	γ °	z бр	Material of the teeth
Groovecutter	140	30	12	16	55	19	6	HM

The cutting speed was calculated by the formula 1 (VLASEV 2007). At a rotation frequency of 6000 min^{-1}/(100 s^{-1}), the calculated cutting speed was v = 44 $m \cdot s^{-1}$.

$$V = \pi \cdot D \cdot n,\ m \cdot s^{-1}, \qquad (1)$$

D – diameter of the cutting tool, *m*;
n –rotation frequency of the cutting tool, s^{-1}.

The research in this paper was conducted at a calculated speed.The experimental part included milling of MDF and plywood samples. Some of the samples can be seen in Fig. 3. The paper examines the influence of some important factors in the cutting process on the impact on the vibration velocity measured in the bearing housings is examined in the paper. Table 2 shows the studied factors and their levels in open and coded form.

Fig. 3 MDF and Plywood test samples.

Tab. 2 Survey factors.

Factors	Factor levels					
	Open	**Cod.**	**Open**	**Cod.**	**Open**	**Cod.**
Feed speed *U*, [$m.min^{-1}$]	2	–1	6	0	10	1
Milling area *A*, [mm^2]	48	–1	96	0	144	1

Determination of the influence of feed speed (U, $m.min^{-1}$) and milling area (A, mm^2) on vibration velocity V $mm.s^{-1}$ (r.m.s) was performed by conducting a planned two-factor regression analysis. Table 3 shows the experimental matrix (VUCHKOV *et al.*1986). The feed speed is indicated by X_1 and milling area X_2. The results were calculated by the software products *QstatLab5* and *Microsoft Excel*.

Tab. 3 Experimental matrix.

№	***U*, $m.min^{-1}$**	***X_1***	***A*, mm^2**	***X_2***
1	10	1	144	1
2	10	1	48	-1
3	2	-1	144	1
4	2	-1	48	-1
5	6	0	96	0
6	6	0	144	1
7	10	1	96	0
8	6	0	48	-1
9	2	-1	96	0

The intensity of the vibrations was assessed on the basis of the root mean square value of the vibration velocity V $mm \cdot s^{-1}$ (r·m·s) measured at the different working modes of the machine. The measurements were performed at two measuring points located on the upper bearing housings of the main shaft of the machine. In the present work, vibration measurement in the lower bearing housing was not done. In the previous studies conducted by the authors, it was found that an increase in oscillations in the lower bearing housing was very small during work (KOVATCHEV 2018). The measurement points on each bearing housing are located mutually perpendicular, radial to the main shaft of the machine Fig. 4. (БДСISO 10816 – 1:2002).

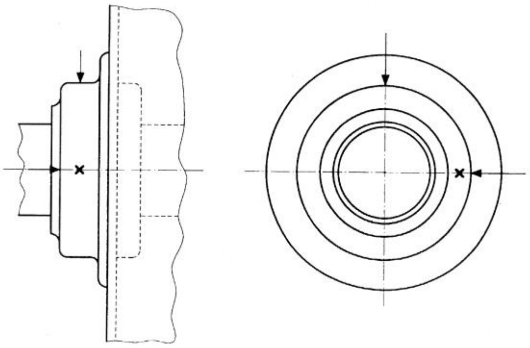

Fig. 4 Measurement points.

Vibration speed was measured using a specialized device model Bruel & Kjaer Vibrotest 60 shown in Fig. 5. The measurement points are located on the bearing housing of the machine. It significantly responds to the dynamic state. The exact vibration state measurements needed to be made in two mutually perpendicular directions Fig. 6.

Fig. 5 Bruel & Kjaer Vibrotest 60.

Fig. 6 Measuring sensor.

The roughness parameter (Rz, μm) was measured on each detail after milling.The Rz parameter was determined using the mean average value from the five measurements in accordance to БДС EN ISO 4287:2006.The roughness was measured using a specialized surface roughness tester Mitutoyo Surftest SJ-210shown in Fig.7.

Fig. 7 Mitutoyo Surftest SJ-210.

RESULTS AND DISCUSSION

The work trials in milling of MDF and plywood were included in the experiment. The intensity of the vibrations is assessed on the basis of the root mean square value of the vibration velocity V mm·s^{-1} (r·m·s) measured at the different feed speed (U, *m.min*$^{-1}$) and milling area (A, *mm*^{2}). The measurement points are indicated by A: A_x– in direction parallel to the feed direction, A_y – in direction perpendicular to the feed direction.

The regression equations 2 and 3 show the influence of factors at the milling of MDF and plywood in the point A_x.

$$Ax_{MDF} = 1.916+0.026x_1+0.057x_2-0.005x_1x_1+0.009x_2x_2+0.008x_1x_2 \quad (2)$$

$$Ax_{Plywood} = 2.109+0.067x_1+0.156x_2-0.053x_1x_1-0.069x_2x_2+ 0.003x_1x_2 \quad (3)$$

x_1 – feed speed, coded;
x_2 – milling area, coded;
As it can be observed in the regression equations obtained, the strongest influence on the vibration velocity V mm.s^{-1} (r.m.s) in the longitudinal milling of MDF and plywood is the first and the most important factor in the milling area (A, *mm*^{2}). The feed speed of the processed material (U, *m.min*$^{-1}$) is the second most important factor. Graphical, the results at point A_x can be seen in Fig.8 and Fig. 9.

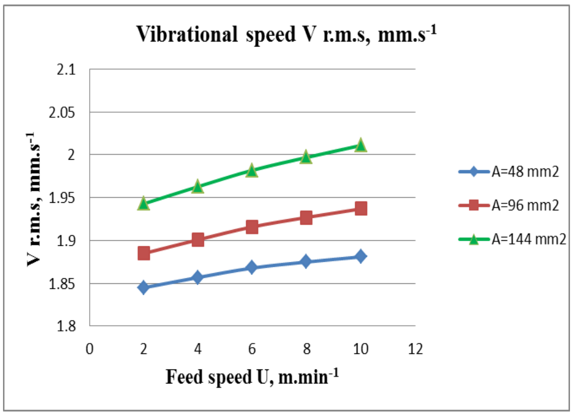

Fig. 8 Vibration speed measured at point A_x in the milling of MDF components.

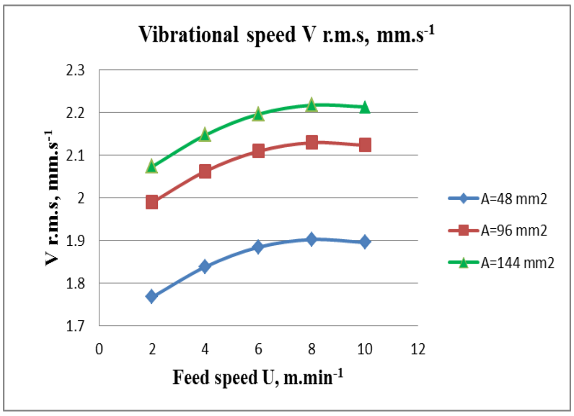

Fig. 9 Vibration speed measured at point A_x in the milling of Plywood components.

Figure 8 shows that by increasing the feed rate of the processed material, the vibration velocity increases. This tendency was observed in all three milling areas. Similar results were observed by the authors (VITCHEV*et al.*2020). Figure 9 shows the same trend as in Fig.8.

The regression equations 4 and 5 show the influence of factors in the milling of MDF and plywood in point A_y.

$$Ay_{MDF} = 2.695+0.049x_1+0.053x_2-0.016x_1x_1-0.017x_2x_2+0.004x_1x_2 \quad (4)$$

$$Ay_{Plywood} = 2.663+0.033x_1+0.093x_2+0.095x_1x_1+0.101x_2x_2-0.011x_1x_2 \quad (5)$$

Here, as in point A_x, the strongest influence on the vibration velocity V $mm \cdot s^{-1}$ (r.m.s) in the longitudinal milling of MDF and plywood is the factor of the milling area (A, mm^2). The feed speed of the processed material (U, $m \cdot min^{-1}$) is the second most important factor. Graphically, the results at point A_y can be seen in Fig. 10 and Fig.11.

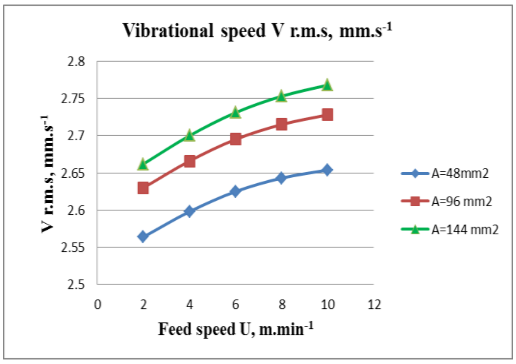

Fig. 10 Vibration speed measured at the point A_y in the milling of MDF components.

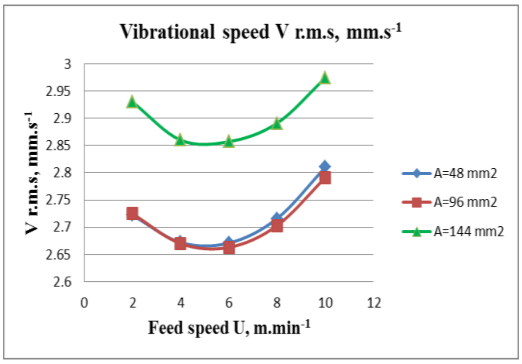

Fig. 11 Vibration speed measured at the point A_y in the milling of Plywood components.

Figure 9 shows us again that by increasing the feed rate of the processed material, the vibration velocity increases. This tendency was observed in all three milling areas. Figure 10 shows that as the feed speed of the treated material increases, the vibration velocity initially decreases and then rises again. The local minimum vibration velocity at the point Ay can be explained by the diffraction of the cutting force in a different direction.At that time the magnitude of the cutting force is not high enough to increase the vibration velocity. After the local minimum, the vibration velocity is rising again, which is a sign that the cutting force is concentrating in the Ay direction. The same trend was observed by the authors in some of their previous studies as well(KOVATCHEV *et al*. 2018).

At the end of the experiment, the roughness of a part of the test samples was measured. The samples of MDF and plywood were selected. Graphically, the results can be seen in Fig. 12 and Fig. 13.

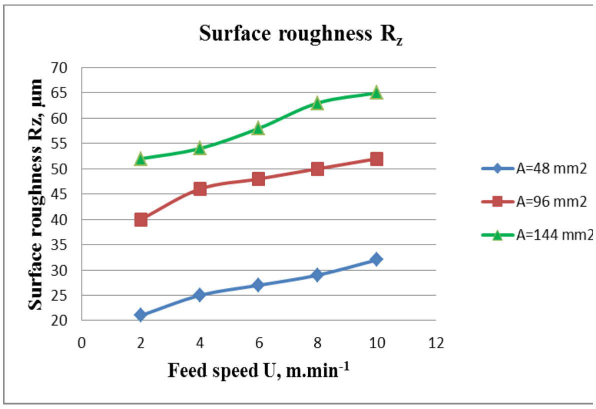

Fig. 12 Surface roughness (Rz) depending on the feed speed in the milling of MDF components.

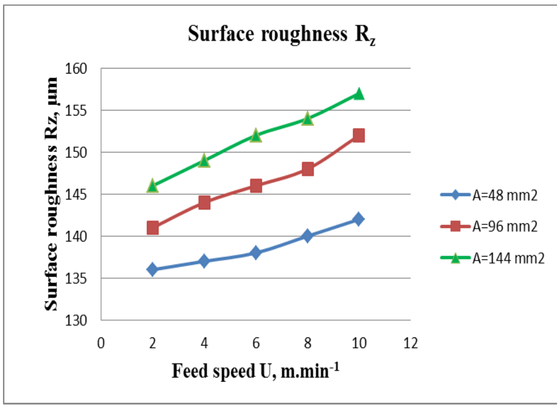

Fig. 13 Surface roughness (Rz) depending on the feed speed in the milling of Plywood components.

CONCLUSION

On the basis of the conducted experimental studies, the following more important conclusions and recommendations can be drawn:

The strongest influence on the vibration velocity V $mm\cdot s^{-1}$ (r·m·s), at the measured points A_x and A_y was the first and the most important factor in the milling area (A, mm^2).

The feed speed of the material (U, $m\cdot min^{-1}$) was the second most important factor.

When the feed rate increases, the surface roughness increases. This trend was maintained for all milling areas and for all MDF and plywood samples. A similar trend was also observed by the authors in their publications: Higher feeding speeds of processed material lead to rougher surface (KMINIAK *et al*. 2016, KMINIAK *et al*. 2017, SEDLECKY *et al*. 2018, SIKLIENKA *et al*. 2016, VITCHEV *et al.* 2018, VITCHEV 2019).

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