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INFLUENCE OF THE CUTTING MODE ON THE SURFACE QUALITY DURING LONGITUDINAL PLANE MILLING OF ARTICLES FROM BEECH WOOD

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Abstract

The objectives of the current study are to investigate the influence of the cutting mode on the surface quality during longitudinal plane milling of details from beech (Fagus sylvatica L.) wood. The influence of the rotation frequency (n) and the feed rate (U) at different thickness of the cut-out layer (h) has been assessed. On the basis of the obtained results, graphical dependencies, representing the relationship between the different studied factors have been derived. In order to achieve a higher quality of the processed surfaces, practical recommendations for the optimal values of the evaluated factors have been suggested. The surface roughness of the material (surface) was measured with a roughness tester, type „Surftest SJ-210"(Mitutoyo, Japan).

Key words: *surface roughens, cutting mode, wood milling, Fagus sylvatica*

INTRODUCTION

Milling is one of the main technological processes involved in the processing of solid wood and wood-based materials, which aims to give a certain shape of the processed details and at the same time to ensure a higher surface quality (higher roughness class). It is well-known that the quality of the processed surfaces may be influenced by different factors, related to the characteristics of the processed material (Sandac et al., 2004), of the cutting tool and at last but not least, to the cutting mode during the material's processing (Keturakis, 2007; Gochev, 2014[b]). When determining the roughness of the wood surfaces, the direction of the wood fibers in which the measurements will be carried out is also important. Due to the anisotropic structure of the wood, the roughness of the surface is different and depends on the orientation of the fibers (Sandac et al., 2004). Some of the influencing factors can be controlled during processing, therefore they should be given more attention and become subject to wider and more comprehensive study in order to be managed in a more adequate way. In the recent years, a number of studies have been focused on investigating the processes related to the longitudinal plane milling and the resulted surface quality (Costes et al., 2002; Keturakis, 2007; Prakasvudhisarn et al., 2009; Rousek et al., 2010; Gonzalez-Adrados et al., 2012; Гочев, 2014[a]; Гочев, 2014[b];). Their common goal was to assess and determine the optimal parameters and conditions, assuring higher surface quality.

In relation to this, the aim of the current experimental study was to investigate the influence of following factors: the rotation speed of the cutting tool (*n*), the feed rate (*U*) and the

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thickness of the cut-out layer (*h*) on the surface roughness of samples from beech wood (*Fagus Sylvatika* L.) during longitudinal plane milling.

MATHERIALS AND METHODS

The experiments have been carried out using woodworking spindle moulder machine, type T1002S (ZMM "Stomana" GmbH, Bulgaria) (Fig. 1). The machine was equipped with a two-speed three-phase electric motor with power 3,2/4,0 kW, which through a belt drive provides the following rotating frequency of the working shaft: 3000, 4000, 5000, 6000, 8000 and 10000 min^{-1}.

Figure 1. Woodworking spindle moulder machine, type T1002S – general view

A cutting tool with an assembled construction for longitudinal plane milling (Metal World, Italy) was used. The technical characteristics of the tool are presented in Table 1, where: *D* is the diameter of the cutter head, *d* – diameter of the threaded hole, *L* – longitude of the main cutting edge, γ – hook angle, *z* – number of teeth.

Table 1. Technical characteristics of the used cutting tool

General look of the milling cutter	*D* mm	*d* mm	*L* mm	β °	γ °	*z* No	Material of the teeth
	125	30	50	47	16	4	Hard alloy (HM)

In the course of the study, the samples from beech (*Fagus sylvatica* L.) wood have been processed, with the following characteristics: density: ρ = 690 $kg.m^{-3}$, moisture content *W* = 12 % and elasticity module $E_{L(12\%)}$ = 13225.10^6 $N.m^{-2}$, have been processed according to BDS ISO 3131, BDS ISO 3130 and EN 310, respectively. The samples had the following characteristics: longitude (*l*) 1000 mm and milling width (*b*) 40 mm. The details were fed automatically by a roller feeder.

In order to investigate the complex influence of the rotation frequency (*n*) of the milling tool, the feed rate (*U*) and the thickness of the cut-out layer (*h*) (milling height) on the quality of the processed surfaces, the methodology of multifactorial planning and subsequent regression analysis have been used (Vuchko et al. 1986). The measurements were performed in accordance with a preliminary designed matrix for three factorial experiment plan of G. Box (Box et. al., 1951; Box et. al. 1999). In Table 2 the levels of the input variables in explicit and coded form are presented. The selected values are in line with the most frequently used in practice.

Table 2. Values of the variables *n*, *U* and *h*

Variables	Minimum value		Average value		Maximum value	
	expl.	**coded**	**expl.**	**coded**	**expl.**	**coded**
Rotation frequency $n = X_1$, min^{-1}	4000	-1	6000	0	8000	1
Feed rate $U = X_2$, $m.min^{-1}$	3,5	-1	7	0	10,5	1
Thickness of the cut-out layer $h = X_3$, m	1	-1	2	0	3	1

In order to assess the quality of the treated surfaces, depending on the variables, the roughness parameter R_z, μm was used. It has been determined separately for five base lengths in the longitudinal direction of the wood fibers of each part. For each base length the parameter R_z is determined by the mathematical equation:

$$R_z = \frac{\sum_{i=1}^{5}\left|y_{p_i}\right| + \sum_{i=1}^{5}\left|y_{V_i}\right|}{5}, \mu m \tag{1}$$

where:
y_{pi} is the height of the biggest roughness of the profile, μm;
y_{vi} – the depth of the greatest slot of the profile, μm.

The surface roughness of each workspace was determined using the mean average value $\overline{R_z}$ from the five measurement. The applied methodology is in accordance with BDS EN ISO 4287 and is described in details by Gochev (2005). The measurements were performed with the digital profilomer, model “Surftest SJ-210“ (Mitutoyo, Japan) (Fig. 2).

Figure 2. Profilometer, model Surftest SJ-210 – general view

For the statystical analysis of the data QstatLab softwear was used.

RESULTS AND DISCUSSION

Based on the performed experiments and after statistical analysis of the data, we received the follwoing regression equation:

$$y = 35{,}661 + 0{,}946X_1 + 3{,}457X_2 + 0{,}611X_3 + 3{,}672X_1^2 - 1{,}393X_2^2 - 1{,}663X_3^2 - 0{,}135X_1X_2 + 0{,}738X_2X_3 + 1{,}390X_1X_3 \quad (2)$$

where:
y is the expected surface quality of the processed detail, defined by the roughness parameter R_z in coded form;
X_1 – rotation frequency of the cutting tool (n) in coded form;
X_2 – feed speed (U) in coded form;
X_3 – thickness of the cut-out layer (h) in coded form.

By using the equation (2) the surface quality, depending on the changes in the rotation frequency (n), feed speed (U) and the thickness of the cut-out layer (h) can be predicted.

In Table 3, the planning matrix for the three-factorial experiment and the mean average value of the roughness parameter, determined for different factor combinations are presented. The regression coefficients are given in Table 4.

Table 3. Planning matrix for three-factorial experiments and mean average values of the roughness parameter $\overline{R_z}$ (μm)

№	$X_1 = n$ min^{-1}		$X_2 = U$ m.min^{-1}		$X_3 = h$ mm		$\overline{R_z}$ μm	№	$X_1 = n$ min^{-1}		$X_2 = U$ m.min^{-1}		$X_3 = h$ mm		$\overline{R_z}$ μm
1	-1	4000	-1	3,5	-1	1	34,98	9	-1	4000	0	7	0	2	34,57
2	-1	4000	-1	3,5	1	3	30,42	10	1	8000	0	7	0	2	46,49
3	-1	4000	1	10	-1	1	38,47	11	0	6000	-1	3,5	0	2	31,98
4	-1	4000	1	10	1	3	41,27	12	0	6000	1	10	0	2	38,95
5	1	8000	-1	3,5	-1	1	29,65	13	0	6000	0	7	-1	1	35,94
6	1	8000	-1	3,5	1	3	35,06	14	0	6000	0	7	1	3	34,45
7	1	8000	1	10	-1	1	37,01	15	0	6000	0	7	0	2	34,30
8	1	8000	1	10	1	3	40,96								

Table 4. Regression coefficients

Coefficient	Coded value	Coefficient	Coded value	Coefficient	Coded value
b_1	0,946	b_{11}	3,672	b_{12}	-0,135
b_2	3,457	b_{22}	-1,393	b_{23}	0,737
b_3	0,611	b_{33}	-1,663	b_{13}	1,390

From the values of the regression coefficients (Tabl. 4) it is visible that during milling of the samples from beech wood, the greatest influence on the surface quality has the feed speed $U = x_2$ with regression coefficient $b_2 = 3{,}457$, followed by the rotation frequency of the cutting tool $n = x_1$ with regression coefficient $b_1 = 0{,}946$. The least influence among the investigated factors has the thickness of the cut-out layer $h = x_3$, with regression coefficient $b_3 = 0{,}611$. The positive values of the three regression coefficients show that by increasing the values of the investigated factors, the surface roughness of the processed surfaces will also increase.

Figure 3 is a graphical representation of the changes in the surface roughness, depending on the rotation frequency at the three different speed feeds and determined by the roughness parameter R_z. From the roughness curves it is visible that by increasing the rotation frequency of the cutting tool (n) from 4000 to 5500 min^{-1}, the roughness of the surface decreased at the three feed speeds. The best surface quality was observed at n = 5500 min^{-1}, and it stays stable up to n = 6500 min^{-1}. With the increase of the rotation frequency of the cutting tool from n = 6500 min^{-1} to n = 8000 min^{-1}, the surface roughness increases as well. At the three feed speeds, the similar tendency in the variations of the roughness curves are observed. The details, processed at feed speed U = 3,5 m.min^{-1} and rotation frequency of the cutting tool n = 6000 min^{-1} have a better surface quality when compared to the other two higher feed speeds and are classified as roughness class IX. At feed speeds U = 7 m.min^{-1} and U = 10 m.min^{-1} and rotation frequency of the cutting tool n = 6000 min^{-1}, the processed details fall in roughness class VIII.

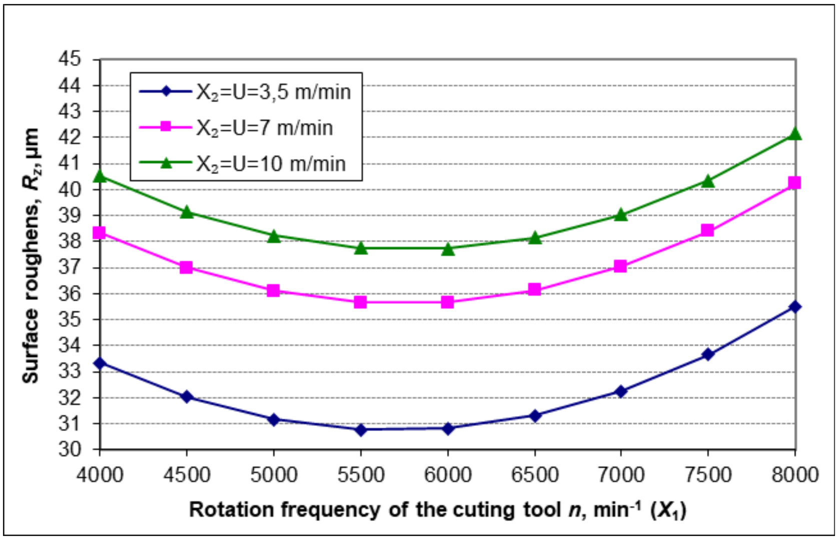

Figure 3. Changes in the surface roughness (R_z) depending on the rotation frequency of the cutting tool (n) at different feed rates (U)

The relationship between the changes in the surface quality (R_z) and the rotation frequency of the cutting tool at three different thicknesses of the cut-out layers, is presented in Figure 4. From the roughness curves it is visible that at three different thicknesses, the best surface quality was observed at rotation frequency of the cutting tool n = 6000 min^{-1}. The similar tendency in the variations of the roughness curves are observed at the three thicknesses of the cut-out layer. At rotation frequency of the tool from 5500 min^{-1} to 8000 min^{-1}, the increase of the thickness of the cut-out layer led to an increase of the surface roughness. At rotation frequency of n = 7000 min^{-1} and above, and the thickness of the cut-out layer (h) 2 and 3 mm, the surface quality is similar.

The relationship between the changes in the surface quality (R_z) and the feed rate (U), at three different thicknesses of the cut-out layers (h) is presented in Figure 5. From the graphs is clearly visible the strong influence of the feed speed (U) on the surface quality of the processed material (R_z). The roughness curves in Fig. 5 are in good correlation with the results, presented in Fig. 4, namely that the increase of the thickness of the cut-out layer resulted in higher surface roughness. At feed rate (*U*) up to 5,2 m.min^{-1} and thickness of the cut-out layer (*h*) 1 and 2 mm, the processed details fall in roughness class IX. While the details, processed at the same feed speed but thicker *h* = 3, fall in class VIII.

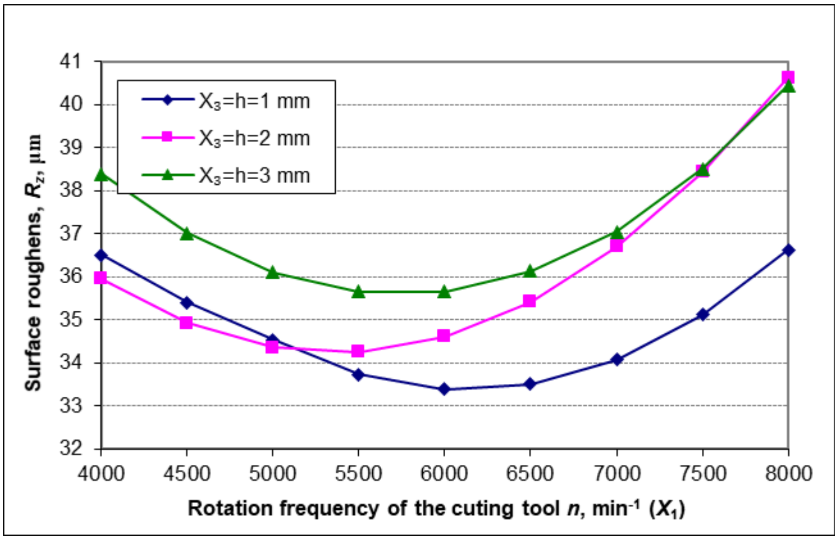

Figure 4. Changes in the surface roughness (R_z) depending on the rotation frequency of the cutting tool (*n*) at thee thickness cut-out layers (*h*)

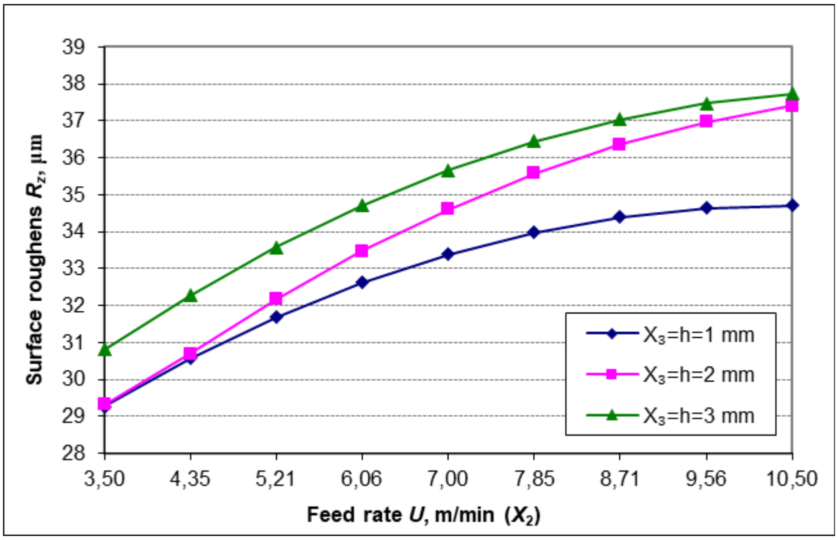

Figure 5. Changes in the surface roughness (R_z) depending on the feed speed (*U*) at thee thickness cut-out layers (*h*)

CONCLUSIONS

The current paper presents results from experimental study, investigating the surface roughness, after milling, of details from beech (*Fagus Sylvatica* L) wood, determined by the roughness parameter R_z (μm), measured along the length of the wood fibres of the samples.

Based on the obtained results, the following conclusions can be made:

- The quality of the milling surface is influenced by the mode of cutting during processing of the wooden details. Among the investigated factors, the greatest influence on the surface quality exerts the feed speed (U), followed by the rotation frequency of the cutting tool (n) and the thickness of the cut-out layer (h). By increasing the feed speed from 3,5 m.min^{-1} to 10,5 m.min^{-1} and the thickness of the cut-out layer h = 3 mm, the surface roughness changes significantly by 18,3 % (from 30,81 μm to 37,73 μm) (see Fig. 5).
- The optimal rotation frequency of the cutting tool is n = 6000 min^{-1}. This frequency, combined with the thickness of the cut-out layer h = 2 mm, gives the following values of the roughness parameter, measured at different feed speeds: at U = 3,5 m.min^{-1}, R_z = 30,81 μm; at U = 7 m.min^{-1}, R_z = 35,66 μm; at U = 10,5 m.min^{-1}, R_z = 37,7 μm (see Fig. 3).

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