

OPTIMIZATION OF WOOD MILLING SCHEDULE – A CASE STUDY

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Abstract

*The paper presents the results of a case study applied to the milling process of solid wood specimens made of black alder wood (*Alnus glutinosa* L. Gaertn.) with a view to find the optimal cutting schedule when two main criteria, such as the minimum power consumption and the best surface quality are fulfilled. The experimental work was performed with black alder wood originating from mature trees from the Buzau Valley region in Romania. All samples were processed on their longitudinal edges by straight milling with a milling cutter having glued straight plates on the vertical milling machine under different cutting schedules. An electronic device connected to the machine engine and an acquisition board were used to record and compute the power consumption during milling. Roughness measurements of the samples were performed by employing an optical profilometer. All data were processed using the regression method and variance analysis. The study revealed that best results are to be obtained in terms of cutting power and surface quality when processing with low feed speeds and light cutting depths.*

Key words: black alder; milling; optimization; cutting schedule; roughness.

INTRODUCTION

Simple, plane and also complex shape surfaces are obtained when wood surface is processed by milling. The rational and economic correlation of the optimal cutting schedule parameters depends on certain criteria, such as: surface quality (Aguilera and Martin 2001; Malkocoglu 2007), cutting dynamics (Vega and Aguilera 2005), acoustic pressure (Cyra and Tanaka 2000; Vega and Aguilera 2005) and cost (Taran 1973). Wood species (Burdurlu et al. 2005; Malkocoglu and Ozdemir 2006), cutting speed (Rousek and Kolarik 2004; Rousek and Kopecky 2005), feed speed (Costes and Laricq 2002; Huang et al. 2003), cutting depth and processing direction to the grain orientation and annual rings (Ohta and Kawasaki 1995; Wong 2002; Salca 2008) are essential elements for an optimal cutting process selected under scientific bases.

Therefore surface quality and power consumption are to be considered essential criteria based on which an optimum for the cutting process may be achieved.

The workability properties of black alder wood are less known and studied. The absence of data has represented a serious obstacle for its use in wood industry and furniture manufacturing in Romania. Some research works were carried out on the rip sawing and planing processes, especially (Malkocoglu and Ozdemir 2006) and a special attention was granted to drying because most of the problems appear during this process (Kivisto and Marketta 1999).

The present work is part of a research project focused on black alder wood native in Romania which tried to capitalize this wood species to be further used in furniture manufacturing.

OBJECTIVE

The main objective of the present research was to evaluate the cutting process by longitudinal milling applied to solid wood specimens made of black alder, in order to find an optimal schedule with respect to a minimum cutting power and the best surface quality.

MATERIAL, METHOD

Samples made of black alder (*Alnus glutinosa* L. Gaertn.) wood provided by Robur Company in Nehoiu, Buzau were processed on their longitudinal edges (1000mm length at 8% MC) by straight milling with a milling cutter (100mm diameter) having glued straight plates made of CMS (sintered carbide) on the vertical milling machine of MNF10 type. The machine technical characteristics are presented in Table 1. Based on the factorial experiment with three variables (feed speed, cutting depth, cutting width), 20 specimens per each milling process and rotation speed were used. The experimental schedule is presented in Table 2.


Table 1

Technical characteristics of MNF10

Characteristic	SI	Value
Dimensions of main table	mm	1100 x 960
Table displacement perpendicularly to the feed direction	mm	160
Dimensions of mobile table	mm	1100 x 350
Maximum displacement of mobile table	mm	900
Vertical displacement of working shaft	mm	160
Inclination angle of working shaft	degree	0...45
Rotation speed of working shaft	rot/min	3000/4500/6000/9000
Rotation speed of electric motor	rot/min	1500/3000
Power of electric motor	kW	2,2/2,8
Overall dimensions	mm	1530 x 2125 x 1340
Weight	kg	1300

Table 2

Experimental schedule

Milling cutter, 100 mm	Processing direction	Rotation speed, rot/min	Cutting width, mm	Feed speed, m/min	Cutting depth, mm
	longitudinal	6620 9732	20	4.5	1
			25	9	2
			30	13.5	3
			35	18	4
			40	22.5	5

Power measurement

An electronic device connected to the machine engine and an acquisition board of ADC11 type were used to record and compute all data (Fig. 1 and Fig. 2).

The power during milling was recorded at millisecond (Fig. 3). Data were processed by using Datafit and Delphi as software. A non-linear regression method was then applied by respecting an equation of 2nd degree type with three variables (eq. 1) followed by an SPSS variance analysis. The effective cutting power was computed as difference between the recorded power and the idle power for each one of the specimens.

$$Y = a + bx_1 + cx_2 + dx_3 + ex_1x_2 + fx_1x_3 + gx_2x_3 + hx_1^2 + ix_2^2 + jx_3^2 \tag{1}$$

where: the three variables (x_1, x_2, x_3) are as follows: feed speed (u), cutting depth (h) and cutting width (b), respectively.



Fig. 1.
Electronic device and MNF10

ADC-11 (Parallel) Data Logger

- 11 channels
- Digital output for control
- No power supply required
- Optional terminal block

ADC-11/10

- 10 bit resolution
- 10kS/s sampling rate
- 0 to 2.5V input range
- ±1% accuracy

Description	Price	Order No.
ADC-11/10	£95	PP084
ADC-11/10 + Terminal Block	£105	PP120

ADC-11/12

- 12 bit resolution
- 10kS/s sampling rate
- 0 to 2.5V input range
- ±0.5% accuracy

Description	Price	Order No.
ADC-11/12	£149	PP151
ADC-11/12 + Terminal Block	£159	PP152

Fig. 2.
Acquisition board of ADC11 type

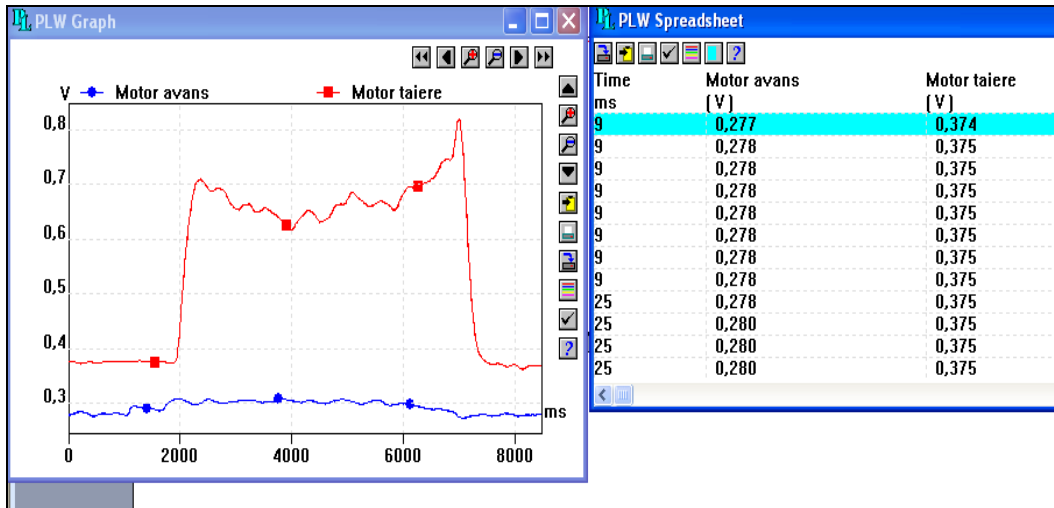


Fig. 3.
Data display for cutting power (red line-cutting; blue line- feed)

Roughness measurements of the samples

An optical profilometer of MicroProf FRT type with white light was used for roughness measurements (Fig. 4). The scanning parameters were selected according to the recommendations for wood surfaces: 2D scanning mode, 750µm/s scanning speed, 10000points per line, 50mm evaluation length, 2.5mm sampling length, 5µm resolution (Gurau 2007).

All samples were measured along the processing direction. According to ISO 13565-2:1996 standard, Rk (the roughness core depth) was evaluated as being the most representative processing roughness indicator (Sandak and Martino 2005; Gurau 2007). The roughness profile was achieved after a pre-filtering of data by using a Gaussian filter, implicitly applied.

All data were processed by using the same regression method (eq.1) and variance analysis. Specific segments of modelling in correlation with those established under industrial conditions and according to the speciality literature were analysed.

Some extreme values were removed and just three feed speeds (9, 13.5 and 18m/min) and three representative cutting depths (1, 2, 3mm) for a cutting width of 30mm were selected.

The cutting width does not influence the surface quality but it has an important impact upon the dynamic elements of the milling process, having an indirect influence upon surface.



Fig. 4.
MicroProf FRT roughness device

RESULTS AND DISCUSSION

3D response surfaces showing the variation of power consumption and R_k roughness parameter for straight milled longitudinal surfaces of black alder wood were achieved. Two 3D spectacular surfaces are offered as examples in Fig. 5 and Fig. 6. They present the variation of power consumption and processing roughness as function of feed speed (u), cutting depth (h) and cutting width (b) during longitudinal milling at two rotation speeds, namely 6620rot/min and 9732 rot/min. Each surface corresponds to a certain cutting width.

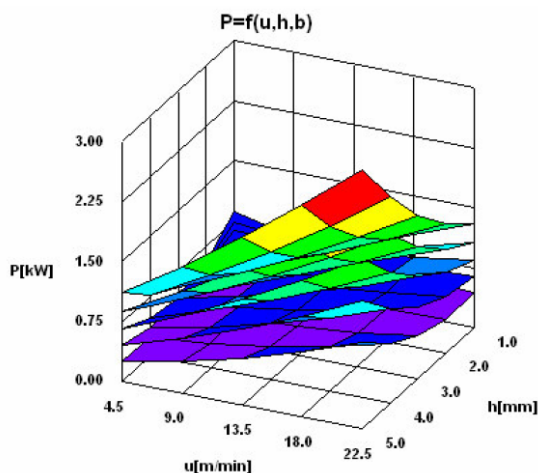


Fig. 5.
Variation of power consumption as function of cutting schedule during longitudinal milling at 6620rot/min

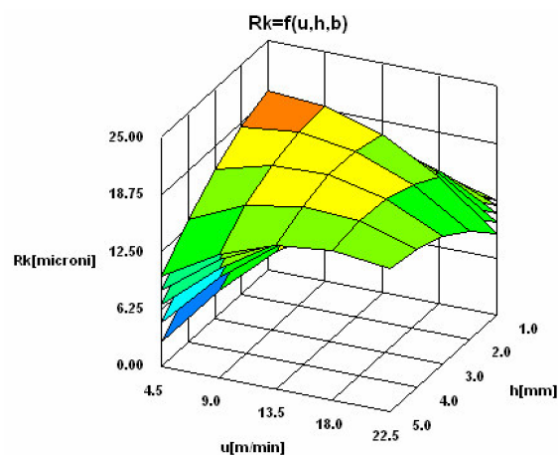


Fig. 6.
Variation of roughness parameter, R_k as function of cutting schedule during longitudinal milling at 9732rot/min

The variation of power consumption during the longitudinal milling of wood samples when using both rotation speeds and same cutting schedule for a cutting width of 20mm is presented in Fig.7. The cutting power decreased with the increase of cutting depth up to 3 or 4mm for low feed speeds and up to 1 or 2mm for higher feed speeds when the cutting process was performed at 6620 rot/min for a cutting width ranging from 20 to 35mm. A parabolic increase of the cutting power occurred after that. When processing samples with low cutting width at a rotation speed of about 9732 rot/min, the decrease of cutting power appeared very soon for 1 and 2mm as cutting depth, as shown in Fig. 7. In this case a minimum value of about 0,7kW was set at 4,5m/min as feed speed and 2mm as cutting depth. For cutting widths higher than 30mm, the cutting power increased for any feed speed. The cutting width and rotation speed presented significant effects on the cutting power and a significant cumulative effect of feed speed and cutting depth was also noticed ($Sig < 0.05$ and $\eta^2 > 0.5$).

Fig. 8. presents the variation of processing roughness, R_k as function of feed speed (u), cutting depth (h) during longitudinal milling at two rotation speeds of 6620rot/min and 9732rot/min for a cutting width of 30mm. The processing roughness expressed by R_k parameter respected and increased trend once the feed speed and cutting depth increased when processing at a rotation speed of 6620rot/min, while just a light increase was noticed when processing at 9732rot/min. The best surface quality expressed by R_k minimum value of about 12.4 μ m was achieved when milling at 6620rot/min with a feed speed of about 9m/min for 1mm as cutting depth. A significant cumulative effect of rotation speed and feed speed on roughness parameter was established ($Sig < 0.05$). The relation intensity was pointed out by $\eta^2 > 0.5$, which indicated their important interaction upon the processing roughness parameter.

CONCLUSIONS

The study revealed that an optimal cutting schedule can be obtained when using and combining two main criteria for processing optimization, such as the minimum power consumption and the best surface quality. The cutting power is mainly influenced by the cutting width apart of other cutting variables when compared to surface roughness. It appeared that best results are to be obtained in terms of cutting power and surface quality when processing with low feed speeds and light cutting depths. Data obtained in this study may be successfully used in wood industry.

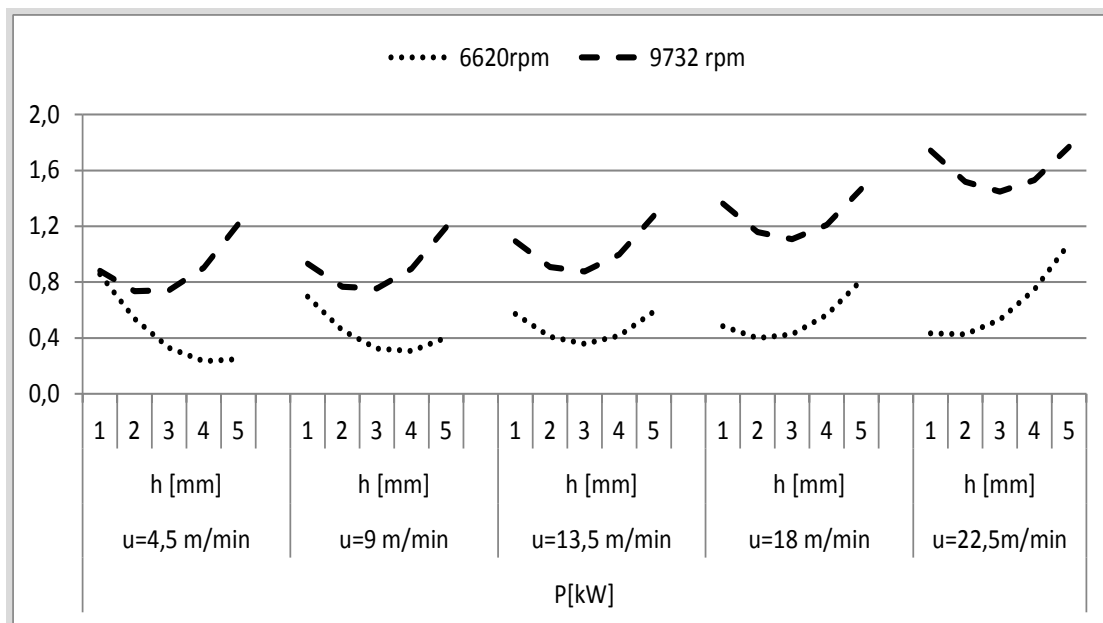


Fig. 7.
Variation of power consumption as function of feed speed (u), cutting depth (h) for 20mm as cutting width (b) during longitudinal milling at 6620 and 9732rot/min

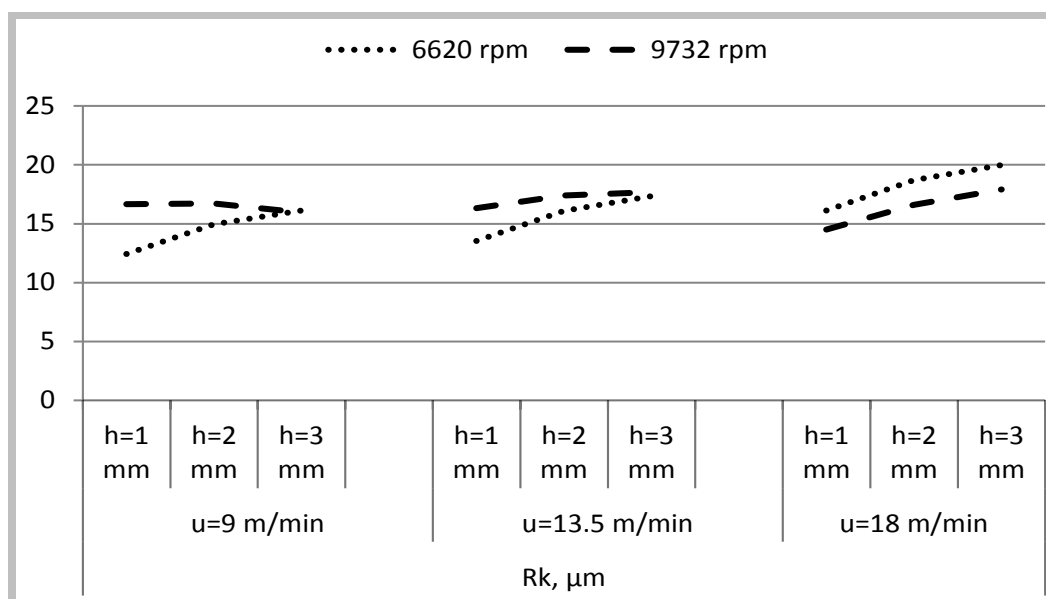


Fig. 8.
Variation of roughness parameter, Rk as function of feed speed (u) and cutting depth (h) for 30mm as cutting width (b) during longitudinal milling at 6620 and 9732rot/min

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