INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 1/2018 (13): 18–24

STUDY ON THE POWER – ENERGETIC INDICATORS OF A UNIVERSAL MILLING MACHINE

Zhivko Gochev, Georgi Vukov, Valentin Atanasov, Pavlin Vitchev
University of Forestry, Sofia, Bulgaria
e-mail: zhivkog@yahoo.com; georgiv@abv.bg; vatanasov_2000@yahoo.com; p_vitchev@abv.bg

ABSTRACT

Experimental studies during milling of solid wood were carried out. The current study was performed at the Laboratory of Woodworking Machinery, University of Forestry, Sofia. The measurements were carried out using universal milling machine FD – 3 (ZDM – Plovdiv). The correlations between fundamental factors influencing the milling process and target functions, such as cutting force and power, specific cutting work, specific power consumption have been investigated. On the basis of the analysis of the obtained results, practical recommendations have been proposed.

Key words: universal milling machine, cutting power, cutting force, specific cutting work, wood milling.

INTRODUCTION

Milling is a widespread process in woodworking and especially in the furniture industry which is done by tools – cutters with a rotating motion, where the trajectory that describes their teeth is cycloid. This process is used to produce flat and profiled surfaces, for making grooves, rebates, tenons, etc. The obtained details are with sufficiently high quality of processing, certain accuracy and roughness of the surfaces (Grigorov 1992, Gochev 2006).

The process can be qualitative and productive only in conditions of optimum cutting modes and with the correct construction and geometry of the cutting tools. Rational use of power should not only mean the full load of the machine's cutting mechanism but the quality of the processed surface of the wood as well.

Despite the widespread use of the milling process, it is difficult to find in literature results on the power-energetic indicators of milling machines. This is what defines the purpose of the present study: *To conduct an experimental study on the power-energetic indicators of a milling machine with lower spindle position*.

METHODOLOGY

To conduct experimental studies a universal milling machine „FD-3“ (ZDM-Plovdiv) with lower spindle position was used. It’s located in the laboratory „Woodworking Machines“ (ULK 216), University of Forestry – Sofia.

Figure 1: General view of the milling machine

Some of the machine's technical parameters are shown in Table 1.

Table 1: Basic parameters of the *FD-3* milling machine

Spindle diameter	30 mm
N_m – power of the electric motor	3 kW
Vertical movement of the spindle	95 mm
n_m – revolutions of the electric motor	48 s^{-1}
Length of the working table	840 mm
Width of the working table	720 mm
Height of the working table	860 mm
Power supply voltage	3 x 380 V/50 Hz

The feed motion in the experiments is provided by a roller feed mechanism with the following technical characteristics:

- feed speed, U = 2, 3, 4, 6, 10, 16, 21, 32 m.min^{-1};
- number of the feed rollers $n_{f.r.}$= 3 pcs.

As a cutting tool a groove cutter was used. Its general appearance, mounted on the mandrel, can be seen in Fig. 3. Its main linear and angular parameters are presented in Table 2.

Figure 2: General view of the roller feeder

Figure 3: General view of the used cutting tool

Table 2: Basic parameters of the cutting tool

Groove cutter	
Construction	Soldered hard-alloy plates, steel body
Material of the cutting plates	HW
Thickness of the cutting teeth (s), mm	12
Number of the cutting teeth	6
Diameter of the body (D), mm	140
Diameter of the attachment hole (d), mm	30
Rake angle (γ), ^{0} /Included andgle (β), ^{0} / Clearence angle (α), ^{0}	20/ 58/ 12
Weight m, kg	0,910

The determination of power-energetic indicators of the machine is achieved by the well-known methods – by calculating the force and power of cutting, the specific cutting work and specific power consumption (Gochev 2008). Needed for the calculations values of input power at idle and working conditions of the cutting mechanism of the machine were recorded using the device *US301EM* (Fig. 4) which is designed to measure single-phase or three-phase electric power. The reported parameters are apparent, reactive and real power (generally and separately for each phase), power consumption, power factor and others. The accuracy of the measurements is 0.1 W.

Figure 4: Measurement device US301EM of Unisyst Engineering Ltd. – Bulgaria

For more accurate processing of the results, the company software and the notebook were used. The results are automatically converted to *Microsoft Excel*. Thus eliminated the mistakes of the human factor.

The scheme for connecting the device to the mains is shown in Fig. 5. For this purpose, three current (*CNC® CURRENT TRANSFORMER* 50/5) and three voltage transformers were used (*UNITRAF AD Ltd 220/100 V*).

The efficiency coefficient of the cutting mechanism is determined by the following dependence

$$\eta = (1 - \frac{N_{np.x}}{N_{вх}}).100 \qquad (1)$$

where N_{inle} is the input power of the cutting mechanism in idle condition, kW;

$N_{load.}$ – the power consumption of the cutting mechanism in load condition, kW.

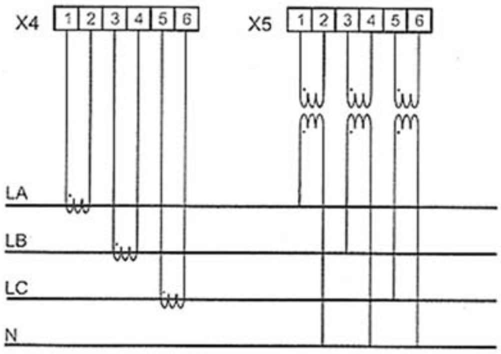

Figure 5. Scheme for connecting the device to the mains

Cutting power is calculated using the formula

$$N_{c.} = (\frac{N_{load} - N_{idle}}{100})\eta. \qquad (2)$$

The tangential force of cutting is defined by the equation

$$P = \frac{1000\,N_c}{V}, \qquad (3)$$

where V is the cutting speed, m.s^{-1}.

The cutting speed was calculated by the gear ratio and the sliding coefficient

$$V = \pi D n = \pi D \frac{n_m}{i}(1-\varepsilon), \qquad (4)$$

where D is the diameter of the cutting tool, m;

n – the revolutions of the spindle, s^{-1};

i – the gear ratio of the belt drive $i = \frac{D_2}{D_1}$ (D_1 and D_2 – are the diameters of the belt pulleys mounted to the electric motor and the spindle of the machine);

ε – the sliding coefficient of the belt.

The specific cutting work was determined by

$$K = \frac{1000.N_{load}.60}{b.h.U}, \qquad (5)$$

where h is the cutting height, m.

The specific power consumption is determined by the following formula

$$E = \frac{N_{load}}{60.U.h}. \qquad (6)$$

Experimental specimens of pine bones (*Pinus sylvestris L.*) with dimensions 50x50x1520 mm were used (Fig. 6). The density of the wood is determined by the weighing method using a RADWAG WLC 1/A2 electronic scales. The moisture content of the processed material is determined by moisture meter *Lignomat Tester* – Germany.

Figure 6: Test specimens for conducting experimental studies

For the purposes of this study, a three-factor regression analysis was performed. The influence of the following factors was studied:

- The cutting speed V (X_1) – the variation levels of this factor are achieved by changing the belt pulleys that are mounted to the electric motor. Respectively $D_{1.1.} = 125$ mm, $D_{1.2.} = 190$ mm, $D_{1.3.} = 250$ mm и $D_2 = 90$ mm. After substitution in formula 4, the following values are obtained – $v = 29$, 44 and 59 m.s^{-1}.
- Feed speed U (X_2) = 2, 6 и 10 m.min^{-1}.
- Cutting area A (X_3) (b – the width of the cutting tool x h – the depth of the groove) = 48, 96 and 144 mm^2.

RESULTS

The measured density and moisture content of the test specimens is $\rho = 450$ kg.m^{-3} and $W = 12$ %.

The factors in coded form and the results for the respective target functions are shown in Table 3: Y_1 – cutting power, kW; Y_2 – cutting force, N; Y_3 – specific cutting work, MJ.m^{-3}; Y_4 – specific power consumption, kWh.m^{-2}.

Table 3: Factors in coded form and results for the target functions

№	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4
1.	-1	-1	-1	0,021	0,745	12,964	2,415
2.	-1	-1	+1	0,175	6,389	38,601	1,074
3.	-1	+1	-1	0,163	5,676	20,393	0,620
4.	-1	+1	+1	0,683	23,548	28,454	0,310
5.	+1	-1	-1	0,042	0,720	26,538	2,856
6.	+1	-1	+1	0,345	5,748	71,883	1,354
7.	+1	+1	-1	0,285	4,826	35,590	0,767
8.	+1	+1	+1	0,709	13,713	33,711	0,359
9.	-1	0	0	0,291	10,038	90,966	1,831
10.	+1	0	0	0,413	7,001	25,816	0,428
11.	0	-1	0	0,182	4,139	18,972	0,530
12.	0	+1	0	0,526	11,949	32,859	0,419
13.	0	0	-1	0,115	2,613	23,951	1,004
14.	0	0	+1	0,625	14,206	43,408	0,508
15.	0	0	0	0,290	6,595	30,226	0,597
16.	0	0	0	0,315	2,163	32,832	0,604
17.	0	0	0	0,294	6,679	30,610	0,593
18.	0	0	0	0,263	5,984	27,425	0,581
19.	0	0	0	0,305	6,933	31,777	0,595
20.	0	0	0	0,334	7,601	34,837	0,610

The resulting regression equations after processing with the software product *QstatLab 5* are as following:

- for cutting power (Y_1):

$$Y_1 = 0{,}354 + 0{,}055\,x_1 + 0{,}169x_2 + 0{,}202x_3 - 0{,}018x_1^2 - 0{,}016x_2^2 + 0{,}000x_3^2 + 0{,}008x_1x_2 + 0{,}072x_2x_3 + 0{,}018x_1x_3; \quad \textbf{(7)}$$

- for the tangential cutting force (Y2):

$$Y_2 = 8{,}056 - 1{,}421x_1 + 4{,}185x_2 + 4{,}920x_3 + 0{,}098x_1^2 - 0{,}378x_2^2 - 0{,}012x_3^2 - 1{,}262x_1x_2 + 2{,}001x_2x_3 - 1{,}198x_1x_3; \quad \textbf{(8)}$$

- for the specific cutting work (Y3):

$$Y_3 = 38{,}765 + 0{,}216x_1 - 1{,}795x_2 + 9{,}662x_3 + 17{,}491x_1^2 - 14{,}985x_2^2 - 7{,}221x_3^2 - 3{,}300x_1x_2 - 8{,}100x_2x_3 + 1{,}221x_1x_3; \quad \textbf{(9)}$$

- for the specific power consumption per unit area (Y4):

$$Y_4 = 0{,}578 – 0{,}049x_1 – 0{,}575x_2 – 0{,}406x_3 + 0{,}556x_1^2 – 0{,}099x_2^2 + 0{,}183x_3^2 – 0{,}066x_1x_2 + 0{,}266x_2x_3 – 0{,}032x_1x_3. \quad \textbf{(10)}$$

When comparing the Fisher calculated value $F_{cal.}$ – the Fisher criterion (0,32 for Y_1; 1,24 for Y_2; 2,34 for Y_3 and 0,18 for Y_4) with the critical one ($F_{cr.}$ – 4,77), used for verification, it becomes clear that the models are adequate and the equations obtained can be used to describe the relevant processes.

As can be seen from the obtained regression equation, related to the target function cutting power, the factors with the greatest influence are the cutting area and the feed speed. Furthermore, the connection between the target functions and output values is straightforward, i.e. with their increase, the cutting power rises as well.

From the regression equation obtained, it is also noted that by increasing the spindle revolutions, hence the cutting speed, the cutting power increases as well. In addition, during the experimental studies, when operating at a cutting speed of 59 m.s^{-1}, as a result of the change of sound, the increase in the load on the electric motor is evident.

Fig. 7 graphically shows the results of the relationship between the factors with the greatest influence on the output function. It is noted that the curve corresponding to a feed rate of 10 m.min^{-1} is the steepest. This means that when the feeding speed is high, the cutting power increases sharply even with small deviations in the milling area. In this case, there is a significant increase in the risk of overloading the engine – especially when there are deficiencies in wood as knots.

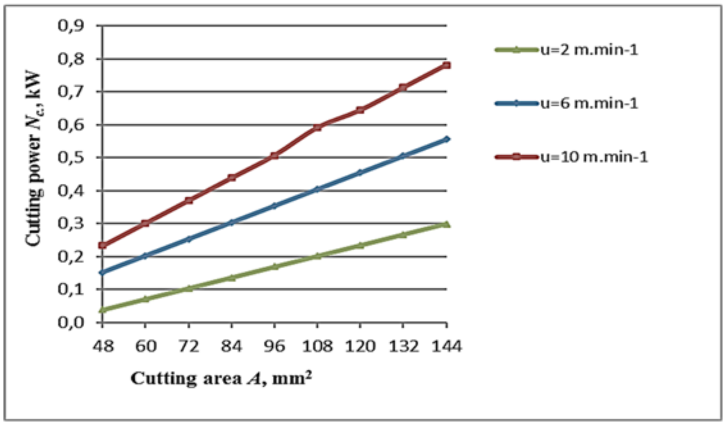

Figure 7: Influence of the cutting area (*A*) on the cutting power (N_c.) at different feed speeds (*U*)

Results in the reporting of the cutting force are similar to those for power (equation 7). The difference is that as the feed speed increases, the cutting power decreases. Figure 8 shows the effect of cutting speed on the cutting power at the three levels of variation in the feed speed factor. It can be seen that the cutting power does not exceed 15 N when milling the pine. Moreover, at the lowest feed rate of 2 m.min^{-1}, the influence of cutting speed is minimal. The greatest influence of the factor is observed at the highest feed rate of 10 m.min^{-1}.

The resulting specific cutting work equation indicates that X_3 has the greatest impact. Figure 9 shows that the corresponding target function marks its maximum at milling areas 120–132 mm^2, then it starts to decrease again.

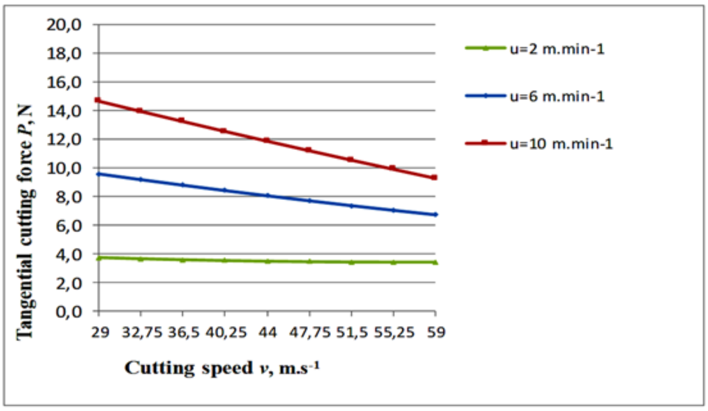

Figure 8: Influence of cutting speed (*v*) on cutting power (*P*) at different feed speeds (*u*)

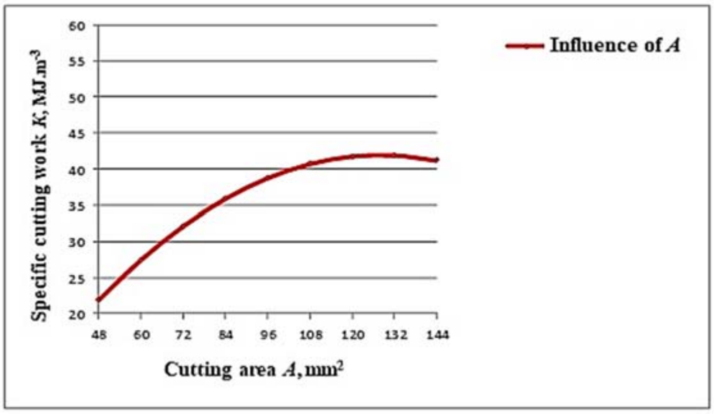

Figure 9: Influence of the cutting area (*A*) on the specific cutting work (*K*)

Regarding the specific power consumption, it is noted that in all factors the connection is inverse. This means that with the increase of the levels of their variation, the ratio of the energy input to the cutted quantity decreases. The feed speed and the cutting area have the greatest influence. Figure 10 shows the relationship between the specific power consumption and the cutting area.

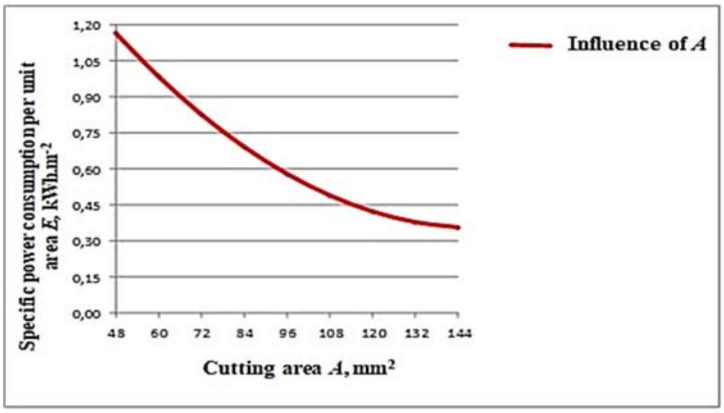

Figure 10: Influence of cutting area (*A*) on specific power consumption per unit area (*E*)

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the experimental tests carried out on the power-energy indicators of a lower spindle milling machine, the following more important conclusions and recommendations can be made:

1. The results obtained for the cutting power show that the milling area and feed speed have approximately the same influence. However, a greater regression coefficient is obtained for the milling area and can be defined as the more significant factor.

2. The results for specific cutting work indicate that the milling area has a greater impact. In addition, the relationship between this factor and the target function is straightforward, and that at the feed speed is reversed.

3. The regression equation for the specific power consumption per unit area indicates that the feed speed has the greatest impact.

4. The results are a prerequisite for conducting more detailed research on cutting power, cutting force during milling, etc. It is possible to study the impact of other factors – wear of cutting tools, cutting tool vibrations, influence of the wood species, type of cutting tool, etc.

5. Outlined dependencies allow for a choice of rational cutting modes and an optimization of processes according to a specific criterion.

REFERENCES

GOCHEV, ZH., ET AL., Theme № 122. 2008. Comparative Investigation on Working Capacity of Wide Band Saw Blades with Setting, Swaging and Stellite teeth: Team leader Assoc. Prof. Zh. Gochev, NIS/LTU, 100 p (in Bulgarian).

GOCHEV, ZH. 2005. Manual for Wood Cutting and Woodworking Tools, Publishing House at University of Forestry, Sofia, 232 p (in Bulgarian).

GRIGOROV, P. 1992. Cutting of wood, Zemizdat, Sofia, 335 p (in Bulgarian).

UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2018

INNO vol. VII Sofia

ISSN 1314-6149
e-ISSN 2367-6663

CONTENTS