The influence of selected factors on energy requirements for plain milling of beech wood

Š. Barcík[1], R. Kminiak[2], T. Řehák[1], M. Kvietková[2]

[1]*Department of Wood Processing, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*
[2]*Department of Wood Working, Faculty of Wood Sciences and Technology, Technical University in Zvolen, Zvolen, Slovakia*

ABSTRACT: The paper deals with differences in energy requirements for cutting input at plain milling of beech wood with and without false heart with different changing parameters of cutting and feed speed and angular geometry of the tool. Created on optimal model from the aspect of not only energy consumption but also the quality of milling, which would also decisively affect the economic indicators of the wood – working process.

Keywords: angular geometry; beech; cutting input; cutting speed; false heart; feed speed; milling

In an effort to make use of the highest volume of wood mass from a tree for the best quality assortments we are looking for ways of utilizing the logs with some defects such as e.g. false heart. On a European scale, the false heart most often occurs in the tree species beech, which is the most important broadleaved species not only in Slovakia from the viewpoint of its commercial use. Therefore some European regions created all-embracing working groups who strive to reach a universal goal, which is an improvement of market acceptance of beech heartwood. Orientation is focused on the production of exclusive furniture (Řehák 2009).

At present, with constantly rising claims for wood processing and a subsequent increase in prices, the question of energy intensity (Gaff 2008) of production has come to the fore. Milling as one of the basic and widespread methods of wood-working strongly depends on electrical energy.

Annual costs of energy used in wood processing reach multi-million amounts. But it is possible to decrease them by a proper use of individual parameters entering into the interactive process machine – tool – workpiece and simultaneously to create an optimization model of the given process. This aspect is a crucial task of each experimental study aimed at the solution of the above-mentioned problems.

For fulfilment of these often contradictory tasks it is also necessary to elaborate input data on electrical energy consumption, i.e. the cutting input.

The present paper tries to furnish the scientific and professional community who should further proceed in these problems with the part of this data aimed at the investigation of the influence of v_c – cutting speed (m·s^{-1}) v_f – feed speed (m·min^{-1}), tool angular geometry and mainly the beech species with and without false heart on cutting input.

MATERIAL AND METHODS

The main aim of the verification experimental investigation was to study, on the basis of measurements of beech species with and without false heart, the influence of selected factors of energy requirements at plain milling of beech wood on cutting input as well as on basic technological parameters v_c and v_f, and on the tool angular geometry of a milling machine in the process of plain milling.

Another goal of the experiment was the determination of bulk density of individual beech assortments and the comparison of results with available information on the given problems.

Energy requirements were assessed on the basis of measurement and evaluation of electric input

Fig. 1. Milling machine with feeding device

consumption (W) of the milling machine drive. All measurements were carried out simultaneously with the measurements aimed at the investigation of the influence of the above-mentioned factors on cutting input.

Machinery and tool

Experiments were realized on a single-spindle drilling machine of FVS type; feed was provided by STEFF feeding device (Fig. 1).

Parameters of the machine: electric current 360/220 (V), frequency 50 Hz, electric motor power requirement (P_{em}) = 4 kW, technical speed (n_t) = 3,000, 4,500, 6,000, 9,000 (rev·min^{-1}) and respective cutting speeds with tool diameter 130 mm, v_c = 20, 30, 40, 60 m·s^{-1}, manufacturer: Czechoslovak Musical Instruments in Hradec Králové.

Parameters of the feeding device 2034: P_{em} = 0.8 kW, n_t = 1,400/2,800 min^{-1}, v_f = 4, 8, 11, 12 m·min^{-1}.

The used tool was a double-tool milling cutter with exchangeable knives (Fig. 2) with 1 mm overhang against each other.

Parameters of the milling machine: tool diameter ø = 125 mm, diameter with offset tools = 130 mm, width = 45 mm, number of knives = 2. Three milling heads with rake angles (γ) = 15°, 20°, 25° and knives with the cutting-wedge angle (β) = 45°, with respective back-angles (α) = 20°, 25°, 30° and cutting angles (δ) = 65°, 70° and 75° were used for the experiment.

Material of knives: Maximus special 55: 19 855 with chemical composition C = 0.7, Cu 4.2, W = 18.0, V = 1.5, CO = 4.7 and hardness after hardening HRC 64.

Characteristics of raw material

The basic experimental raw material consisted of beech samples – dimension timber (*Fagus sylvatica* [L.]) with false heart (heartwood) and without heart (softwood), length 1 m, width 50 mm and thickness 35 mm, knot-free and straight grained, radial. Dimension timber was handled from sawn timber 3 m long, kiln dried to moisture content 10% and trimmed to initial thickness 30 mm. Their average density was determined according to the Standard ČSN 49 0108 with false heart at 708 kg·m^{-3} and without false heart at 725 kg·m^{-3}, which represents 2.4% difference.

Measuring of cutting input

At experimental measurements of cutting input the common principle of measurement was used based on monitoring changes in the current drawn by an electric motor from the mains by Metrel Power Q

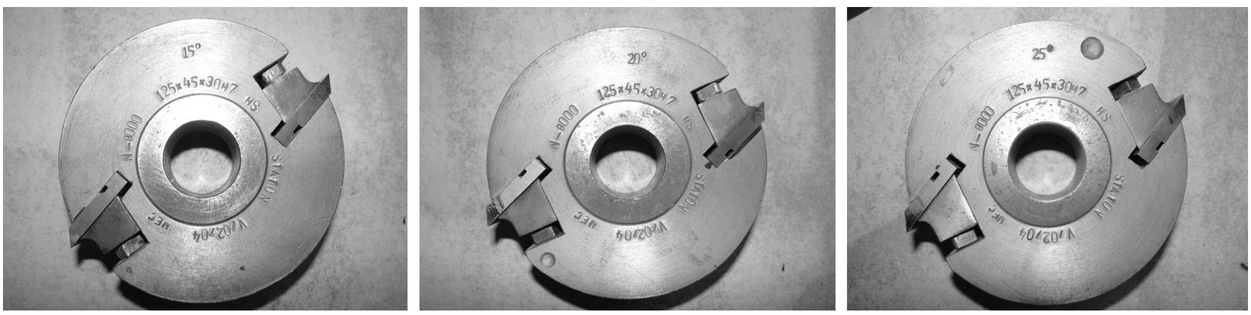

Fig. 2. Milling machine with exchangeable knives

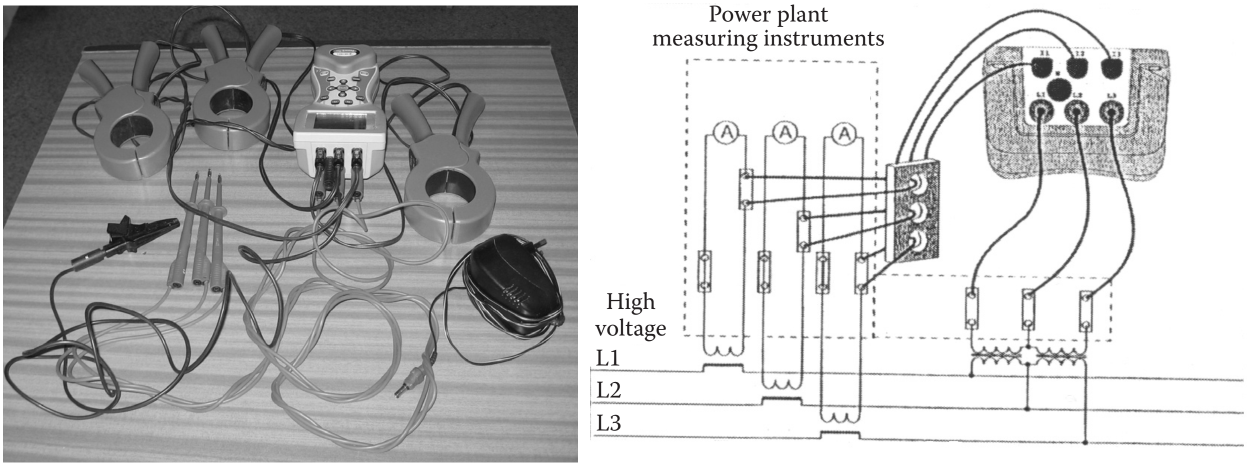

Fig. 3. Metrel Power Q plus MT 2390 measuring equipment with the wiring scheme

plus MT 2392 measuring equipment (Fig. 3) according to the methods, i.e. the analysis of the quality of mains (Rousek, Kopecký 2005; Siklienka, Fryková 2009).

The equipment records changes in drawn current, actual value of voltage U and on the basis of the recorded phase shift (3rd phase) the equipment is able to evaluate the input of an electric motor; the recorded values were in an interval of 1 second (1,024 values·s^{-1}).

The equipment calculated from the measured values the actual cutting output according to

$$P_x = \frac{1}{1{,}024} \sum_{\phi=1}^{1{,}024} U_{jx} \times I_{jx}$$

and total input $P_s = P_1 + P_2 + P_3$ (W).

where:

P_x – actual cutting output
U_{jx} – voltage factor
I_{jx} – stream factor
P_s – total cutting output
P_1–P_3 – phases cutting output

The equipment was connected to a computer through RS232 interface and the data were processed by means of Power QLink 2.1. software (Hajník 2008). Measured values of cutting input were evaluated by Microsoft Excel program and subsequently processed statistically by the program STATISTICA in 8.0 multifactor analyses of variance.

Experimental measurements

The experiments were conducted in operating conditions of the workshops and laboratories of Cyech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Department of Wood Processing. The opposite direction principle of move in plain milling parallel with grains in tangential direction was used according to Liščan Jozef et al. (1996). The measurements were accomplished, with observed parameters on three levels: v_c = 20, 30, 40 m·s^{-1}, v_f = 4, 8, 11 m·min^{-1} and angular geometry of rake angles γ = 15, 20, 25° separately for beech with true heart and without false heart and

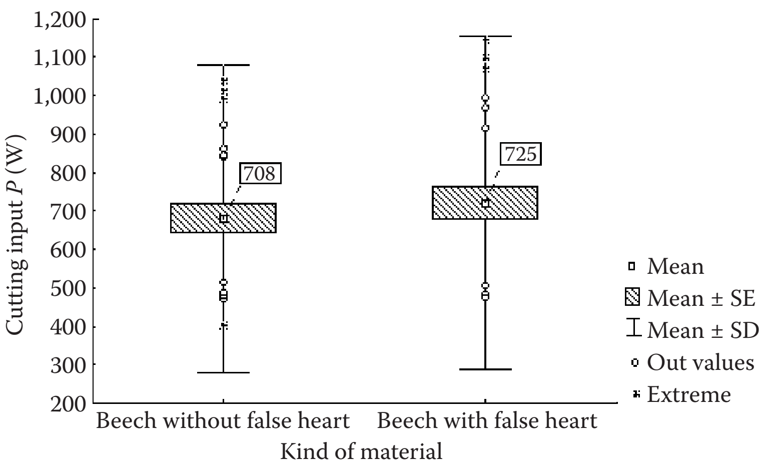

Fig. 4. Dependence of cutting input on the kind of material (SE – standard error, SD – standard deviation)

Table 1. Concrete values of cutting input at different combinations of measured parameters

Feed speed v_f (m·min^{-1})	Rake angle γ (°)	Cutting input P (W) without false heart	Cutting input P (W) with false heart	Difference (%)
4		705.97	760.48	7.17
8	15	777.96	806.83	3.58
11		799.48	815.84	2.0
4		615.13	649.67	5.32
8	20	676.05	729.03	7.27
11		727.97	779.03	6.55
4		566.08	604.80	6.4
8	25	619.46	682.18	9.19
11		641.56	652.22	1.63
Feed speed v_f (m·min^{-1})	Cutting speed v_c (m·s^{-1})			
4		462.96	513.76	9.89
8	20	528.99	556.55	4.95
11		536.81	568.53	5.58
4		535.71	564.39	5.08
8	30	608.86	637.78	4.53
11		666.67	651.03	–2.40
4		888.50	936.81	5.16
8	40	935.62	1,023.70	8.60
11		965.53	1,027.52	6.03
Cutting speed v_c (m·s^{-1})	Rake angle γ (°)			
20		574.13	597.90	3.98
30	15	679.07	680.11	0.15
40		1,030.22	1,105.14	6.78
20		501.00	551.55	9.17
30	20	598.29	625.60	4.36
40		919.86	980.58	6.19
20		453.64	489.38	7.30
30	25	533.88	547.50	2.49
40		839.58	902.31	6.95

the size of taken off layer was e = 3 mm (thickness of remote layer). For each combination of parameters, the experimental material was investigated with double motion of the machine, i.e. 2 bm (common meter) milled length, where the scanned values created one date file.

RESULTS AND DISCUSSION

The evaluation of the influence of beech with false heart and without it on cutting input is presented in Fig. 4 and Table 1 showing average values of the combination of observed parameters with

Table 1 to be continued

Cutting speed v_c (m·s^{-1})	Feed speed v_f (m·min^{-1})	Cutting input P (W) without false heart	Cutting input P (W) with false heart	Difference (%)
20		462.96	513.76	9.89
30	4	535.71	564.39	5.08
40		888.50	936.81	5.16
20		528.99	556.55	4.95
30	8	608.86	637.78	4.53
40		935.62	1,023.70	8.60
20		536.81	568.53	5.58
30	11	666.67	651.03	–2.40
40		965.53	1,027.52	6.03
Rake angle γ (°)	Feed speed v_f (m·min^{-1})			
15		705.97	760.48	7.17
20	4	615.13	649.67	5.32
25		566.08	604.80	6.40
15		777.96	806.83	3.58
20	8	676.05	729.03	7.27
25		619.46	682.18	9.19
15		799.48	815.84	2.00
20	11	727.97	779.03	6.55
25		641.56	652.22	1.63
Rake angle γ (°)	Cutting speed v_c (m·s^{-1})			
15		574.13	597.90	3.98
20	20	501.00	551.55	9.17
25		453.64	489.38	7.30
15		615.13	649.67	5.32
20	30	676.05	729.03	7.27
25		727.97	779.03	6.55
15		1,030.22	1,105.14	6.78
20	40	919.86	980.58	6.19
25		839.58	902.31	6.95

percentage expression of differences between both materials.

It follows from the results of evaluation that the average cutting input of beech with false heart is slightly higher (by an average value 5.7%) than in beech without false heart. The difference in percentage did not exceed 10% in any of these cases in the given combination of studied parameters; a higher value of cutting input was always reached in materials with false heart. The main reason for this fact lies in their different density.

From the practical point of view, the given difference is not significant; therefore in the next statistical processing of the influence of observed parameters on cutting input we used both these materials together.

Table 2. Analysis of variance for the dependence of cutting input on feed speed, cutting speed and angular geometry

	SS	Degrees of freedom	*PC*	*F*	*P*
Absolute term	26,574,862	1	26,574,862	14,854.59	0.000000
Rake angle γ (°)	210,269	2	105,134	58.77	0.000000
Cutting speed v_c (m·s^{-1})	1,926,095	2	963,048	538.32	0.000000
Feed speed v_f (m·min^{-1})	64,417	2	32,208	18.00	0.000011
Rake angle × cutting speed	11,427	4	2,857	1.60	0.203811
Rake angle × feed speed	6,555	4	1,639	0.92	0.468889
Cutting speed × feed speed	2,482	4	620	0.35	0.843870
Rake angle × cutting speed × feed speed	8,053	8	1,007	0.56	0.798650
Error	48,303	27	1,789		

SS – sum of squares, PC – disspersion, F – *F*-test, P – p-level of signifikance

The results of the influence of observed parameters from the common values of both these materials are presented in Table 2 and in Figs. 5–8. It follows from the statistical evaluation by multifactor analysis of variance that the influence of all observed factors on cutting input is significant, and the order of their significance was v_c – cutting speed, γ – rake angle, i.e. angular geometry of the tool, and v_f – feed speed.

The common relation was confirmed that with the rising feed speed the cutting input also increases. The reason is that with an increase in v_f, the feed of the material which must be taken off within the same time unit also increases. This requires a higher cutting input. The higher increase in cutting input was recorded in transition from the feed speed 4 to 8 m·min^{-1}, namely by 9.5%.

In transition from v_f = 8–11 m·min^{-1}, an increase in cutting input only by 2.8% was recorded.

An increase in cutting speed v_c was manifested similarly like in v_f by an increase in cutting input

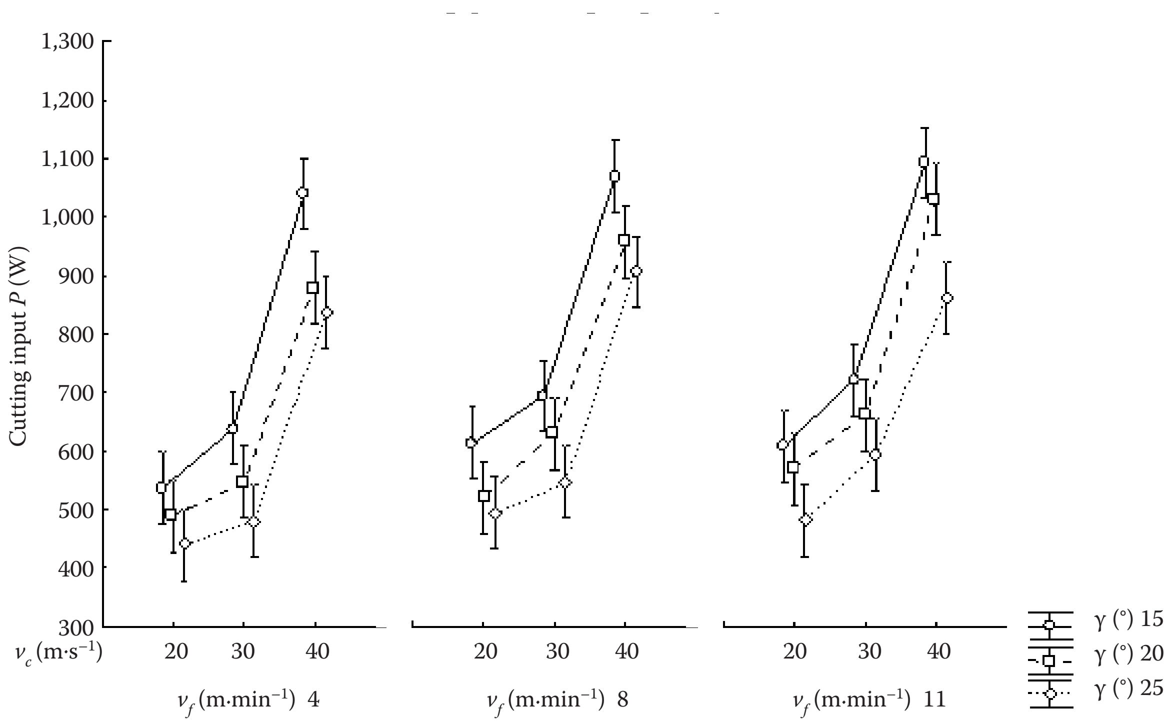

Fig. 5. Graph of the analysis of variance for the dependence of cutting input on feed speed, cutting speed and angular geometry

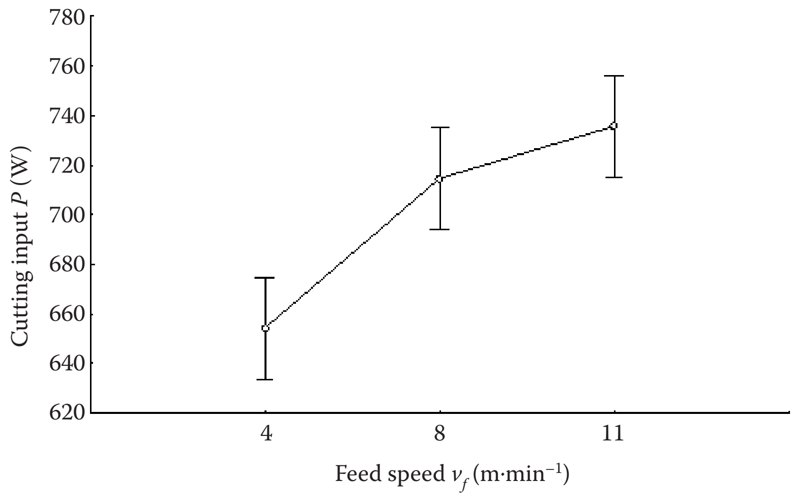

Fig. 6. Dependence of cutting input on feed speed

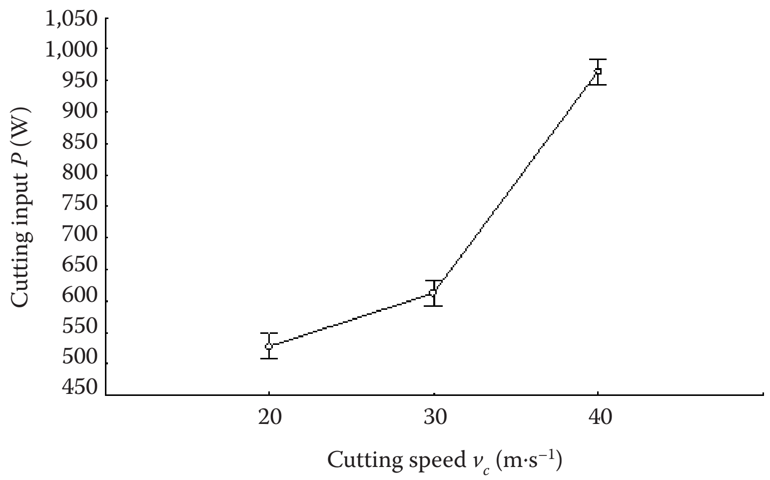

Fig. 7. Dependence of cutting input on cutting speed

but in this case it was manifested more significantly, when the rise from 20–30 m·s^{-1} was more gradual, and represented the change from v_c = 30–40 m·s^{-1}, which means as much as 36.6%.

Among the evaluated rake angles the angle γ = 25° was shown as optimal, with the lowest cutting input. The cutting input decreases almost linearly with the decreasing angle; with the change of the angle γ from 15° to 20°, a decrease in cutting input by 11.8% was observed and with the change of the angle γ from 20° to 25° there was a decrease in input by 111%.

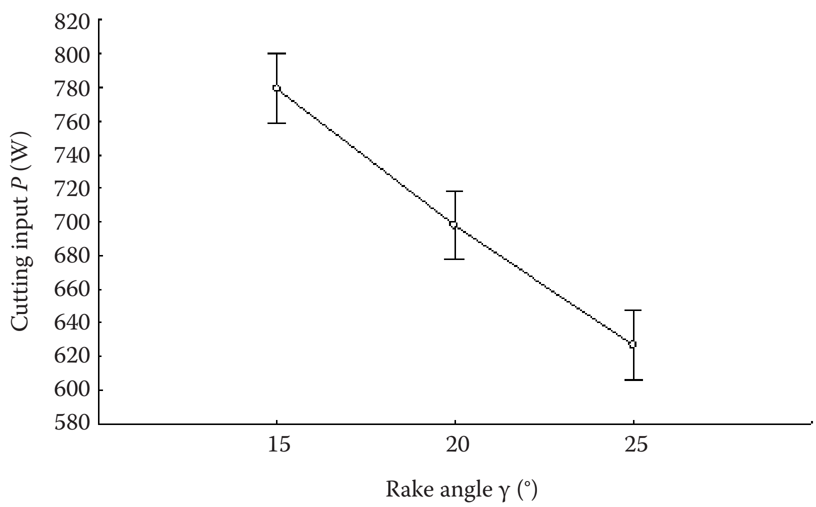

Fig. 8. Dependence of cutting input on rake angle

Based on the experiments an equation was determined arising from the regression of cutting input, i.e. from the energy requirements of the plain milling process with the following observed parameters:

$$P = 262.057 + 15.27\gamma + 21.8v_c + 11.82v_f$$

where:
P – cutting input (W)
γ – rake angle (°)
v_c – cutting speed ($m \cdot s^{-1}$)
v_f – feed speed ($m \cdot min^{-1}$)

CONCLUSION

From the presented results of experimental measurements we can draw a conclusion that the experiments have univocally confirmed the fact that a change in the observed parameters v_c, γ and v_f leads to significant changes in energy requirements for plain milling (Barcík et al. 2007) of beech wood; the difference between cutting inputs in milling of beech wood with and without false heart is negligible.

With the increasing feed speed, the cutting input also increases, as well as with an increase in cutting speed, when the rise is the most intensive above 30 $m \cdot s^{-1}$; an increase in the value of the rake angle causes a decrease in cutting input. So, with regard to the acquired results of cutting input, in plain milling it is ideal to choose the lowest possible rake angle and feed speed. On the other hand, it is also necessary to consider the fact that such a decrease in cutting input will result in a decrease in production capacity.

In conclusion it is necessary to state that the issue of plain milling of beech wood is very complex and in the context of the results of the above-mentioned experiments it is inevitable to further extend the knowledge of investigated parameters concerning individual influences from the aspect of e.g. geometry and quality of machining. This would create an optimal model from the aspect of not only energy consumption but also the quality of milling, which would also decisively affect the economic indicators of the wood-working process.

References

Barcík Š., Pivolusková E., Kminiak R. (2007): The influence of technological and material factors on energy output at plane milling of juvenile poplar wood. In: Proceedings Ambienta 2007, 18th International Conference, New Technologies and Materials in Forest Based Industries. Zagreb, 19. November 2007. Sveučilište u Zagrebu, Šumarski Fakultet: 107–112.

ČSN 49 0108 Wood density survey. (in Slovak)

Gaff M.: (2008) Embassed surface of the wood moding. [Ph. D. Thesis.] Zvolen, Technická univerzita vo Zvolene: 86. (in Slovak)

Hajník I. (2008): Effect of cutting height on beech prize cutting power horizontal band saw trisal HTŽ – 1100. In: Proceedings VI. MVK – Trieskové a beztrieskové obrábanie dreva 2008. Štúrovo, September 2008. Město vydání a vydavatel doplnit: 105–111. (in Slovak)

Lisičan J. (1996): Theory and technology of wood processing. Zvolen, Matcentrum: 102. (in Slovak)

Rousek M., Kopecký Z. (2005): Monitoring of power consumption in high speed milling. Drvna industrija, ***56***: 121–126.

Řehák T. (2009): Influence of technical and technological and material factors in the energy intensity in plane milling. [M.Sc. Thesis.] Praha, ČZU: 78. (in Czech)

Siklienka M., Fryková D. (2009): The influence of the selected factors on the cutting input power in sawing frozen beech wood. In: Proceedings 3rd ISC Woodworking Technique. Zalesina, September 2009. Zagreb, Faculty of Forestry: 101–108.

Received for publication December 21, 2009
Accepted after corrections March 1, 2010

Corresponding author:

doc. ing.Štefan Barcík, CSc., Česká zemědělská univerzita v Praze, Fakulta lesnická a dřevařská,
165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 383 737, fax: + 420 224 383 732, e-mail: barcik@fld.czu.cz