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Monitoring of power consumption in high-speed milling*

Mjerenje snage pri blanjanju velikim brzinama*

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ABSTRACT • *This paper presents the current condition of research in the field of high-speed milling at the Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry, Brno. The arrangement of a trial stand is described, as well as the development of methods for measuring passive and aerodynamic resistances, characterization of the basic parameters and accuracy of repeated measurements in open milling. The results are documented by means of selected diagrams.*

Keywords: *wood machining, milling, high-speed, measurement, measuring stand*

SAŽETAK • *U radu se opisuju istraživanja blanjanja velikim brzinama u laboratoriju Fakulteta šumarstva i drvne tehnologije Mendelova sveučilišta agronomije i šumarstva u Brnu. Opisan je stroj za blanjanje, mjerna oprema i razvoj metoda za mjerenje pasivnoga i aerodinamičnog otpora, osnovni mjerni parametri te točnost ponavljanih mjerenja u otvorenom rezu. Rezultati istraživanja predočeni su dijagramima.*

Ključne riječi*: obrada drva, blanjanje, velike brzine, mjerenje, mjerna oprema i stroj*

1 INTRODUCTION
1. UVOD

At present, milling is carried out at constant rotation speed amounting to about 4500 – 6000 rpm and relatively small feed speed of a workpiece. We speak about high-speed milling if the rotation speed of a cutting tool exceeds 9000 rpm. Thus, the cutting speed v_c=70 m·s^{-1} is nowadays considered as a high-speed rate of wood milling.

In high-speed milling, increased milling speed is tried to be achieved maintaining the determined quality of the machined wood surface. At present, it refers to the study of surface milling at high cutting speeds in a testing stand (Fig. 1). Regarding the stand, tests and measurements are carried out for the purpose of comparing the data of various authors published so far, determining the limit values of high-speed machining and the optimum way of research and development of woodworking machines and tools in future.

Within the EUREKA programme and in co-operation with TOS Svitavy Co., the prototype was manufactured of a measuring stand and our Department took part in its development. The stand provides the possibility to experiment in the field of milling with the cutting speed exceeding v_c = 70 m·s^{-1} and feed speed v_f ≤ 100 m·min^{-1}. It refers particularly to the measurement of passive resistance, especially aerodynamic resistance

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Figure 1 A testing stand for high-speed milling
Slika 1. Stroj za blanjanje drva velikim brzinama pripremljen za istraživanje

and cutting resistance. The results of these characteristics of milling (Kolektiv, 2003) obtained so far show a number of problems related to the methods of measurement and evaluation of results.

They have to be studied using the method of analysis of arising problems. Theoretical problems of milling, which are the subject of our research, were presented by Lisičan in 1996 and the actual measurements carried out in 2002 were published by Kolařík in 2003. This paper is a follow-up of the evaluation of tests of high-speed machining of wood and measurements and evaluation of dissipated power and aerodynamic resistances published by Rousek and Kolařík in 2004. The aim of these papers is to show that the used method of sensing and assessing parameters leads to the achievement of consistent results even in repeated trials.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

The measuring stand is devised for surface milling of machined wood under continuously changeable speed of the cutting tool and continuously changeable feed speed of a workpiece independently from each other and thus setting an arbitrarily large draught per a tooth. It refers to the trial prototype of a CNC machine for high-speed milling of wood.

The measuring stand (Fig. 2) consists of a basic supporting part, ie a stand. Construction changes were also carried out of the stand, for example, the replacement of the main engine of 5.5 kW by a 12 kW engine. The speed of the drive unit can be continuously changed in the whole range of engine speed (4000 - 14 200 rpm). The transmission of torque between the drive unit and the milling cutter shaft is carried out by a belt transmission 1:1. The shaft and the drive unit are placed on a support, which is continuously vertically adjustable by means of a separate servo-motor. The stand also consists of a fixed table designed for the movement of the workpiece. On the upper part of the stand, three groups of feed rollers are placed. Each group of rollers has got a separate drive unit and the units are mutually synchronized. Two groups of feed rollers are placed in front of the shaft (front rollers) and one group is behind the shaft (back rollers). Back rollers are rubberized so as not to damage the machined surfaces during milling. The pressure of feed rollers is implemented through a pneumatic device of Festo Co. The units can continuously change feed speeds ranging between $v_f = 4$ and 100 m·min^{-1} by means of a frequency converter of Lenze Co.

The stand is operated from a control board (Fig. 3) installed on a swinging arm of the machine. Unit control buttons used to switch on/off drive units, rotary potentiometers used to set their speed, central STOP button and a touch display used for entering all necessary data (tool, workpiece, machine setting) are placed on the control board.

Various dimensions of cylindrical milling heads of two types of tools differing also by their position on the shaft are used for the experiments (Fig. 4):

- milling cutter A, 161 mm in diameter, 60 mm in width, four knives KARNED (Fig. 4 a),
- milling cutter, B 124.5 mm in diameter, 130 mm in width, 6 knives PILANA (Fig. 4 b).

Problems were studied of the measurement and evaluation of dissipated power and aerodynamic resistance using a point method followed by the measure-

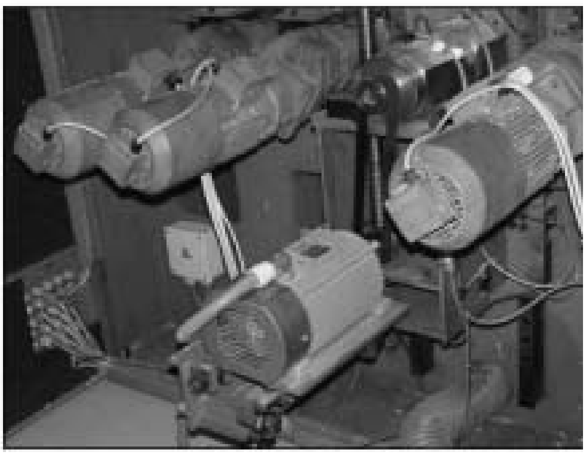


Figure 2 Drive units and machining space of the experimental stand
Slika 2. Pogonski motori i prostor za obradu na eksperimentalnom stroju

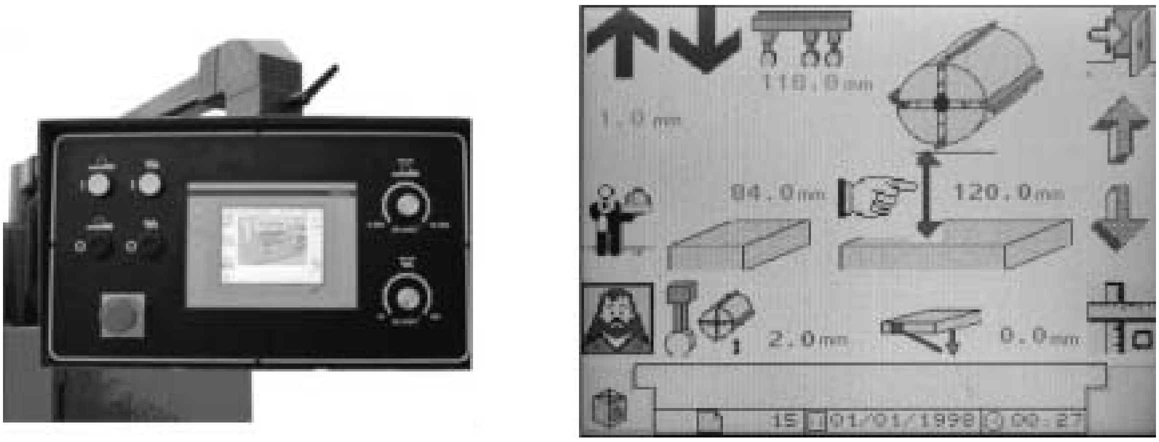


Figure 3 Main control board and a detail of the touch display
Slika 3. Glavna kontrolna ploča i detalj *touchscreen* sučelja

a) Milling cutter A b) Milling cutter B
a) glava za blanjanje A b) glava za blanjanje B

Figure 4 Milling cutters used
Figure 4. Glave za blanjanje upotrebljavane u istraživanju

ment of cutting resistance using a continuous method and then the problem was studied of repeated measurements and their resolution. The basic problem is to show the effects of resistances under conditions of variable power in the main stand engine and comparison of resistance properties under conditions when drive units use engines of both powers.

2.1 Dissipated power and aerodynamic resistance
2.1. Gubitak snage i aerodinamični otpor

Dissipated power was first measured in a dismantled milling cutter and dismantled spindle used for mounting the cutter. In measuring the dissipated power and aerodynamic resistance (generally stable processes) of particular tools, values were visually read from the stand display after reaching the required speed and stabilization.

The dissipated power is the power of an engine used to overcome various resistances (in bearings, belt transmission losses), which are different for every machine and very probably affected by the engine speed. Aerodynamic resistance is the resistance of air counteracting the tool rotation being particularly affected by the tool speed and its geometry. The dissipated power

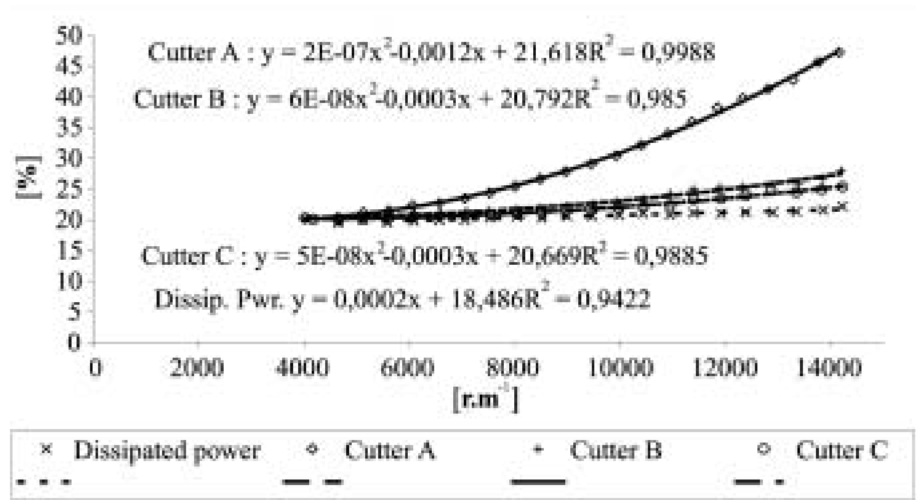
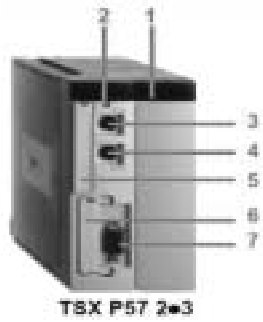


Figure 5 Comparison of the dissipated power and aerodynamic resistances in milling cutters A and B, 12 kW engine
Slika 5. Usporedba gubitka snage i aerodinamičnog otpora noževa za blanjanje A i B; motor snage 12 kW



Modicon description - *Opis Modicona*:
1. LED diode board (*ploča s LED diodama*)
2. Reset button (*tipka za resetiranje*)
3. Connector for data output / PC connection (*konektor za izlaz podataka / veza za računalo*))
4. Connector for data input (*konektor za unos podataka)*
5. Position for an expansion memory card (*mjesto za dodatnu memorijsku karticu*)
6. Position for a special card (*pozicija za posebnu karticu*)
7. Special connector for data output (*specijalni konektor za izlaz podataka*)

Figure 6 Modicon control unit
Slika 6. Kontrolna jedinica Modicon

increases proportionally with the tool speed and the growth rate of aerodynamic resistances is significantly higher than the growth of dissipated power as shown in Fig. 5. After determining the dissipated power and aerodynamic resistances, it is possible to determine more exactly how much power was actually consumed to overcome the cutting resistances in milling.

2.2 Measurement of cutting resistances – measurement and control system of the stand
2.2. Mjerenje otpora rezanja – mjerenje i sustav kontrole eksperimenta

The measurement of cutting resistances is a dynamic process and, therefore, values and records were determined in the control unit memory. Rotation speed and power input of the main drive unit and of feed rollers are read by electronic sensors and recorded in the strand memory (sampling 10 ms, time of sensing 15 s). For the machine control and data management, Modicon TSX P57-203 control system is installed in the stand with a separate processor and possibilities of extension of Schneider-Electric Co. (Fig. 6). As the stand memory shows low capacity it is always necessary to transfer data to a PC (where the data are backed up) after two measurements.

The measured data are transferred through the LPT interface and stored in the processor code format. For further processing, it was necessary to transform them by a single-purpose conversion program "Modicon to Excel Converter" and then to adapt them to a table form, e.g. in Excel.

For all measurements, 1 mm chip draught was used in setting the milling parameters. Further on, an example is given of the experimental milling on a trial stand using a milling cutter with six knives of a diameter of D = 125 mm. Spruce sawn timber was milled with the moisture content w = 10 % , 60 mm wide and 2000 mm long.

Test parameters were set as follows:

- tool speed n = 10 300 rpm
- height of the milled layer a_e = 1 mm
- feed speed v_f = 40, 36, 32, 24 and 16 m·min^{-1}

2.3 Determination of the measurement reproducibility
2.3. Određivanje ponovljivosti mjerenja

Within test measurements, the problem was elaborated of the measurement reproducibility and its resolution in milling two pieces of spruce wood of the same length, width and unified parameters of moisture, temperature and cutter knives sharpness. Differences between SM1 and SM2 samples were given by the occurrence of knots in SM1 sample. The aim was to show the possibility of the mesuring method to record changes in cutting resistances when running against knots and also to achieve consistent results in repeated experiments. Gradually, six layers were milled and data were processed and presented in diagrams according to methods described by Kolektiv, 2003; Kolařík, 2003; Rousek – Kolařík, 2004.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

Within the measurement of aerodynamic resistances, the relationship was shown between the quickly growing power requirement and increasing rotation speed, both significantly affected by the geometrical structure of tools.

To compare data obtained at various feed speeds, it was necessary to determine a suitable parameter for graphical comparisons. The machined board length proved to be a suitable parameter (Fig. 7).

The problem of the measurement process stabilization lies in the increasing feed speed. In the feed speed v_f= 16 m·min^{-1}, a curve stabilizes at the value I = 8.7 A. In higher feed speeds, the curve is not stabilized and in feed speeds 36 and 40 m·min^{-1}, current peaks are very probably truncated at a value of I = 10.4 A. For feed speeds exceeding 16 m·min^{-1}, it is necessary to use longer sawn timber to stabilize the process of milling. Drawbacks mentioned above were removed after the installation of a 12 kW motor.

To determine the reproducibility of measurements, 2 pieces of spruce wood were used for the experiment (hereafter SM1 a SM2) showing virtually identical properties. In SM1, a knot appeared in the milling zone (see Fig. 8).

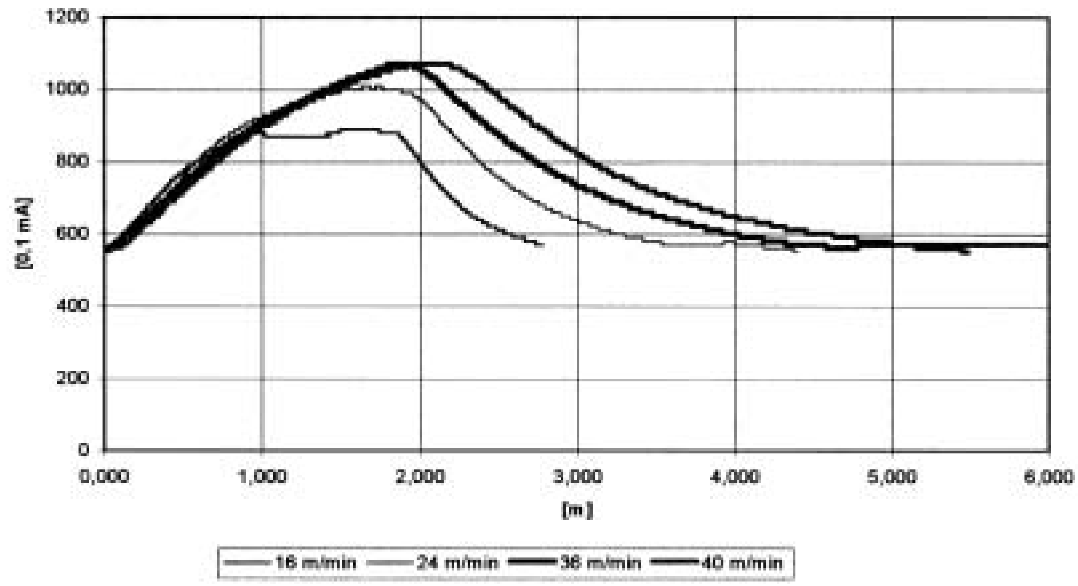


Figure 7 Comparison of various feed speeds at 10 300 rpm in milling spruce (engine 5.5 kW)
Slika 7. Utjecaj posmične brzine na mjereni napon pri piljenju smreke uz frekvenciju vrtnje alata od 10 300 okr./min (snaga motora 5,5 kW)

As an example, a diagram is presented of measurements with a knot. In each of the diagrams, six courses are plotted of the dependence of the main engine power consumption on time not giving the time sequence of specific measurements.

Based on the results obtained, it is evident that the used method of measurement and evaluation of milling parameters gives consistent results, the variance of values not exceeding ±10 % in SM1 and in SM 2, the variance is ± 5 %, which deemed good enough from the viewpoint of obtaining sufficiently accurate data. Even the changes in wood structure, specifically the appearance of knots, do not have a considerable effect on the parameters of milling (increase in power consumption ranging between 2.5 and 3 s).

4 CONCLUSION
4. ZAKLJUČAK

The objective of the authors was to inform professional public on results obtained in the study of high-speed milling of wood. These results show a realtively good quality of the method for recording and evaluating the parameters of study. It has been shown that the developed measuring system and methods are suitable for the research.

It has been proved that in high-speed milling a marked increase occurs in aerodynamic resistances with the increase of rotation speed. This can be a limiting factor for power consumption required in high-speed machining. It has been shown that, in addition to tool geometry and rotation speed, the construction design and manner of installation of the tool also affect aerodynamic resistances.

In the field of measurement of the cutting resistance in milling, measurements have been developed for 5.5 and 12 kW engines and a procedure has been prepared for faster conversion of data expressed in amperes to data expressed in kW. This provides the possibility to compare experimental results with theoretically calculated results according to technological/statistical methods, volume and analytical methods and methods of table force.

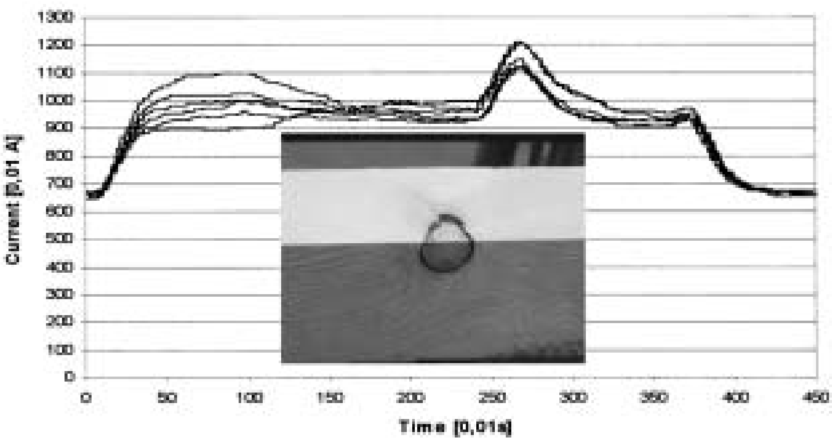


Figure 8 Diagram showing comparison of the main motor loads in milling the SM1 sample with knot
Slika 8. Opterećenje glavnog motora pri blanjanju uzorka SM1 s kvrgom

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