Zdeněk Kopecký, Miroslav Rousek[1]

Determination of cutting forces in cutting wood materials*

Određivanje sila rezanja pri obradi drvnih materijala*

Stručni rad • Professional paper
Prispjelo - received: 29. 9. 2005. • Prihvaćeno - accepted: 25. 4. 2006.
*UDK: 630*822.02; 630*822.332.4*

ABSTRACT • *The paper gives information on a part of research and educational orientation of the Department of Forest and Forest Products Technology, Mendel University of Agriculture and Forestry in Brno. The design and measuring device of a "cutting stand" are presented. After the stand modernization, the quality of torque measurement was considerably increased by use of a HBM T34 tensometric sensor equipped with a data logger. Results obtained show a very good sensitivity of the measuring device for cutting solid wood and agglomerated materials.*

Keywords: *measuring stand, wood agglomerated materials, cutting, circular saw blade*

SAŽETAK • *Rad informira o istraživačkoj i obrazovnoj orijentaciji Odjela za šumarstvo i tehnologiju šumskih proizvoda Mendelova sveučilišta poljoprivrede i šumarstva u Brnu. U njemu se opisuje stroj na kojemu se obavljaju mjerenja te mjerni uređaji koji se upotrebljavaju za mjerenja. Nakon modernizacije stroja i mjernih uređaja kvaliteta mjerenja momenta znatno se povećala uporabom tenzometričkog senzora HBM T34 opremljenoga snimačem podataka. Dobiveni rezultati pokazuju vrlo dobru osjetljivost mjernog uređaja pri mjerenju sila rezanja tijekom obrade cjelovitog drva i materijala na bazi drva.*

Ključne riječi: *stroj i mjerna oprema, materijali na bazi drva, rezanje, kružna pila*

1 INTRODUCTION
1. UVOD

Within a research plan and educational training conducted by our Department, a stand for cutting solid wood and agglomerated materials has been modernized recently (Fig. 1). In educational training, the stand is particularly used in subjects "Construction of Machines and Devices" and "Theory of Machining", where students are acquainted with the stand design and used measuring equipment. Moreover, within laboratory training in the course "Theory of Machining", they can verify theoretical calculation methods for determining cutting forces and resistances. At present, it is also possible to use the stand for carrying out researches related to determining and comparing cutting forces in cutting agglomerated materials.

The results obtained can help in dimensioning the machine and tool equipment of dimension saws and at the same time, in optimizing technological conditions of machining in order to prevent unnecessarily high energy consumption and damage to machines and tools. The

[1]Authors are assistant and assistant professor at Department of Forestry and Forest Product Technology, Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry in Brno, Czech Republic
[1]Autori su asistent i docent na odsjeku za šumarstvo i Tehnologiju šumskih proizvoda, Fakultet šumarstva i drvne tehnologije, Mendelovo poljoprivredno i šumarsko sveučilište u Brnu, Češka.
* Rad je pripremljen za sastanak Interkatedra 2005 „Woodworking technique"
* The paper was prepared for meeting Interkatedra 2005 „Woodworking technique"

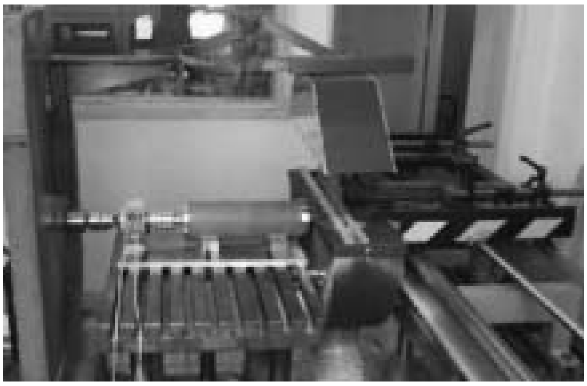


Figure 1 General view of the stand in the Department laboratory
Slika 1. Prikaz stroja s mjernom opremom u laboratoriju Odjela

aim of this paper is to give information on stand possibilities and to present part of our research in the field of cutting solid wood and agglomerated materials.

The stand is equipped with the sensor of torque and rotation speed on the saw shaft and with the sensor of feed force on a carriage for feeding the material to be cut. The measured values were recorded by a data logger Spider 8 and evaluated by use of the Conmes Spider program in the form of diagrams.

2 EXPERIMENTAL STAND, MATERIAL AND TOOLS
2. STROJ ZA PROVOĐENJE MJERENJA, MATERIJALI I ALATI

The diagram of the stand and the measuring chain are shown in Figure 2. The experimental device enables continuous change of the circular sawblade speed and feed of the material to be cut. The saw spindle is driven by the dynamometer DC motor, whose rotation speed is continuously changed by the Leonard machine set in a range of 0 to 11 500 rpm with a maximum torque of $M_{k\,max}$ = 14 Nm. The movement of the track carriage to fix a workpiece is carried out by means of a ball screw driven by an asynchronous electric motor with a frequency converter FC. Thus, the feed speed v_f can be changed in a range of 3 to 5 m·min^{-1}.

The circular sawblade rotation speed and torque are measured by a contactless sensor T34 FN – HBM, and the force for feeding a workpiece is determined tensometricly by a S2 –HBM sensor. Sensor signals are processed by a Spider 8 data logger (Fig. 3) and then transferred to a computer and presented in the form of diagrams by use of the Conmes Spider program.

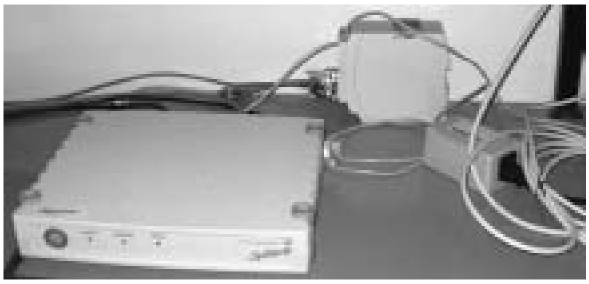


Figure 3 Spider 8 data logger
Slika 3. Snimač podataka Spider 8

2.1 Material
2.1. Materijal

Within this research, more extensive and accurate measurements and evaluations were carried out of torque, power and feed forces in various types of solid wood and agglomerated materials, some of which are presented in the paper:

The following materials were processed:

Spruce sawn wood
(*smrekovina*) h = 18 mm, L = 1 m, w = 15 %
Beech sawn wood
(*bukovina*) h = 18 mm, L = 1 m, w = 8 %
Laminated particleboard, standard quality
(*laminirana iverica standardne kvalitete*)
h = 18 mm, L = 1 m, w = 7 %
Untreated particleboard
(*neobrađena iverica*) h = 18 mm, L = 1 m, w = 7 %
Seven-ply plywood sheet
(*sedmoslojna šperploča*) h = 18 mm, L= 1 m, w = 7 %
OSB board (*OSB ploča*) h = 18 mm, L = 1 m, w = 7 %
HOBRA fibreboard
(*HOBRA vlaknatica*) h = 15 mm, L = 1 m, w = 7 %
Five-ply plywood sheet
(*peteroslojna šperploča*) h = 17 mm, L = 1 m, w = 7 %

Where: h – cutting height (*visina rezanja*), L – cutting length (*dužina rezanja*), w – moisture (*sadržaj vode*)

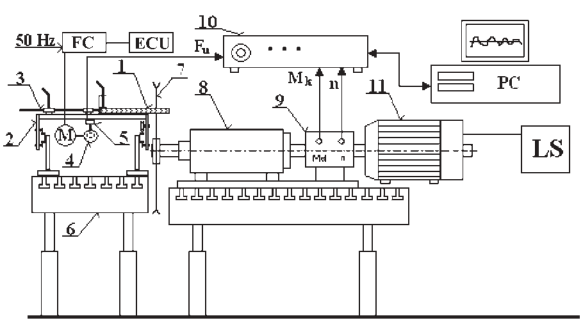


Figure 2 Experimental device arrangement
Slika 2. Shema stroja i mjernih lanaca

1 – material, 2 – carriage, 3 - clamping the material, 4 - ball screw , 5 - sensor of S2 force –HBM, 6 - grate table, 7 - circular sawblade, 8 – spindle, 9 - sensor of torque and rotation speed T34 FN - HBM, 10 – data logger Spider 8, 11 – dynamometer DC, FC - frequency converter, ECU - electronic control unit, PC – personal computer, LS - Leonard machine set

1 - materijal, 2 - kolica, 3- pričvršćenje materijala, 4 - kuglični vijak, 5 - senzor sile S2 –HBM, 6 - rešetka, 7 – kružna pila, 8 – vreteno, 9 – senzor momenta i brzine rotacije T34 FN – HBM, 10 – snimač podataka Spider 8, 11 – dinamometar DC, FC – frekvencijski konverter, ECU – elektronička kontrolna jedinica, PC – osobno računalo, LS – Leonardov set za stroj

2.2 Tools
2.2. Alati

A. A standard circular sawblade with HW cutting tips (Pilana 22 5380 – 40 FZ)

Figure 4 Sawblades “A”
Slika 4. List pile “A”

Diameter D = 350 mm
Saw kerf thickness s = 3.6 mm
Number of teeth z = 28
Maximum height of cut h_{max} = 150 mm
Cutting-edge:
- side rack γ = 20°
- sharpness angle β = 50°
- clearance angle α = 20°
- cutting angle δ = 70°
- edge radius ρ = 0.02 mm.

B. A circular sawblade with HW cutting tips for cutting agglomerated materials by precutting (Pilana 22 53 97 – 11 TFZ L)
Diameter D = 350 mm
Saw kerf thickness s = 3.6 mm
Number of teeth z = 108
Maximum height of cut h = 150 mm

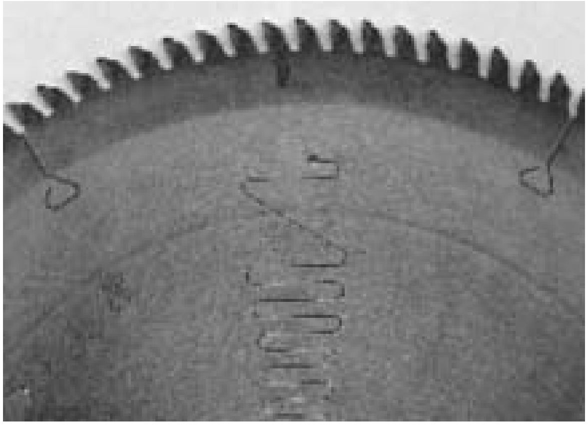


Figure 5 Sawblades “B”
Slika 5. List pile “B”

Cutting-edge:
- side rack γ = 5°
- sharpness angle β = 75°
- clearance angle α = 10°
- cutting angle δ = 80°
- edge radius ρ = 0.02 mm.

3 METHODS
3. METODE

The measurement was carried out under standard cutting conditions. The rotation speed of both types of saws was set to n = 3500 rpm. It corresponded to the cutting speed v_c = 64 m·s^{-1}. The rate of the workpiece feed was set by the frequency converter to v_f = 5 m·min^{-1}. Each cutting was repeated several times. Theoretical shift per saw tooth for sawblade A: f_z = 0.24 mm per tooth, for sawblade B: f_z = 0.014 mm per tooth. The moment of torsion M (Nm) and rotation speed n (rpm) and feed force F_u (N) were measured quantitatively. The configuration for measurement (beech – BK, n = 3500 rpm) is shown in Fig. 6.

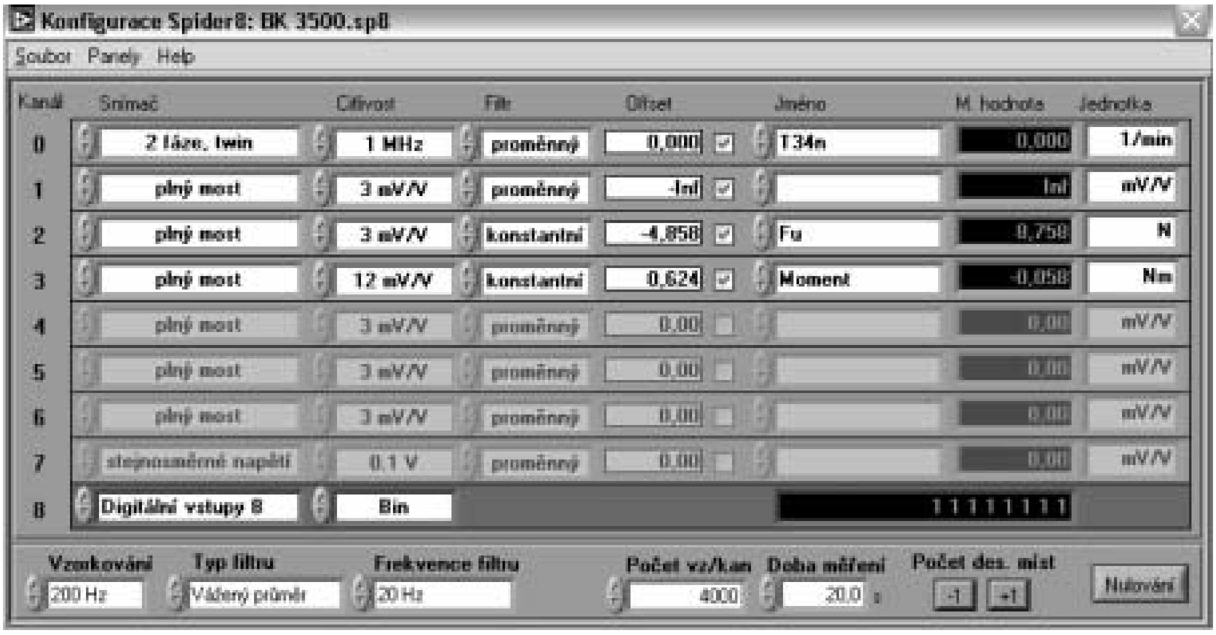


Figure 6 Spider 8 measurement configuration
Slika 6. Konfiguracija mjerenja na Spideru 8

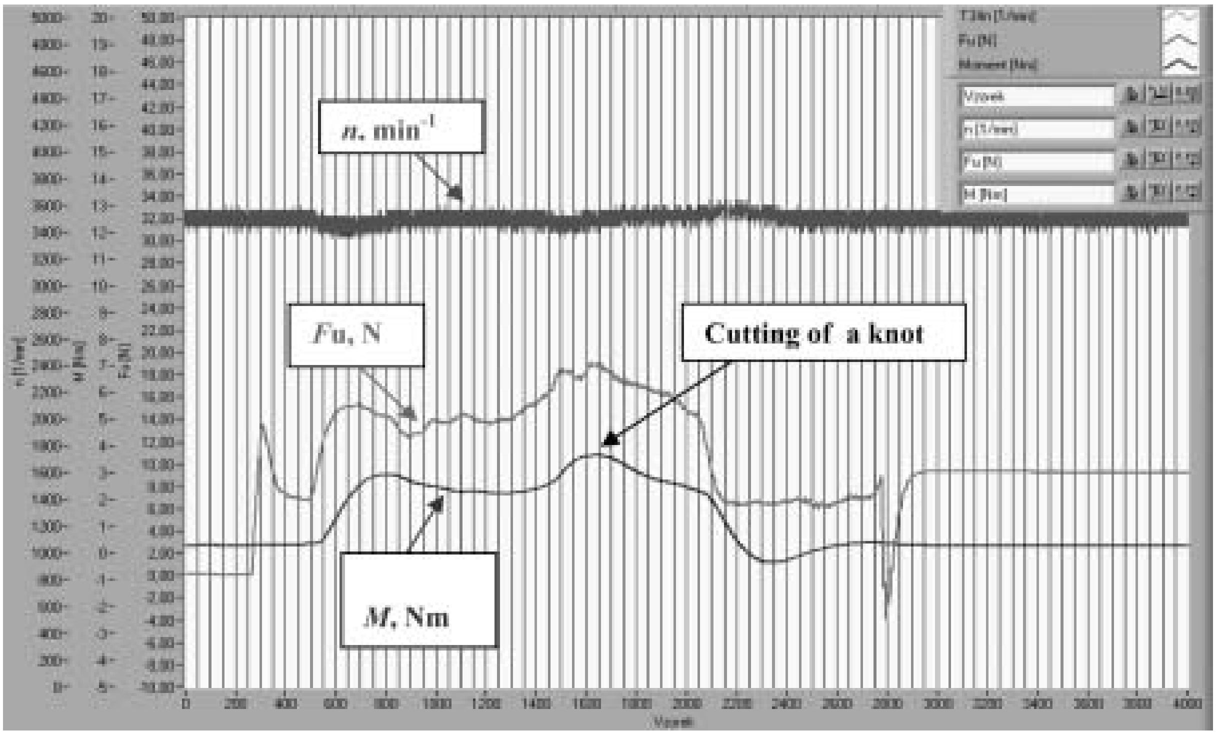


Figure 7 Measured sensitivity of testing parameters in cutting spruce
Slika 7. Osjetljivost mjerenja ispitnih parametara pri rezanju smrekovine

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

Our study was primarily aimed at verifying the measuring device sensitivity, which is documented by results in cutting solid wood, see Figure 7.

The sensitivity of the measuring device was tested by the measurement of dynamic processes in cutting spruce sawn wood including knots. Figure 7 shows the graphical record of the measurement of rotation speed n, moment M and feed force F_u in relation to the number of samples in ripping spruce lumber by a circular sawblade "A".

Dynamically changing parameters were sampled at a frequency of f = 200 Hz, which amounted to 4000 samples at the time of measurement of 20 seconds (Fig. 6). The course of the moment M curve shows an increase in the interval of measurement (samples 550 to 750) which indicates the start of cutting, ie the cutting tool penetration into the material. The moment reaches the value of 2.7 Nm there. In the range between 1000 and 1400 samples, the stabilized process of cutting occurs with a moment of 2.1 Nm (free of passive and aerodynamic resistances). The range of between 1650 and 1700 samples showed the presence of cutting knots where the moment value increased to 3.5 Nm. In another part roughly about 2050 samples, the moment returns to the value of 2.1 Nm for a short time and then up to the sample 2350 decreases to a value of -0.4 Nm which can be interpreted by the circular sawblade inertia in leaving the tool from the material and finishing the cutting.

Comparison of the measured results was carried out by theoretical calculations, see Table1. The survey mentioned above shows that the "Volume Method" gives the closest results to the experimental results, and it is followed by the "Technological-Statistical Method". However, if all four methods are taken as approximate methods with respect to the selection of various tabulated values fluctuating about a mean value, then the obtained result can be considered as a relatively good result.

The second aim of this study was to compare the cutting forces in cutting agglomerated materials. As an example, the direction is given of the moment M and the feed force F_u in cutting laminated particleboard by a circular sawblade "B" (see Fig. 8). Determination of mean values of the moment of torsion M and feed force F_u was carried out in the area of the stabilized process of cutting.

Moments on the saw spindle required for cutting the selected agglomerated materials are shown in Figure 9. The highest moment was achieved in cutting an OSB board using a circular sawblade "B". In using the circular sawblade "A", the moment was by 25 % lower. From the viewpoint of energy, the fact was favourable and however from the viewpoint of the cutting surface quality, the situation was unfavourable. During the visual inspection of the cutting surface quality, fibres were torn up on the lower side of the board. It was partly caused by the absence of pre-cutting teeth in the circular sawblade "A", which are usual in sawblades for agglomerated materials, and by high value of draft per tooth.

Figure 10 shows the relative comparison between cutting forces of circular sawblades "A" and "B". The lowest relative increase of the cutting force was recorded in an OSB board (25%) while the highest one was recorded in a five-ply plywood sheet (44%).

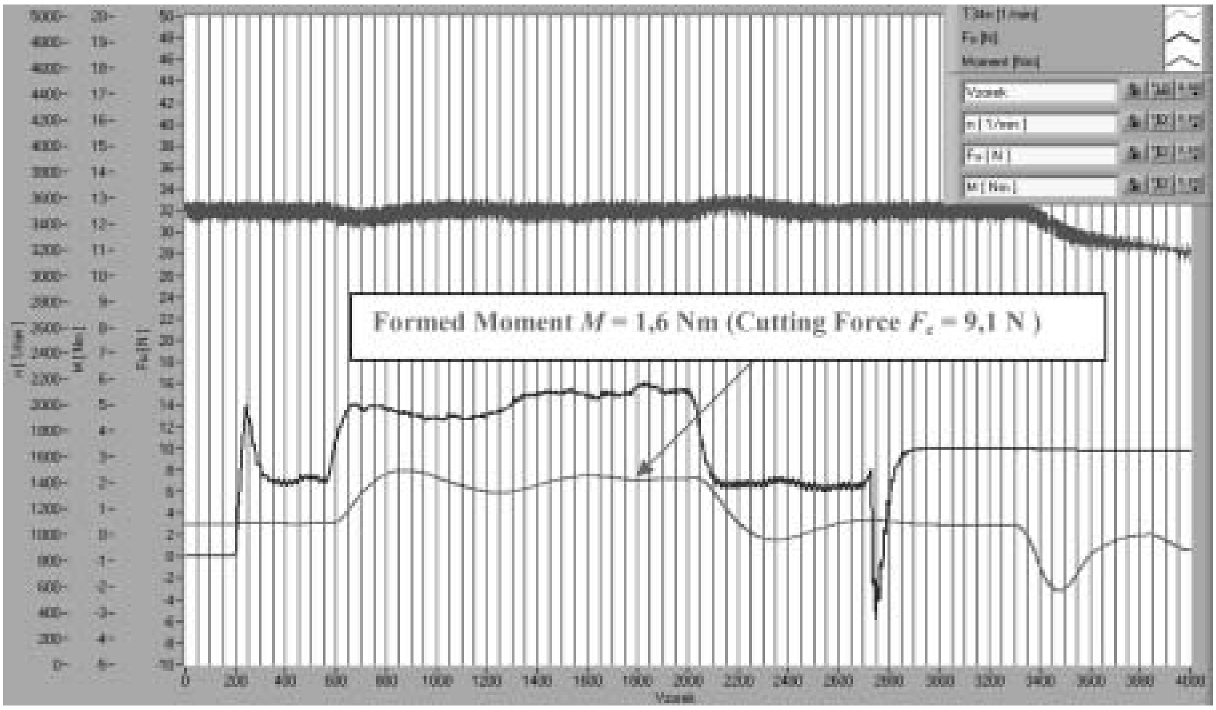
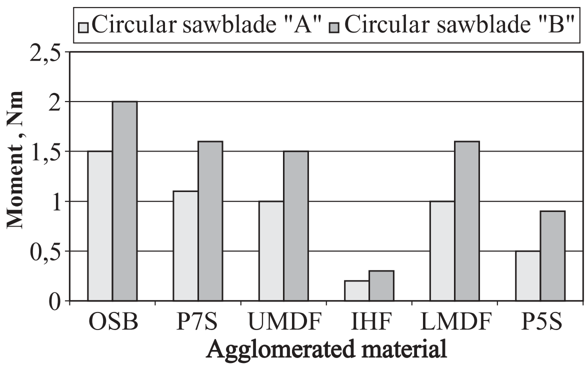


Figure 8 Graphical output of Conmes Spider program, laminated particleboard – circular sawblade "B"
Slika 8. Grafički izlaz programa Conmes Spider, laminirana iverica – kružna pila B



1 – OSB Oriented Strand Board, 2 – P7S Foliated Water-resistant Seven-ply Plywood Sheet, 3 – UMDF Untreated Medium Density Board, 4 – IFH Insulation Fibreboard Hobra, 5 – LMDF Laminated Medium Density Board, 6 – P5S Five-ply Plywood Sheet

1 – OSB ploča s orijentiranim iverjem, 2 – P7S vodootporna sedmeroslojna šperploča s folijom, 3 – UMDF neobrađena ploča srednje gustoće, 4 - IFH izolacijska vlaknatica Hobra, 5 – LMDF laminirana ploča srednje gustoće, 6 – P5S peteroslojna šperploča

Figure 9 Comparison of parameters for cutting agglomerated materials
Slika 9. Usporedba momenata rezanja materijala na bazi drva

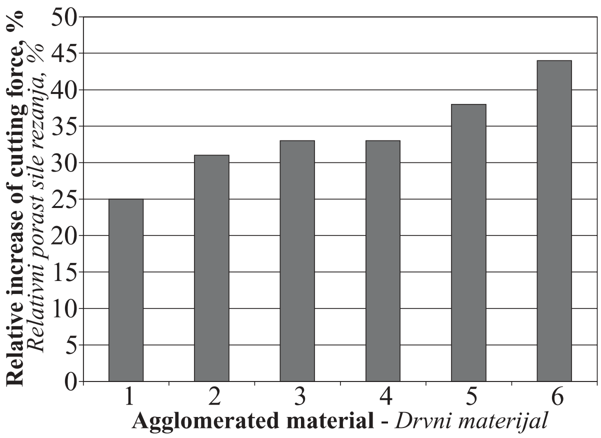


Figure 10 Relative comparison of a cutting force
Slika 10. Relativna usporedba sila rezanja

5 CONCLUSION
5. ZAKLJUČAK

After having completed the experiment and compared the diagrams showing parameters of the moment and cutting force it can be concluded that the obtained results indicate that the sensitivity of the measuring device was very good. In cutting agglomerated materials, there is an evident harmony between measured curves of all types of materials and only in cutting HOBRA fibreboards the curve of parameters is different.

Moreover, it has also been established:

- the measured results are not quite comparable in view of setting various values of draft per tooth, which will be taken into consideration in further experiments,
- measurements can be carried out resulting in the determination of coefficients for the use of theoretical calculation methods (e.g. volume method and the method of table force),
- graphical outputs from a dynamometer make it possible to read the value of the moment consumed to overcome passive moments of tool mounting.

Table 1 Comparison between the experiment and theoretical calculations
Tablica 1. Usporedbe eksperimentalnih i teorijskih kalkulacija

Theoretical calculations *Teorijska kalkulacija*		
Cutting power *snaga rezanja*	Volume method *volumna metoda*	P_c = 780.5 W
	Analytical method *analitička metoda*	P_c = 558.4 W
	Technological-statistical method *tehnološko-statistička metoda*	P_c = 675.1 W
	Table force method *metoda tablice sila*	P_c = 586.5 W
Experimental measurement and calculation *Eksperimentalno mjerenje i kalkulacija*		
Cutting power *snaga rezanja*	$P_c = M \cdot \omega$ = 769.6 W	

6 REFERENCES
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Acknowledgment:

This paper was prepared in relation with a partial project within the MŠM 6215648902 research plan. Authors highly acknowledge the financial support of the project.

Corresponding address:

Dr. ZDENĚK KOPECKÝ

Department of Forestry and Forest Product Technology
Faculty of Forestry and Wood Technology
Mendel University of Agriculture and Forestry in Brno
Zemědělská 3
613 00 Brno
CZECH REPUBLIC
e-mail: kopecky@mendelu.cz