Ľubomír Javorek[1], Richard Kminiak[2], Mária Vargovská[1], Etele Csanády[3], Szabolcs Németh[3]

Feed Cutting Force Component in Up and Down Sawing of Pine

Komponenta posmične sile rezanja pri istosmjernom i protusmjernom piljenju borovine

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 23. 2. 2022.
Accepted – prihvaćeno: 25. 4. 2022.
UDK: 630*82; 674.05
https://doi.org/10.5552/drvind.2022.0018

ABSTRACT • *The monitoring of cutting force components is one of the possibilities to control machining processes from the point of view of its stability, machine tool spindle or cutting tool loading. This paper presents and compares the results of experimental longitudinal sawing of pine wood with 4 saw discs with different teeth number (16 and 24) and rake angle (10° and 20°) during up (conventional) and down (climb) cutting with different revolutions (4000 min^{-1}, 5000 min^{-1}, 6000 min^{-1}) and feed speed (15 m/min, 20 m/min, 25 m/min). The signal was obtained from Quart 3-components piezoelectric dynamometer.*

KEYWORDS: *pine wood; sawing; feed speed; rake angle; teeth number; feed force*

SAŽETAK • *Praćenje komponenata sile rezanja jedna je od mogućnosti kontrole procesa obrade drva sa stajališta stabilnosti alata te opterećenja osovine ili oštrice alata. U radu su prikazani rezultati istraživanja eksperimentalnoga uzdužnog piljenja borovine pilom s četiri lista i različitim brojem zuba (16 i 24) te pod različitim prsnim kutom (10° i 20°) tijekom protusmjernoga (konvencionalnog) i istosmjernog rezanja, uz različit broj okretaja osovine alata (4000 min^{-1}, 5000 min^{-1}, 6000 min^{-1}) i tri posmične brzine (15 m/min, 20 m/min, 25 m/min). Signal je dobiven uz pomoć Quart 3-komponentnoga piezoelektričnog dinamometra.*

KLJUČNE RIJEČI: *borovina; piljenje; posmična brzina; prsni kut; broj zuba; posmična sila*

1 INTRODUCTION
1. UVOD

Circular sawing is one of the most advanced technologies in woodworking industry. Saw discs (blades) are designed as universal rip saw blades for longitudinal or transversal cutting or trimming of all types of wood, soft or hard, dry or wet. Saw discs are used in single or multi-rip saw tools with single or double shaft or in splitting machines. Circular sawing has been in the focus of many researchers due to its widespread application.

[1] Authors are researchers at Department of Manufacturing and Automation Technology, Faculty of Technology, Technical University in Zvolen, Zvolen, Slovak Republic.
[2] Author is researcher at Department of Woodworking, Faculty of Wood Technology, Technical University in Zvolen, Zvolen, Slovak Republic.
[3] Authors are researchers at Institute of Wood Industry and Technology, Faculty of Wood Engineering and Creative Industrie, University of Sopron, Sopron, Hungary.

Table 1 Mechanical properties of Swiss stone pine (*Pinus cembra* L) (Klement *et al*., 2011)
Tablica 1. Mehanička svojstva drva švicarskog bora (*Pinus cembra* L) (Klement *et al*., 2011.)

Properties *Svojstvo*	**Parallel with grain** *Paralelno s vlakancima*		**Perpendicular to grain** *Okomito na vlakanca*	
	w = 12 %	*w* > 30 %	*w* = 12 %	*w* > 30 %
Tensile strength, MPa / *Vlačna čvrstoća,* MPa	104		3	2.4
Compression strength. MPa / *Tlačna čvrstoća,* MPa	45	21	4.0	
Shearing strength, MPa / *Čvrstoća na smicanje,* MPa	11.3	5.9		
Bending strength, MPa / *Čvrstoća na savijanje,* MPa	83	44		
Modulus of elasticity, MPa / *Modul elastičnosti,* MPa	11 700		430	
Toughness J/cm^2 / *Žilavost,* J/cm^2			4.12	3.63
Brinell hardness, MPa / *Tvrdoća prema Brinellu, MPa*	40			
Janko hardness*, MPa / *Tvrdoća prema Janki,* MPa	30		25.8	19.6

Cutting forces are very important variables in machining performance; they affect surface roughness, tool life, energy consumption.

The process of material removing was studied from the beginning of machining; the studies are related to detachment of chips, shear angle, friction angle, grain orientation (Piispanen, 1948; Kivimaa, 1950; Fischer, 1979; Teng *et al*., 2014:). The research is also oriented on the influence of mechanical and physical properties or moisture content of the machined material on power consumption (Beer, 2002; Lučić *et al.,* 2004; Dange *et al.,* 2011; Nasir and Cool, 2018). Consumption of energy depends on the type of machined material. The medium density fibreboard was researched by Aquilera (2011), oak and Douglas fir by Goli and Porankiewicz (2014), beech and spruce were researched in the experiments of Aguilera and Martin (2001). The value of cutting moment or force components received from machining can be used for comparing different models of machining (Kivimaa, 1950; Orlowski *et al.*, 2013; Orlowski *et al.,* 2017; Hlaskova *et al.*, 2019). The influence of technological factors on the main cutting force or its components or power parameters is analysed very often in the scientific papers (Ioras *et al.,* 2002; Naylor *et al.,* 2012; Palubicki, 2021).

For measuring cutting power, consumption energy or cutting forces were determined by different experimental stands and methods. The pendulum dynamic tester was used (Dange *et al.,* 2011) for studying energy consumption and cutting forces during orthogonal cutting with two blades, sharpened at 30° and 45°. Cutting velocity in the range between cca 2.3 m/s to 7.3 m/s was used. The experimental device with long arm (535 mm) rotated in vertical plane was used for monitoring and evaluation semi-orthogonal cutting and for designating multi-factors and dependency between tangential and normal force (Porankiewicz *et al.*, 2011; Porankiewicz and Goli, 2014). On the other hand, measurement of cutting power and then calculation of the main cutting (tangential) force from electrical cutting power is used very often (Kopecky and Rousek, 2005). Another way how to reduce energy consumption is to reduce the friction between saw disc body and workpiece (Fekiač *et al.*, 2022).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Material of workpieces
2.1. Materijal uzoraka

The workpieces of nominal dimensions of 170 mm × 100 mm and 23 mm thickness were prepared and before sawing all samples were air-conditioned to the moisture content of 14 %. The properties of Swiss stone pine are presented in Table 1.

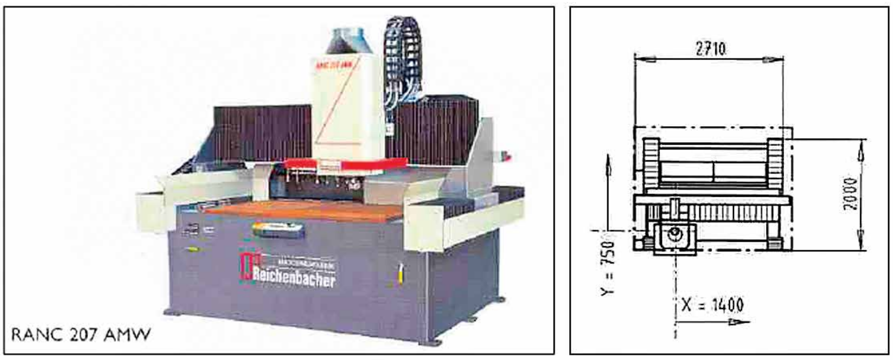

Figure 1 CNC machine tool Reichenbecher RANC 207 AMW (27)
Slika 1. CNC alatni stroj Reichenbecher RANC 207 AMW (27)

Figure 2 Saw discs 1, 2, 3, 4
Slika 2. Listovi pila 1, 2, 3 i 4

Table 2 Saw disc parameters
Tablica 2. Parametri listova pile

Saw disc *List pile*	**Dimensions, mm** *Dimenzije,* mm $D_1 \times d_3 \times a \times s_T$	**Teeth number** *Broj zuba*	**Body thickness** ***a*****, mm** *Debljina lista a,* mm	**Kerf width** s_T**, mm** *Širina propiljka* s_T, mm	**Tool cutting edge angle** k_r**, °** *Kut glavne oštrice* k_r, °	**Rake angle** γ**, °** *Prsni kut* γ, °	**Clearance** angle α, ° *Leđni kut* α, °
SD 1	190 × 30 × 1.8 × 2.6	16	1.8	2.6	90	10	12
SD 2	190 × 30 × 1.8 × 2.6	16	1.8	2.6	90	20	12
SD 3	190 × 30 × 1.8 × 2.6	24	1.8	2.6	90	20	12
SD 4	190 × 30 × 1.8 × 2.6	24	1.8	2.6	90	10	12

2.2 Machine tool
2.2. Alatni stroj

The vertical CNC router Reichenbecher RANC 207 AMW (Figure 1) was used for experiments. Machine tool is defined as training centre and assigned for the machining of small and plane parts. All experiments were carried out in the laboratory of the University of Sopron, in Hungary.

Technical specifications:
- one working spindle: 7.5 kW at 18 000 min^{-1};
- working feed rate: 20 m/min in *X*, *Y* axis;
- positioning speed up to 28 m/min;
- tool magazine: for 8 tools;
- fastening: SK30;
- working motion: *X*=1400 mm; *Y*=750 mm; *Z* = 250 mm;
- machine table: 1550 mm × 900 mm.

2.3 Woodworking tools
2.3. Alati za obradu drva

The Polish company GASS Suwalki (at present ASPI sp.o.o./s.k.) prepared 4 saw discs (Figure 2) for the experiment; parameters are given in Table 2. The tips of teeth of all discs were from tungsten carbide.

2.4 Technological conditions
2.4. Tehnološki uvjeti

The experiment was designed as full factorial experiment based on a model of a classical experiment plan, with three independent factors.

As input factors with influence on output characteristics, the following factors and their levels were determined:

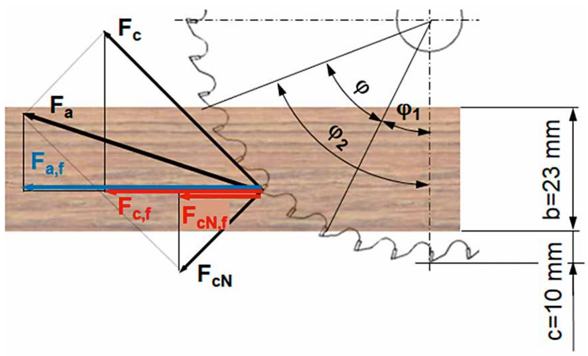

Figure 3 Execution of sawing experiment: *c* – saw projection up the workpiece; *b* – workpiece thickness; j_1 – saw enter angle; j_2 – saw exit angle; φ – saw cutting angle; F_a – active force and its projection $F_{a,f}$ to feed direction; F_c – cutting force and its projection $F_{c,f}$ to feed direction; F_{cN} – passive (thrust, deflecting) force and its projection $F_{cN,f}$ to feed direction
Slika 3. Parametri eksperimentalnog piljenja: *c* – istak pile iznad obratka; *b* – visina uzorka; j_1 – kut ulaska pile u zahvat; j_2 – kut izlaska pile iz zahvata; φ – kut zahvata; F_a – aktivna sila i njezina projekcija $F_{a,f}$ na pravac posmične brzine; F_c – sila rezanja i njezina projekcija $F_{c,f}$ na pravac posmične brzine; F_{cN} – odrivna sila i njezina projekcija $F_{cN,f}$ na pravac posmične brzine

- rotational speed (min^{-1}): 4000; 5000; 6000;
- feed speed (m/min): 15; 20; 25;
- up and down cutting.

The projection of saw disc up of workpiece: 10 mm.

Dependent (measured) factors were:
- feed force F_f (as sum of force $F_{c,f}$ and $F_{cN,f}$) measured in Y axis of measure platform;
- force F_{fN}, perpendicular to feed force measured in *X* axis of experimental platform (Figure 3).

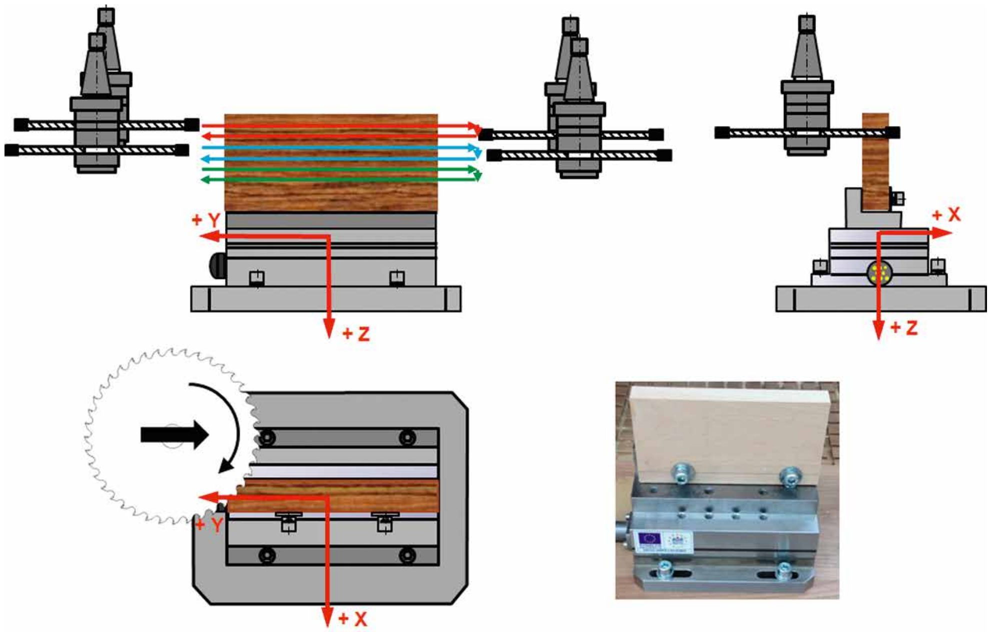

Figure 4 Saw disc position vs. workpiece
Slika 4. Položaj lista pile u odnosu prema obratku

2.5 Experimental device
2.5. Mjerna oprema

Piezoelectric measuring system (Figure 5) made by Kistler (Kistler Instrumente AG, Switzerland) was used for measuring the cutting force components. The basic parts of the system were:

1. Quart 3-components dynamometer 9275B (parameters see Table 3).
2. Multichannel Charge Amplifier 5070A.
3. A/D Converter – DAQ System 5657A1.
4. NTB + software DynoWare.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The components F_f and F_{fN} are the basis for determining the active force F_a. Figure 5 illustrates the orientation of force components F_f, F_{fN}, and final (active) force F_a based on the coordinate system of measure platform. This figure clearly shows that the feed force was positive for both types of cutting (down and up), but F_{fN} was in harmony with the positive coordinate axis of the platform for down cutting, while this component was negative for up cutting.

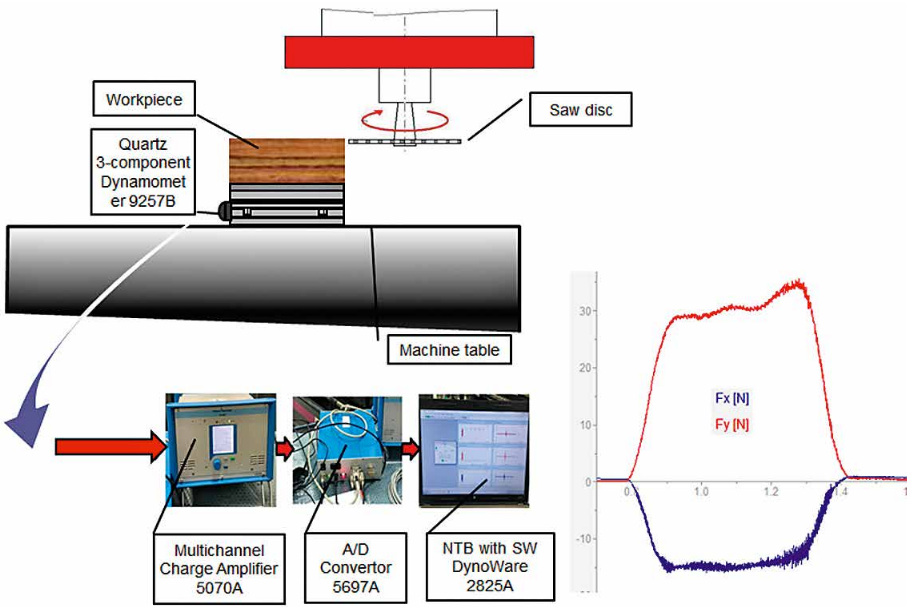

Figure 5 Measuring chain
Slika 5. Mjerni lanac

Table 3 Dynamometer type 9257A – chosen technical parameters
Tablica 3. Dinamometar tipa 9257A – odabrani tehnički parametri

Range force application / *Raspon sila*	F_x, F_y, F_z	kN	– 5 ... 5
Overload / *Preopterećenje* / F_x and $F_y \le 0{,}5\ F_z$	F_x, F_y, F_z	kN	–7,5 / 7,5
	F_z	kN	–7,5 / 15
Response threshold / *Granica odziva*		N	< 0,01
Sensitivity / *Osjetljivost*	F_x, F_y	pC/N	≈ –7,5
	F_z	pC/N	≈ –3,7
Linearity (all ranges) / *Linearnost (svi rasponi)*		% FSO	±1
Rigidity / *Krutost*	c_x, c_y	kN/µm	>1
	c_z	kN/µm	>2
Natural frequency / *Prirodne frekvencije*	$f_n\ (x, y, z)$	kHz	≈ 3,5
Operating temperature range / *Raspon radne temperature*		°C	0 …70
Temperature coefficient of sensitivity / *Temperaturni koeficijent osjetljivosti*		% / °C	– 0,02
Capacitance (of channel) / *Kapacitet (kanala)*		pF	220
Ground insulation / *Izolacija tla*		W	$>10^8$

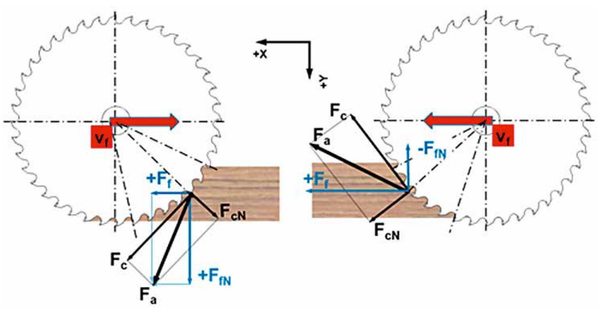

Figure 6 Force components orientation based on coordinate system of dynamometer: down (in feed direction) – up (against feed direction)
Slika 6. Orijentacija komponenata sile zbog koordinatnog sustava dinamometra: istosmjerno (u smjeru posmične brzine) – protusmjerno (suprotno smjeru posmične brzine)

The data processing for every saw disc and technological parameters (i.e. type of sawing, revolutions, number of teeth, rake angle and feed speed) was the basis for evaluating feed force. The graphs (Figure 7) clearly show that feed force was smaller during down sawing for all revolutions, feed speeds and both rake angles.

3.1 Influence of sawing type
3.1. Utjecaj vrste piljenja

Influence of sawing type (valid for SD1, z=16, γ=10°), Figure 7

A more detailed analysis of the values shows that the ratio between feed force during up sawing and feed force during down sawing oscillates within the range from 1.25 to 2.42 (Table 4 or Figure 7).

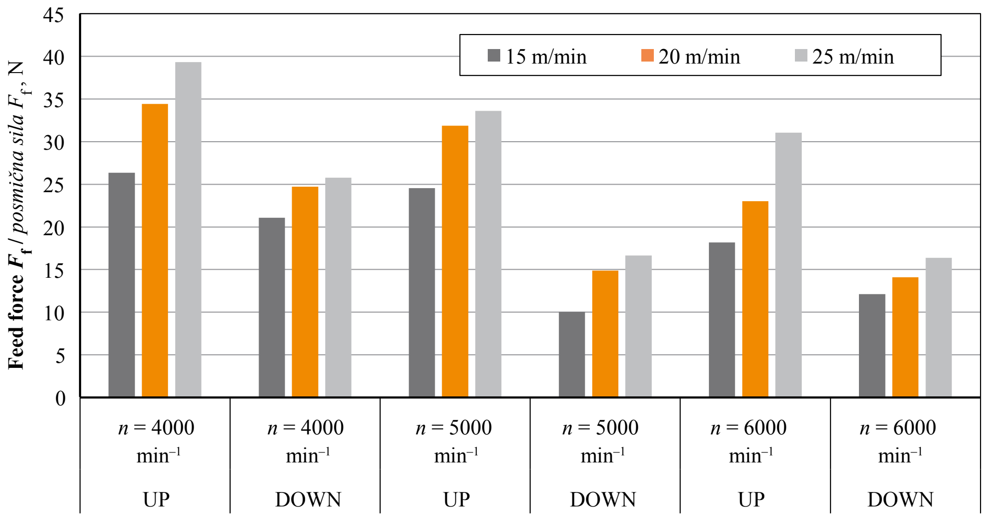

Figure 7 Influence of feed speed v_f, revolutions n and type of cutting to feed force F_f (SD1; z = 16; γ = 10°); pine wood
Slika 7. Utjecaj posmične brzine v_f, frekvencije vrtnje n i vrste piljenja na posmičnu silu F_f (SD1; z = 16; γ = 10°); borovina

Table 4 Ratio of up sawing feed force to down sawing feed force for SD1
Tablica 4. Omjer posmične sile pri protusmjernom piljenju u usporedbi s istosmjernim piljenjem za pilu SD1

Feed speed v_f, m/min *Posmična brzina* v_f, m/min	**Rotational speed *n*, min^{-1}** *Frekvencija vrtnje* *n*, min^{-1}	**Up sawing** *Protusmjerno piljenje* **Feed force F_f, N** *Posmična sila* F_f, N	**Down sawing** *Istosmjerno piljenje* **Feed force F_f, N** *Posmična sila* F_f, N	**Ratio: Up sawing feed force to down sawing feed force** *Omjer posmične sile pri protusmjernom piljenju u usporedbi s istosmjernim piljenjem*
15	4000	26.36	21.07	1.25
	5000	24.5	10.1	2.42
	6000	18.7	12.13	1.54
20	4000	34.44	24.71	1.39
	5000	31.87	14.88	2.14
	6000	23.03	14.10	1.63
25	4000	39.32	25.77	1.52
	5000	33.61	16.64	2.02
	6000	31.04	16.39	1.89

Influence of sawing type (valid for SD4, z=24, γ=10°), Figure 8

Analogous to saw disk SD1 that has 16 teeth and rake angle of 10°, the results of a similar analysis for saw disc SD4 with rake angle of 10° but 24 teeth are displayed in Table 5. In this case the ratio between feed force during up sawing and feed force during down sawing oscillates within the range from 1.30 to 1.83 (Table 5 or Figure 8). The maximal difference is 0.50 compared to 1.17 for SD1. It seems that increasing of teeth number from 16 to 24 made the process more even.

3.2 Influence of feed speed (valid for SD1, z = 16, γ = 10°; Figure 9, Figure 10)
3.2. Utjecaj posmične brzine (vrijedi za SD1, z = 16, γ = 10°; sl. 9. i 10.)

The analysis of values displayed in Figure 9 and 10 shows partial results based on interactions of dependent variables: ratio between feed forces and different feed speeds during up and down sawing is:

- for up sawing, revolutions 4000 min^{-1}, feed speed 15 m/min, feed force $F_{f\,(Up,4000,15)}$ = 26.36 N and for feed speed 20 m/min, up sawing and the same revolutions feed force $F_{f\,(Up,4000,20)}$ = 34,44 N, i.e. ratio is 1.30;
- for up sawing, revolutions 4000 min^{-1}, feed speed 20 m/min, feed force $F_{f\,(Up,4000,20)}$ = 34.44 N and for feed speed 20 m/min, up sawing and the same revolutions feed force $F_{f\,(Up,4000,25)}$ = 39.32 N i.e. ratio is 1.14.

More detailed information for other conditions are presented in Table 4 and 5.

For both cases (down and up sawing), the slope of a straight line is quite similar.

The ratio between feed speeds v_f=20 m/min and v_f=15 m/min is 1.33; ratio between v_f=25 m/min and v_f=20 m/min is 1.25; ratio between v_f= 25 m/min and v_f=15 m/min is 1.66.

The ratio between revolution n_2 = 5000 min^{-1} and n_1= 4000 min^{-1} is 1.25; ratio between n_3=6000 min^{-1} and n_2=5000 min^{-1} is 1.2; ratio between n_3=6000 min^{-1} and n_1=4000 min^{-1} is 1.5.

As shown in Table 7 and 8, the rate of feed force is not the same as the rate of feed speed. The reason may lie in the fact that there are other force components, such as the depth of workpiece, etc.

Table 5 Ratio of up sawing feed force to down sawing feed force for SD4
Tablica 5. Omjer posmične sile pri protusmjernom piljenju u usporedbi s istosmjernim piljenjem za pilu SD4

Feed speed v_f, m/min *Posmična brzina* v_f, m/min	**Rotational speed *n*, min^{-1}** *Frekvencija vrtnje* *n*, min^{-1}	**Up sawing** *Protusmjerno piljenje* **Feed force F_f, N** *Posmična sila* F_f, N	**Down sawing** *Istosmjerno piljenje* **Feed force F_f, N** *Posmična sila* F_f, N	**Ratio: Up sawing feed force to down sawing feed force** *Omjer posmične sile pri protusmjernom piljenju u usporedbi s istosmjernim piljenjem*
15	4000	28.4	18.5	1.53
	5000	21.23	14.85	1.43
	6000	19.96	11.56	1.72
20	4000	32.61	19.71	1.65
	5000	31.7	17.33	1.83
	6000	23.28	16.43	1.41
25	4000	39.65	27.37	1.44
	5000	36.83	23.10	1.59
	6000	27.2	20.83	1.30

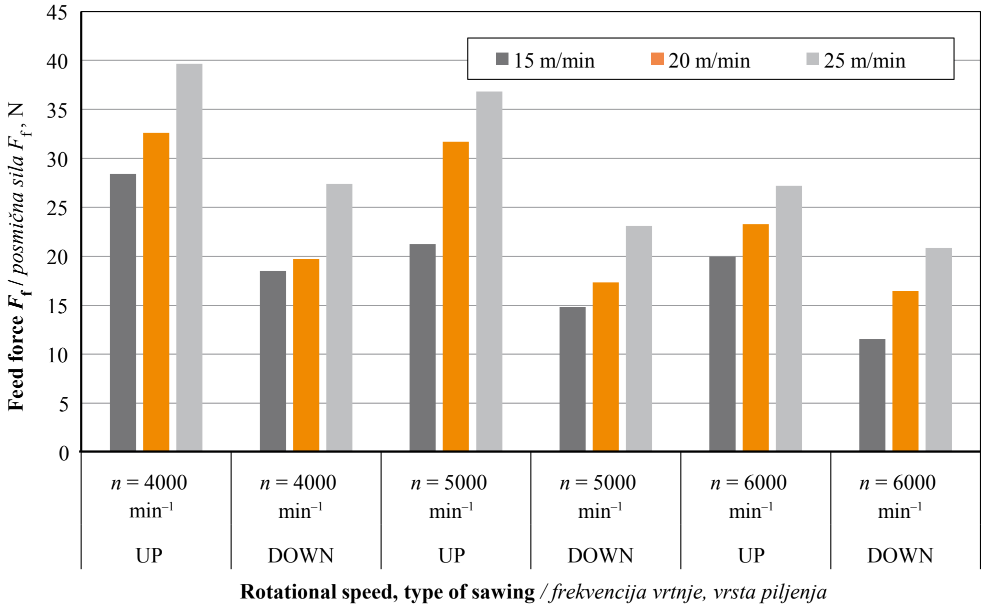

Figure 8 Influence of feed speed v_f, revolutions n and type of cutting to feed force F_f (SD4; z = 24; γ = 10°); pine wood
Slika 8. Utjecaj posmične brzine v_f, frekvencije vrtnje n i vrste piljenja na posmičnu silu F_f (SD4; z = 24; γ = 10°); borovina

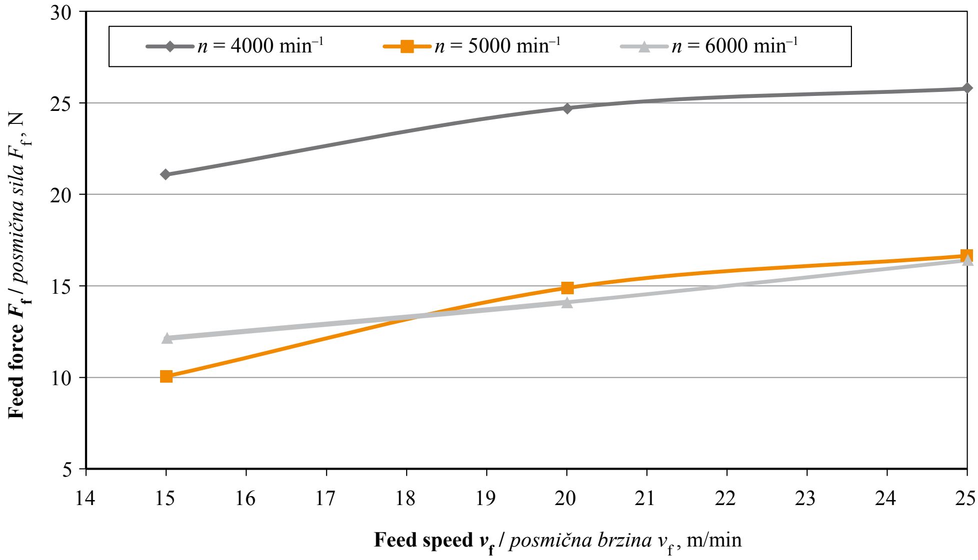

Figure 9 Influence of feed speed v_f and revolutions n on feed force F_f (SD1; z = 16; γ = 10°); down sawing
Slika 9. Utjecaj posmične brzine v_f i frekvencije vrtnje n na posmičnu silu F_f (SD1, z = 16, γ = 10°); istosmjerno piljenje

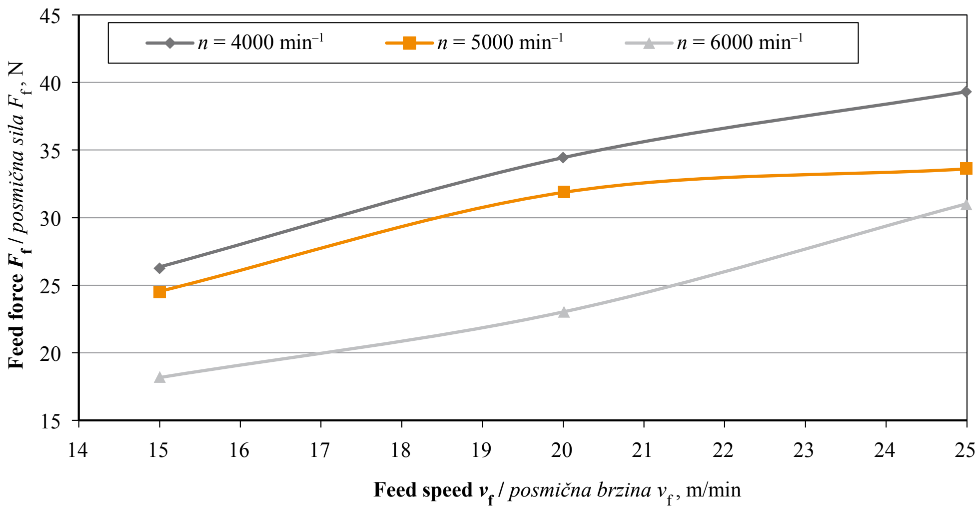

Figure 10 Influence of feed speed v_f and revolutions n on feed force F_f (SD1; z = 16; γ = 10°); up sawing
Slika 10. Utjecaj posmične brzine v_f i frekvencije vrtnje n na posmičnu silu F_f (SD1, z = 16, γ = 10°); protusmjerno piljenje

Table 6 Influence of feed speed v_f, revolutions n and type of cutting on feed force F_f (SD1; z = 16; γ = 10°); pine wood
Tablica 6. Utjecaj posmične brzine v_f, frekvencije vrtnje n i vrste piljenja na posmičnu silu F_f (SD1; z = 16; γ = 10°); borovina

Feed speed v_f, m/min *Posmična brzina v_f,* m/min	**Type of sawing** / *Vrsta piljenja*					
	Up *Protusmjerno*	**Down** *Istosmjerno*	**Up** *Protusmjerno*	**Down** *Istosmjerno*	**Up** *Protusmjerno*	**Down** *Istosmjerno*
	Revolutions n / *Frekvencija vrtnje n*, min^{-1}					
	4000	4000	5000	5000	6000	6000
	Feed force F_f / *Posmična sila F_f*, N					
15	26.36	21.07	24.54	10.05	18.17	12.13
20	34.44	24.71	31.87	14.88	23.03	14.1
25	39.32	25.77	33.61	16.64	31.04	16.39

Table 7 Increased rate of feed force due to increase of feed speed (SD1; z = 16; γ = 10°); pine wood
Tablica 7. Povećanje posmične sile zbog povećanja posmične brzine (SD1; z = 16; γ = 10°); borovina

	Type of sawing / *Vrsta piljenja*					
	Up *Protusmjerno*	**Down** *Istosmjerno*	**Up** *Protusmjerno*	**Down** *Istosmjerno*	**Up** *Protusmjerno*	**Down** *Istosmjerno*
	Revolutions n / *Frekvencija vrtnje n*, min^{-1}					
	4000	4000	5000	5000	6000	6000
Ratio / *Omjer*						
$F_{f\,(vf=20)} / F_{f\,(vf=15)}$	1.31	1.17	1.30	1.48	1.27	1.16
$F_{f\,(vf=25)} / F_{f\,(vf=20)}$	1.14	1.04	1.05	1.12	1.35	1.16
$F_{f\,(vf=25)} / F_{f\,(vf=15)}$	1.49	1.22	1.37	1.66	1.71	1.35

Table 8 Increased rate of feed force due to increase of feed speed (SD4; z = 24; γ = 10°); pine wood
Tablica 8. Povećanje posmične sile zbog povećanja posmične brzine (SD4; z = 24; γ = 10°); borovina

	Type of sawing / *Vrsta piljenja*					
	Up *Protusmjerno*	**Down** *Istosmjerno*	Up *Protusmjerno*	**Down** *Istosmjerno*	**Up** *Protusmjerno*	**Down** *Istosmjerno*
	Revolutions n / *Frekvencija vrtnje n*, min^{-1}					
	4000	4000	5000	5000	6000	6000
Ratio / *Omjer*						
$F_{f\,(vf=20)} / F_{f\,(vf=15)}$	1.15	1.07	1.49	1.17	1.17	1.42
$F_{f\,(vf=25)} / F_{f\,(vf=20)}$	1.22	1.39	1.16	1.33	1,17	1.27
$F_{f\,(vf=25)} / F_{f\,(vf=15)}$	1.40	1.48	1.73	1.56	1.36	1.80

3.3 Influence of rake angle (valid for SD1, z = 16, γ = 10°; SD2, z = 16, γ = 20°; Figure 11, Figure 12)
3.3 Utjecaj prsnog kuta (vrijedi za SD1, z = 16, γ = 10°; SD2, z = 16, γ = 20°; sl. 11. i 12.)

Saw discs SD1 and SD2 have the same number of teeth but different rake angle. The graph in Figure 11 shows the values for up sawing and in Figure 12 for down sawing.

When comparing the results obtained during up and down sawing separately, there are small differences for various revolutions and feed speeds within limits from 1.36 N to 5.75 N (Figure 11) and from 0.24 N to 5.43 N (Figure 12). The results show that the rake angle has some influence but, as there are many influencing factors such as wood structure, grains orientation, position of samples in tree trunk, it is very difficult to make explicit conclusions.

4 CONCLUSIONS
4. ZAKLJUČAK

The aim of this experiment was to confirm that feed force practically depends on feed speed proportionally, but the ratio of feed forces is not the same as the ratio of feed speeds.

The line slope depends on the type of sawing; it is higher for up (conventional) sawing than for down (climb) cutting.

The absolute value of feed force is higher for up sawing compared to down cutting. (On the other hand, the force perpendicular to feed force is higher for down cutting.)

The results of this experiment did not confirm the hypothesis that higher rake angle generally leads to the decrease of the feed force.

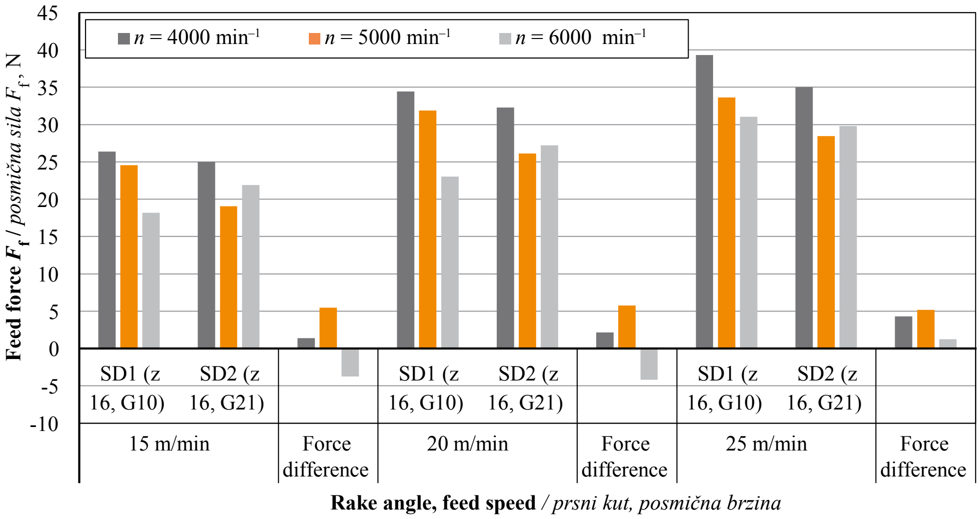

Figure 11 Influence of feed speed v_f, revolutions *n*, rake angle γ on feed force F_f (SD1 γ = 10°; SD2 γ = 20°; z = 16); up sawing
Slika 11. Utjecaj posmične brzine v_f, frekvencije vrtnje *n* i prsnog kuta γ na posmičnu silu F_f (SD1 γ = 10°; SD2 γ = 20°; *z* = 16); protusmjerno piljenje

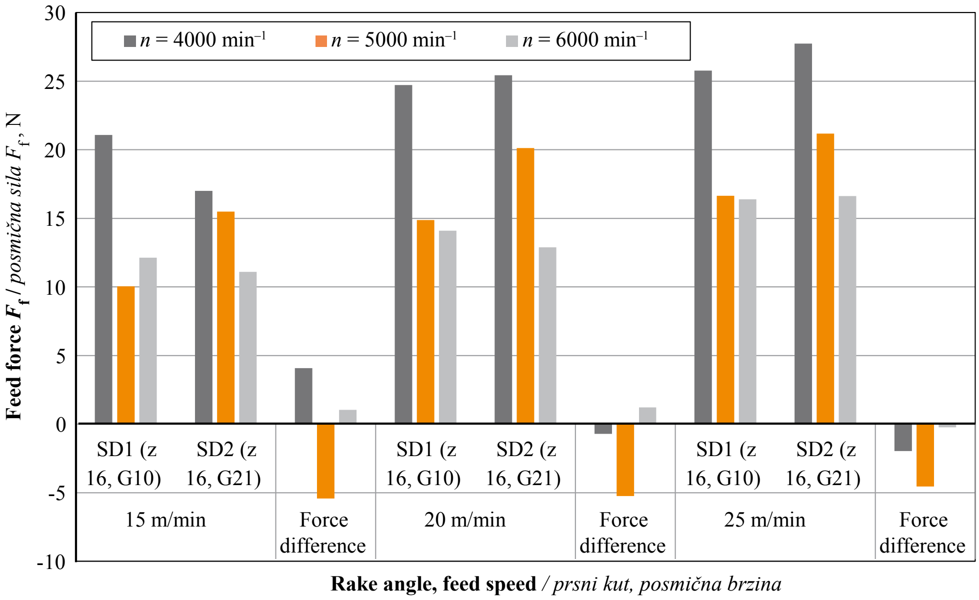

Figure 12 Influence of feed speed v_f, revolutions *n*, rake angle γ on feed force F_f (SD1 γ = 10°; SD2 γ = 20°; *z* = 16); down sawing
Slika 12. Utjecaj posmične brzine v_f, frekvencije vrtnje *n* i prsnog kuta γ na posmičnu silu F_f (SD1 γ = 10°; SD2 γ = 20°; *z* = 16); istosmjerno piljenje

Acknowledgements – Zahvala

A part of this article was created within the framework of Grand Project No. APVV-20-0403 "FMA analysis of potential signals suitable for adaptive control of nesting strategies for milling wood-based agglomerates" as a result of the author's research activity with the support of the agency APVV-SR.

5 REFERENCES
5. LITERATURA

1. Aguilera, A., 2011: Cutting energy and surface roughness in medium density fibreboard rip sawing. European Journal of Wood and Wood Products, 69: 1-18. https://doi.org/10.1007/s00107-009-0396-z
2. Aquilera, A., 2011: Surface roughness evaluation in medium density fibreboard rip sawing. European Journal of Wood and Wood Products, 69: 489-493. https://doi.org/10.1007/s00107-010-0481-3
3. Aguilera, A.; Martin, P., 2001: Machining qualification of solid wood of *Fagus silvatica* L. and *Picea excelsa* L.: Cutting forces, power requirements and surface roughness. European Journal of Wood and Wood Products, 59 (6): 483-488. https://doi.org/10.1007/s001070100243
4. Beer, P., 2002: Obróbka skrawaniem obwodowym drewna nowo opracowanymi narzędziami (In English: Wood peeling with new elaborated tools). Roczniki Akademii Rolniczej w Poznaniu, Rozprawy Naukowe, Zeszyt 330. Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego w Poznaniu, Poznań.
5. Beljo Lučić, R.; Goglia, V.; Pervan, S.; Đukić, I.; Risović, S., 2004: The influence of wood moisture content on the process of circular rip-sawing. Part I: Power require-

ments and specific cutting forces. Wood Research, 49 (1): 41-49.
6. Dange, A. R.; Thakare, S. K.; Rao, I. B., 2011: Cutting energy and force as required for Pigeon pea stems. Journal of Agricultural Technology, 7 (6): 1485-1493.
7. Fekiac, J.; Svoren, J.; Gaborik, J.; Nemec, M., 2022: Reducing the Energy Consumption of Circular Saws in the Cutting Process of Plywood. Coatings, 12: 55. https://doi.org/10.3390/coatings12010055
8. Fischer, R., 1979: Orientierende Versuche zur Reibung beim Schneiden von Holz. Holztechnologie, 20 (2): 111-115.
9. Goli, G.; Porankiewicz, B., 2014: Cutting forces by Oak and Douglas Fir machining. Maderas. Ciencia y tecnología, 16 (2): 199-216. https://doi.org/10.4067/S0718-221X2014005000016
10. Hlaskova, L.; Kopecky, Z.; Solař, A.; Patočka, Z., 2019: Cutting test as a source of fracture toughness and shear yield strength for axial-perpendicular model of wood cutting. Wood and Fiber Science, 51 (1): 1-11
11. Hlaskova, L.; Orlowski, K. A.; Kopecky, Z.; Jedinak, M., 2015: Sawing processes as a Way of Determoning Fracture Toughness and shear Yield stresses of Wood. BioResources, 10 (3): 5351-5394.
12. Ioras, H.; Nicholls, T.; Perkins, M. C.; Münz, V.; Larmann, A., 2002: A Review for Cutting Forces and Stresses in Circular Saws. Holz als Roh- und Werkstoff, 60: 55-59.
13. Kivimaa, E., 1950: The cutting force in woodworking. Report No. 18. The State Institute of Technical Research, Helsinki, Finland, pp. 103.
14. Klement, I.; Réh, R.; Detvaj, J., 2011: Základné charakteristiky lesných drevín – spracovanie drevnej suroviny v odvetví spracovania dreva (In English: The basic characteristics of forest wood species – the processing of wood raw in wood industry). Národné lesnícke centrum, pp. 82.
15. Kopecky, Z.; Hlaskova, L.; Orlowski, K., 2014: An innovative approach to prediction energetic effects of woo cutting process with circular-saw blades. Wood Research, 59 (5): 827-834.
16. Kopecky, Z.; Rousek, Z., 2006: Determination of cutting forces in cutting wood Materials. Drvna industrija, 56 (4):171-176.
17. Nasir, V.; Cool, J., 2018: A review on wood machining: characterization, optimization, and monitoring of the sawing process. Wood Material Science and Engineering, 15 (1): 1-16. https ://doi.org/10.1080/17480272.2018.1465465
18. Naylor, A.; Hackney, P.; Perera, N.; Clahr, E., 2012: A predictive model for the cutting force in wood machining developed using mechanical properties. BioResources, 7 (3): 2883-2894.
19. Orlowski, K. A.; Ochrymiuk, T.; Atkins, A.; Chuchala, D., 2013: Application of fracture mechanics for energetic effects predictions while wood sawing. Wood Science and Technology, 47 (5): 949-963.
20. Orlowski, K. A.; Ochrymiuk, T.; Sandak, J.; Sandak, A., 2017: Estimation of fracture toughness and shear yield stress of orthotropic materials in cutting with rotating tools. Engineering Fracture Mechanics, 178: 433-444.
21. Palubicki, B., 2021: Cutting Forces in Peripheral Up-Milling of Particleboard. Materials, 14, 2208. https://doi.org/10.3390/ma14092208
22. Piispanen, V., 1948: Theory of Formation of Metal Chips. Journal of Applied Physics, 19: 876. https://doi.org/10.1063/1.1697893
23. Porankiewicz, B.; Axelsson, B.; Gronlund, A.; Marklund, B., 2011: Main and normal cutting forces by machining wood of Pinus sylvestris. BioResources, 6 (4): 3687-3713.
24. Porankiewicz, B.; Goli, G., 2014: Cutting forces by Oak and Douglas Fil machining. Ciencia y tecnología, 16 (2): 199-216. https://doi.10.4067/S0718-221X2014005000016
25. Teng, Y.; Ding, J.; Wang, B.; Guo, X.; Cao, P., 2014: Cutting forces and Chip Morphology in Medium Density Fiberboard Orthogonal Cutting. BioResources, 9 (4): 5845-5857.
26. ***EN 847-1, 2017: Tools for Woodworking – Safety Requirements. Part 1: Milling Tools, Circular Saw Blades.
27. ***RANC 207 AMW – technical data.

Corresponding address:

ĽUBOMÍR JAVOREK
Technical University in Zvolen, T. G. Masaryka 24, 960 00 Zvolen, SLOVAKIA, e-mail: lubomir.javorek@tuzvo.sk