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RELATIONSHIP BETWEEN CUTTING CONDITIONS AND FORCE / MOMENT PARAMETERS DURING DRILLING

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Abstract:
Drilling (boring) is one of the oldest technologies of machining in all of the branches of production industry. Of course, it is an integral part of wood cutting technologies in the furniture production industry, in which are used mainly chip boards, building industry, wooden building, as well as in packing and transport materials production. It is inevitable to determine real boring conditions, the thrust, cutting power (torque moment), the force balancing the cutting friction etc., for the production efficiency increasing. The cumulative cutting force can be divided into its individual components. The relationships between the force components and the load of the material and boring tools change in the boring process, especially with respect to different physical and mechanical performances of both the spring and late wood.

The presented work analyses the data concerning the torque moment and the value of the axial force (thrust) which have been gathered in the process of experimental boring of the fir wood (Abies alba). There have been used three different drilling directions with three different diameters of the borers in different conditions of the rotation and support velocities in the experimental process.

Key words: *drilling; fir (Abies alba); feed force; torque moment.*

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INTRODUCTION

Drilling is one of the most common material removal processes, used especially in the furniture industry for creating cylindrical holes in solid or composite wood. Slovak industry processes 95% of spruce or fir. At present this type of wood covers 77.350, 47ha, i.e. ca. 4% of the forest area. This wood is light, soft, very good machinable, scisible, suitable for treating, though worse to impregnate. After spruce and pine, fir (Abies alba) is the third most important conifer in Slovakia. It was object to many studies dealing not only with cutting process in general, but also with special aspects, e.g. relationship between wood samples, its properties, grain orientation and technological conditions as cutting speed, feed speed, depth of cut and its influence on cutting force (Wilkowski *et al.* 2011, Podziewski and Górski 2012), cutting power (Javorek and Balko 2011, Pastierovic 2013), tool life, wearing of cutting wedge, or surface quality (Szymański and Pinkowski 2012), surface roughness, surface integrity (Podziewski and Górski 2012), noise or dust generated during cutting etc. (Jaybal and Natarjan 2010) describe the exploitation of information about cutting forces, power and wearing on the optimization of the process or predicting cutting forces. On the basis of extensive database of information from previous experiments, (Tsao 2008) makes use of a neuron net.

Drilling has been widely used for creating holes, mainly in the furniture sector. To improve drilling quality and capability, it is necessary to understand the drilling process characteristics as a principle of chips creation, its orientation for removing from the zone of cutting, forces and their value and orientation during cutting, fracture mechanics during delamination of wood layers etc.

This article presents values of cutting force (thrust) and cutting power during machining - drilling wood samples of fir (Abies alba) in different grain directions towards feed direction.

MATERIALS AND METHODS

Specimen preparations

Drilling experiment was carried out in order to determine the effects of cutting conditions on thrust force and torque moment.

Samples of wood were cut to rectangle cubes 40x40x40mm from a square prism with length 2500mm, so that samples for every 4-pieces group were composed of cubes cut consecutively. Klement et al. declares mechanical properties of the raw material with moisture content 12% and more 30% are in the Table 1, wood samples and drilling direction in Fig. 1.

Table 1

Properties of samples

The basic mechanical properties of fir				
Properties	Parallel with grain		Perpendicular to grain	
	w = 12 %	w > 30 %	w = 12 %	w > 30 %
Tensile strength [MPa]	84	48	2.3	
Compression strength [MPa]	41	29	4,0	
Shearing strength [MPa]	9.8	6.1		
Bending strength [MPa]	73	47		
Modulus of elasticity [MPa]	11000	6600		
Toughness [$J \cdot cm^{-2}$]			4.2	3.0
Brinell hardness [MPa]	34	18	16	13
Janko hardness* [MPa]			26.7	18.9

*Notice: Janka hardness is common used in home country of authors. Kudela 1998 compared results obtained by both methods and confirmed justness Janka hardness for evaluation of wood hardness by methodology according to Pozgaj 1987.

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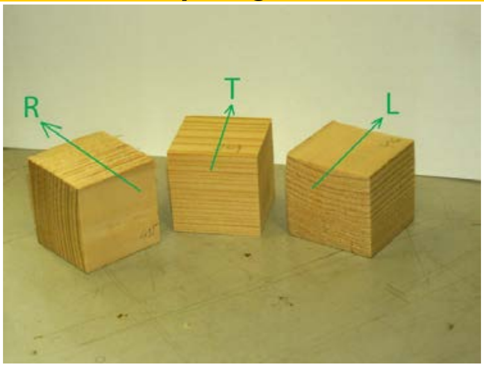

Fig. 1
Drilling directions: R - radial, T - tangential, L – longitudinal.

Equipment and machines used in experiment

In the experiment was used the RFh 75/1750 drilling machine, which parameters are in Table 2.

Table 2

Parameters of the drilling machine

Machine dimensions	2970 mm x 1130 mm x 3400 mm
Range of the revolutions (velocity speed)	19 rpm – 1900 rpm
Range of the feed per revolution	0,047 mm – 2 mm
Number of feeds per revolutions	12
Total power	15 kW

The complete equipment used in the experiment is showed on Fig. 2. Signal obtained from machining was transported via amplifier to computer and then it was performed using program DynoWare written by Kistler Co. More detailed information is in Table 3.

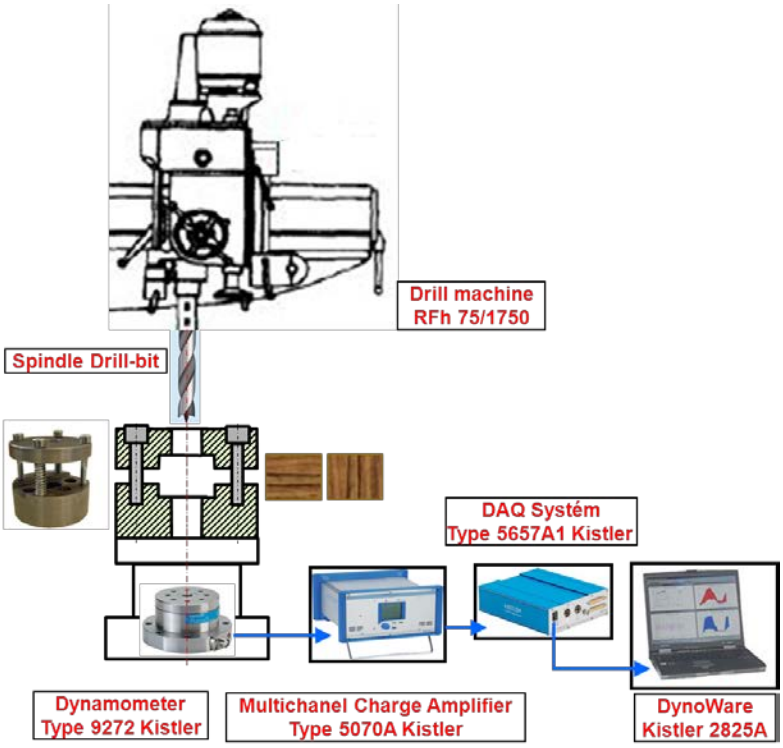

Fig. 2
Measuring chain.

Table 3

Parameters of the Kistler measure kit

Piezoelectric multichannel dynamometer	type 9272
Multichannel (eight channels) charge amplifier	type 5070A
DAQ System	type 5657A
PC with software DynoWare	type 2825A

For measuring the torque moment and thrust (feed force) we used measuring system (completely from Kistler co.) consisting from marked parts.

Data were obtained by measuring the above mentioned parameters during drilling, with use of a dynamometer. In the second stage, data were analysed by statistical methods.

Drilling process and tools

Tests were performed for various directions towards grain orientation – i.e. radial, tangential and longitudinal. Machining of samples was performed with different diameters of drills, different feed speed and revolutions. The drilling force and torque moment measurement plan is shown in Fig. 3.

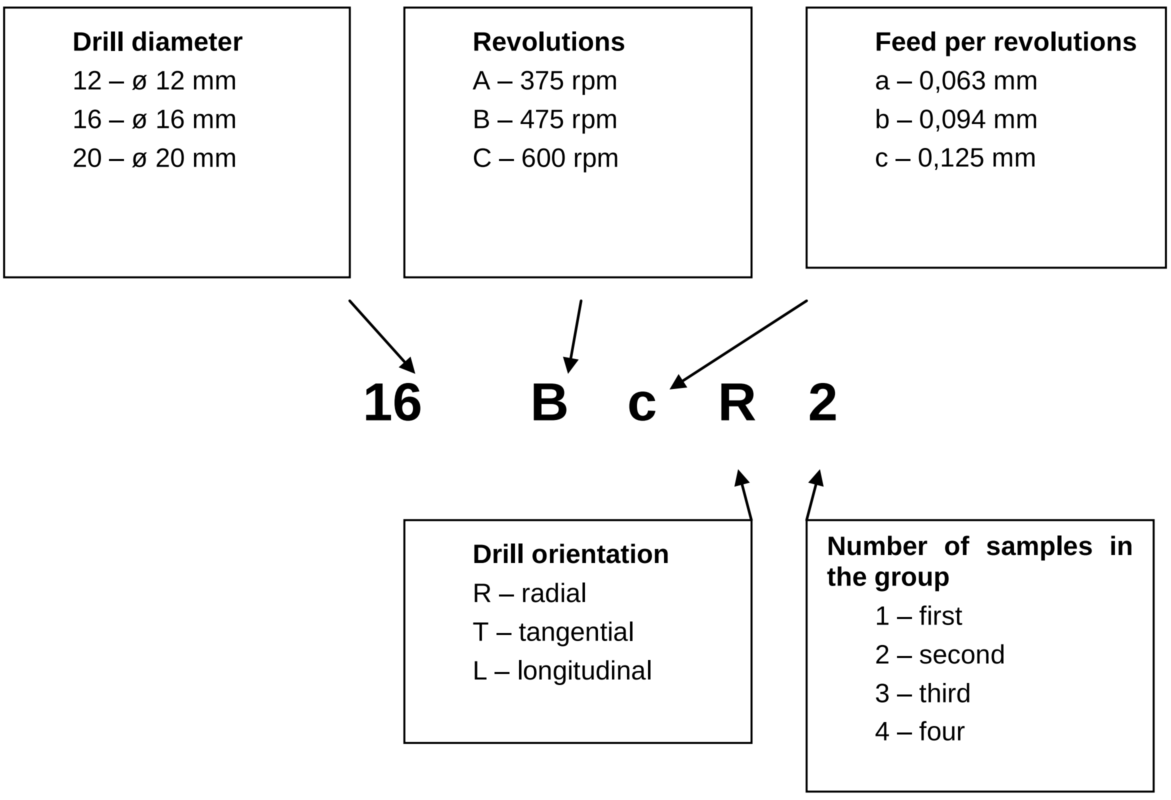

Fig. 3
Measuring plan.

To minimize vibration during machining, the dynamometer with the sample of wood was fixed to the table of machine, which was independent from other structures of machine.

Results and discussion

The values of thrust and torque were recorded (Fig. 4) by DynoWare software and saved into NTB with the frequency of sampling 100 Hz for the whole time of measuring.

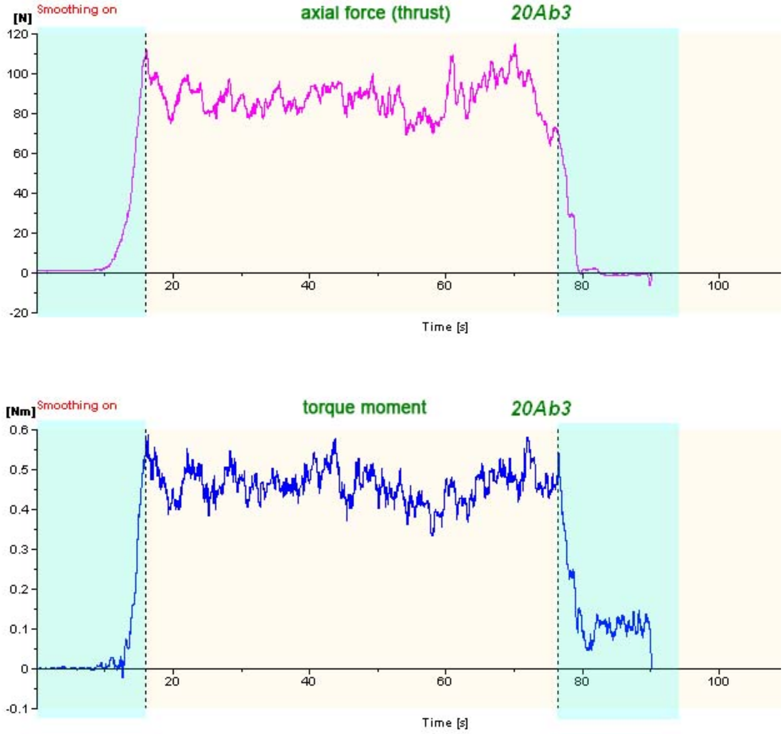

Fig. 4
Records of thrust and torque signal.

As a next step we used Box-Jenkins analysis of time series, which contains a module for analysing auto-regression models and models of running average. The first computation confirmed that running average is not significant for drilling process. In the second step, auto - regression of second variable was implicated in the following form:

$$y_t = a_0 + a_1 \cdot y_{t-1} + a_2 \cdot y_{t-2} \qquad (1)$$

y – dependant variable
y_{t-1} – for one time step shift to the Y variable which is selected for the independent variable
a_0 – the level constant of the model
a_1 – the auto-regressive parameter of the first range
a_2 – the auto-regressive parameter of the second range
y_{t-2} – for two time steps shift to variable Y.

The values from all experiments are displayed in the Table 4 for thrust and in Table 5 for torque moment. Taking into consideration that the tables present all the values, only results for drills with diameter 12mm, 16mm and 20mm are displayed in Tables 4 and 5, graphs – Fig. 5 and Fig. 6 present results for drill with diameter 12mm, radial direction and three feed rate.

Table 4

Values of thrust (feed force)

Revolutions [min^{-1}]	Feed per revolution 0.063 [mm]			Feed per revolution 0.094 [mm]			Feed per revolution 0.125 [mm]		
	Drill diameter [mm]								
	12	16	20	12	16	20	12	16	20
	Thrust [N] (drilling in radial direction)								
375	**64.89**	66.21	77.30	**68.65**	70.75	86.79	**78.16**	72.52	94.40
475	**74.29**	77.63	82.83	**76.35**	78.16	98.90	**79.71**	78.92	109.47
600	**77.46**	79.34	84.52	**78.42**	80.76	113.27	**82.43**	81.90	117.79

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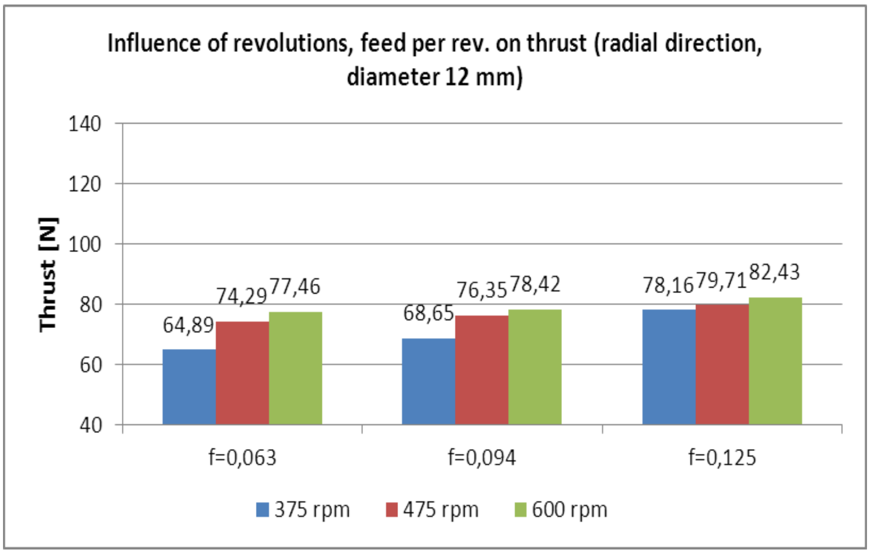

Fig. 5
Influence of revolutions and feed on thrust.

With regard to the statistical analyse we can say, that the change of feed has no principal influence on thrust. For the **drill diameter 12mm and 0.063mm feed per revolution** the results were as follows: revolutions are in geometric progression with quotient 1.25, but quotient between 77.46N and 74.63N is only 1.03, respectively 1.15 (74.63N vs. 64.89N). Difference between 600rpm and 475rpm is 125rpm, resp. 100 (475rpm vs. 375rpm), but differences of thrust for the same revolutions and feed are 2.83N, resp. 9.77N, i.e. while revolutions increased by 26.3% (from 475rpm to 600rpm), thrust increased by 3.8% (from 74.63N to 77.46N). For 375rpm and 475rpm the same values were following: 26.3% for revolutions – 15% for thrust increase.

For the **drill diameter 20mm and 0.125mm feed per revolution** the results were as follows: revolutions are in the same geometric progression, but quotient between 117.79N and 109.47N is only 1.07, resp. 1.15 (109.47N vs. 94.40N). Differences in thrust for the same differences in revolutions and feed mentioned above are 8.32N, resp. 15.07N, i.e. while revolutions increased by 26.3% (from 475rpm to 600rpm), thrust increased by 7.6% (from 109.47N to 117.79N). For 375rpm and 475rpm the same values were following: 26.3% for revolutions – 15.9% for thrust increase.

Table 5

Values of torque moment

Revolutions [min^{-1}]	Feed per revolution 0.063 [mm]			Feed per revolution 0.094 [mm]			Feed per revolution 0.125 [mm]		
	Drill diameter [mm]								
	12	16	20	12	16	20	12	16	20
	Torque [Nm] (drilling in radial direction)								
375	**0.27**	0.38	0.41	**0.36**	0.39	0.46	**0.36**	0.47	0.54
475	**0.30**	0.40	0.42	**0.37**	0.42	0.54	**0.38**	0.48	0.63
600	**0.33**	0.39	0.46	**0.38**	0.44	0.63	**0.39**	0.51	0.67

The same analysis for torque moment and the same drill diameters 12mm, resp. 20mm brought following conclusion:

Drill diameter 12mm and 0.063mm feed per revolution: quotient between 0.33Nm and 0.30Nm is only 1.1, resp. 1.11 (0.30Nm vs. 0.27Nm). The difference between 600rpm and 475rpm is 125rpm, resp. 100 (475rpm vs. 375rpm), but differences in torque moment for the same revolutions and feed are 0.03Nm for both cases, i.e. while revolutions increased by 26.3% (from 475rpm to 600rpm), torque moment increased by 11.1 % (from 0.27Nm to 0.30Nm). For 375rpm and 475rpm the same values were following: 26.3% for revolutions – 10% for torque moment increase.

Drill diameter 20mm and 0.125mm feed per revolution: revolution are in the same geometric progression, but quotient between 0.67Nm and 0.63Nm is only 1.06, resp. 1.16 (0.63Nm vs. 0.54Nm). Differences in torque moment for the same differences in revolutions and feed mentioned above are

0.04Nm, resp. 0.09Nm, i.e. while revolutions increased by 26.3% (from 475rpm to 600rpm), torque moment increased by 6.3% (from 0.63Nm to 0.67Nm). For 375rpm and 475rpm the same values were following: 26.3% for revolutions – 16.6% for the torque moment increase.

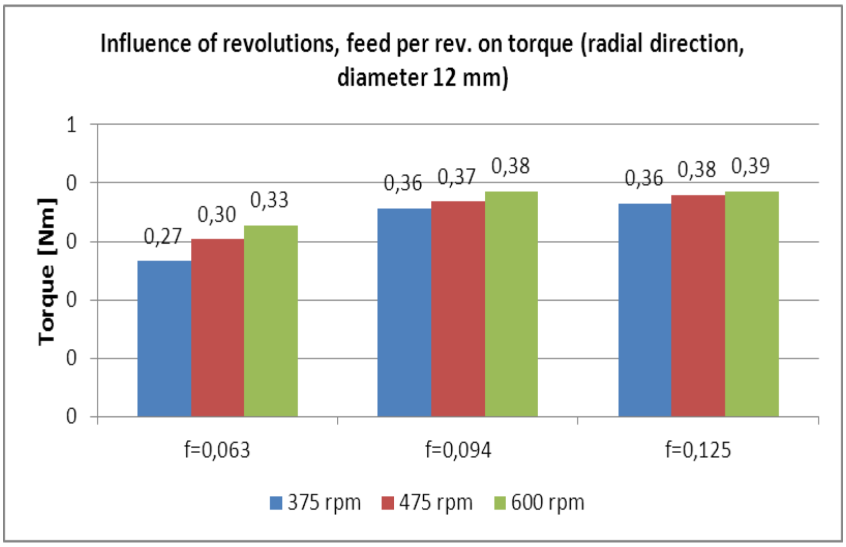

Fig. 6
Influence of revolutions and feed on torque moment.

CONCLUSION

In the beginning of this experiment, the aim was to find influence of feed speed, revolutions and grain orientation due feed speed on feed force and torque moment. In this contribution are presented only partial results – in tables for drill diameter 12, 16 and 20mm and radial direction, the graphs only for drill diameter 12mm and radial direction of drilling. Mathematic formulas for thrust force and feed 0,063 mmpr and revolution 375rpm, 475rpm, 600rpm are following:

- Revolutions 375 per minute: $y = 6,63x + 57,3; R^2 = 0,94$;
- Revolutions 475 per minute: $y = 2,71x + 71,34; R^2 = 0,98$;
- Revolutions 600 per minute: $y = 2,48x + 74,4; R^2 = 0,88$;

Mathematic formulas for torque moment and feed 0,063mmpr and revolution 375rpm, 475rpm, 600rpm are following:

- Revolutions 375 per minute: $y = 0,049x + 0,23; R^2 = 0,813$;
- Revolutions 475 per minute: $y = 0,0378x + 0,27; R^2 = 0,856$;
- Revolutions 600 per minute: $y = 0,029x + 0,30; R^2 = 0,761$.

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