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# THE EFFECT OF SELECTED FACTORS ON OUT-OF ROUNDNESS DURING THE GREEN WOOD DRILLING

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## ABSTRACT

The issue of the out-of roundness during the process of green wood drilling is presented in the paper. The focus is placed on analysing the moisture content, direction and position during drilling and revolutions in respect to selected commercial tree species. The aim of the research was to determine the correlation between the accuracy of roundness and the changes in the mentioned factors and parameters associated with drilling. The results can be used to optimise the process of the CNC drilling. The samples of the following tree species – European beech, English oak and Norway spruce were used to measure the roundness. The data were gathered when drilling the samples in longitudinal, tangential and radial directions at the revolutions of 710, 1000 and 1400 min$^{-1}$, feed rate of φ= 0.225 mm and the moisture content of 12 %, (in the case of European beech also 18%).

**Key words:** drilling, tree species, out-of roundness, drill, operational direction and position, revolution, moisture content.

## INTRODUCTION

Innovations and developments in machinery and technology in order to increase the productivity at work, to improve quality and at the same time, to reduce the production costs must be implemented in the manufacturing industry to stay competitive on the domestic and international markets (CHOUHAN *et al*. 2016, KALITA and NATH 2016, BAKO and BOŽEK 2016, PRADEEP KUMAR *et al*. 2017, KAMBLE *et al*. 2019). Therefore, CNC technology has been widely applied so far. Optimizing the machining operation of CNC machines requires the optimal settings for the cutting parameters of the processes under given conditions of machining. Wood is orthotropic and anisotropic material, i.e. cutting parameters changes depending upon the tree species, its physical and mechanical properties (KOLEDA *et al*. 2016, KÚDELA *et al*. 2018, SIKLIENKA *et al*. 2017). Quality indicators of machining such as accuracy and surface roughness, indicators relating to the forces and energy (cutting force and cutting performance) are considered the machining process parameters (KRILEK *et al*. 2014, KMINIAK *et al*. 2015, KORČOK *et al*. 2015 and KOLEDA *et al*. 2019, SZWAJKA and TRZEPIECIŃSKI 2017).

Drilling the commercial tree species typical in temperate zone is mentioned in scientific literature very rarely. In foreign literature, attention is paid to exploring tropical tree species, tree species of North America and Japan. Drilling refers to the process of creating round holes using a drill. During drilling, the cutting tool is fed in a direction parallel to its axis of rotation. The function of the face of cutting edge is the most important. Drill construction depends on many factors, such as drilling conditions in regard to wood grain direction, drill diameter and geometry, drilling depth, hole positional accuracy, productivity at work. In the case of drilling wood across the grain, taper drill bit and centering drill bit can bend and the grains are cut in the direction perpendicular to their longitudinal axes. On the contrary, when drilling wood along the grain direction, grains are cut in the direction parallel to their longitudinal axes. Drilling parallel to the grains is defined by parallel axial movement with the grains. Cutting edges are inclined to drill axis, and because of the same conditions in any positions during one revolution, the taper drill bit is not necessary. The research of most authors are focused on observing the torque and axis power depending upon selected drilling parameters. MCMILLIN and WOODSON (1972) dealt with the quality of drilled holes in the Borealis pine wood using the twist drill with centering bit and taper drill bit and flat drill. They found out that the chip thickness and revolution did not affect the hole quality. Flat drill was excellent in the hole quality during drilling dry wood in longitudinal direction and the holes drilled in longitudinal direction in the wet wood were of better quality using the twist drill. When drilling in the direction across the grain, twist drill was excellent in drilling wet as well as dry wood. KOMATSU (1976) investigated the quality of holes drilled using the Japanese drill with taper drill bits and centering bit and the twist drill with flat bit at the revolutions of n= 250, 1000, 1500, 2500 and 5000 $min^{-1}$. When drilling using the Japanese drill, out-of roundness and roughness were almost constant at the revolutions ranging from 1500 to 5000 $min^{-1}$. Little out-of roundness and the roughness of drilled holes drilled using the twist drill with V-bit was in the case of the revolutions of 1500 or 2500 $min^{-1}$. KOMATSU (1978c) investigated drilled hole inclination angle ranging from $80^o$ to $180^o$. In the case of a top angle of $100^o$, the value of out-of roundness of the drilled hole was the smallest. The hole size changes with variation in wood moisture content. An increase in the moisture content can result in an increase in the hole size. An increase across the grains is more marked than an increase parallel to the grains.

The aim of the paper is to analyse the effect of selected factors on the out-of roundness during drilling the selected commercial tree species. Timber is drilled in three basic anatomical directions – longitudinal, radial, tangential.

## MATERIAL AND METHODS

### Description and preparation of samples

Samples from tree species European beech (*Fagus sylvatica* L.), English oak (*Quercus robur* L.) and Norway spruce (*Picea abies* L.) were used to observe the phenomena generated during drilling. The samples with the dimensions of 50 × 50 × 50 mm were used in the experiment (Fig. 1). The dimensions of the samples were according to the requirements and construction of the test equipment. 81 samples were from beech wood and 54 samples were from oak and spruce wood respectively.

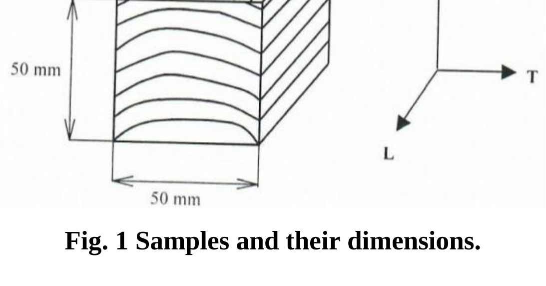


**Fig. 1 Samples and their dimensions.**

All samples were air-conditioned to the moisture content of 12 ± 1%. The density of samples was as follows: qEB = 0.711 g.cm$^{-3}$, qEO = 0.720 g.cm$^{-3}$, qNS = 0.421 g.cm$^{-3}$. Some of the samples from beech wood were subsequently air-conditioned to the moisture content of 18 ± 1%.

**Description of drills and drill conditions**

Twist drills with taper bits and centering bits made of alloy steel were used for drilling the samples in the experiment. Drill used marked as Art. 517.200.31 were produced by the company Pesaro with diameter 20 mm.

Drill direction: longitudinal (L), radial (R), tangential (T)
Revolution: n = 710, 1000, 1400 min$^{-1}$
Feed rate: f = 0.225 mm

**Wood drilling**

Wood drilling was carried out using the vertical milling machine FA 4 AV in three basic directions (radial R, tangential T and longitudinal L) as it is illustrated in Fig. 1. Four holes with the depth of 2D were drilled into the samples with the dimensions of 50 × 50 × 50 mm. The samples were placed in the milling machine (SIKLIENKA and ŠAJBANOVÁ 2002, 2003). In the case of samples air-conditioned to the moisture content of 12 ± 1 %, two samples of each tree species for one drill diameter, one value of revolution and one drill direction were used, thus 8 holes were drilled.

**Measuring the out-of roundness of the drilled hole**

The out-of roundness of the drilled hole was observed on the holes drilled in the samples of all tree species using the drill with the diameter of 20 mm. The holes were drilled in longitudinal, radial and tangential directions. Selected holes were divided by 15°, i.e.12 diameters D1–1´ – D12–12´ were measured. These diameters were measured using the calliper. In the case of the holes drilled in the longitudinal direction, the out-of roundness of the drilled hole was measured in the transverse plane (Fig. 2). Fig. 2 shows that the diameter D1–1´ was measured in the radial direction and the diameter D7–7´ in the tangential direction.

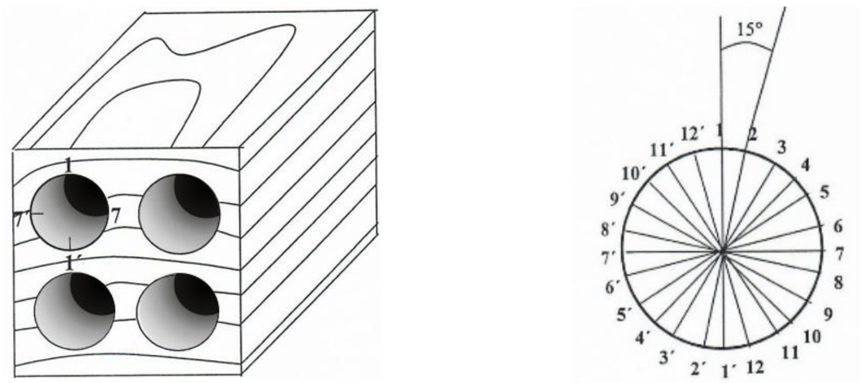


**Fig. 2 Measuring the out-of roundness of the drilled hole A in the longitudinal direction to the transverse plane.**

The holes drilled in the tangential direction were drilled in the longitudinal-radial plane. The diameter D1–1´ was measured in the longitudinal-radial plane in the direction parallel to the grain direction and the diameter D7–7´ was measured in the longitudinal-radial plane in the direction across the grain (Fig. 3).

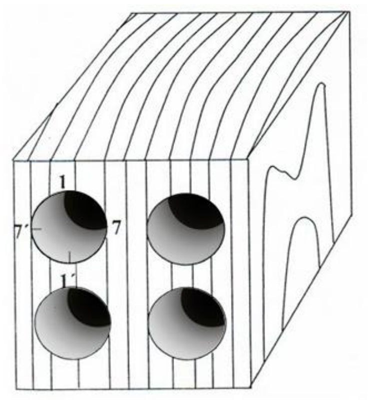


**Fig. 3 Measuring the out-of roundness of the drilled hole A in the tangential direction to the longitudinal-radial plane.**

In the radial direction, the holes were drilled to the longitudinal-tangential plane. The diameter D1-1´ was measured in longitudinal-tangential plane in the direction parallel to the grains and the diameter D7–7´ was measured to the longitudinal-tangential plane in the direction across the grains (Fig. 4.)

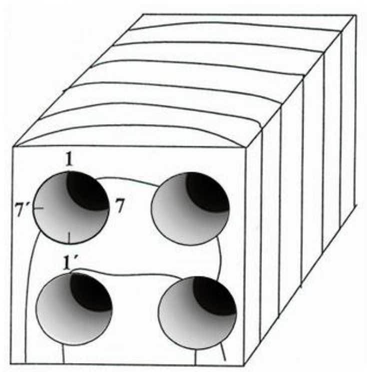


**Fig. 4 Measuring the out-of roundness of the drilled hole A in the radial direction to the longitudinal-tangential plane.**

Measured results were evaluated using the program STATISTICA. In the case of beech wood samples, the effect of the drill direction, revolution, operation location and moisture content on the out-of roundness of drilled hole was observed. In the case of other tree species, the effect of revolutions, operation direction and location was observed. Moreover, the effect of tree species on the out-of roundness of the drilled hole was evaluated.

## RESULTS AND DISCUSSION

**Evaluation of the out-of roundness of the drilled hole in the case of beech wood samples**
The effect of the moisture content, operation direction, revolutions and operation location on the out-of roundness of the drilled hole are evaluated in this part. Tab. 1 shows that the effect of the moisture content, opeartion direction, revolutions and operation location on the out-of roundness of the drilled hole was statistically significant. Fig. 5 illustrates the effect of the moisture content, operation direction, revolutions and operation location on the out-of roundness of the drilled hole in all operation directions. In the case of the holes drilled in samples of other tree species, the fact that the effect of individual parameters associated with drilling on the out-of roundness of the drilled hole was almost the same can be stated.

**Tab. 1 Four factor analysis of variance for the out-of roundness of the drilled hole A.**

| *Factor* | *SS* | *df* | *MS* | *F* | *p - level* |
|---|---|---|---|---|---|
| *1* | 0,042 | 1 | 0,042 | 2494,56 | 0,000 |
| *2* | 0,042 | 2 | 0,021 | 1246,46 | 0,000 |
| *3* | 0,022 | 2 | 0,011 | 668,86 | 0,000 |
| *4* | 0,133 | 11 | 0,012 | 726,37 | 0,000 |
| *12* | 5,14E-05 | 2 | 2,57E-05 | 1,55 | 0,214 |
| *13* | 0,001 | 2 | 6,79E-04 | 40,80 | 0,000 |
| *23* | 6,08E-05 | 4 | 1,52E-05 | 0,91 | 0,456 |
| *14* | 0,006 | 11 | 5,80E-04 | 34,81 | 0,000 |
| *24* | 0,004 | 22 | 1,62E-04 | 9,71 | 0,000 |
| *34* | 0,001 | 22 | 4,55E-05 | 2,73 | 0,000 |
| *123* | 3,29E-04 | 4 | 8,23E-05 | 4,94 | 0,001 |
| *124* | 0,001 | 22 | 5,93E-05 | 3,56 | 0,000 |
| *134* | 4,74E-04 | 22 | 2,15E-05 | 1,29 | 0,166 |
| *234* | 9,11E-04 | 44 | 2,07E-05 | 1,24 | 0,139 |
| *1234* | 6,05E-04 | 44 | 1,37E-05 | 0,83 | 0,782 |

1 – the effect of the moisture content on the out-of roundness of drilled hole, 2 – the effect of the operation direction on the out-of roundness of drilled hole, 3 - the effect of the revolutions on the out-of roundness of drilled hole, 4 - the effect of the operation location on the out-of roundness of drilled hole, 12, 13, 23, 14, 24, 34, 123, 124, 134, 234, 1234 – mutual interaction of the factors.

The effect of the moisture content on the out-of roundness of the drilled hole:

The fact that the moisture content affected the out-of roundness of the drilled hole in a significant way can be stated. Moreover, higher values of the out-of roundness of the drilled hole were measured in the case of higher moisture content. KOMATSU (1976) also mentions that there is a correlation between the moisture content and the hole size. Bigger increase was observed when drilling across the grains than along the grains.

The effect of the revolutions on the out-of roundness of the drilled hole:

In our experiment, there was a decrease in the out-of roundness of the drilled hole when the revolutions increased. KOMATSU (1976) found out that when drilling using the twist drill with flat bit, the out-of roundness of the drilled hole were almost constant with the revolutions ranging from 1500 to 5000 $min^{-1}$.

The effect of the drill direction and location on the out of roundness of the drilled hole:

The effect of both factors are evaluated together because they are interconnected. The fact that the highest values of the out-of roundness of the drilled hole were measured in the case of the holes drilled in the radial direction, lower values were measured in the tangential direction and the lowest in the longitudinal direction can be stated. In general, the results were gained in the case of all revolutions and moisture contents. In terms of quality, the size of the drilled hole should be accurate in a shape of cylinder. However, the accuracy of machining is affected by lots of parameters and factors. In our experiment, the fact that the holes in the point entering the wood were in a shape of ellipse was found out. This conclusion is confirmed by the experiment of KOMATSU (1978c, 1979b, d) who changed the top angle of the drill and the feed speed.

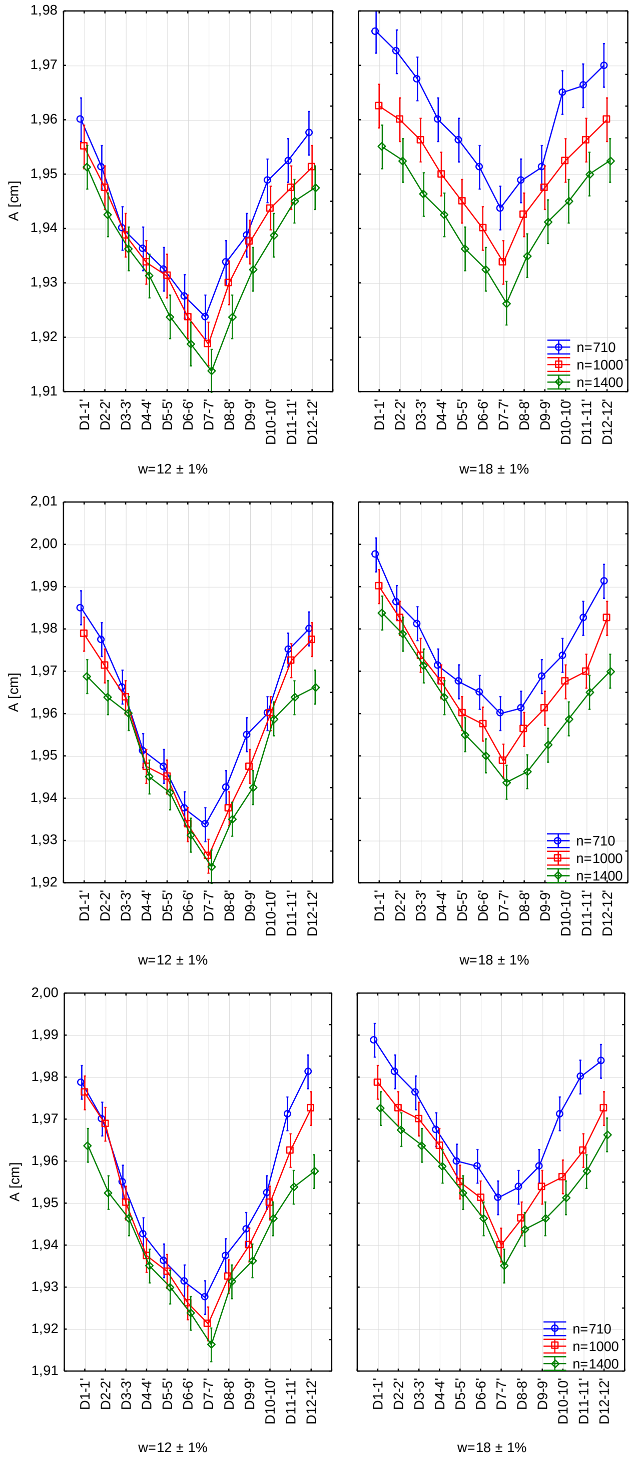


**Fig. 5 The effect of the moisture content w, revolutions n and the location of measurement on the out-of roundness of drilled hole A in the case of beech wood samples (a – longitudinal direction, b – radial direction, c – tangential direction).**

The smallest diameters in the holes drilled in the longitudinal direction to the transverse plane were measured in the tangential direction (the diameters D7–7´) and the largest diameters were measured in the radial direction (the diameters D1–1´).

In the case of the holes drilled in the tangential direction to the longitudinal-radial plane, the diameters D1–1´ were the largest ones and the diameters D7–7´ were the smallest ones. The diameters D1–1´ were measured in the longitudinal-radial plane in the direction parallel to the grains and the diameters D7–7′ were measured in the longitudinal-radial plane in the direction across the grains.

The fact that in the case of the holes drilled in the radial direction to the longitudinal-radial plane, the diameters D1–1′ were the largest ones and the diameters D7–7′ were the smallest ones can be mentioned. The diameters D1–1′ were measured in the longitudinal-tangential plane in the direction parallel to the grain direction and the diameters D7–7′ were measured in the longitudinal-tangential plane in the direction across the grains. In the scientific literature, there are data associated with the dimensional accuracy of the hole measured using the beech wood samples. KOMATSU (1976) measured the largest diameters of the holes along the grains and the smallest ones across the grains.

**Evaluation of the out-of roundness of the drilled hole in the case of other tree species**

Graphs illustrating 95 % confidence intervals for the out-of roundness of the drilled hole for the individual tree species are in Fig. 6.

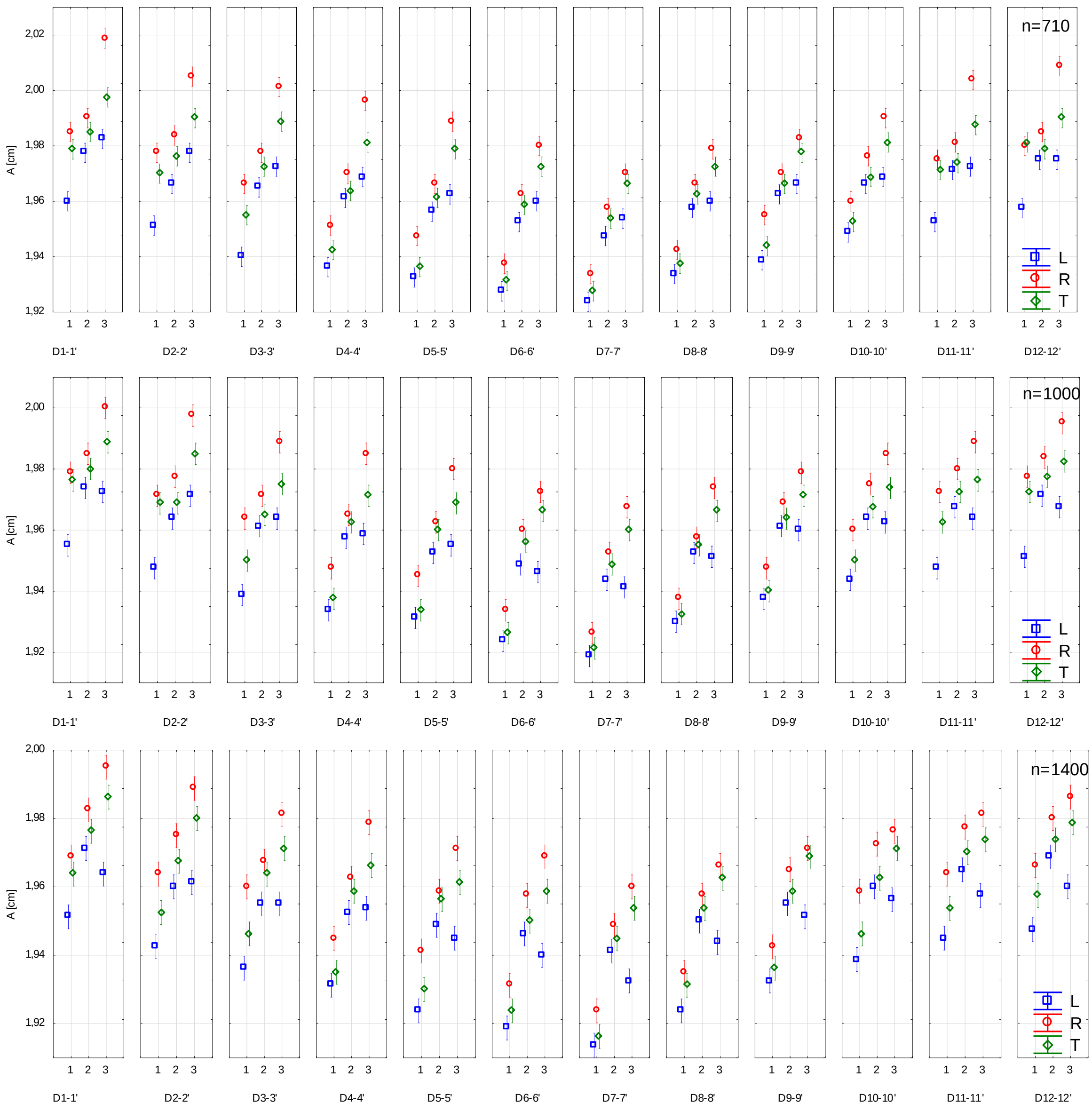


**Fig. 6 The effect of the location of measurement, tree species, and revolutions on the out-of roundness of the drilled hole A in the case of the holes drilled in the L - longitudinal direction, R – radial direction, and T – tangential direction, 1-European beech, 2-English oak, 3-Norway spruce.**

The quality of drilled holes is affected significantly by wood hardness and elasticity. In our experiments, softwoods were drilled: Norway spruce, as well as hardwood: European beech and English oak. Fig.6 shows that the highest values of the out-of roundness of the drilled hole were measured in the case of the holes drilled in spruce wood with the density of 0.421 $g \cdot cm^{-3}$. Thus the fact that when drilling softwood, the quality of the hole is lower comparing to the holes drilled in hardwood with higher density can be stated. The holes of the highest quality resulted from drilling beech wood samples. Fig.6 also shows that the largest diameters D1-1´ were observed in the case of all values of revolution in other tree species and the diameters D7–7´ were the smallest ones. The fact that in the case of all other tree species, there was a correlation between the revolutions and diameters can be seen. When the revolutions increased the out-of roundness of the drilled hole decreased.

## CONCLUSIONS

Knowledge associated with observing the phenomena generated during drilling were presented in the paper. Especially the effect of technological factors on the out-of roundness of the drilled hole was analysed in the paper. In the case of the holes drilled in the beech wood samples, the effect of the moisture content, revolutions, operation direction and measurement location on the values of the out-of roundness of the drilled hole. In the case of the holes drilled in the samples of other tree species, the effect of revolutions, operation direction and measurement location were investigated. The effect of the tree species on the out-of roundness of the drilled hole was evaluated as well. Measured results can be summarised as follows:

- When measuring the hole accuracy, the fact that the holes in the point drill entering the wood were in a shape of ellipse can be stated.
- When the evolutions increased, the values of the out-of roundness of the drilled hole decreased slightly.
- When the moisture content increased, the values of the out-of roundness of the drilled hole increased as well.
- The highest value of the out-of roundness of the drilled hole were measured in the case of the holes drilled in the radial direction, lower in the tangential direction and the lowest ones in the longitudinal direction.
- The smallest diameters of the holes were measured in the case of the holes drilled in the longitudinal direction to the transverse plane and the largest diameters were in the case of the radial direction.
- In the case of the holes drilled in the tangential direction to the longitudinal-radial plane, the largest diameters were measured in the longitudinal-radial plane in the direction parallel to the grains. On the contrary, the smallest diameters were measured in the longitudinal-radial plane across the grains.
- In the case of the holes drilled in the radial direction to the longitudinal-tangential plane, the largest diameters were measured in the longitudinal-tangential plane in the direction parallel to the grains. On the contrary, the smallest diameters were in the longitudinal-tangential plane across the grains.
- Higher values of the out-of roundness of the drilled hole were measured in the case of the holes drilled in samples generated from the softwoods, In the case of hardwood, the values of out-of roundness were lower. More accurate holes were drilled in the hardwood samples.

## REFERENCES


BAKO, B., BOŽEK, P. 2016. Trends in simulation and planning of manufacturing companies. In International Conference on Manufacturing Engineering and Materials, ICMEM 2016, Procedia Engineering, 6 June 2016 Vol. 149, p. 571–575.

CHOUHAN, Y. S., SALODA, M. A., JINDAL, S., AGARWAL, C. 2016. Optimalization of drilling process parameters for thrust force. In International Journal of Fracture and Damage Mechanics 1, p. 1‒7.

KALITA, B., NATH, T. 2016. An experimental investigation and optimization of cutting parameter in drilling AISI B1113 using M2 HSS drill bit. In International conference on explorations and innovation in engg. tech. (ICEIET)

KAMBLE, N., JATTI, V. 2019. Optimalization of drilling process parameters during of drilling of AISI 317L stainless steel. In Engineering Research Express vol. 1, N. 2., p. 9. http://doi.org/10.1088/2634-8695/ab2dcl.

KMINIAK, R., GAŠPARÍK, M., KVIETKOVÁ, M. 2015. The Dependence of Surface Quality on Tool Wear of Circular Saw Beades during Transversal Sawing of Beech Wood. In BioResources 10(4). p. 7123–7135.

KOMATSU, M. 1976. Machine boring properties of wood. II. : The effects of boring conditions on the cutting forces and the accuracy of finishing. In Journal of the Japan Wood Research Society, vol. 22, 1976, no. 9, p. 491‒497.

KOMATSU, M. 1978. Machine boring properties of wood. V. : The effects of the point angle of twist drill on the boring forces. In Journal of the Japan Wood Research Society, vol. 24, 1978, no. 8, p. 526–532.

KOMATSU, M. 1979 a. Machine boring properties of wood. VIII. : The effects of grain angle of wood on the boring properties of Japanese boring bit. In Journal of the Japan Wood Research Society, vol. 25, 1979, no. 2, p. 117–124.

KOMATSU, M. 1979. b. Machine boring properties of wood. IX. : The effects of grain angle of wood on the cutting force of twist drill. In Journal of the Japan Wood Researcch Society, vol. 25, 1979, no. 9, p. 573–581.

KOMATSU, M. 1979. c. Machine boring properties of wood. X. : The effects of grain angle of wood on the cutting accuracy of twist drill. In Journal of the Japan Woos Research Society, vol. 25, 1979, no. 9, p. 582–587.

KOLEDA, P., BARCÍK, Š., SVOREŇ, J., NAŠČÁK, Ľ., DOBRÍK, A. 2019. Influence of Cutting Wedge Treatment on Cutting Power, Machined Surface Quality, and Cutting Edge Wear When Plane Milling Ofak Wood. In BioResources 14(4), p. 9271–9286.

KORČOK, M., KOLEDA, P., BARCÍK, Š., VANČO, M. 2018. Effects of technical and technological parameters on the surface quality when milling thermally modified European oak wood. In BioResources 13(4), p. 8569–8577.

KRILEK, J., KOVAČ, J., KUČERA, M. 2014. Wood crosscutting process analysis for circular saws. In BioResources 9(1). p. 1417‒1429. ISSN: 1930-2126. http://dx.doi.org/10.15376/biores.9.1.1417‒1429

KÚDELA, J., MRENICA, L., JAVOREK, Ľ. 2018. The influence of milling and sanding on wood surface morphology. In Acta Facultatis Xylologiae Zvolen, Vol. 60, no. 1, p. 71–83, ISSN 1336-3824.

MC MILLIN, CH. W., WOODSON, G. E. 1972. Moisture content of southern pine as related to thrust, torque, and chip formation in boring. In Forest Product Journal, vol. 22, 1972, no. 11, p. 55–59.

PRADEEP KUMAR, B., INDRA KIRAN, N. V. N., PHANI KUMAR, S. 2017. Effect of cutting parameters in drilling of EN8 (080M40) Carbon steel to obtain max. MRR and min. temp. By using RSM (under dry condition). In International Journal of Engineering and Management Research 7, p. 533–539.

SIKLIENKA, M., ŠAJBANOVÁ, D. 2002. The influence of chosen factors on torque and thrust during boring of some kinds of woods. In Trieskové a beztrieskové obrábanie dreva ´02, 2002, Zvolen: TU Zvolen, 2002, s. 231–234. ISBN 80-228-1190-4.

SIKLIENKA, M., ŠAJBANOVÁ, D. 2003. The influence of chosen factors on torque and thrust during boring of pine wood. In Forest and wood processing technology and the enviroment, 2003, Brno: MZLU; Praha : Ministerstvo zemědelství ČR, 2003, s. 385‒392. ISBN 80-7157665-4.

SIKLIENKA, M., KMINIAK, R., ŠUSTEK, J., JANKECH, A. 2017. Delenie a obrábanie dreva. Zvolen: TU vo Zvolene, 357 s., 2017. ISBN 978-80-228-2845-1.
SZWAJKA, K., TRZEPIECIŃSKI, T. 2017. An examination of the tool life and surface quality during drilling melamine faced chipboard. In Wood Research, 62(2), p. 307–318.
ŠAJBANOVA, D., SIKLIENKA, M., VACEK, V. 2002. Vplyv vybraných faktorov na osovú silu a krútiaci moment pri vŕtaní smrekového dreva. In Valivé ložiská a strojárska technológia 2002, Žilina: TU Žilina, 2002, s. 136–140. ISBN 80-7135-999-7.

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