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DEVELOPMENT AND APPLICATIONS OF A FREE CUTTING BY NONCONVENTIONAL TOOLS

VÝVOJ A APLIKÁCIA VOĽNÉHO OBRÁBANIA NEKONVENČNÝMI NÁSTROJMI

Abstract

In publications concerning unconventional schemes can be seen working draft of different designs of rotation turning tools and tools with linear cutting edge. Sporadically, this tools has appeared in the specialized publications. So far its operational characteristics, mainly its considerable influence on machined surface quality, exceptional durability and possibility to be used to turn hard machinable and other materials. Some of its priorities are verified in this paper.

Abstrakt

V publikáciách, ktoré sa týkajú nekonvenčných schém obrábania možno vidieť návrh rôznych konštrukcií rotujúcich sústružníckych nožov a nožov s lineárnou reznou hranou. Tieto nástroje sa sporadicky objavujú v odborných publikáciách. Doteraz nie sú docenené ich prevádzkové charakteristiky, najmä významný vplyv na kvalitu obrobenej plochy, ich mimoriadnu trvanlivosť a možnosť aplikácie na obrábanie ťažkoobrábateľných a iných materiálov. V tomto príspevku sa pokúsime niektoré z ich priorít verifikovať.

Keywords

Rotation turning tools, quality, durability, hard machinable materials.

1 INTRODUCTION

Around year 1250 a pedal, from which a rope loop lead to the workpiece towards a flexible bar, which was hung and worked as a return spring (Fig. 1), started to be used for turning. It meant that the lathe operator had his hands free for the work with knife. The engraving shows the process of turning very illustratively. The lathe operator used a blade knife adjusted to the purpose. A tree branch worked as a spring. Support had not existed yet. The power of cutting resistance was caught by hands, therefore the knife handle had to be long enough. The principle of turning could be called „*rotary planing*“. Wide and thin chip, the direction of which is equivalent to the movement direction of all elements along the cutting edge, is released. Machined surface is smooth like after planing, because it copies only micro uneveness of the cutting edge.

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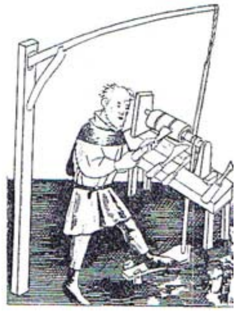


Fig. 1 Pedal lathe with reversible rotary movement from year 1250

Fig.2 shows two original tools from the collection of the author. It is necessary to say that at the time of their production (1770) they were probably thoroughly forged as they are subjects of minimal corrosion.

Fig. 2 Original tools for turning at pedal lathe (collection of author)

Angular cut (Fig. 3) is the alternative to the free cut. In Fig. 3 there is a scheme of angular cut during planing (term „*rhombic-angle cut*" is used as well because the cutting edge is placed obliquely towards the vector of cutting speed).

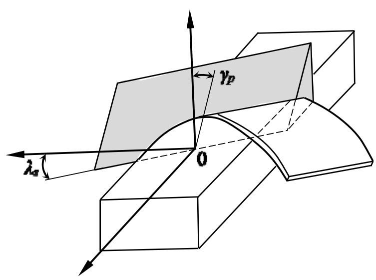


Fig. 3 Scheme of free cut during planing

2. BOUND CUT AND ITS ASPECTS

However, the development came to knives with rounded tip. By this, the mechanism of chip and surface creation got more complicated. The term „*bound cut*" emerged. At bound cut, the elements of machined material move from the chip verically towards the cutting edge, that means that they stand in the way of their motion (Fig. 4 and 5). This is the reason why the chip is more deformed. The force of cutting resistance has grown considerably. Machined surface is not given by copying the linear cutting edge any more, but by its rounded part. The height of surface uneveness has grown sharply in comparison with free cut. [1-4]

The direction of the chip leaving can be determined as the result of vectors of motion of different elements of chip according to Fig. 5. Another way is linking the points of the start and end of the contact of cutting edge with the workpiece. The chip leaves in the direction of the perpendicular to this line segment. [5,6]

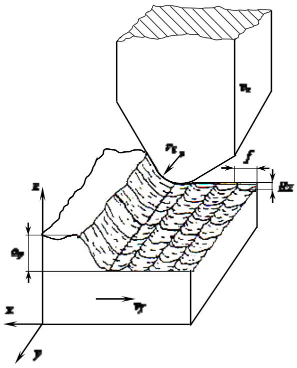


Fig. 4 Bound cut during planing

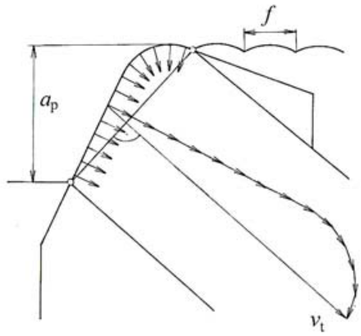
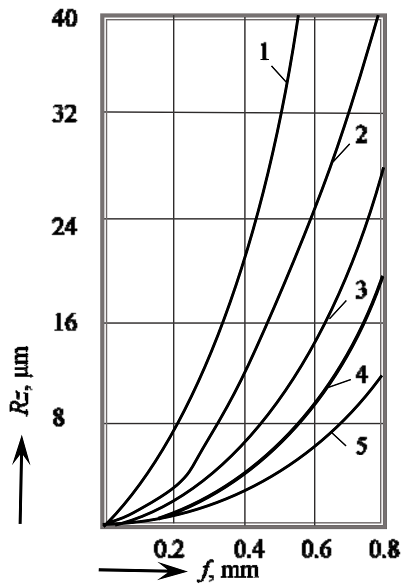


Fig. 5 Determination of the direction of chip leaving for bound cut, a_p-cut depth, *f*-shift, v_t- vector of chip leaving

3. TURNING BY FREE CUT

It is well-known that by increasing the tip rounding radius of the tool the quality of machined surface increases. [7,8] In Fig. 6 there is graphic interpretation of famous equation for the determination of the highest profile height unevenness *Rz*:



$$Rz = \frac{f^2}{8.r_\varepsilon} \qquad (1)$$

Fig. 6 Theoretical dependence among *Rz,* shift and radius of tool tip. 1-5, gradually $r_\varepsilon = 1 \div 5$mm

A tool with infinite radius or linear (single) cutting edge (Fig. 1 and 2) are limit case of increasing the radius of tool tip. Basically it is a principle of necking tool but inclined by the angle λ_s. Turning principle with such a tool is pictured in Fig. 7. It is possible to implement bidirectional tool shift. [9-13]

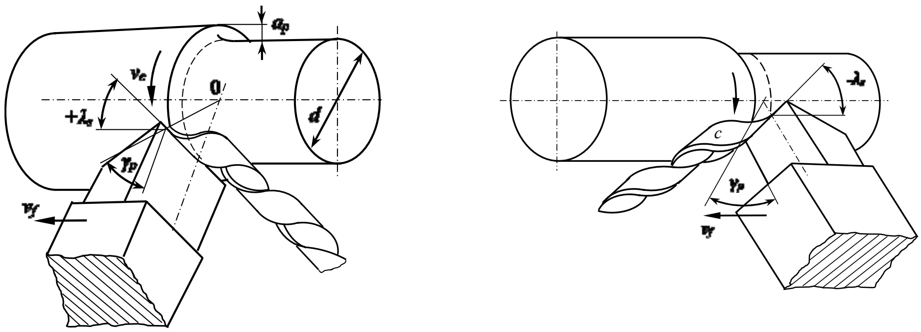


Fig. 7 Scheme of turning by a knife with linear cutting edge, inclined by angle $\pm\lambda_s$

In comparison with the tools with tip radius, the lenght of side cutting edge in gear is much greater than of the main one. It can be determined from Fig. 8.

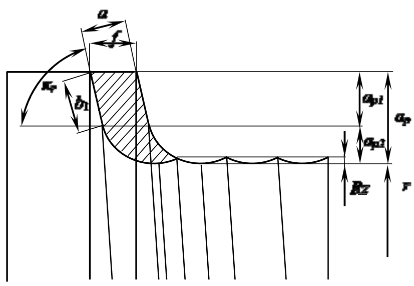


Fig. 8 Area of chip cross section created by turning by a tool with linear cutting edge

Cutting edge is placed nonparallelly towards the workpiece axis, according to Fig. 9.

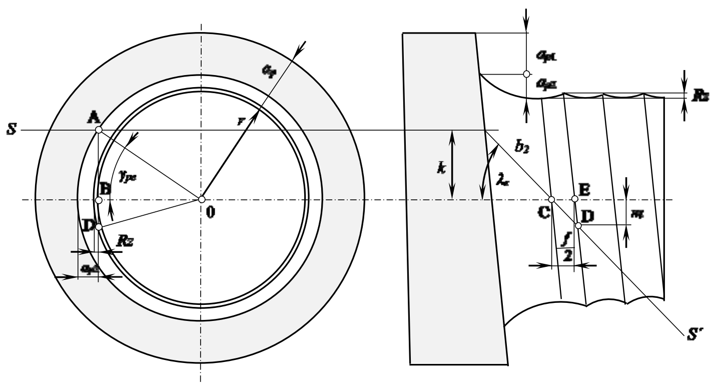


Fig. 9 Scheme for determination of length of side cutting edge in gear

If, for the sake of simplicity, we select $\kappa = 90°$

$$b_1 = \frac{h}{\sin\kappa_r}$$

From Fig. it is clear that:

$$AO = \sqrt{AB^2 + OB^2}\ .$$

After installing

$$r + a_{p2} = \sqrt{k^2 + r^2} \ .$$

From that, it is true for finishing cut depth:

$$a_{p2} = \sqrt{k^2 + r^2} - r. \qquad (2)$$

For the length of side cutting edge in gear we can write:

$$b_1 = \frac{a_{p1} - \left(\sqrt{k^2 + r^2} - r\right)}{\sin \kappa_r} \qquad (3)$$

The length of side cutting edge in gear consists of two sections, b_1 and b_2. It is valid that:

$$\sin \lambda_s^{'} = \frac{k}{b_2} .$$

From that

$$b_2 = \frac{k}{\sin \lambda_s} .$$

It is also true that:

$$\cos \lambda_s^{'} = \frac{f}{2.b_2} \cdot$$

Because for total length of cutting edge in gear it passes that:

$$b = b_1 + b_2 + b_2^{'} , \qquad (4)$$

After installing we get the following equation:

$$b = \frac{a_p - \left(\sqrt{k^2 + r^2} - r\right)}{\sin \kappa_r} + \frac{k}{\sin \lambda_s} + \frac{f}{2.\cos \lambda_s} . \qquad (5)$$

For maximum thickness of cut-off layer it is true that:

$$a = f.\sin \kappa_r^{'} .$$

From Fig. 7 also the equation for the highest machined surface uneveness height can be derived:

It is valid:

$$tg\lambda_s^{'} = \frac{2.m}{f} .$$

From that:

$$m = \frac{f}{2}.tg\lambda_s^{'} .$$

It is also true that:

$$m^2 = (r + Rz)^2 = r^2 .$$

After adjustment:

$$r + Rz = \sqrt{m^2 + r^2} - r .$$

After installing we get the resulting equation:

$$Rz = \sqrt{\frac{f^2}{4}.tg^2\lambda_s^{'} + r^2} - r\,. \tag{6}$$

We have got an equation, which defines the height of profile uneveness created by side linear cutting edge. [14]

The tool has certain specifications also in the creation of working angles. For example, working angle of main cutting edge inclination in point *A* is defined from Fig. 9:

$$\lambda_{se} = \gamma_{pe} = arctg\frac{k}{r + a_{p1}} \tag{7}$$

and reaches zero value as far as point *C*.

It is also valid that:

$$\lambda_s = \gamma_{fe} \tag{8}$$

and when $\kappa_r = 90°$ and $\gamma_o = 0$, also

$$\lambda_s = \gamma_{fe} = \gamma_{fn} \tag{9}$$

Many experimental test during turning different materials have been made with this tool. Typical constructions of cutting tools can be seen in Fig. 10.

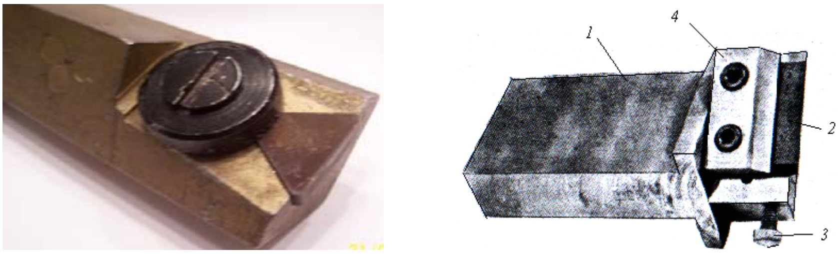


Fig. 10 Tools with linear cutting edge. 1 - holder, 2 - cutting plate, 3 - adjusting screw, 4 - clamp

With the first tool, it is possible to turn the operational part of cutting plate after it becomes worn out, with the second one it will do just to move it to a new position by the screw, number 3. For the first tool, also worn out plates on the tip from previous classical turning can be used.

4. APPLICATION FOR WOOD TURNING

As our predecessors used this principle for wood turning, they obviously knew about its excellent features. We will try to copy it with the use of modern tools.

In Fig. 11 there is experimental dependence of the highest profile uneveness height on cutting speed obtained during turning of wooden workpiece. As it can be seen, uneveness maximum is at the tool with tip in the range 50-170 $m.min^{-1}$. Adhesive co-interception of the chip with tool face can be presupposed in this range of cutting speeds also with this material. When using tools with linear cutting edge, the influence of cutting speed on uneveness height is very small.

Decrease of the highest profile uneveness height is substantial in all range of used cutting speeds.

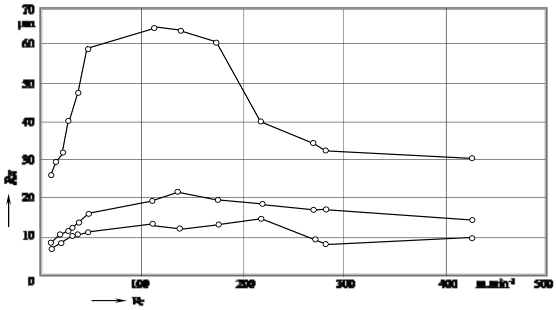


Fig. 11 Experimental dependence of highest profile uneveness height on cutting speed for wood cutting. a_p = 0,5 mm, f = 0,3 mm, workpiece: hornbeam, tool: SK P20

Similar result has been obtained for turning different kinds of wood.

Observation of thin cut of creating chips shows substantial plastic deformation similarly to ones of steel (Fig.12). In observed case, the chip pressure has value $k = 4$.

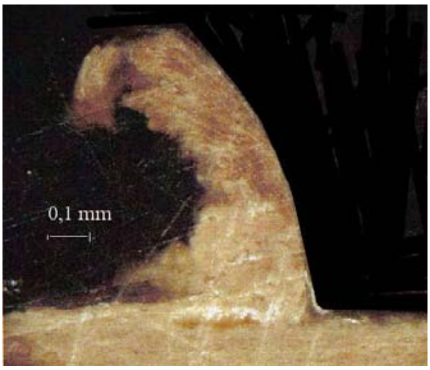


Fig. 12 Chip root recorded during turning wood with cutting speed 100 m.min^{-1}.

In Fig. 13 there is recording of three surfaces, machined by tools with different tip radiuses, made by profilometer.

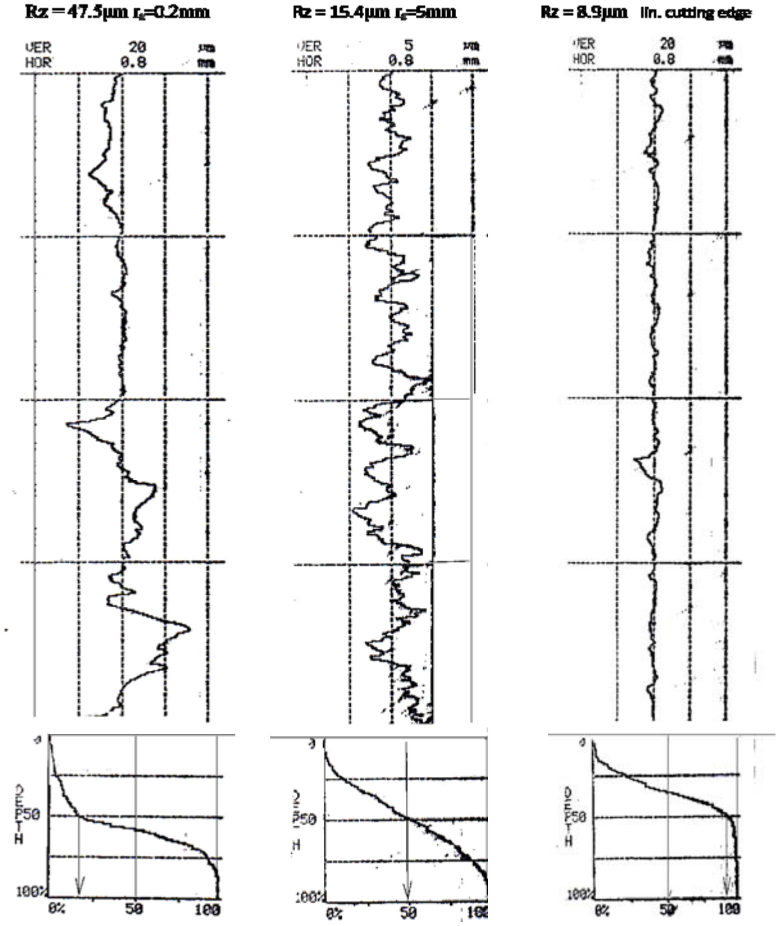


Fig. 13 Recording of machined surface profile of wood after turning with tools with different tip radiuses.

It can be seen that the curve of material share has different character. With radius r_ε = 0,2 mm, the material share is only 20% for 50% profile depth. With the increase of r_ε material share grows. With r_ε = 5mm it is 50% and for turning with a tool with klinear cutting edge it is as high as 90%. This profile is highly sufficient.

5. TURNING WOOD WITH BOWL-SHAPED ROTATING KNIFE

As it can be seen from Fig. 6, with increased tool tip radius the quality of machined surface improves, it means we are approaching the conditions of free cut. Bowl-shaped rotating knives are typical example of tools with large radius. Their application used to be hindered by the problem of their suitable placement. Rolling bearings used to have distinctive dimensions, sliding bearings used to be sensitive to sliding clearance. The problems was solved by adjustable conic sliding bearing (Fig. 14).

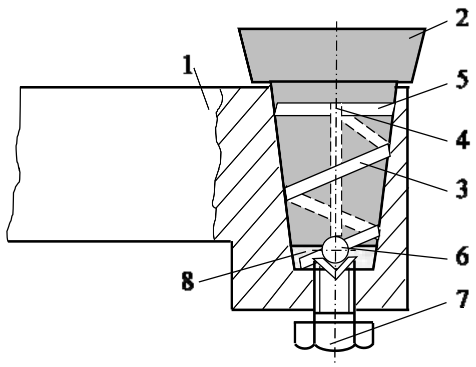


Fig. 14 Sliding bearing with adjustable clearance [15]. 1 - holder, 2 - bowl-shaped knife, 3 - lubricative groove, 4 - radial hole, 5 - groove, 6-ball, 7 - adjusting screw, 8-oil

The tool can rotate by cutting speed or with the help of outer drive. Besides, it can have positive or negative angle of inclination of cutting edge. In Fig. 15 there is a case of turning with negative angle of inclination. Active section of cutting edge, which is in gear with the workpiece, is under the level of workpiece axis. If tool face angle equals zero, face working angles will be negative in every point of active cutting edge.

In Fig. 16 there is an opposite case. The angle of cutting edge inclination is positive and the face angles are positive in all points of active cutting edge.

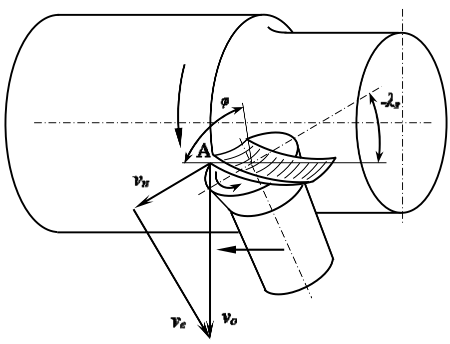


Fig. 15 Turning with bowl-shaped rotating knife at - λ

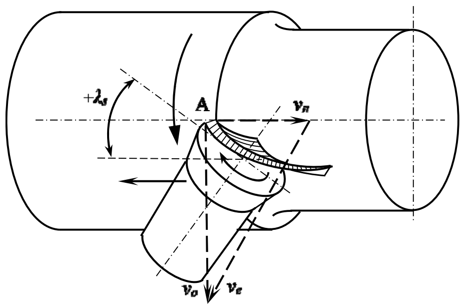


Fig. 16 Turning with bowl-shaped knife with positive angle of cutting edge inclination

To determine the height of uneveness of machined surface, it is necessary to use the scheme of cutting edge position in basic plane, according to Fig. 17.

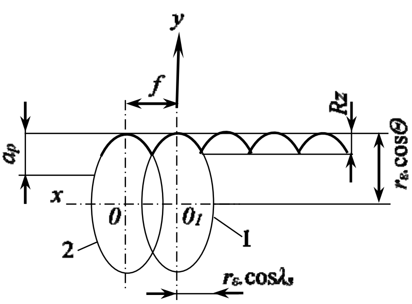


Fig. 17 Scheme for determination of height of profile uneveness for turning with round tool. 1; 2- positions of tool after one turn

The equation of ellips *1* in coordinate system *x- y* will be:

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1. \tag{10}$$

Ellips *2* is presented by the position of the tools at previous turn of the workpiece:

$$\frac{(x-x_0)}{a^2}+\frac{(y-y_0)}{b^2}=1. \tag{11}$$

For ellipses axes from Fig. 7.89 it is true that

$$a=r_\varepsilon.\cos\theta$$
$$b=r_\varepsilon.\cos\lambda$$
$$x_0=0$$
$$y_0=f$$

After installing:

$$\frac{x^2}{r_\varepsilon^2.\cos^2\theta}+\frac{(y-f)^2}{r_\varepsilon^2.\cos^2\lambda_s}=1 \tag{12}$$

Because $y=\frac{f}{2}$, after the substitution for x axis it will be:

$$x=\frac{\cos\theta}{2.\cos\lambda_s}.\sqrt{4.r_\varepsilon^2-\cos^2\lambda_s-f^2}. \tag{13}$$

For *Rz* it is valid that:

$$Rz=r_\varepsilon.\cos\theta-x.$$

After installing and adjustment:

$$Rz=r_\varepsilon.\cos\theta-\frac{1}{2.\cos\lambda_s}\sqrt{4.r_\varepsilon^2.\cos\lambda_s-f^2}. \tag{14}$$

It can be seen that *Rz* depends on three parameters: $Rz=\mathrm{f}(\lambda_s;r_\varepsilon;f)$. Given equation does not include cutting speed because it is not geometric characteristic. Its influence on *Rz* depends on deformation characteristics of machined material. This dependence can be determined only experimentally.

In Fig. 18 there is a view on the process of turning of wooden workpiece by a bowl-shaped knife.

Fig. 18 Turning of wood with rotating bowl-shaped knife

In Fig. 19 there is an example of experimental dependence of highest profile uneveness height on workpiece circumference speed v_o. (Note: This speed is not cutting speed. Cutting speed v_c is vector difference of workpiece circumference speed v_o and tool circumference speed v_n):

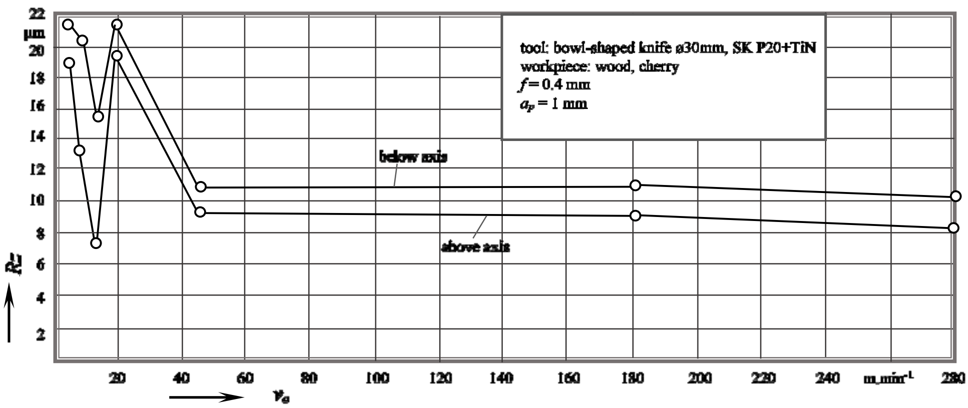


Fig. 19 Experimental dependence Rz on v_c for wood turning

It can be seen, that with low circumference speeds, *Rz* oscillates in wide limits. After reaching certain circumference speed of workpiece, *Rz* is constant in both cases. This fact can be explained by real cutting speed, which is relative speed between the rotating tool and rotating workpiece. However, technology presents interesting perspective for turning and milling wood.

6. CONCLUSION

The application of free cut for machining wooden workpieces shows as perspective one. With suitable construction of cutting tools and their geometry, interesting practical results can be reached.

REFERENCES

[1] GRANOVSKIJ, G. I., GRANOVSKIJ, V. G.: Cutting metallov. Moscow: Higher School 1985, 304 s.

[2] HOSHI, K., HOSHI, T.: On the metal cutting mechanism with the built-up edge. *Mem.Fac. Engng. Hekkaide University* 12, č.3, 1969

[3] PETRU, J.; SCHIFFNER, J.; ZLAMAL, T.; CEP, R.; KRATOCHVIL, J.; STANCEKOVA, D.: Wear progress of exchangeable cutting inserts during Ti(6)Al(4)v alloy machining. In. *METAL 2015*: 24Tth International conference on metallurgy and materials, pp. 1147 – 1155

[4] KALPAKJIAN, S.: *Manufacturing engineering and technology.* New York: Addison Wesley Publishing Company, 1989, pp.1999, ISBN 0-201-12849-7

[5] WEBER, H., LOLADZE, T.N.: *Grundlagen des Spanens.* Berlin: VEB Verlag Technik, 1986, 255 s.

[6] NOVAK, M.; NAPRSTKOVA, N.; JOZWIK, J.: Analysis of the surface profile and its material share during the grinding inconel 718 alloy. In. *Advances in science and technology-research journal*, 2015, Volume: 9, Issue: 26, pp. 41-48

[7] VASILKO, K., PILC, J.: New technological knowledge of the rotary turning tool. In. *Manufacturing Technology*, Volume 13, Issue 4, December 2013, Pages 571-575, ISSN: 1213-2489

[8] RUDAWSKA, A., RESZKA, M., WARDA, T., MITURSKA, I., SZABELSKI, J., STANČEKOVA, D., SKOCZYLAS, A.: Milling as a method of surface pre-treatment of steel for adhesive bonding, *Journal of Adhesion Science and Technology*, 2016.

[9] FELHÖ, Cs., KUNDRÁK, J.: Surface roughness determination in turning of cylindrical surfaces. *Manufacturing Technology,* vol.. 9, December 2009, pp.16-22, ISSN: 1213-2489

[10] MÁDL, J,: Design for Machining. In. *Manufacturing Technology*, vol.. 9, December 2009, pp.81-85, ISSN: 1213-2489

[11] ČEP, R.; JANÁSEK, A., ČEPOVÁ, L.; PETRŮ, J.; HLAVATÝ, I.; CAR, Z.; HATALA, M. Experimental Testing of Exchangeable Cutting Inserts Cutting Ability. *Tehnicki Vjesnik-Technical Gazette*, Vol. 2013, 20, No. 1, pp. 21-26, ISSN 1330-3651.

[12] FULEMOVÁ, J., ŘEHOŘ, J.: Influence of form Factor of the Cutting Edge on Tool Life during Finishing Milling. In *Procedia Engineering*. Vídeň: Elsevier Ltd, 2015. s. 682-688.

[13] VALÁŠEK, P., MÜLLER, M., HLOCH, S.: Recycling of corundum particles – two-body abrasive wear of polymeric composites based on waste. In. *Tehnicki Vjesnik-Technical Gazette*, vol. 22, 3/2015, pp 567-572.

[14] PILC, J. – MIČIETOVÁ, A.: *Metalworking auto rotating tools*. Žilina: EDIS, 2003. 105 p.

[15] VASILKO, K., PILC, J.: Sliding fit rotating lathe knife. *Patent SR No*. 211831, 21.3.1980