CHIP REMOVAL CHARACTERISTICS IN ROTATIONAL TURNING AND THE EFFECT OF THE TOOL DIAMETER ALTERATION

Kundrák, J.; **janos.kundrak@uni-miskolc.hu**
Sztankovics, I.; **istvan.sztankovics@uni-miskolc.hu**
Deszpoth, I.; **istvan.deszpoth@uni-miskolc.hu**

Abstract: *The cutting procedures applied in finishing operations differ from each other in the characteristics of the chip-removal and the quality (or integrity) of the machined surface. Furthermore, the values of efficiency and the expenditure are varying as well. In this paper we show some of the characteristic properties of material removal and the topography of the machined surface in rotational turning. In addition, we show the alteration effect of the tool diameter on the axial feed of the tool and the roughness parameters of the surface.*
Keywords: *rotational turning, chip removal, hard turning, complex edge geometry*

1. INTRODUCTION

From the machining operations used in the manufacturing of various products, special interest and attention to development are given to finishing operations. This is because these procedures crucially determine the surface quality of the machined parts and hereby its lifetime (Shaw, 2005). As more and more parts with hardened surface are produced, hard machining in finishing operations became more important. The effectiveness of machining procedures with defined and undefined cutting edge geometry needs to be raised continuously in these operations to achieve the proper economical goals. Nowadays it can be obtained with hard turning which was only accessible with grinding procedures in the first century of production technology: surfaces with 65 HRC hardness can be machined with the proper accuracy (IT5-IT6) and surface roughness (R_z = 1…3 μm).
This procedure must be developed further so it can be more effective and more suitable for the requirements of the working conditions.
One way of development can be the research of procedures which have different kinematic relations and inevitably different cutting edge geometry. The rotational turning (Weisser, 2004) is one of these procedures. With this hard turning method the goal is the achievement of equivalent chip removal conditions with precision machining and the reach of at least the same accuracy and roughness values as in grinding while the effectiveness of the cutting can be increased. With this procedure the variety of the machinable part geometries increases compared to the traditional hard turning due to the alteration of the force components rate (for example long shafts can be machined). Further advantage of rotational turning can be the untraditional surface topography (Klocke et al., 2013).
The special cutting tool and the kinematics of rotational turning allow us to generate different surface topography from those machined in other procedures. This is more suitable for different working conditions as well.

2. GEOMETRICAL AND KINEMATICAL CHARACTERISTICS

The untraditional kinematic relations of rotational turning are explained based on Figure 1. One of the most important features of this procedure is the specially constructed tool whose edge has a helical geometry parallel with the workpiece symmetry axis. The material removal is done by the slow rotation of the tool during the fast rotation of the workpiece.

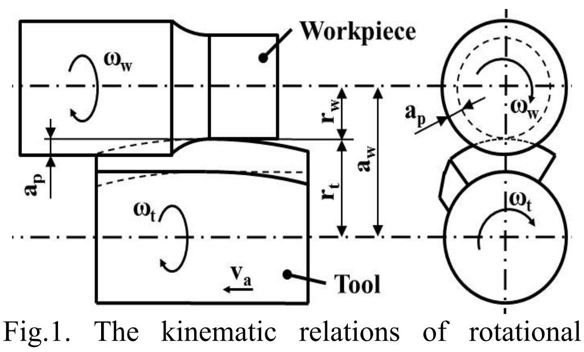

Fig.1. The kinematic relations of rotational turning ($\omega_w >> \omega_t$)
The procedure is characterized by these parameters:
Geometrical parameters:

- initial surface radius of the workpiece (R_w)

- machined surface radius of the workpiece (r_w)
- inclinational angle of the cutting edge (λ_s)
- radius of the tool (r_t)

Parameters to be adjusted on the machine:

- revolutions of the workpiece (n_w)
- revolutions of the tool (n_t)
- symmetry axles distance (a_w)
- supplementary axial feed rate (v_a)

The basic geometrical setting of rotational turning can be described with two bound skew lines. One of these is the centre line of the workpiece. The other line is the tangential line to the helical curve of the workpiece, which are oscular in the reference plane. The normal transverse, which connects the two lines, is the machined surface radius of the workpiece. The inclination angle is defined in the cutting edge plane due to the bound position of the two lines.

For the continuous chip removal the main cutting speed and feed rate must be provided. The former is generated with the fast rotation of the workpiece. In the definition of the feed rate source the two main cases of rotation must be taken into consideration: in the first case (basic) the length of the surface of the workpiece to be machined is lower than the axial projection of the helical edge of the cutting tool; however in the other case the length of the workpiece is higher than the later. In the first case the axial feed rate generated from the rotational movement of the tool is enough to machine the whole length of the workpiece. This axial feed rate is generated by the inclinational angle of the cutting edge. In the second case along with the rotational movement additional axial feed must be applied to the tool in order to finish the machining of the whole surface. The axial motion of the intersection point of the transverse and the edge is caused by the previously described feed. The line defined by the intersection point is one generatrix of the machined surface of the workpiece.

By the definition of the basic geometrical settings and the kinematic relations the chip removal characteristics can be.

3. CHIP REMOVAL CHARACTERISTICS

The construction of the tool, which is used in the rotational feed procedure, is significantly different from the one used in traditional turning. Therefore, the load on the tool, which comes from different sources, will be different as well. In traditional turning the same point of the cutting edge moves along the generatrix of the cylindrical machined workpiece surface. Therefore, the wear of the tool is focused in the nose of the cutting edge, while this effect decreases in other points of the main and side cutting edge. In rotational turning all points of the edge osculate the generatrix of the workpiece due to the rotational movement of the tool. That is why the wear of the cutting edge is scattered along the edge. Furthermore in traditional turning the heat is also focused in one point (in the nose of the edge) due to the one point generation of the machined surface. In rotational turning the heated part of the cutting edge leaves the chip removal zone due to the rotation of the tool while another lower temperature section of the edge continues the cutting. In this case the heat stress of the tool becomes more balanced.

Due to the helical edge geometry of the tool the inclinational angle between the edge and the reference plane is higher than the usual values in traditional turning. While in the latter case this parameter covers several degrees, rotational turning can be specified by tools with 30…50° inclinational angle. Thereupon different characteristics are shown by the arising forces during the cut. The dominant force on the workpiece will be the axial – or feed directional – component of the force system instead of the radial component due to the high inclinational angle. Therefore, the opportunity presents itself to use rotational turning in case of machining workpieces whose machinability is limited by hard turning (for example shafts with high length to diameter ratio).

The cross-sectional area of the chip will also be different from traditional turning. The cut surface will be hyperbolical due to the cutting conditions characterised by the two skew lines. Therefore, the shape of the chip cross-sectional area will be similar to the shape in side milling as compared with the parallelogram shape in traditional turning.

During the machining three main phases of the cut can be separated by the alteration of the chip cross-sectional area in rotational turning. In the first phase the chip cross-sectional area increases as the tool rotates (run-in phase), then it shows constant values during the further rotation of the tool (constant phase). Lastly this parameter continuously decreases as the cutting edge gets out from the workpiece (run-out phase). The axial length of the first and third phase can be considerable in rotational turning. There are cases when the constant phase does not occur during the cut.

Due to the hyperbolical shape of the cut surface another feature will be different from traditional turning: the theoretical roughness topography. The productivity of the manufacturing is limited greatly by the quality specifications of the surface machined by the traditional longitudinal turning. As is well known, in finishing operations the feed rate is defined by the nose radius of the tool, by the major and side cutting edge angles and by the surface roughness determined by the designer. The reason for this is that periodically structured, easily measurable micro-grooves are generated by the nose of the cutting edge.

However, in rotational turning this is also different. It can be stated that the surface topography will be decisively different from traditional turning due to the special kinematic relations and the untraditional construction of the tool. During the examination of the theoretical roughness profile we stated that the total height of profile will be substantially smaller than in traditional turning (Sztankovics & Kundrák, 2013). In addition the wave length of the profile will be higher. In Figure 2 the roughness profile of the traditional and rotational turning can be seen. For the comparison we defined a single point cutting tool with 0.8 mm nose radius and 0.1 mm feed. The parameters of the rotational turning tools are the followings: tool radius: 100 mm; inclinational angle of the edge: 50°; revolutions of the tool: 0.43 1/min; revolutions of the workpiece: 450 1/min. The different roughness profile in rotational turning can be seen in Figure 2.

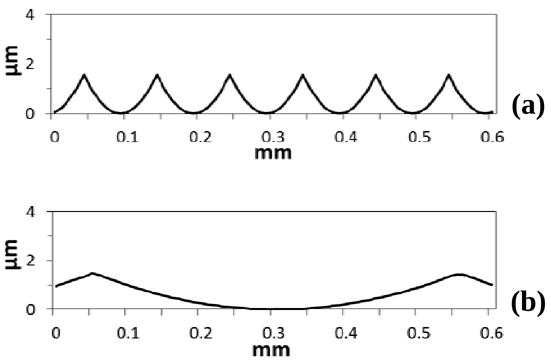

Fig.2. Roughness profile of traditional (a) and rotational (b) turning

4. THE ALTERATION EFFECT OF THE TOOL DIAMETER

Finally we calculate the characteristic parameters of rotational turning through an application example with previously determined methods. Furthermore, we examine the alteration effect of the tool diameter on the axial feed and the arithmetic mean deviation of the roughness profile. The initially taken values are the followings:

- workpiece diameter: d_w=60 mm
- workpiece length: L_w=40 mm
- depth of cut: a_p=0.2 mm
- tool diameter: d_t=20 mm
- axial length of the tool: L_t=35 mm
- tangential feed: f_t=0.18 mm/rev.
- inclinational angle: λ_t=30°
- cutting speed: v_c=180 m/min

First the machining time can be calculated from these parameters (Kundrák et al., 2012). Hence the workpiece length is higher than the axial length of the tool the additional axial feed rate of the tool must be calculated.

$$t_m = \left[2\pi\sqrt{\frac{a_p d_t d_w}{d_t + d_w}} + \frac{L_w}{\tan\lambda_t}\right]\frac{1}{d_t \pi \omega_t} \cong 4.5\ \mathrm{s} \quad (1)$$

$$v_a = \frac{L_w - L_t + 2}{t_m} = 94\ \frac{\mathrm{mm}}{\mathrm{min}} \quad (2)$$

The revolutions of the workpiece and the tool can be calculated from the cutting speed and the tangential feed:

$$n_w = \frac{v_c}{2\pi r_w} = 955\ \frac{1}{\mathrm{min}} \quad (3)$$

$$n_t = \frac{v_{f,t}}{2\pi r_t} = \frac{f_t n_w}{2\pi r_t} = 2.72\ \frac{1}{\mathrm{min}} \quad (4)$$

With these parameters the resultant axial feed is determined (Sztankovics & Kundrák, 2013):

$$f_a = \frac{v_f}{n_w \tan\lambda_t} + \frac{v_a}{n_w} = 0.41\ \frac{\mathrm{mm}}{\mathrm{rev}} \quad (5)$$

The values of the total height of profile and the arithmetic mean deviation based on previous calculations (Sztankovics & Kundrák, 2013; Sztankovics, 2013):

R_{max}=0.2343 µm, R_a=0.058 µm.

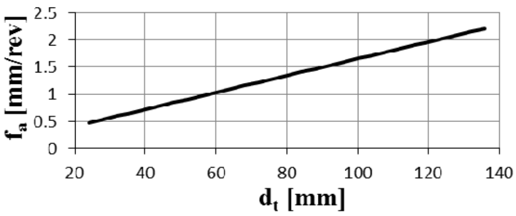

Fig.3. Resultant axial feed (f_a) in function of the tool diameter

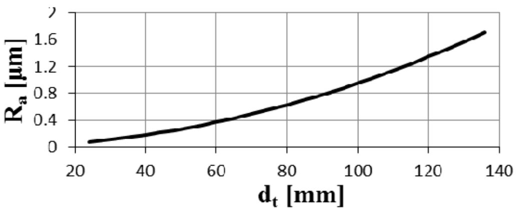

Fig.4. Arithmetic mean deviation (R_a) in function of the tool diameter

It can be seen from the calculations above that the feed is higher than the feed in other finishing procedures while the theoretical roughness values remain suitable.

The following task is the examination of the alteration effect of the tool diameter. The need for the change of this parameter occurs for example if we want to increase productivity. Therefore the effect of the tool construction alteration on the axial feed rate and the theoretical roughness must be defined (with leaving the other parameters unchanged).

As it can be seen in Figure 3, the effect of the tool diameter alteration on the resultant axial feed is almost linear. This is caused by the increase of the tangential feed – and hereby the axial feed – by the increase of the tool diameter while the tool revolutions per minute remains the same.

Therefore as the tool diameter increases the machining time will decrease. However it must be taken into consideration that the requirements of the surface quality must be met. Therefore, the alteration of the theoretical roughness must be examined as well. The change of the arithmetic mean deviation is almost linear as can be seen in Figure 4. This is caused by the changed tool geometry which transforms the cut surface. In this way the theoretical roughness parameters will increase as the feed increases.

5. SUMMARY

The geometrical and kinematical relations of rotational turning and the description of the chip removal are more complex than traditional turning. These come up in the construction of the tool, the shape of the chip cross-sectional area and the characteristics of chip removal. In this study these features are described and the alteration effect of the tool diameter is defined on the resultant axial feed and the theoretical arithmetic mean deviation by an application example. It is determined that with the three-fold increase of the tool diameter – while the other parameters remain the same – the axial feed increases to almost triple its original value while the theoretical value of the arithmetic mean deviation increases to eight-fold its original value (but it does not exceed its expected value).

6. ACKNOWLEDGMENTS

This research was (partially) carried out in the framework of the Center of Excellence of Innovative Engineering Design and Technologies at the University of Miskolc.

The work was presented by the support of the Hungarian Scientific Research Fund (Number of Agreement: OTKA K 78482), which the authors greatly appreciate.

7. REFERENCES

►J.G. Weisser Söhne GmbH & Co (2004). Patent Anmeldung, St.Georgen, Germany

►Klocke, F.; Bergs, T. & Degen, F. (2013). Presentation of a novel cutting technology for precision machining of hardened, rotationally symmetric parts. *Production Engineering*, Vol. 7, Issue 2-3, pp. 177-184, ISSN: 0944-6524

►Kundrák, J.; Gyáni, K.; Deszpoth, I. & Sztankovics, I. (2012). Technology planning of hard turning in case of rotational feed. *Proc. of International Conference on Innovative Technologies*, pp. 295-299, ISBN:978-953-6326-77-8

►Shaw, M. C. (2005). *Metal Cutting Principles*, Oxford University Press, New York

►Sztankovics, I. & Kundrák, J. (2013). Theoretical Value of Total Height of Profile in Rotational Turning. *Applied Mechanics and Materials*, Vol. 309, pp. 154-161, ISSN: 1662-7482

►Sztankovics, I. (2013). Theoretical Value of Arithmetic Mean Deviation in Rotational Turning. *Műszaki Tudományos Füzetek - Fiatal Műszakiak Tudományos Ülésszaka XVIII.*, pp. 391-394, ISSN: 2067-6808 (in Hungarian)