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ROTATIONAL TURNING IN PRECISION FINISHING

I. SZTANKOVICS✉

University of Miskolc, Department of Production Engineering, H-3515 Miskolc Egyetemváros, Hungary
✉E-mail: istvan.sztankovics@uni-miskolc.hu

This paper shortly describes modern hard machining methods and some of the possibilities of rotational turning. The methods of tangential feed turning are grouped by the numbers of cutting edges, the path of the feed rate and the position of the cutting edge. The important geometrical characteristics of rotational turning are summarized to analyse it for simplification. Finally, based on the results simpler tool geometry was created and some calculations were made for the preparation of an experiment.

Keywords: rotational turning, hard turning, tangential feed

Introduction

Nowadays the use of hard machining methods in finishing operations plays a crucial role. These operations use super hard cutting tools in the machining of hardened steels (HRC>45). Hard turning and hard milling appeared in the industrial environment.

Earlier the operations used in precision finishing of cylindrical surfaces were the followings: rough and smooth turning before heat treatment for specified hardness, followed by grinding operation. In grinding the tool and the workpiece are in contact in a continuous, long line. The heat development caused by the frictional force is high. Therefore we need to use some kind of coolant intensively, which will turn into hazardous waste after the process [1].

The appearance of super hard cutting tools (e.g. PCBN) has enabled to develop appropriate machining methods to fulfil the demands of environmental protection. One of the most important features of cubic boron nitride tools is their great hardness and for this reason these tools can be used in machining of hardened steels. [2, 3] Other attributes of these tools are also acceptable for machining operations. It is significant that there is no need to use any kind of coolants contrary to other cutting tool materials.

With the use of super hard cutting tools the machining technologies of hardened surfaces have been altered. Grinding operations are not necessary to use because hardened surfaces can be machined by PCBN tools, therefore the machining operations will be more environment-friendly unlike older methods [2, 3].

However, like every technology hard turning has some disadvantages. One of this is caused by the path of the tool during turning operations. Since the edge of the tool moves one unit in axial direction during one turn of the workpiece, the chip is cut off from the surface helically. The depth of this generated groove depends on the construction of the tool, the used technological parameters and the hardness of the machined surface. The dimension of the depth is around 10 μm.

Due to this micro-thread on the workpiece the areas of applications of the hard machined surfaces are limited. Hard turning cannot be used in some cases, for example on the treads of needle roller bearings and on surfaces below sealings.

The easiest solution of this problem is to partially return to grinding operations. To do this we must apply a machine which can make the turning and grinding operations in one place without the movement of the workpiece [2]. This way the punctuality of the operations can be increased. The thickness of the material cut during the process is lower than in regular grinding operations, therefore this combined technology is more environment-friendly unlike the grinding operations in the past decades [3].

Another solution for the micro-thread problem is the application of a new hard machining technology, which does not create helical grooves on the surface. One of the applicable methods is the turning with tangential feed.

Tangential feed in turning operations

Tangential feed is a turning method if the direction of the feed is tangent to the machined surface. There is a special form of tangential feed, if the edge of the tool is on a circular path. In that case the direction will be tangent in the cutting zone.

Tangential feed can be achieved with different tools: it can be executed with standard tools or with designed monolithic prismatic or cylindrical cutting tools.

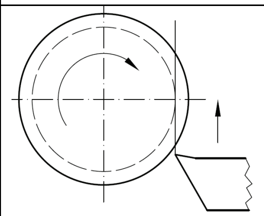
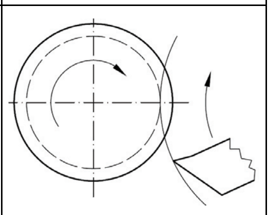
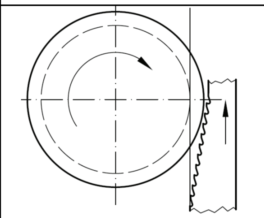
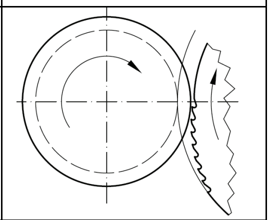
Grouping of tangential feeds
by the path of the tool edge

By the path of the tool edge the tangential feeds can have two groups. These methods can be linear or circular. The operation uses linear tangential feed, if the edge is on a linear path and the path is tangent to the machined surface of the workpiece. The tangential speed of the surface, caused by the rotation of the workpiece, needs to be much higher than the speed of the tool. The other method is the circular tangential feed. In this case the edge of the tool is on a circular path, and this circle will be tangent to the machined surface. The vector of the workpiece's speed and the cutting tool's speed will be parallel. During the machining the angular speed of the cutting tool needs to be much lower than the angular speed of the workpiece.

Grouping of tangential feeds
by the number of the cutting edges

Two groups can be created by the number of the cutting edges in tangential feed turning operations. The cutting tool can be single-edged or multi-edged. In the previous case the design of the tool is very simple. The production is easier and in case of fracture or if the tool wear passes beyond the wear-criteria the replacement is quicker. In multi-edged design the depth of cut splits up in multiple segments. The combined grouping by the number of cutting edges and by the path of the tool edge is shown in *Table 1*.

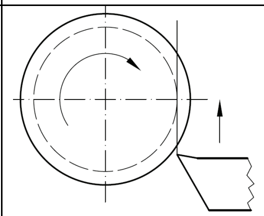
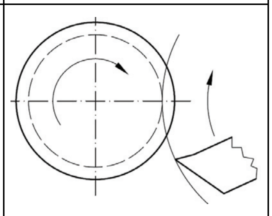
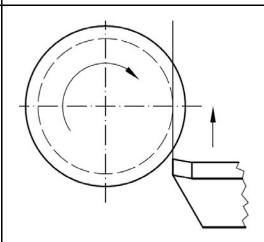
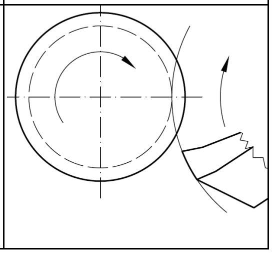
Table 1: Grouping of tangential feeds by the path of the tool edge and the number of cutting edges

		Path of the tool edge	
		Linear	Circular
Number of edges	Single-edged		
	Multi-edged		

Grouping of tangential feeds
by the spatial position of cutting edge

Similar to other cutting tools, the cutting tools for methods using tangential feed can have different cutting edge inclination angles. The grouping by the spatial position of cutting edge is presented in *Table 2*. When the cutting edge inclination angle is equal to zero (λ=0°), the design and the production of the tool is simpler. Therefore the acquisition cost of the tool is lower and in case of fracture or if the tool wear passes beyond the wear-criteria the replacement is quicker. However, when the cutting edge inclination angle is not equal to zero (λ≠0°) just a part of the edge is in contact with the workpiece at the beginning of the process. During the machining the depth of cut continuously grows to the defined value and it remains constant until the ending phase of the cut. Accordingly, from the viewpoint of the load this case is substantially better than the zero inclinational angled case. At the beginning of the cutting the dynamic force is low. In the middle phase the static force does not affect the tool life dramatically.

Table 2: Grouping of tangential feeds by the path of the tool edge and the inclinational angle of the edge

		Path of the tool edge	
		Linear	Circular
Inclinational angle	$\lambda = 0$		
	$\lambda \neq 0$		

Comparison of tangential feed turning methods

According to the observations above the following conclusions can be made:

By the direction of the feed it is better to use circular feed operations. In this case the efficiency of the machining will be better.

By the design of the tool it is better to favour a single-edged construction. With the simpler design and production some of the tool costs can be spared.

By the spatial position of the tool edge it is better to design the tool with some inclination angle. However, the production of the tool will be more difficult, but it is better because there is no significant dynamic force.

To sum up we can make the following conclusions: in hard machining methods with tangential feed it is practical to use single-edged tool with non-zero inclination angle and to apply circular feed. The best solution is when the edge is on a helical curve on the superficies of the tool. This way we get the tool for rotational turning [4].

Machining with rotational turning

Henceforth the paper presents one of the recent tangential feed methods of hard machining. In tangential feeds the rotational turning is a method with circular feed, and uses a single-edged tool with non-zero inclination angle.

Fig. 1 shows the sketch of rotational turning [5]. The symbols in Fig. 1 are the following:

d_{wz} – blank diameter
d_w – workpiece diameter
d_s – tool diameter
n_w – revolutions per minute of the workpiece
n_s – revolution per minute of the tool
a_p – depth of cut
$f_{a,v}$ – virtual axial feed

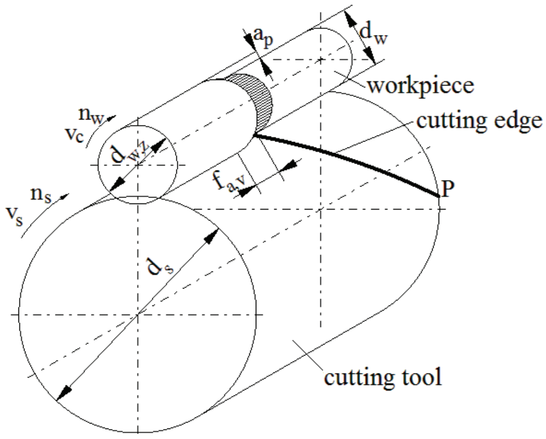


Figure 1: Sketch of rotational turning

In Fig. 1 we can see that during the cutting the edge of rotating tool generates a hyperboloid-like surface. Therefore it is difficult to define the cross-section of the chip. Point P is the point of the tool's edge which touches the workpiece first. The depth of cut continuously grows during the beginning phase of the cut by the rotation of the tool [4]. During the ending phase the edge continuously leaves the workpiece, therefore the depth of cut decreases smoothly. In the middle phase the cross-section of the chip remains constant.

The characteristics of the cutting tool

Rotational turning requires a special tool. The edge is on a helical curve on the superficies of the tool. With this design the relative angular offset of the edge can be guaranteed. The pitch of the helical curve affects the cutting conditions: if the pitch is high the relative angular offset of the edge will be small in the cutting zone; if the pitch is low the tool will be very short. By circular feed the method demands a special machine-tool and tool clamping system so the rotational motion of the tool can be ensured [6].

Machinable workpiece length

The machinable workpiece length cut by rotational turning depends on the use of axial feed by the circular feed. Basically the value of the axial feed is equal to zero. In this case the machinable workpiece length is shorter than the axial length of the tool. In the other case there is an axial feed besides the circular feed. If the values of the circular and axial feed are correctly calculated and set in the machine then longer surfaces can also be machined by rotational turning.

In *Fig. 2* a machining case is shown, where the axial feed of the tool is equal to zero [5]. The symbols of Fig. 2 are the following:

L_w – machinable workpiece length
d_w – workpiece diameter
n_w – revolutions per minute of the workpiece
$v_{f,t}$ – relative tangential feed speed
$v_{f,a}$ – relative axial feed speed
P – beginning point on the cutting edge
P' – beginning point on the workpiece
V – ending point on the cutting edge
U' – ending point on the workpiece

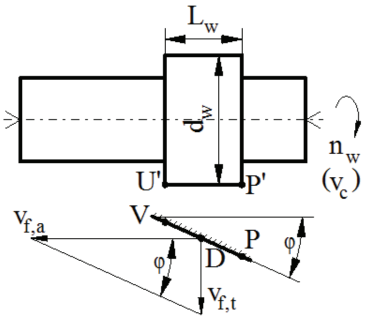


Figure 2: Explanation of the machinable workpiece length

In Fig. 2 we can see that at point P of the edge begins the cutting in point P' of the workpiece and at point V of the edge finishes the cutting in point U'. If the workpiece is longer than the axial length of the cutting tool additional axial feed speed is also applied. Its value must be high enough to enable point V of the tool's edge to reach point U' of the workpiece.

Simpler tool edge geometry

Simpler tool edge geometry was created for further experiments on rotational turning. The basis of the simplification is the following: in the cutting zone the helical curve of the cutting edge is equal to a line with the pitch angle of α. With this method we can use a linear edge instead of the complicated helical curve edge for geometric investigation of the process.

For the preparations of the experiments it is necessary to make it clear how long the cutting edge should be for the cutting. To make these calculations we need to create a sketch based on the simplifications.

This sketch is presented in *Fig. 3*. The symbols in Fig. 3 are the following:

l – minimal length of the cutting edge
b – projected length of the cutting edge
d – diameter of the machined workpiece
a – depth of cut
α – theoretical pitch angle

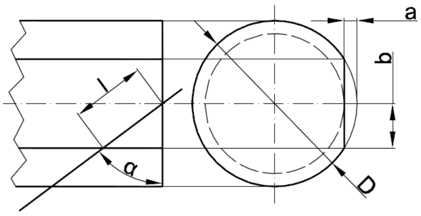


Figure 3: The theoretical sketch of the linear edge

The last point of the edge which is involved in the cutting stays at the middle line of the workpiece (there is no cutting above the middle line because the surface is already machined). The depth of the cut can also be seen in Fig. 3. However, in this case axial feed is applied, but this model is geometrically a good approximate solution to observe the alterations in the cutting zone during machining.

The calculation of the cutting edge's minimal length

The minimal length of the cutting edge can be calculated with the formula based on the sketch; the length is in function of the diameter of the machined workpiece, the depth of cut and the theoretical pitch angle. The projected length of the cutting edge is calculated first with the use of the Pythagorean Theorem and the result will be the function of the workpiece's diameter, the depth of cut. The minimal length of the cutting edge will be the function the pitch angle and the projection length of the edge.

Equation (1) is applied to calculate the minimal length of the cutting edge, which is a function with three variables.

$$l(D,a,\alpha)=\frac{\sqrt{\frac{p^2}{4}-\left(\frac{p}{2}-a\right)^2}}{cos\,\alpha} \quad (1)$$

Two of the three variables is locked down to plot the function. The diameter of the machined surface has to be constant; this way the minimal length can be analysed to a given workpiece. The pitch angle is also locked down so the depth of cut will be the variable. The minimal length of the cutting edge is presented in *Fig. 4*. In this graph various cases of the pitch angle are drowned to choose the optimal case for a 100 mm diameter workpiece.

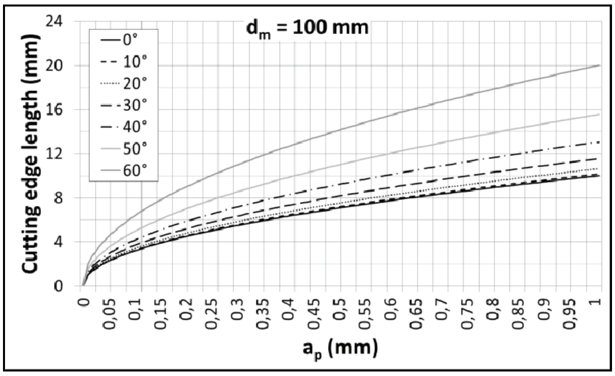


Figure 4: Cutting edge length, d_m=100 mm

Conclusions

It has been shown that in tangential feed machining methods rotational turning is a good and productive alternative in hard machining methods. With the examination of the minimal length of the cutting edge we can conclude that there is no need of a long edged tool for the initial experiments of the research.

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