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DEVELOPMENT IN MACHINING TECHNOLOGY

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This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

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PREFACE

Machining is one of the most popular technique to change shape and dimensions of the objects. Machining operations can be applied to work metallic and non-metallic materials such as ceramics, composites, polymers, wood.

Cutting tools have been used since ancient times to remove excess material from forgings and castings. Nowadays, metal cutting became one of the primary manufacturing processes for finishing operations. In the last few years we have observed a rapid development in automation of manufacturing processes, especially in automatic control systems. Progress in cutting stimulates a significant increase in the metal removal rate and achieving high accuracy in terms of dimensions and shape of machine parts. New materials, which play the key role here, are used to produce cutting tools.

To meet today's high demands concerning accuracy and efficiency of the manufacturing process of machine parts, it is necessary to use computer methods for designing of technological processes.

This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

Wojciech Zębala

PART 1

Machining of Difficult-To-Cut Materials

Chapter 1.4

HARD TURNING WITH ROTATIONAL FEED PROCEDURE

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***Abstract**: The rotational feed turning is the newest version of hard turning. Its tool is made from PCBN whose edge is a slowly turning helix with high helix angle, the feed of which originates from the axial velocity components lying on the edge points of the helix. Its feeding methods differs from the traditional hard turning, because, theoretically, on the generated surface there are no feeding tracks created in this case. The cutting relations are complicated from geometrical point of view, therefore, in this paper our aim was to clarify the cutting relations of this procedure as well as to determine the characteristic sizes and cross section of chips.*

***Keywords**: hard machining, rotational feed, chip formation*

1. Introduction

Hard turning in precision or ultraprecision procedures are of great importance both for researchers and for manufacturers. Among them the latest introduced hard turning stands in the focus of interest, because it rapidly became widespread due to its undoubted technical, economic and environmental benefits. Hard turning makes it possible to finish steel surfaces of up to 65-70 HRC hardness, with IT5 or smaller size accuracy and $Rz \leq 3$ μm surface smoothness. In over the first 100 years of production engineering, such rather demanding quality for steel machining was possible to be produced only by grinding procedure. The grinding procedure, however, having been applied so far (wide wheel, small depth of cut) are slower and more expensive processes than hard turning. As a results on a world scale the piece number of certain components – first of all short, disc-type components – ready machined by hard turning amounts to billions [1], for example in automobile industry. The reason for that is that the accuracy of hard turning, the roughness parameters of the turned surfaces are equal to that of grinding or they may be even better.

The quick development of the procedure and the research results drew the attention to some factors influencing the safety of the process. Machining by a single point cutting tool, the tool wear may cause problems affecting both the surface quality [2, 3, 4] and the process safety. Moreover, the process kinematics causes scroll-forming [5, 6] on the surface, which is not allowed on sealing surfaces and joint surfaces. Furthermore, the high values of passive force raise problems of the achievable accuracy, rigidity problems of axes with large ℓ/d relation and those of clamping problems is components with small wall thickness.

The turned topography is periodical, which actually is a thread surface where the lead of thread is equal to the feed, however, the thread depth is equal to the maximal roughness. Connecting with steel surfaces the danger of pitting increases, and the self-holding taper surfaces connect, a higher force is needed to separate them. The ground topography, however, consists of irregular, random set of scratches of different sizes.

Retaining the extraordinary economic advantages of hard turning, a new version of this procedure has been developed – the rotational feed turning – which creates another types of surface topography. One of the theoretical characteristics of rotational feed turning is the turning done with 0° tool cutting edge angle, its special tool and special kinematics make it possible to reduce or eliminate the disadvantages of turning. Rotation turning is a hard machining procedure defended by a firm related patent, which generates completely smooth, twistfree surfaces [1, 7] keeping all the advantages of hard turning.

2. The characteristics of the machining

The main characteristic feature of the procedure is a very slowly rotating PCBN tool. So the helix cutting edge, as a result of the slow rotation, can be interpreted as axial and tangential feed. And thus, the whole length can be ready machined (Fig. 1) for example in case of external cylindrical surfaces – to which this paper is confined first of all – with a very significant time saving, if some further conditions are net. In the presented scheme (Fig. 1) the clamping of the workpiece and the "theoretical" tool correspond to reality. But the turned aside position of the tool is distorted. On the workpiece in stopped position $\mathbf{a_p}$ depth of cut, can be interpreted, $\mathbf{d_w}$ ready diameter, $\mathbf{d_{w,z}}$ prefabrication diameter can be seen, which contains $\mathbf{z}$ diameter allowance. And also can be marked the hyperbolic transitional surface connecting the two sections whose width equals to $\boldsymbol{\ell}_a$. For the workpiece cutting speed ($\mathbf{v_c}$) is indicated, which is about 160÷200 m/min so that the optimal conditions of cutting are provided. The body of the tool is of cylindrical shape with $\mathbf{d_s}$

diameter, on it there is the PCBN cutting edge with a steep helix. The whole operating length of the tool edge is marked **P'V** in Fig. 2. In the figure the tool angle state is in a position having just finished the material removal and its last point indicated **V** is leaving the workpiece. The rotation of the tool is very slow, enough only for some determined axial feed interpreted $\mathbf{f_a}$ in the figure, during one revolution of the quickly rotating workpiece, because of the bevel helix edge. From the theory of operation it is clear that the tool edge moves along the generatrix lying in the common tangent of the workpiece and the tool, not forming either any furrows or any periodical patterns.

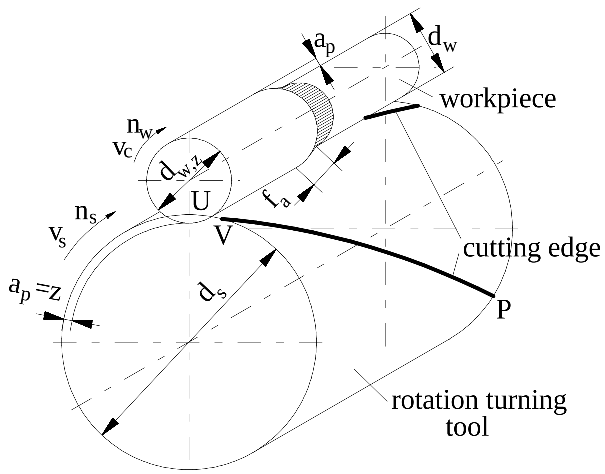

Fig. 1. Theory of material removal in rotation turning (typical phases)

3. Characteristics of chip formation

The tool positioned in the right working state begins to rotate slowly and the starting point of the edge marked **P** reaches the workpiece (Fig. 2). Turning on, **b** width of chip gradually increases and when **P** reaches **P'** position, **b** also reaches its maximum **P'V** maximum value of the three dimensional helix. This phase is called initial phase during which the tool turns aside by $\boldsymbol{\vartheta_{in}}$ angle. It is followed by the constant phase when **b** width of chip is constant and at last **V** point leaves the material. In this phase too, the typical points introduced in the initial phase can be interpreted. That is, they complete material removal as "running point" and generate the surface of the workpiece. During leaving **b** width of chip decreases until **U** edge point in **U'** leaves the material. The other size of the chip, **h** width of chip is constant along the edge, its numerical value can be calculated on the basis of the geometrical and kinematic relationships that are shown in the figure. Part **c** of Fig. 2 displays the spatial chip cross section in two views with distorted geometrical conditions due to its delineatebility. Further investigations are needed to determine the limit value, $\mathbf{h}_{\mathbf{min}}$ of the cutting yet achievable.

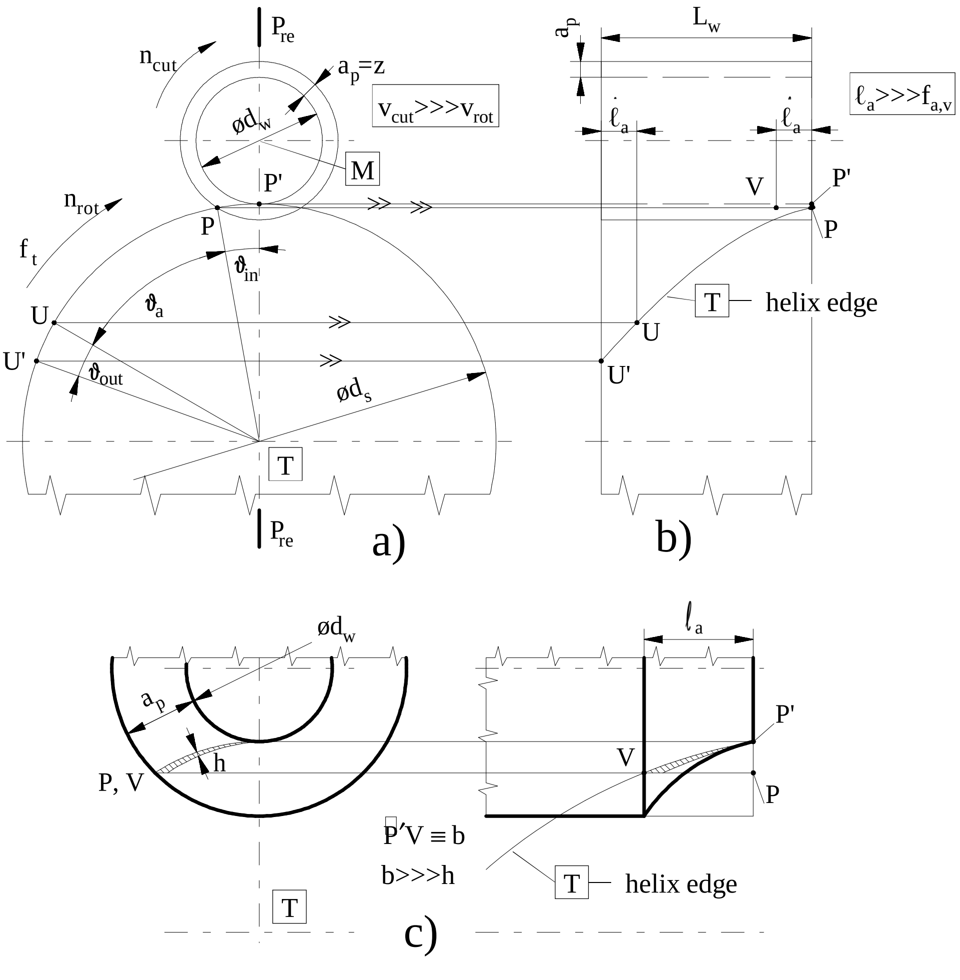

Fig. 2. Chip formation in rotational turning (distorted geometrical relations)

a) motions in plane perpendicular on axle

b) typical positions of tool edge

c) spatial chip cross section in views

Interpretation of indication:

n_w	rotary speed of workpiece:	1/min
n_s	rotary speed of tool:	1/min
d_w	diameter of workpiece:	mm
d_s	diameter of tool:	mm
a_p	depth of cut:	mm
f_a	axial “virtual” feed:	mm/workpiece revolution
f_t	tangential “virtual” feed:	mm/workpiece revolution
z	allowance in radius:	mm
ϑ_{in}	initial angular displacement:	degree
ϑ_{out}	running out angular displacement:	degree
ϑ_a	constant angular displacement:	degree
b	chip width	mm
h	chip thickness	mm

Definition of angular displacement of the tool

To calculate ϑ_{in} initial angle PP’ arc length is needed to be known. When going out, through the symmetry ϑ_{out} is the same. As it is very short, $a_p \approx 0.1$ mm or smaller, an approximation is applied: instead of a circular arc a chord is used for calculation. Accordingly:

$$PP' = \left(a_p \cdot \frac{d_s \cdot d_w}{d_s + d_w} \right)^{1/2} \quad \vartheta_{in} = \vartheta_{out} = \frac{360 \cdot PP'}{d_s \cdot \pi} \tag{1}$$

To calculate the angular displacement of the constant phase it is needed to know the “lead of thread” of the tool edge (**p**), and the length of the workpiece to be machined. On the basis of technical literature [6]:

$$\vartheta = \frac{L_w}{p} \cdot 360 \tag{2}$$

The **p** lead of thread according to technical literature [6]:

$$p = d_s \cdot \pi \cdot tg\left(90° - \varphi\right) \tag{3}$$

The relationship between the tool angle displacement and the width of chip is shown in Fig. 3. The **b** width of chip can be calculated on the basis of Fig. 2.

The shape of the chip is ribbon-like, whose width is b and its thickness is of micrometer scale.

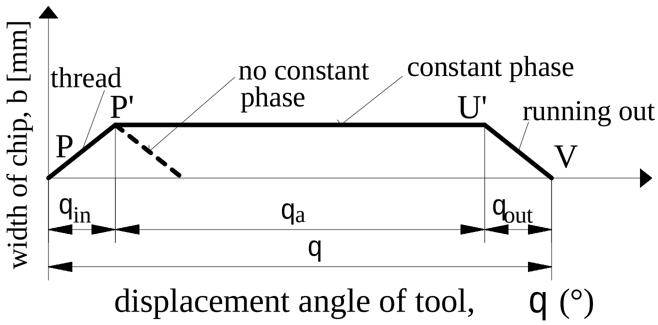

Fig. 3. Change of the width of chip, its phases during the operation of the cutting edge

4. The application of rotational turning

The procedure, the tools and the needed lathe machine family are J. G. Weisser Werkzeugmaschinenfabrik's patent application (St. Georgen, Schwarzwald, Deutschland) [8]. It can be applied for the machining of internal and external cylindrical surfaces, planes and cones. Intermittent surfaces can be machined too. The greatest advantage of this procedure is the creation of twistfree surfaces and its productivity surpassing traditional hard turning. The following also belongs to the advantages: the machining goes dry, the investment expenditure is lower and the process safety is higher [3, 9].

The roughness that can be reached is Rz≤4μm and Ra≤0.6μm that is the same as by grinding but it is possible to reach even Ra≈0.2μm either. While the accuracy of the machining can reach IT5 ISO quality. The parallelism of the generatrixes is ≈4 μm, their straightness is ≈3 μm. In Fig. 4 the rotation turning of an external cylindrical surface is shown with the characteristic cutting data.

Let us note that the newest tools are single pointed and the expensive PCBN tool material is soldered on the hard metal substrate in a lath-like formation. The tool edge can be captured in a fixture which is fastened in the turret of the lathe in the same way as the other tools [4]. The PCBN applied as tool edge is of medium CBN content, TiN bonded, with 2 μm grain size. Its hardness and impact strength make it suitable for intermittent surfaces too. The cost of the tool is moderate, about five times higher than that of an advanced wiper-insert [9]. The length of the cutting edge can be maximum 30 mm. If it is not enough, the tool must give straight-line feed along Z-axle besides rotation. This, however, does not spoil the quality of the generated surface. It lengths the size of the so called constant phase that can be seen in Fig. 3.

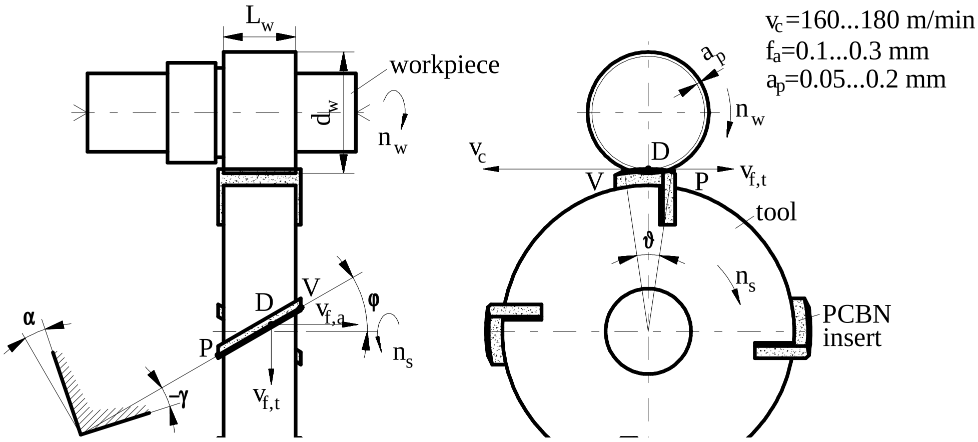

Fig. 4. Rotation turning of an external cylindrical surface

5. Conclusion

The specific surface creating method of rotational turning that differs from the traditional turning makes new topography on the surfaces of workpieces. It can be applied for sealing, needle roller bearings rings and synchronous conical surfaces. On the places it is not necessary to apply the expensive and slower grinding. Chip formation goes on with highly complicated geometrical relations. The generatrix of the ready cylindrical surfaces is theoretically twistfree, free from any feed tracks, lining or periodical formation. The advantages of the environmentally friendly dray and clean machining is kept, its productivity, however, increases – because of the relatively longer feed along the axle – as compared to the traditional hard turning.

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