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MATERIAL REMOVAL CHARACTERISTICS IN ROTATIONAL AND TANGENTIAL TURNING

Rotational and tangential turnings are two special variants of hard turning. They can eliminate a disadvantageous characteristic of ordinary hard turning, namely, the generation of periodical topography. This study reveals common and different features of both rotational method and the long-known tangential turning method. Common features make the complex chip removal mechanism of rotational turning easier to understand. The calculation of chip thickness and width becomes simpler. However, while the cutting technical parameters can be drawn on planar surfaces in a tangential method, these parameters obtain a 3D spatial form in rotational turning due to the helical edge. The extremely high productivity of rotational turning and the kinematical relations of the machining system are illustrated by several examples. Both methods are supplementary solutions because their extensive use requires expensive tools, which result in economic problems.

4. INTRODUCTION

The rapid spread of hard turning has significantly increased the economic efficiency of machining hardened parts. This type of turning often replaced grinding methods and grinding machines and thus, manufacturing processes were significantly shortened. Although there is no significant difference between accuracy and roughness parameters, the surface topography or texture produced by the two methods is different.

The hard machined topography is periodical; it consists of regularly repetitive elements, which are extremely delicate and are located in a thread-like form on the surface of a workpiece. The pitch of this thread-like topography is equal to the feed per revolution and the depth of the thread is the same as the value of the maximal roughness (R_{max}). Although the sharp thread produced on the hardened steel surface is very fine, it cannot be applied in some functional roles of mechanical mechanisms. It is not applicable in the following cases: sealing, needle roller bearings and synchronisation cones in transmissions [1, 2].

The main aim of the development of hard turning was to avoid the application of the grinding method and to make the random topography similar to the ground one possible to create.

5. MATERIAL REMOVAL PRINCIPLE IN ROTATIONAL TURNING

The material removal principle in rotational turning can easily be understood from Figure 1. For practical reasons, the rotated position of the tool is illustrated in the phase when the whole length of the edge of the **PV** helical cutting edge leaves the cutting zone. However, the workpiece is shown in a half-finished state so that the occurring definitions of the cutting method can be interpreted.

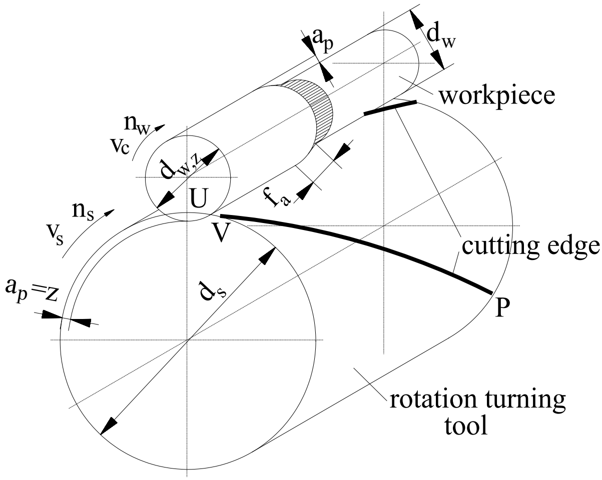

Figure 1 – Material removal principle in rotational turning (typical phases)

The shape of the tool shank is theoretically cylindrical with ds diameter and the PCBN (polycrystalline cubic boron nitride) cutting edge is located on a helical curve. The acting length of the cutting edge is the section marked **PV**. The pitch angle of the helical curve must be defined during tool design processes and it must be known for technology planning processes. The slowly rotating tool reaches the workpiece with its **P** point and leaves it with its **V** point at the **U** point marked on the workpiece. The rotation of the slowly rotating tool generates a feed value of several tenth millimetres for one revolution of the swiftly rotating workpiece due to the skewness of the edge. This feed is marked $\mathbf{f_a}$ in Fig. 1. It becomes clear from the operation principle that the edge of the tool moves on a path of the common tangent plane of the workpiece and does not create a groove or any other kind of periodical pattern on its surface.

Figure 1 illustrates the workpiece sketched in the half way position with the depth of cut ($\mathbf{a_p}$), the axial feed ($\mathbf{f_a}$), the finished diameter ($\mathbf{d_w}$), the diameter ($\mathbf{d_w}$) increased by the allowance (**z**), the hyperboloid-like surface connecting the rough and finished diameters and representing the cutting zone, the cutting speed ($\mathbf{v_c}$) with its values varying between 160…200 m/min in order to eventuate the optimal condition for the PCBN tool. The remaining symbols are as follows: peripheral speed ($\mathbf{v_s}$) and angular speed ($\mathbf{n_s}$) of the tool, angular speed ($\mathbf{n_w}$) of the workpiece.

6. CHIP REMOVAL MECHANISM IN ROTATIONAL TURNING

Rotational turning is one of the newly used hard machining methods with an announced pattern of a firm [5]. This method keeps all the advantages of hard turning, but besides this, it generates a smooth twist-free surface. However, it has a disadvantage since it requires a special tool, whose machining costs are far more expensive than those of standard tools.

While conducting research into the history of rotational turning, this study came across tangential turning existence in the technical literature for a long time [6]. Figure 2 demonstrates the close relation between the two methods and illustrates the geometrical relations of rotational and tangential turning. The figure shows a section view in an optionally chosen **A** point of the tool in the work plane. The allowance **z** on the workpiece is slightly overdrawn so that some of the regularities can clearly be seen.

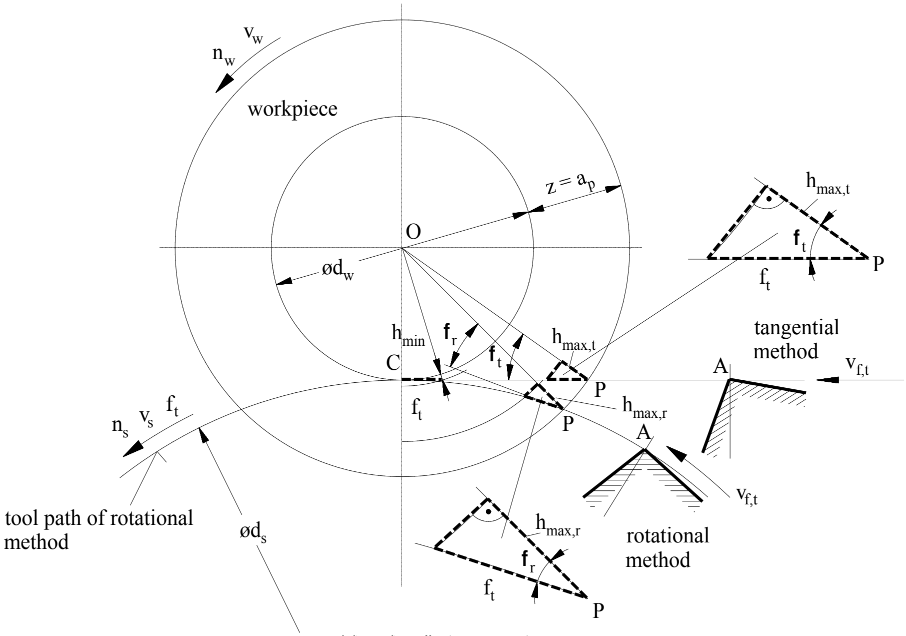

Figure 2 – Relation between rotational and tangential turning

The main difference between the two methods is well illustrated in Figure 2. It is shown that the tangential feed ($\mathbf{f_t}$) describes a linear path in one case and a circular path in the other case. The diameter of the rotary movement is the tool diameter ($\mathbf{d_s}$) in Fig. 2. The chosen **A** point of the cutting edge describes a linear path in tangential turning and a circular path in rotational turning while reaching **C** point. The speed – the $\mathbf{v_{f,t}}$ tangential component –in both cases is the same, because the tangential feed ($\mathbf{f_t}$), whose dimension is mm/workpiece revolution, is also the same. It can be stated that tangential turning is a special case of rotational turning performed by an infinity-diameter tool. The differences may be interesting from a theoretical point of view. However, in practice these differences are hardly visible due to the very small chip size. This statement is confirmed by the technical literature dealing with this issue [7].

As for the rotational turning dealt with in this paper, it can be stated that one of the important sizes of the chip (the chip thickness) varies when the tool performs a rotary movement. The definition of the chip thickness (**h**) can be seen in Figure 2; the maximal value (**h_{max}**) occurs at the beginning of cutting phase and is of minimal value (**h_{min}**) in the last phase. The maximal value can easily be calculated by applying the tangential method. In rotational turning some parts are to be neglected because the hypotenuse and one of the legs of the rectangular triangle used in the calculation are formed by circular arcs. From Figure 2 the following equation is obtained:

$$h_{max} = f_t \cdot \cos\varphi = f_t \cdot \frac{\overline{PC}}{d_w + z} = f_t \cdot \frac{\sqrt{z \cdot (d_w + z)}}{d_w + z} \text{ mm.} \tag{1}$$

The chip thickness (**h**) gradually decreases while the tangential feed (**$v_{f,t}$**) is constant. The minimal value is reached in the last required revolution of the workpiece (**C** point). While performing technological planning, it is important to note, that:

$$h_{min} \geq 0{,}1 \cdot r_\beta \tag{2}$$

where **r_β** is the fillet radius of the cutting edge or in shorter form: edge radius. Several researchers dealing with cutting method share the opinion that there is no chip formation if the value of the edge radius is less than 0.1 **r_β** [8, 9, 10].

In order to calculate h_{min}, the number of revolutions during which point A of the tool gets from point **P** to point **C** must be known (Figure 3). If **f_t**, one of the system input data, is known, the calculation is as follows:

$$n_{w,szüks} = \frac{\overline{PC}}{f_t} = \frac{\sqrt{z \cdot (d_w + z)}}{f_t} \text{ 1/min,} \tag{3}$$

Whereby

$$h_{min} = \frac{z}{n_{w,szüks}} = \frac{z \cdot f_t}{\sqrt{z \cdot (d_w + z)}} \text{ mm.} \tag{4}$$

The value of **r_β** for an average quality cutting tool is 30 μm, whereby 0,003 mm comes for **h_{min}**. The chip thickness will increase from this value to **h_{max}** along the tool path (**PC**) which is linear in tangential method and circular in rotational turning method (Figure 3).

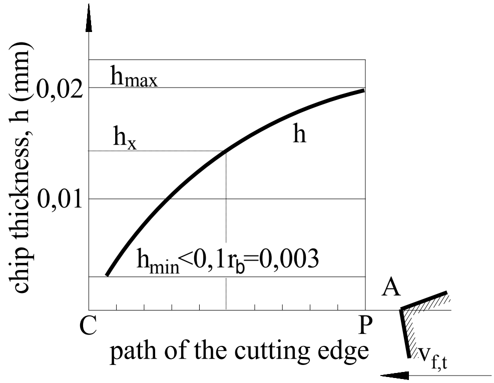

Figure 3 – Chip thickness is different along the points of the cutting edge

7. THE EFFECT OF THE SKEW ANGLE ON THE CHIP FORMATION

In order to describe further details the skewness of the cutting edge must be taken into consideration, which is characterised by the **λ** skew angle. As the previously cited technical literature states, the value of **λ** can be between 20° and 45°. The importance of the skew angle can be experienced firstly in the productivity and then in the surface quality parameters. As for productivity realised in the main usage of the machine, it can be shown on a geometrical basis that if the tangential feed is the same, the smaller **λ** angle (e.g.,20°) results in higher axial feed (**f_a**) than the larger **λ**.

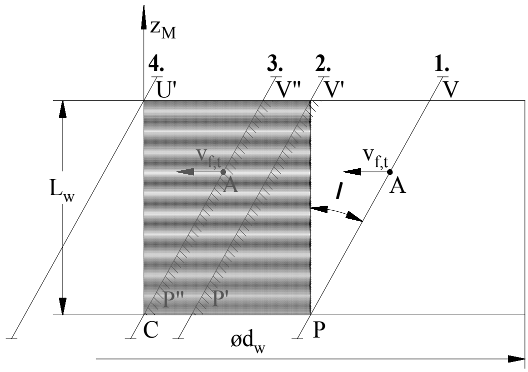

Figure 4 – The 4 main position of the cutting edge, transformed into the main plane

By extending our approach to the whole length of the edge, we get from one point of the cutting edge (**A** point) to the geometrical relations in Figure 4. The figure is accurate in a tangential turning method; however, we obtain exactly the same relations in rotational turning if the tool is transformed into a plane. We can imagine this if the cylinder of the tool is split and then it is unfolded to a plane. From a geometrical view both methods are completely the same. Figure 4 shows four specific edge positions which are very important. In the first position the oblique edge touches the workpiece in **P** point and then it moves on at a speed of $\mathbf{v_{f,t}}$. During this motion the active part of the edge gets longer and longer until the **V** point touches the workpiece. During this time both the chip width and the cutting force constantly grow. The **P'V'** section is the constant phase which stretches as far as the **P"V"** section of the edge. The second and the third positions of the edge show these two sections in Figure 4. After this the cutting edge gradually exits the material: both the chip width and the cutting force continuously decrease. Finally, in the fourth position the edge exits the material, namely, the tool's V' point leaves the workpiece at the **U'** point. The time required by the three machining phases – initial-, constant- running out phase – depends on the function of the $\mathbf{f_t}$ tangential feed (mm/workpiece revolution), the tool's $\mathbf{v_s}$ speed and the **λ** skewness or pitch angle.

Figure 5 illustrates the operation of the cutting edge and makes it easy to understand since the method in this figure is shown in its real ratio. Special attention should be paid to how the short part of the edge performing cutting passes along the whole length of the edge while the allowance from the workpiece is cut off.

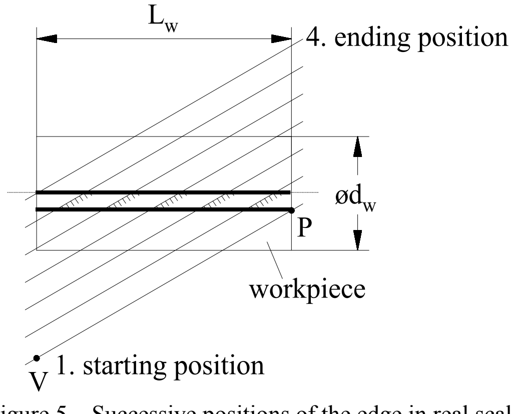

Figure 5 – Successive positions of the edge in real scale

One of the hardly understandable concepts of the method is the chip section. One of the dimensions of this is the chip thickness (**h**), whose minimal and maximal values have already been described earlier in this study when only one point of the edge was working. The other dimension is the edge length in cut (**b**) which was mentioned in Figures 4 and 5. However, if we wanted to draw the cross section of the chip (A_c) with the two parameters (**h, b**), we would be confused, because there would be no plane where the cross section ($A_c=b \bullet h$) could be illustrated in an exact form. In the case of the tangential method with its most simple geometry, the cross section appears in different planes in every revolution of the workpiece (Figure 6.). The position of the plane which contains h is defined by the $\varphi_1 \ldots \varphi_5$ angles. (In Figure 6 only five revolutions are shown, in reality the initial phase contains around 30-40 different workpiece revolutions.) If the skewness angle of the edge (λ) is taken into consideration, the initial point of the cutting edge marked with **P** point generates lower chip thickness than the last working point of the edge (**V** point). Consequently, the shape of the cross section is not a parallelogram, but a trapezoid. The cross sections appearing in edge in Figure 6 are planes whose normal vector exits the plane of the drawing and changes its position by workpiece revolutions.

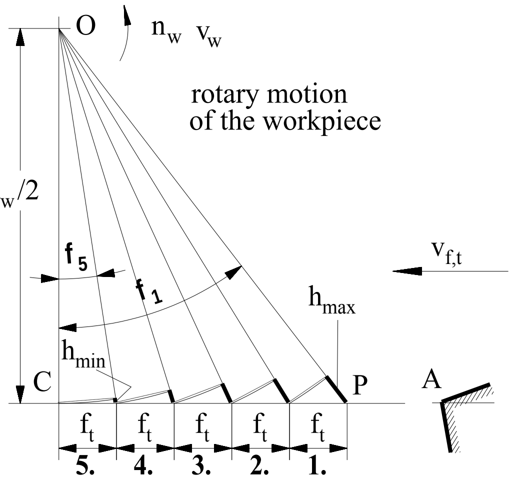

Figure 6 – Position of the chip thickness and its continuously changing size

If the cross section (A_c) is drawn in the plane defined by this normal vector, we get the shape presented in Figure 7. However, this is true only if the tangential method is applied. The situation is more difficult in rotational method, because the edge geometry is not a linear line, but a helical curve. Accordingly, the cross section of the chip is enclosed by curves of that kind. Therefore, its geometry leaves the two-dimensional plane and becomes a three-dimensional surface. This is one of the main differences between the two methods.

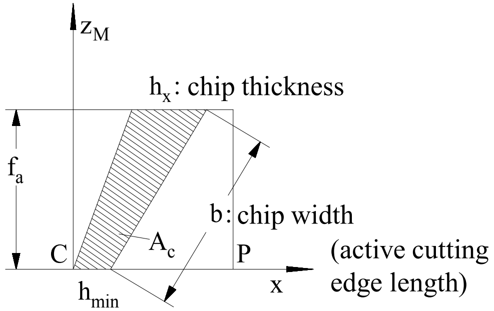

Figure 7 – Approximate description of the cross section of the chip in tangential method

SUMMARY

Rotational turning works with different material removal and chip formational mechanisms than classical turning. It has been known for a long time in some aspects, but in a broader sense it has never been applied in the tangential method. Since the tool makes a slow rotary movement instead of the rectilinear movement, this method substantially differs from the tangential method. Rotational turning has become a more widely applied method in making bores, flat surfaces, shape surfaces and cones than the tangential method. There is no observable periodical topography on the surface, so it is suitable for sealing, needle roller bearings and connecting surfaces. In addition, its productivity is the highest among the hard turning methods. Precision ground surfaces are made in a few seconds.

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