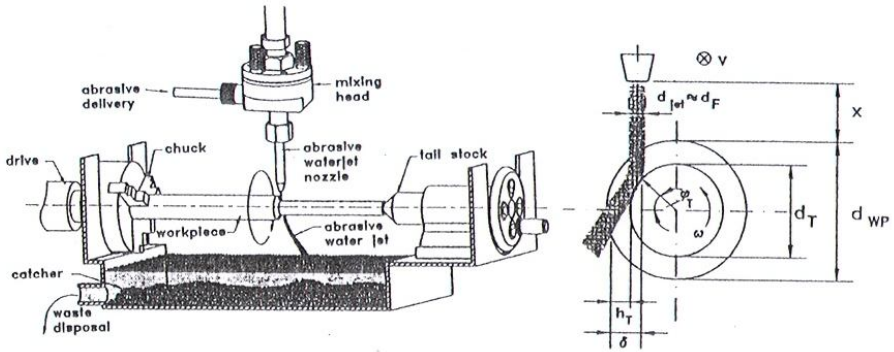


Figure 4 – Principle and geometry of the abrasive waterjet turning [5]

*3. THE POSSIBLE TRENDS OF FURTHER PROGRESS IN RESEARCH WORK*

The application of water jet for cutting needs further investigation in the machining procedures. As the trends for that the following tasks can be assigned: investigation of the conditions when abrasive waterjet can be applied as a cutting edge; analysis of the kinetic relations of the machining procedures; analysis of the geometrical relations of material removal and its efficiency.

*Acknowledgement*

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## PRECISION HARD TURNING OF EXTERNAL CYLINDRICAL SURFACES BY ROTATION PROCEDURE

*Я. КУНДРАК, К. ДЬЯНІ, І. ДЕЗПОТ*
*ЧИСТОВЕ ТОЧІННЯ ЗАГАРТОВАНИХ ДЕТАЛЕЙ ЗОВНІШНІХ ЦИЛІНДРИЧНИХ ПОВЕРХОНЬ МЕТОДОМ ОБЕРТАННЯ*

*Точність обробки точінням загартованих сталей і параметри шорсткості циліндричних поверхонь дорівнюють шліфуванню або навіть перевершують його. Проте геометрична форма обробленої поверхні показує значну розбіжність. Зберігаючи надзвичайні економічні переваги точіння загартованих сталей, у новій версії був розроблений метод обертання, що усуває недоліки шорсткості поверхні, що було причиною порушення операції.*

*Точность обработки точением закаленных сталей и параметры шероховатости цилиндрических поверхностей равна шлифованию или даже превосходит его. Тем не менее, геометрическая форма обработанной поверхности показывает значительное расхождение. Сохраняя чрезвычайные экономические преимущества точения закаленных сталей, в новой версии была разработан метод вращения, который устраняет недостатки шероховатости поверхности, что являлось причиной нарушения операции.*

*The accuracy of hard turning, the roughness parameters of the turned surfaces are equal to that of grinding or even better. However, the surface topography shows significant divergence. Retaining the extraordinary economic advantages of hard turning, a new version of this procedure has been developed – the rotation turning – which eliminates the deficiencies of the surface topography that cause operation disturbances.*

*1. INTRODUCTION*

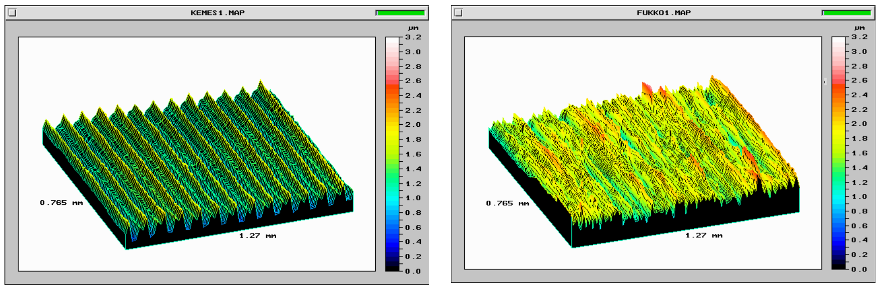
By the term "hard turning" the precision finish machining of hardened surfaces is meant by polycrystal cubic boron nitrid (in abbreviation PCBN) tools. The extreme hardness of PCBN tools, similar to that of diamond, makes it possible to finish steel surfaces of up to 65-70 HRC hardness, with IT5-IT6 size accuracy and Rz=1÷3 μm surface smoothness. In the first 100 years of production engineering, such rather demanding quality was possible to be produced only by grinding procedure. Grinding, however, in its usual, traditional form (wide wheel, small depth of cut) is a more expensive, slower process than the new hard turning. That is why hard turning have spread at record speed for the last 2 to 3 decades and forced the traditional version of grinding back. On a world scale the piece number of components ready machined by hard turning amounts to billions [1]. The main reason for its quick spread was by all means the higher productivity, the smaller manufacturing cost, but the environment friendly character of the procedure was also significant motive power, operating dry, with no coolants or lubricants.

The accuracy of hard turning, the roughness parameters of the turned surfaces are equal to that of grinding or even better. However, the surface topography shows significant divergence and the divergent topography causes considerable disturbance on some operating surfaces especially on sealing surfaces while at high speed flow (gas, water) it reduces efficiency. Retaining the extraordinary economic advantages of hard turning, a new version of this procedure has been developed – the rotation turning – which eliminates the deficiencies of the surface topography that cause operation disturbances.

## 2. THE TOPOGRAPHY OF HARD TURNED SURFACES

By surface topography the shape and pattern of the track of the tool is meant that generates the surface. At present it is a quality-like surface parameter that can be represented by 3D surface analytical technique or by AFM microscope. The turned topography consists of periodical, regularly repeating elements, however, the ground topography actually is a thread surface where the lead of thread is equal to the depth of maximal roughness. It is not suitable for sealing surfaces because on the one hand, the sharp tips damage the sealing material, on the other hand a typical conveyance effect emerges as a result of which oil leaking happens, the quality damaging effect of which is inadmissible (Figure 1).

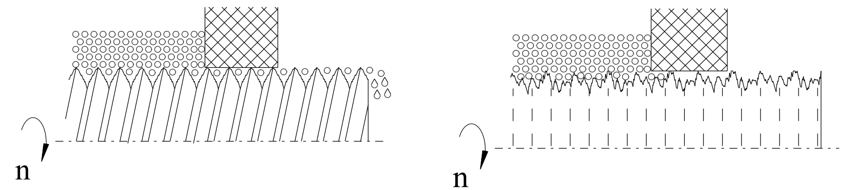
*HARD TURNED* surface | *GROUND* surface



*The character of topography*

regular, periodical | accidental, random

*Result in seal*




there is conveyance effect | no conveyance effect

Figure 1 – Periodical and random topography behaviour in mobile seals



This unfavourable effect of hard turning based on traditional, point-like surface creation is completely eliminated by the new version of the procedure: the rotation turning. Rotation turning goes without any feed, its special tool and special kinematics make it possible to machine long surface.

## 3. KINEMATICS, TOOLS OF ROTATION TURNING AND THE THEORY OF ITS SURFACE CREATION

Rotation turning is a new hard machining procedure defended by a firm related patent, which generates completely smooth, twistfree surfaces [2, 3] keeping all the advantages of hard turning. The main characteristic feature of the procedure is a very slowly rotating PCBN tool with a special form and also that on its cutting edge, along the helix, axial feed emerges as a result of the slow rotation and thus, the whole length can be ready machined (Figure 2).

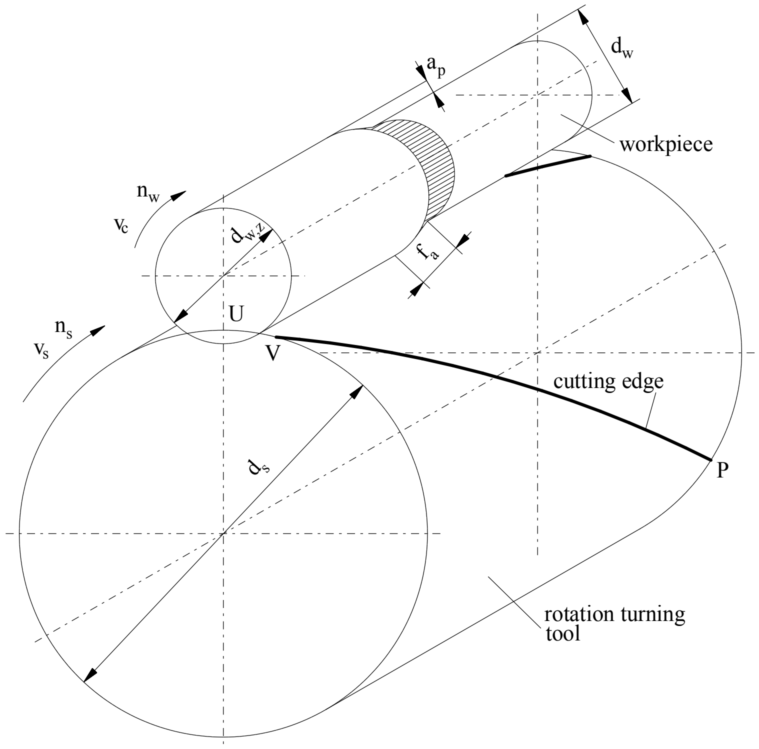



Figure 2 – Theory of material removal in rotation turning

In Figure 2 the clamping of the workpiece and the theoretical tool correspond to reality, but the turned aside position of the tool and the semi-finished state of the workpiece are independent of each other. On the workpiece stopped at half time $\mathbf{a_p}$

depth of cut, $f_a$ axial feed can be interpreted, $d_w$ ready diameter, $d_{w,z}$ prefabrication diameter can be seen, which contains **z** diameter allowance, and also the hyperbolic transitional surface connecting the two diameters whose width equals to $f_a$. Cutting speed ($v_c$) is indicated, which is about 160÷200 m/min so that the optimal conditions of cutting are provided.

Theoretically the body of the tool is of cylindrical shape with $d_s$ diameter, on it there is the PCBN cutting edge with a steep helix. The operating length of the tool edge is the line section marked $\overline{PV}$ in Figure 2. In the figure the tool angle state is in a position having just finished the material removal and its last point indicated **V** has left the workpiece. The rotation of the tool is very slow, enough only to cut some tenths mm-s of feed indicated $f_a$ in the figure, during one revolution of the quickly rotating workpiece, because of the bevel 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.

## *4. MECHANISM OF CHIP FORMATION IN ROTATION TURNING*

The basic phases of chip formation are indicated in Figure 3. The tool positioned in the right working state begins to rotate slowly and the starting point of the edge marked **P** reaches the workpiece (1st edge position). Turning on, **b** width of chip gradually increases and when **P** reaches **P'** position, **b** also reaches its maximum $\overline{P'V}$ distance.

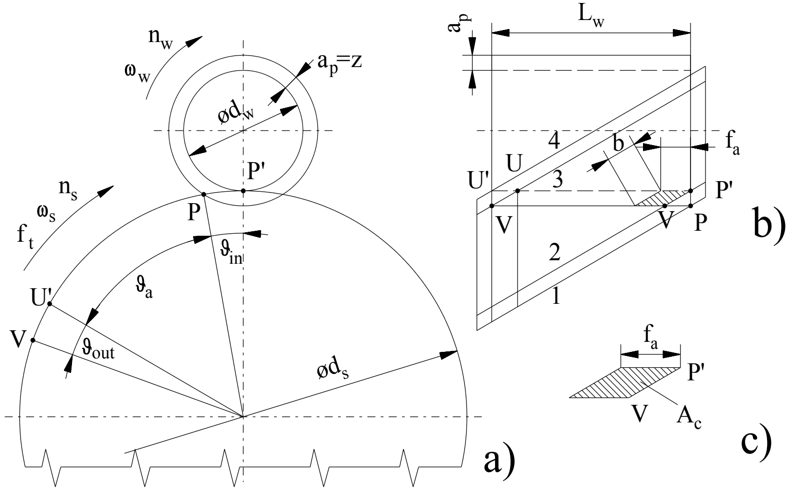



Figure 3 *a* – motions in plane perpendicular on axle; *в* – typical positions of tool edge; *c* – approximate shape of chip cross section



Interpretation of indication:

| | | |
|---|---|---|
| $n_w$ | rotary speed of workpiece: | 1/min |
| $n_s$ | rotary speed of tool: | 1/min |
| $\omega_w$ | angular speed of workpiece: | rad/min |
| $\omega_s$ | angular speed of tool: | rad/min |
| $d_w$ | diameter of workpiece: | mm |
| $d_s$ | diameter of tool: | mm |
| $a_p$ | depth of cut: | mm |
| $f_a$ | axial feed: | mm/workpiece revolution |
| $f_t$ | tangential feed: | mm/workpiece revolution |
| z | allowance in radius: | mm |
| $A_c$ | chip cross section: | $mm^2$ |
| $\theta_{in}$ | initial angular displacement: | degree |
| $\theta_{out}$ | running out angular displacement: | degree |
| $\theta$ | constant angular displacement: | degree |
| b | width of chip: | mm |
| $\varphi$ | bevel angle of tool edge: | degree |

This phase is called initial phase during which the tool turnes aside by $\vartheta_{in}$ angle. It is followed by the constant phase when **b** width of chip is constant (2nd edge position) and this lasts until **V** point leaves the material (3rd position). From now on **b** width of chip decreases until **U** edge point in **U'** leaves the material (4th edge position). The other size of the chip, **h** width of chip is varied along the edge, its numerical value can be calculated on the basis of the geometrical and kinematic relationships that are shown in the figure.

In connection with Figure 3 it must be noted that in rotation turning it is not possible to represent the chip form and cross section precisely in the traditional planes of representation. Our aim was only to make the terms and kinetic relations needed later for technological planning clear. An example for the foregoing is **PP'** arc length which is a circular arc according to the projection in a, part of the figure but by the time point **P** of the tool reaches **P'** and point **P** of the workpiece reaches **V**. Therefore in reality **PP'** is not a circular arc but a space curve from **V** to **P'**.

### *Definition of angular displacement of the tool*

To calculate $\theta_{in}$ in initial angle $PP'$ arc length is needed to be known. As it is very short, $a_p$≈0.1 mm or smaller, an approximation is applied: instead of a circular arc a chord is used for calculation. Accordingly:

$$\overline{PP'} = \left( a_p \cdot \frac{d_s \cdot d_w}{d_s + d_w} \right)^{1/2}$$

On the other hand the approximate proportionality exists:

$$\overline{PP'} : d_s \cdot \pi = \theta_{in} : 360$$

$$\vartheta_{in} = \frac{360 \cdot \overline{PP'}}{d_s \cdot \pi}.$$

When going out, through the symmetry $\theta_{out}$ is the same:

$$\theta_{out} = \theta_{in}.$$

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 [4]:

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

The **p** lead of thread according to technical literature [4]:

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

The relationship between the tool angle displacement and the width of chip is shown in Figure 4. The **b** width of chip can be calculated on the basis of Figure 3.

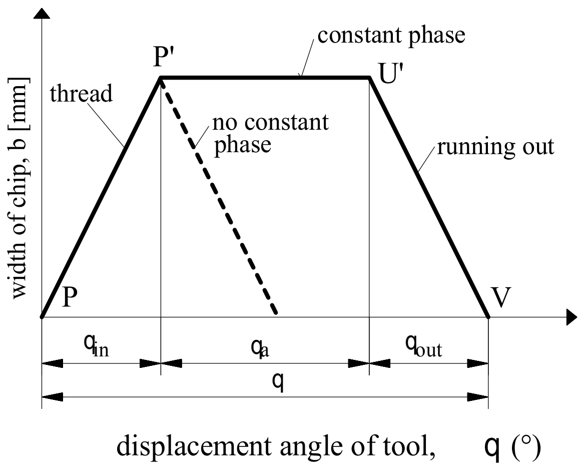


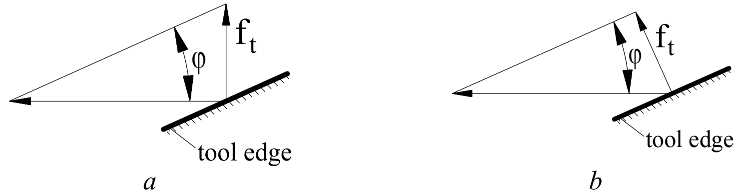

Figure 4 – Change of the width of chip, its phases during the operation of the cutting edge

It is also expedient to note that rotation turning is cutting carried out under ideal circumstances, because in fact orthogonal cutting – in other word free cutting is done. The shape of the chip is ribbon-like whose width is b, its thickness is the order of μm-s.



*Defining feed along the axle*

The feed along the axle – that falls on one revolution of the workpiece – (in Figure 3: $\mathbf{f_a}$) is calculated from $\mathbf{f_t}$ tangential feed. On the basis of technical literature the suggested values of $\mathbf{f_t}$ are between 0.14÷0.18 (mm/workpiece revolution). But the data in technical literature can be interpreted in two ways (Figure 5). There is small difference between the two procedures, the smaller φ angle is, the less the difference is. Hereafter the interpretation of figure 5a) is used.




$$f_a = \frac{f_t}{tg\varphi} \qquad\qquad f_a = \frac{f_t}{\sin\varphi}$$

if eq. φ=30°, and

$f_t$=0.18 mm/ workpiece revolution, then

$f_a$=0.32 mm/workpiece rev. $f_a$=0.36 mm/workpiece rev.

Figure 5 – Two ways of interpretation of tangential feed *a* – feed is of the same direction as circumferential velocity; *b* – feed is perpendicular on circumferential velocity

## 5. *PRACTICAL REALIZATION OF ROTATION TURNING*

Rotation turning is suitable not only for machining of external cylindrical surfaces but also of plane and conical surfaces as well as bore holes. A broken interrupted surface is not an obstacle either. Rotation turning as opposed to the expensive grinding has got the following advantages:

- shorter machining times
- dry machining is possible
- smaller investment costs
- higher process security [5]

The procedure, the tools and the needed lathe machine family are J. G. Weisser Werkzeugmachinenfabrik’s patent (St. Georgen, Schwarzwald, Deutchland).

The greatest advantage of this procedure is the creation of twistfree surfaces with very fine surface roughness. As it is experienced up to now the roughness that can be reached is Rz≤4μm and Ra≤0.6μm but it is not rare to reach Ra≈0.2μm either. While the accuracy of the machining is IT5 ISO quality. The parallelism of the generatrixes is ≈4 μm, their straightness is ≈3 μm. Besides all these its productivity is higher than that of the hard turning procedures hither to. In Figure 6 the rotation turning of external cylindrical surface is shown with the characteristic cutting data.

The tool material is PCBN, its slant is φ=30÷45°, the edges needs thoroughful preparation: both the face and flank surface are multiply polished and superfinished. The applied PCBN is of medium CBN content, TiN bonded, with 2 μm grain size and its stability and impact strength make it suitable for broken surfaces too. One solution was that the inserts containing the edges were fixed on a tool head with big diameter (Figure 7) in which there was only a thin slat-like insert made from monolithic PCBN. Thus the cost of the tool is moderate, about five times higher than that of an advanced wiper-insert.

The length of the edges can be maximum 30 mm. If it seems not enough, the tool must give some feed along Z-axle besides rotation to lengthen the constant phase. Lately tools with a so called modular system have been applied, with one insert and can be clapped on a given place of the tool fixture head (Figure 8).
A separate CNC shaft is employed to position and rotate the rotation tools.

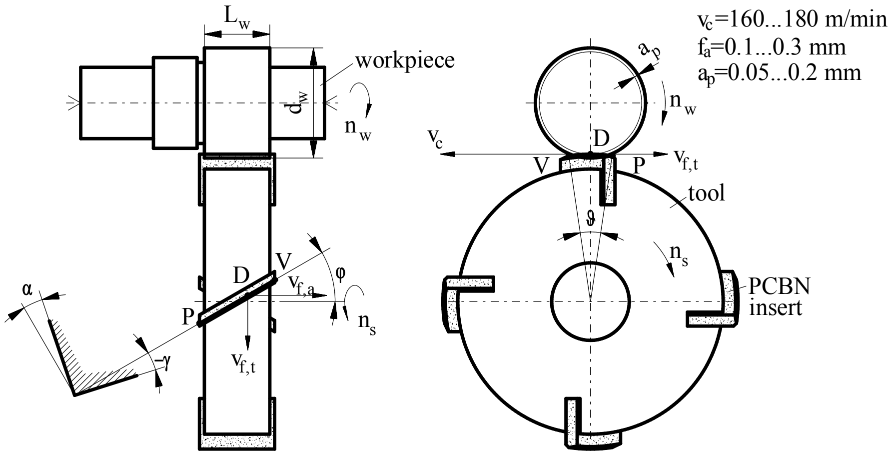


Figure 6 – Rotation turning of an external cylindrical surface


Figure 7 – The tool of rotation turning fixed on a tool head [6]



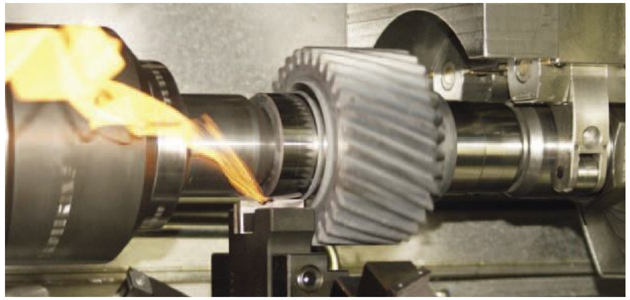


Figure 8 – Clamping of a modular-like tool with one insert into a revolver head [7]

## 6. *TECHNOLOGICAL PLANNING OF ROTATION TURNING*

For the precise interpretation of kinematic circumstances and surface creation, a simple case has been worked out for the application of rotation turning. The simple case means that the feed along Z axle is not needed because the edge length spans the workpiece, that is $L_w \le PV \cdot \cos\varphi$ (Figure 9).

For what follows some date are needed taken from practice and suggestion. These are:

- cutting speed $v_c$=180 m/min
- tangential feed $f_t$=0.14÷0.18 mm/workpiece revolution
- tool data:
  - tool head diameter $d_s$=200mm
  - angle of inclination φ=30°

Knowing the data above each technological parameter can be calculated.

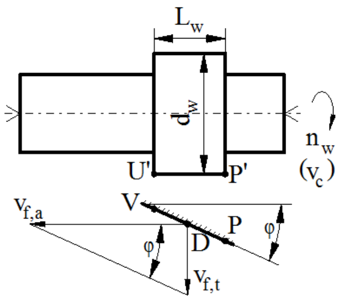


Figure 9 – Rotation procedure, $L_w \le PV \cdot \cos\varphi$

Workpiece data:

Material: 16MnCr5, 62 HRC

$L_w$=20 mm

$d_w$=60h5 mm,

Rz=4 μm

Allowance: z=0.2 mm in diameter

Number of clamps: 1

Rotary speed of workpiece: $$n_w = \frac{1000 \cdot v_c}{d_w \cdot \pi} = \frac{1000 \cdot 180}{60 \cdot \pi} = 955 \text{ 1/min} \cdot$$

Depth of cut: $a_p$=z/2=0.1 mm

Tangential feed: $f_t$=0.14 mm/workpiece rev.

Speed of tangential feed: $v_{f,t} = n_w \cdot f_t = 955 \cdot 0.14 = 133.7$ mm/min.

Feed along the axle: $f_a = f_t / tg\varphi = 0.14 / tg30° = 0.242$ mm/workpiece rev.

Speed of feed along the axle: $v_{f,a} = n_w \cdot f_a = 955 \cdot 0.242 = 231.6$ mm/min.

Rotary speed of tool: $n_s = \frac{v_{f,t}}{d_s \cdot \pi} = \frac{133.7}{200 \cdot \pi} = 0.212$ 1/min

Angular velocity of the tool: $\omega_s = \frac{n_s}{9.55} = \frac{0,212}{9.55} = 0.023$ rad/min

Main time of machining: $t_g = \frac{L_w}{v_{f,a}} = \frac{20}{231.6} = 0.086$ minute $\rightarrow$ 5.2 secundum.

*SUMMARY*

The technique of surface creation of rotation turning is different from hard turning procedures applied so for. In the new procedure the generatrix of the cylindrical surface is a straight line theoretically as well which is free from feed traces usual in turning or furrows from feed. Thus, on the generated surface there are no periodical topography patterns. The turned surface is suitable for sealing and changing for the more expensive grinding is not necessary. Beyond that the advantage of dry machining is kept and because of the relatively longer feed along the axle its productivity is significantly higher than that of the traditional hard turning.

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## INVESTIGATION ON WEAR AND TOOL LIFE OF CUTTING TOOLS

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*ДОСЛІДЖЕННЯ ЗНОСОСТІЙКОСТІ РІЗАЛЬНИХ ІНСТРУМЕНТІВ*
*Зношування різального інструменту визначає відвід стружки й стійкість інструменту з погляду економічної ефективності різання. Причина в тому, що надтверді інструменти коштують дорого, а оброблені деталі повинні мати строгі параметри відносно точності і якості. Саме тому дослідження цих інструментів має велике значення. Стаття присвячена деяким особливостям кубічного нітриду бора та інструментів, що впливають на визначення терміну служби інструмента.*
*Ключові слова: зношування інструмента, термін служби інструмента, інтенсивність зношування*

*Износ режущего инструмента определяет отвод стружки и стойкость инструмента с точки зрения экономической эффективности резания. Причина в том, что сверхтвердые инструменты стоят дорого, а обработанные детали должны иметь строгие параметры в отношении точности и качества. Именно поэтому исследование этих инструментов имеет большое значение. Статья посвящена некоторым особенностям кубического нитрида бора и инструментов, влияющим на определение срока службы инструмента.*
*Ключевые слова: износ инструмента, срок службы инструмента, интенсивность износа*

*The wear of cutting tools is determinant in chip removal and tool life is in economic efficiency of cutting. The reason is that superhard tools are expensive and surfaces or parts machined by them have to fulfill strict requirements referring to the accuracy and quality. That is why investigation on these tools have a major importance. The paper focuses on some wear feature of CBN tools and on determining of tool life.*
*Keywords: tool wear, tool life, wear intensity*

*INTRODUCTION*

Hard machining is characteristic of the machining of hardened parts with 50-65 HRC hardness. Owing to superhard tool materials in finish machining hard turning more and more comes into view against grinding. The advantages of hard turning are the higher production flexibility, the higher material removal rate, the higher productivity and through all these, the reduction of costs of manufacturing [1, 2]. Despite the machining that uses no CL at all, the produced part has got good surface integrity and roughness appropriate for precision machining. These advantages however return just in case these tool materials ensure the appropriate shape and dimensional accuracy besides optimal tool life. Therefore several researchers deal with the examination of the wear mechanism of CBN tools. The typical CBN tool wear mechanisms are decisively abrasion as well as adhesion and diffusion wear [3]. Several mathematical models have been created to describe these wear mechanisms [4, 5]. The main wear patterns that can be observed on CBN tools are: decisively flank wear as well as crater wear, edge wear, nose wear, chipping, thermal shock cracks [3]. The observed wear patterns are caused by not only one wear process, but the simultaneous appearance of the above mentioned wear processes.