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EFFECT OF PARAMETERS ON CHIP SHRINKAGE IN ULTRASONIC TURNING OF OILFIELD PARTS

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Abstract. Various methods of repairing parts are used at repair enterprises of the oil and gas industry to ensure the restoration of full or partial operational life of equipment damaged during operation. The problem of improving the efficiency and maintenance period of equipment is an urgent task in the repair and restoration of oilfield equipment. The purpose of the work is to analyze the factors affecting chip shrinkage during turning, while maintaining constant parameters such as tool sharpening angles, physical and mechanical properties of the material, cutting speed and feed. Studies have been conducted using cutting modes, both in traditional processing and ultrasound application. The studies conducted on the basis of this technique make it possible to determine the effect of the use of ultrasonic waves in turning on mechanical properties, shear forces and processing quality. As a result of experimental studies, it has been established that the use of ultrasonic waves can significantly increase the efficiency of turning operations. Studies have confirmed that ultrasonic vibration helps to reduce chip thickness, reduce shrinkage, improve cutting conditions and improve the quality of the treated surface. Increasing the frequency of ultrasonic waves makes it possible to achieve higher surface quality and processing accuracy. When using ultrasonic vibrations, the chip removal rate increases by 1.8–2.0 times compared to traditional turning. This helps to effectively remove heat from the cutting area, reduce temperature loads and, as a result, improve the quality of the treated surface.

Keywords: oil and gas equipment, turning processing, chips, thickness, shrinkage, frequency, amplitude

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МҰНАЙ-ГАЗ САЛАСЫНЫҢ БӨЛШЕКТЕРІН УЛЬТРАДЫБЫСТЫҚ ЖОНУ КЕЗІНДЕ ЖОҢҚА ШӨГУІНЕ ПАРАМЕТРЛЕРДІҢ ӘСЕРІ

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Аннотация. Мұнай-газ өнеркәсібінің жөндеу кәсіпорындарында пайдаланылған кезде зақымданған жабдықтың қызмет ету мерзімін толық немесе ішінара қалпына келтіру үшін бөлшектерді қалпына келтірудің түрлі әдістері қолданылады. Жабдықтың тиімділігін арттыру және оның техникалық қызмет көрсету кезеңін ұзарту мәселесі мұнай кен орындарындағы жабдықтарды жөндеу және қалпына келтіру саласында өзекті міндет болып табылады. Бұл жұмыстың мақсаты – жону үдерісінде жоңқаның шөгуіне әсер ететін факторларды талдау. Ол үшін құралдың қайрау бұрыштары, материалдың физикалық-механикалық қасиеттері, кесу жылдамдығы мен беріліс секілді параметрлер тұрақты сақталды. Зерттеулер дәстүрлі өңдеу режимдерімен қатар, ультрадыбыстық тербелістерді қолдану арқылы да жүргізілді. Ұсынылған әдістеме негізінде жүргізілген зерттеулер ультрадыбыстық толқындарды жону процесінде қолданудың материалдың механикалық қасиеттеріне, ығысу күштеріне және өңдеу сапасына әсерін анықтауға мүмкіндік береді. Эксперименттік зерттеулер нәтижесінде ультрадыбыстық толқындарды пайдалану жону операцияларының тиімділігін айтарлықтай арттыратыны дәлелденді. Зерттеулер ультрадыбыстық тербелістердің жоңқа қалыңдығын азайтып, оның шөгуін төмендететінін, кесу жағдайларын жақсартатынын және өңделген бет сапасын арттыратынын көрсетті. Ультрадыбыстық толқындардың жиілігін арттыру — бет сапасын және өңдеу дәлдігін жақсартуға мүмкіндік береді. Ультрадыбыстық тербелістерді қолданғанда жоңқаны шығару жылдамдығы дәстүрлі жонумен салыстырғанда 1,8–2,0 есеге дейін артады. Бұл кесу аймағындағы жылуды тиімді шығаруға, температуралық жүктемелерді төмендетуге және нәтижесінде өңделген бет сапасын жақсартуға ықпал етеді.

Түйін сөздер: мұнай-газ жабдықтары, жонушылық өңдеу, жоңқалар, қалыңдық, шөгу, жиілік, амплитуда

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ВЛИЯНИЕ ПАРАМЕТРОВ НА УСАДКУ СТРУЖКИ ПРИ УЛЬТРАЗВУКОВОЙ ТОКАРНОЙ ОБРАБОТКЕ ДЕТАЛЕЙ НЕФТЕГАЗОВОГО ОБОРУДОВАНИЯ

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Аннотация. На ремонтных предприятиях нефтяной и газовой промышленности широко применяют различные способы ремонта деталей, обеспечивающие восстановление полного или частичного эксплуатационного ресурса нефтяного оборудования нарушенных при эксплуатации. Проблема повышения работоспособности и повышение межремонтного периода эксплуатации оборудовании является актуальной задачей при ремонте и восстановлении нефтепромыслового нестандартного оборудования. Цель работы анализ факторов, влияющих на усадку стружки при точении, при сохранении постоянными таких параметров, как углы заточки инструмента, физико-механические свойства материала, скорость резания и подача. Проводились исследования с использованием режимов резания — как при традиционной обработке, так и при наложении ультразвука. Исследования, проводимые на основе данной методики, позволяют определить влияние применения ультразвуковых волн при токарной обработке на механические свойства, силы сдвига и качество обработки. В результате экспериментальных исследований установлено, что применение ультразвуковых волн позволяет существенно повысить эффективность токарной операции. Проведенные исследования подтвердили, что ультразвуковая вибрация способствует снижению толщины стружки, уменьшению коэффициента усадки, улучшению условий резания и повышению качества обрабатываемой поверхности. Увеличение частоты ультразвуковых волн позволяет достичь более высокого качества поверхности и повышенной точности обработки. При использовании ультразвуковых колебаний скорость удаления стружки возрастает в 1,8–2,0 раза по сравнению с традиционной токарной обработкой. Это способствует эффективному отводу тепла из зоны резания, снижению температурных нагрузок и, как следствие, повышению качества обработанной поверхности.

Ключевые слова: нефтегазовое оборудование, токарная обработка, стружка, толщина, усадка, частота, амплитуда

Introduction. The practice of operating oil and gas field and transportation equipment shows that their service life is limited mainly by intensive abrasive wear of the contacting surfaces. The problem of improving the operability of such surfaces is an urgent task in the repair and restoration of non-standard oilfield equipment.

The current trend in the development of scientific research in the field of enhanced oil recovery is the scientific justification of innovative technology, the achievement of the maximum possible increase in the maintenance period of oil wells and the operation of oilfield equipment (Mikhailov et al., 2019; Zakenov et al., 2022; Nurshakhanova et al., 20245; Drozdov et al., 2020).

An ultrasonic wave is a sound wave with a frequency exceeding 18 kHz. Depending on the frequency and amplitude, such waves have different effects on materials. They can be longitudinal, transverse, rotational or inclined, and their propagation is determined by the characteristics of ultrasonic wave generators and transmitters. The use of ultrasonic waves in turning helps to improve surface quality, optimize the vibration characteristics of the cutting tool and reduce wear. Ultrasonic exposure affects the molecular structure of the material, creating conditions for changing its physical properties. The impact on the tool causes elastic vibrations along its length, which leads to micro-vibrations of the cutting edge. These vibrations penetrate the structure of the material, providing more precise and efficient destruction.

Ultrasonic technology allows to achieve a number of positive effects: reduction of surface roughness, reduction of cutting tool wear, increase in processing speed and accuracy, reduction of internal stresses, thermal effects and deformations. Studies show that the use of ultrasound makes the turning process more stable and manageable.

High-frequency ultrasonic waves create microscopic changes in the internal structure of the material, which contributes to better processing. Compared with traditional methods, ultrasonic technology provides higher accuracy, lower material loss and faster production process (Morgunov et al., 2012; Duman et al., 2024).

The vibrations created by ultrasound in the tool body reduce the pressure on the cutting edge, reduce heat generation and prevent distortion of the treated surface. By adjusting the oscillation frequency and amplitude, optimal cutting conditions can be ensured. Together, this creates a more homogeneous and stable processing process. In addition, the effect of ultrasonic waves is realized in the form of microscopic pulses, which increases the speed and accuracy of cutting (Martins et al., 2023).

This technology is particularly in demand in industries where high precision is required, such as microelectronics, the aviation and shipbuilding industries. The results of ultrasound application confirm its ability to improve the quality, productivity and accuracy of processing (Ghule et al., 2024; Zaytsev et al., 2014). The use of ultrasound in the processing of metals, polymers and ceramics ensures the prolongation of tool life, reduction of thermal effects and minimization of material losses. With the constant development of ultrasound technology, new achievements are becoming possible that meet the requirements of modern industry (Hasanov et al., 2024). Recently, the effects of ultrasonic exposure on high-frequency instruments and the internal structure of materials have been intensively studied. Of particular interest is the potential of this technology in eliminating microcracks and improving the properties of various materials, including metals and polymers (Ghule et al., 2022).

Thus, the use of ultrasonic treatment in turning processes is justified by its advantages - from improving quality to increasing the life of equipment. This makes ultrasound technology a promising direction in modern material processing.

Materials and Methods. At the initial stage of processing, when the cutting tool comes into contact with the processed metal, the greatest stress occurs in the chip formation zone - around the sliding plane, in the chip separation area, as well as at the points of contact of the front and back surfaces of the cutter with the processed material. As a result of the processes occurring in the contact area, the treated surface is subjected to plastic deformation, which complicates the chip formation process. In this case, the chips change their geometric parameters, starting from the root, due to the action of shear and friction forces, causing its plastic deformation. The actual chip sizes often differ significantly from the theoretical ones calculated based on the accepted cutting modes.

Changes in chip size when using ultrasound can be caused by a number of factors. The effect of ultrasonic waves on the material is accompanied by changes in pressure and temperature, which leads to microscopic and macroscopic effects such as the formation of microcracks or local deformation. Internal stresses caused by ultrasonic vibrations disrupt the structure of the material, contributing to a reduction in chip size. However, in some cases, the opposite situation is possible - ultrasound can cause thickening of the material, changing the geometry of the resulting chips. Thus, the degree of influence of ultrasound is determined by both the properties of the material and the parameters of the ultrasonic effect.

In conventional turning, due to plastic deformation, the chip length decreases, and its thickness and width increase compared to the path traveled by the cutter. This phenomenon persists even with the use of ultrasound, however, the deformation process and the nature of chip shrinkage have their own characteristics. If in traditional turning the main influence is exerted by numerical values of deformation, sliding coefficient and mechanical properties of the material, then with ultrasonic action the picture changes. The influence of ultrasonic waves transforms the nature of plastic deformation in the cutting area.

For comparative analysis, parallel studies were conducted using the same cutting modes, both in traditional processing and in ultrasound application. Ultrasonic exposure is used to intensify the cutting process, especially when working with difficult-to-process materials. The main parameters determining the efficiency of the process are the frequency and amplitude of ultrasonic waves.

As the frequency of the wave increases, the frequency of micro-vibrations increases, which makes it easier to remove the material. High-frequency vibrations contribute to improving the mechanical properties of the material, increasing its elasticity. However, excessively high frequencies can have a negative effect on the structure of some materials.

The amplitude of the waves determines the strength of the vibrations. Large amplitudes enhance the material removal process, but their excessive value can cause damage to the surface. Therefore, it is important to select the optimal parameters for achieving the best cutting quality and efficiency.

The use of ultrasonic waves in turning contributes to the formation of new physical and mechanical properties on the surface of the part. Under the influence of vibrations, microstructural changes occur, increasing the hardness of the material.

Sinusoidal pulses arising in the process ensure an even distribution of internal stresses, and also contribute to a more uniform heat exchange, preventing thermal deformations. Reducing the contact time of the tool with the material leads to an increase in the service life of the cutting edge (Airao et al., 2022; Jiao et al., 2011).

Ultrasonic waves propagating in a solid cause elastic vibrations. When exposed to a cutting tool, they cause its micro-deformations and length changes. The direction of oscillation depends on the direction of wave propagation. If they propagate in a certain plane, then the displacements occur in this plane, improving the quality of processing. In comparison with traditional turning, the microstructure of the chips becomes more homogeneous with the ultrasonic method, which increases the wear resistance and manufacturability of the machined parts (Maslov et al., 2018).

The studies conducted on the basis of this technique make it possible to determine the effect of the use of ultrasonic waves in turning on mechanical properties, shear forces and processing quality. The use of ultrasonic turning in industrial production is considered as a promising approach to increase service life, reduce energy consumption and better processing of parts requiring high precision.

Analysis of the factors affecting chip shrinkage during turning, while maintaining constant parameters such as tool sharpening angles, physical and mechanical properties of the material, cutting speed and feed, allows us to identify the influence of the frequency and amplitude of ultrasonic waves. This, in turn, contributes to a deeper understanding of the physical nature of the process.

Results and discussion. The change in chip thickness depending on the amplitude of ultrasonic vibrations and cutting speed is shown in Figure 1. Experimental data were obtained during finishing turning of steel 45 with a T5K10 hard alloy cutter.

It was found that during traditional turning, the chip thickness varies from 0,14 mm (at V = 20 m/min) to 0,24 mm (at V = 70 m/min). At the same time, the chip thickness increases with increasing cutting speed (Fig. 2, curve 5).

With the use of ultrasonic vibrations (frequency f = 20 kHz) and an increase in amplitude, the chip thickness decreases compared to conventional processing. For example, at an amplitude of 2A = 2 microns, the chip thickness is 0,1 mm at low speeds and 0,21 mm at V = 70 m/min (curve 1). As the amplitude increases to 2A = 14 microns, the chip thickness decreases to 0,07 mm (at V = 20 m/min) and 0,12 mm (at V = 70 m/min) (curve 4).

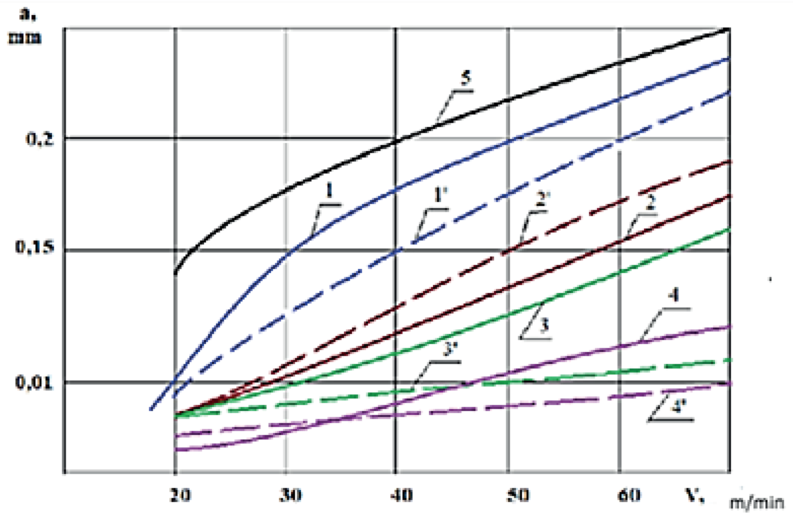

Figure 1. Dependence of the chip thickness on the amplitude of the ultrasonic wave and the cutting speed (Material - steel 45, cutter -T5K10, $\gamma = 20^0$, $\alpha = 10^0$) f = 20 kHz; S = 0,19 mm/rev; t= 0,15 mm; 1 - 2A = 1 μm, 2 - 2A = 3 μm; 3 - 2A = 5 μm, 4 - 2A = 7 μm, 5 - A = 0; 1,2,3,4 - curves obtained from theoretical calculations

As can be seen from the figure, the chip thickness in both cases increases monotonously with increasing cutting speed. As the thickness increases, the shape and type of chips change due to deformations in the cutting area. The chips can take a flat, mixed or spiral shape.

One of the key factors influencing the chip deformation and crushing process is the frequency of ultrasonic vibrations. Ultrasonic turning is used to improve the accuracy and productivity of material processing. The frequency of ultrasound has a significant effect on the plastic deformation process and the quality of the resulting surface.

High-frequency oscillations (20 kHz and higher) are characterized by a smaller amplitude, having a less intense but more precise effect. They cause micro-deformations and microstructural changes on the surface of the material, improving its quality. Low-frequency waves (1-5 kHz), on the contrary, are accompanied by a larger amplitude, providing deeper and stronger deformations, but may impair the cleanliness of the treated surface.

The frequency of ultrasound also affects the crystal structure and hardness of the material. High-frequency vibrations have a more effective effect on solid materials, causing micro-explosions on the surface, which contribute to local destruction and decrease in hardness, facilitating subsequent processing.

Figure 2 shows the dependence of the chip thickness on the frequency of the ultrasonic wave during processing of various materials. With an increase in frequency from f = 15 kHz to f = 30 kHz, an increase in chip thickness is observed. For example, at f = 20 kHz, the chip thickness for steel 45 is a = 0,134 mm, for steel X12M - 0,137 mm, and for copper - 0,168 mm. At f = 25 kHz, these values increase to 0,152 mm, 0,16 mm, and 0,184 mm, respectively. This is due to the high ductility of copper.

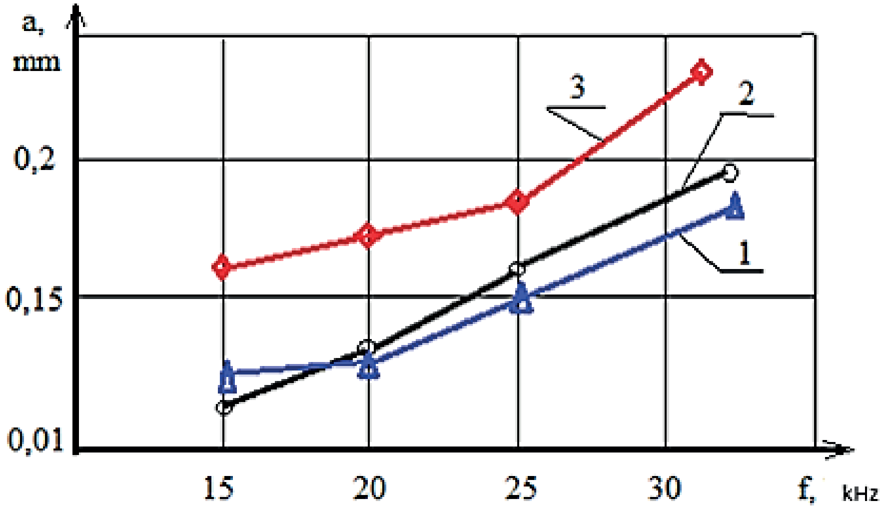

Figure 2. Dependence of the chip thickness on the frequency of the ultrasonic wave during processing of various materials. V = 40 m/min; t = 0,15 mm; S = 0,19 mm/rpm; A = 3 µm; 1 - 45 steel; 2 - X12M; 3 - copper

One of the important parameters of the cutting process is the chip shrinkage coefficient. It is defined as the ratio of the initial volume of the material to the volume of the resulting chips and depends on the nature of the deformation in the shear zone and the cutting conditions. During ultrasonic processing, the shrinkage coefficient decreases, as vibrations help to reduce friction between the chips and the front surface of the cutter, and also contribute to the rapid removal of chips from the cutting area.

The chip shrinkage coefficient can be determined by the well-known formula (Granovsky, 1985):

$$K_l = \frac{G \cdot 10^3}{L_c \rho \cdot a \cdot b} \qquad (1)$$

where: G - is the mass of the chips, mgr; ρ - is the density, g/mm^3; L_c - is the length of the chips taken, mm

On the other hand, it is known that,

$$a \cdot b = S \cdot t \qquad (2)$$

then

$$K_l = \frac{10^3 \cdot G}{L_{c} . \rho \cdot st} \tag{3}$$

where: S - is the transmission, mm/ turnover; t - is the cutting depth, mm.

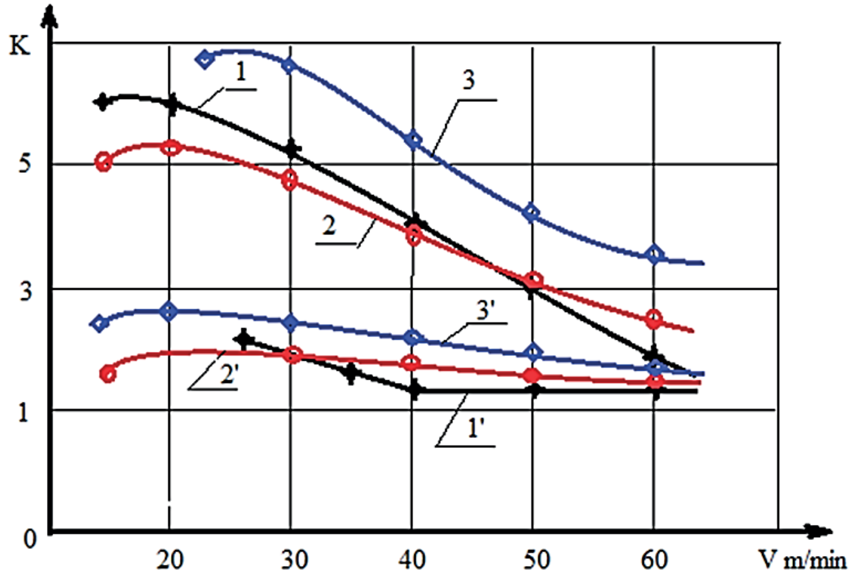

Figure 3. Chip shrinkage coefficient for various processing methods. Cutting material - T5K10; cutting modes – t = 0,15 mm; S = 0,14 mm/turnover; α=10⁰; γ=20⁰; in conventional turning, 1 - 45 steel; 2 - X12M; 3 - copper. When turning with ultrasound at f = 20 kHz, 2A = 3 µm; 1 - 45 steel, 2 - X12M, 3 - copper

As a result of the experiments, the shrinkage coefficient was applied depending on the cutting speed during turning of copper, 45 steel and X12M material using conventional turning and ultrasonic methods, and the results are shown in Figure 3.

As can be seen from the figure, the chip shrinkage coefficient in all materials with conventional chips is significantly higher than with chips using ultrasonic waves. It is characterized by the fact that when ultrasonic waves are applied, the chips formed during turning are intact and are little susceptible to deformation. Ultrasonic waves in the cutting area remove the chips from the front face of the cutter as a result of vibrations and limit its meeting with the front face.

Experimental results have shown that with traditional turning, the shrinkage coefficient ranges from 2,5–7,5, while with ultrasonic processing it ranges from 1,3–2,0. This is due to a decrease in plastic deformation and temperature in the cutting area when using ultrasound. In addition, the speed of chip removal during ultrasonic turning increases by 1,8–2 times, which helps to remove heat and stabilize the process.

Thus, the results of the conducted research have confirmed that ultrasonic vibration helps to reduce the chip thickness, reduce the shrinkage coefficient, improve cutting conditions and improve the quality of the treated surface. This makes ultrasonic turning an effective method for finishing difficult-to-process materials.

Conclusion. Based on the conducted experimental studies, the following conclusions can be drawn:

1. Ultrasonic vibration turning is an effective method for improving accuracy and productivity in processing metals and other materials. The frequency of ultrasonic waves has a significant effect on the processes of deformation of the material and the quality of the resulting surface. Under the influence of ultrasound, microscopic cracks and local deformations occur in the material, which reduce its hardness and facilitate the cutting process.

2. It has been found that increasing the frequency of ultrasonic waves makes it possible to achieve higher surface quality and increased processing accuracy. On the contrary, the use of waves with a lower frequency contributes to the intensification of the process due to more pronounced deformations. Changing the frequency affects the deformation conditions in the cutting area, since the vibrations of the cutting edge become variable, and the thickness of the chips being removed is uneven.

3. Ultrasonic turning is accompanied by the action of high-frequency sound waves, which have a significant effect on the chip formation process and the formation of the treated surface. The nature and structure of the chips vary depending on the frequency and amplitude of the ultrasonic vibrations. This is due to the fact that waves with a high frequency form smaller but more intense pulses that effectively affect the material, ensuring a smooth and precise surface.

4. The frequency and amplitude of ultrasonic vibrations are key parameters that determine the efficiency of the process. Their optimal choice, taking into account the properties of the processed material, the requirements for accuracy and the purpose of the part, ensures an increase in the quality and productivity of turning.

5. It has been found that when using ultrasonic vibrations, the chip removal rate increases by 1.8–2.0 times compared with traditional turning. This helps to effectively remove heat from the cutting area, reduce temperature loads and, as a result, improve the quality of the treated surface.

6. Reducing the temperature in the cutting area and reducing deformation processes in comparison with conventional turning also help to reduce the likelihood of shrinkage defects in the chips.

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