Tool Performance Under Ultrasonic Reaming

S I Agapov*, Y I Sidyakin and S N Olshtynsky
Volgograd State Technical University, Lenin Avenue, 28, Volgograd, 400005, Russia

*agapovsi2020@gmail.com

Abstract. The widespread adoption of ultrasonic processing methods was hindered by the lack of reliable ultrasonic heads. Currently, in connection with the widespread production of piezoceramic transducers of various shapes and sizes, it has become possible to abandon bulky magnetostrictive transducers requiring individual cooling. The creation of light piezoceramic heads and their implementation in production is associated with targeted comprehensive studies to determine the magnitude and direction of ultrasonic vibrations, the influence of technological factors on the surface roughness and accuracy of the obtained holes. This processing method is especially important in aircraft engine building, where the issue of obtaining quality holes is particularly acute. Difficulties in the processing of holes by reaming are associated with the low machinability of the used steels and alloys in aircraft engine construction. The cutting edges wear out at the intersection of the intake cone and the calibrating part the more intensively, the higher the processing conditions. The process of holes reaming is one of the most difficult and critical stages of machining, on which the quality and the final result of the machined parts depend. This paper describes the experiment and gives experimental data on the influence of the magnitude and direction of ultrasonic vibrations on the resistance of a cutting tool, as well as the effect of wear on surface roughness and accuracy of machined holes. The research has established a significant advantage of ultrasonic reaming in terms of surface roughness, the accuracy of holes, and the resistance of the cutting tool in workpieces made of difficult-to-process materials.

When finishing holes in parts of new high-strength steels and titanium alloys with traditional cutting methods used in aircraft and engine building, there are a number of difficulties. One of the effective methods to increase the durability and quality of the processed surface is to introduce ultrasonic vibrations into the cutting zone with a frequency of 18...22 kHz and an amplitude of 4...6 μm.

Wear of the reamers was observed mainly along the posterior surface of the tooth, with the maximum values of wear being localized at the intersection of the starting taper and the sizing part, i.e. in the area of contact of the tooth with the cutting surface. To study the nature of patterns and the rate of wear of the reamers for the entire period of durability, (after processing 6...8 holes), the back surface of the cutting part of the tooth was measured periodically by using a BMI-1 instrument microscope, as well as a Brinel magnifier with a division of 0.05 mm.

The materials on which the studies were carried out were 12X18H10T stainless steel and VT-20 titanium alloy. Reamers were made of high-speed steels P6M5 and P6M5K5, geometry in accordance with GOST 7722-77. Cutting modes were as follows: the speed varied widely, the feed and the cutting depth were assumed to be constant S = 0.14 mm / rev (t = 0.05 mm for 12X18H10T, and t = 0.15 mm for VT-20), cutting with 10 percent emulsion watering.
To study the blunting criterion, we studied the dependence of surface roughness and accuracy of machined holes on the rate of wear. The surface roughness and the accuracy of hole machining are decisively influenced by wear at the point where the starting taper goes to the sizing part, since it is this section that forms the machined surface, and besides, the highest specific loads are observed in this area [1].

With wear $h_3 = 0.3$ mm, vibrations occur (with traditional cutting), leading to chipping of the cutting edges, a sharp increase in surface roughness and a decrease in the accuracy of the holes. To remove chips on the cutting edges during regrinding, an increased allowance is required, which reduces the already small number of reamer regrindings. Based on this, wear criterion $h_3 = 0.3$ mm was taken as a criterion for blunting the tool.

When studying the spacing and surface roughness of the holes, the influence of ultrasonic vibrations on the resistance during the reaming of both 12X18H10T stainless steel and VT-20 titanium alloy was also evaluated. The experiments showed that the imposition of ultrasonic vibrations on the instrument has a significant effect on its durability [2, 3, 4].

Figure 1 shows the dependences of the resistance of the $\varnothing 14$ mm reamers made of P6M5K5 steel on the amplitude of ultrasonic vibrations when processing stainless steel 12X18H10T and titanium alloy VT-20. A non-monotonic dependence of the resistance on the amplitude of oscillations is observed. The greatest increase in resistance (2.16 times) is observed at $\xi = 5$ μm; at $\xi > 5$ μm, it decreases. In case of ultrasonic vibrations with an amplitude of up to 5 μm, the scan resistance increases by 1.8 ... 2.2 times. With a further increase in amplitude from 5 to 8 μm, tool life decreases.

This nature of the change in resistance can be explained as follows: when ultrasonic vibrations are introduced into the cutting zone, tool wear is generally determined by the combined action of three main factors:

1) a change in the stress-strain state in the cutting zone;
2) the occurrence of high fatigue stresses in local volumes of the tool material;
3) an increase in instantaneous cutting speed.

Depending on the cutting conditions and the oscillation amplitude of the cutting part of the tool, the influence of each of these factors can be different. At small amplitudes, the improvement of cutting conditions (reduction in the volume of plastic deformation, reduction in cutting forces and friction coefficient) is of primary importance, which reduces abrasive and adhesive wear and increases tool life compared to conventional cutting [5, 6]. At $\xi = 5 ... 6$ μm, a change in the loading conditions and an increase in the true cutting speed, which violates the interatomic bonds due to irreversible

![Figure 1](image-url)
distortions of the crystal lattice during the mass exit of dislocations to the surface, predominates on the scan wear. With further operation of the tool and an increase in loading cycles, submicroscopic cracks develop to the size of microcracks, and fatigue failure of the working part of the tool begins.

With an increase in the amplitude of the oscillations, the instantaneous velocity sharply increases. Axial vibrations are transmitted directly from the waveguide to the part. To create complex vibrations on the waveguide, angular flutes of variable depth were made at an angle of 30°.

Preliminary experiments established that the maximum tool life is achieved at 4 μm < ξ < 6 μm, so all further studies were carried out with an amplitude of 4 ... 6 μm.

When processing difficult-to-machine materials, wear of the reamers is observed mainly on the back surface of the tooth, and the maximum values are observed at the intersection of the starting taper and the sizing part, i.e. at the point of contact of the tooth with the cutting surface.

To compare the resistance of reamers used in traditional and ultrasonic processing methods, studies were carried out when machining VT-20 titanium alloy with an instrument made of R6M5K5 high-speed steel at a cutting speed of 11 m / min, a feed of 0.14 mm / rev, a depth 0.15 mm and a 10% emulsion coolant. The geometry of the cutting part of the tool was as follows: rake angle γ = 0, relief angle α = 8°, angle of the starting taper = 15°, band width = 0.15 ... 0.20 mm, the pitch of the teeth was evenly divided. After processing 30 holes (tool operating time 10 minutes), the cutting part of the tool was photographed with a 24-fold increase. The adopted photographing scheme is shown in Fig. 2, and the photographs are represented by Fig. 3, photographs 3a and 3b show the reamers that worked without ultrasonic vibrations, and photographs 3b and 3b are of the reamer that worked with ultrasonic vibrations.

Photos 3a and 3b show chips on the front surface and wear on the rear surface of the sizing part. There are no chips in photographs 3c and 3d, and the width of the band exceeds the original by only 0.1 mm, which indicates a significant decrease in both the cutting forces acting on the corner and the friction forces acting on the sizing part of the reamer. Under the influence of ultrasound, the duration of the stationary contact of the tool and the part is reduced, thus compromising the effective friction forces, due to a decrease in the adhesive and deformation components.

In addition, ultrasonic vibrations contribute to the development of structural defects (microcracks, micropores), and also due to the presence of vibrations of the tool relative to the part, the gap starts pulsing, which contributes to the absorption of coolant. These factors lead to a decrease in tool wear, a decrease in surface roughness and hole reaming [7, 8, 9].

The wear of the reamer along the back surface and the introduction of ultrasonic vibrations into the cutting zone significantly affect the microroughness and accuracy of the machined holes. Thus, in the traditional processing of stainless steel 12X18H10T, the surface roughness increases from Ra = 0.9 μm to Ra = 1.2 μm with increasing wear on the rear surface from zero to h3 = 0.3 mm, and when ultrasonic vibrations are introduced into the cutting zone, the roughness surface increases from Ra = 0.22 μm to Ra = 0.46 μm, at the same wear rate. As it can be seen from the hereinabove, the surface roughness of the holes, even at the maximum wear rate h3 = 0.3 mm, is much lower than in the case of traditional machining with an unworn reamer.
When processing VT-20 titanium alloy, the nature of the change in surface roughness is the same to the case of processing 12X18H10T. So, when processing with a P6M5K5 reamer without introducing ultrasound, the surface roughness increases from Ra = 0.64 μm to Ra = 0.9 μm with increasing wear from zero to h3 = 0.3 mm, while ultrasonic cutting, the surface roughness increases, respectively, with Ra = 0.18 μm to Ra = 0.52 μm, which is also significantly lower than the common reaming data (Figure 4).

![Figure 3](image1.png)

**Figure 3.** Reamer wear during the reaming of the VT-20 both without and with ultrasonic testing.

- v = 11 m / min; S = 0.14 mm / rev; \( \xi = 4 \ldots 6 \) μm; t = 0.15 mm
- a - on the rake surface without ultrasonic testing; b - on the back surface without ultrasonic testing,
- c - on the rake surface with ultrasonic testing; d - on the back surface with ultrasonic testing.

![Figure 4](image2.png)

**Figure 4.** Changes in surface roughness in samples of 12X18H10T from wear on the rear surface.

1 - without ultrasonic testing; 2 - with ultrasonic testing. Scan φ 14 mm, material of the cutting part P6M5K5, v = 5.5 m / min; S = 0.14 mm / rev; \( \xi = 4 \ldots 6 \) μm.
This phenomenon is explained by the low ductility of titanium alloys. As mentioned above, for titanium alloys, $\delta_{0,2}/\delta_{v}$ is 0.8-0.85, while for stainless steel 12X18H10T it is 0.54 [10, 11, 12]. Due to the fact that the reamers have a small number of regrindings, the increased amount of wear on the rear surface and the chip size significantly affect the overall performance of the tool.

When machining stainless steel 12X18H10T with reamers from P6M5K5 to wear $h_3 = 0.3$ mm, the tool was working for 90 minutes, and when ultrasonic vibrations were applied to it, it lasted 160 minutes, i.e. resistance increased by 1.78 times [1].

Increasing the productivity of cutting by cutting heat-resistant and stainless steels and titanium alloys largely depends on the correct choice of the grade of tool material. To process the VT-20 titanium alloy, reamers made of high-speed steels P6M5 and P6K5M5 were tested. Tools with a cutting part made of tungsten-molybdenum steel (P6M5) are most widely used. Tools made of tungsten-molybdenum steel with cobalt (P6M5K5) are the main for the manufacture of reamers used in the processing of both stainless and heat-resistant steels and titanium alloys.

The best results were obtained when testing reamers from P6M5K5, because this steel retains the hardness of NRK 60 after heating for 4 hours to 630-650 °C, which is higher than that of steel P6M5 [11,12].

Compared to reamers with a cutting part from P6M5, the tool from P6M5K5 has the following advantages. When ultrasonic vibrations were applied to the instrument, the surface roughness decreased by 30% (Figure 4), and the working capacity increased by 20%. With ultrasonic reaming, the roughness decreased by 25% (Figure 5), and the performance increased by 22%. The test results coincide with the recommendations for the selection of tool material for processing high-strength titanium alloys.

One of the positive effects of applying ultrasonic vibrations to the tool is the ability to achieve the same surface roughness obtained by conventional deployment at significantly higher cutting speeds. The studies were carried out on steel 12X18H10T and titanium alloy VT-20 with reamers made of high-speed steels P6M5 and P6M5K5.

Based on the experimental data, the dependence of resistance on cutting speed and grade of tool material is obtained. The best results were obtained when using reamers with a cutting part from P6M5K5, tool life increases by 20 ... 22% compared to reamers with a cutting part from P6M5 both with and without ultrasonic vibrations.

On the basis of the experimental data, the following dependence was obtained:

$$T = \frac{C_T}{v^k}.$$
The values of the coefficient of $C_T$, the degree of $X_T$ depending on the material being processed and the grade of high-speed steel are summarized in Table 1.

When applying ultrasonic vibrations to the reamer, not only the resistance, but also the stability of obtaining accurate holes increased. The wear of the back surface of the teeth when working at different cutting speeds was more uniform, the difference in the amount of wear on each of the eight teeth did not exceed 0.05 ... 0.10 mm, tooth chipping was not observed both during processing 12X18H10T and during processing VT-20. The best results of increasing the resistance were shown by reamers with a cutting part from P6M5K5.

Table 1. The cutting properties of high-speed steel reamers in conventional and ultrasonic reaming.

| Material machined | Tool material | $C_T$ Without ultrasonic vibration | $C_T$ With ultrasonic vibration | $X_T$ Without ultrasonic vibration | $X_T$ With ultrasonic vibration |
|-------------------|---------------|-----------------------------------|---------------------------------|-----------------------------------|---------------------------------|
| 12X18H10T         | P6M5K5        | 115                               | 118                             | 0.364                             | 0.509                           |
| VT-20             | P6M5          | 21                                | 45                              | 0.344                             | 0.287                           |
|                   | P6M5K5        | 31                                | 64                              | 0.404                             | 0.384                           |

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