Evaluation of tribo-vibration characteristics of the finishing turning process of heat-resistant structural steel 20MnMoNi5-5

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Abstract. This article is devoted to determining the rational range of cutting speeds during longitudinal finish turning of heat-resistant steel 20MnMoNi5-5 based on a set of tribological and vibration parameters of the cutting process. Turning workpieces with diameters D=120 mm made of 20MnMoNi5-5 steel with T15K6 carbide plates without cooling at finishing feeds and allowance values at cutting speeds of 100-220 m/min was carried out and studied. It was experimentally established that the local minimum for vibration energy was located within the speed range of 190-220 m/min. According to the results of tool life tests in this speed range, the wear rate of the cutting inserts was also minimized and the operating time of the tool was increased, making it possible to ensure the required surface roughness Ra≤1.6 μm.

1 Introduction

Increasing the wear resistance of cutting tools is a very urgent problem, which is solved in various ways: by creating new tool materials with improved physical, mechanical and cutting properties [1-4], by modifying the working edges of the tool with wear-resistant coatings [5-8], by assessment of the thermal load of the tool [23] and by selecting optimal technological operating modes for the tool [9-11]. One of the main factors that contribute to the intensification of wear processes of tool cutting materials is significant vibrations in the cutting system. This can also lead to sudden failures of the cutting part of the tool, it also limits the range of possible processing speeds, and increases temperature fluctuations in the cutting zone. A high level of vibrations in the cutting system also leads to a quality decrease of the machined surface and to an increase in the average roughness [12-14]. High-quality, high-alloyed, heat-resistant structural steels are used to manufacture a wide range of parts in mechanical engineering. Steel 20MnMoNi5-5 (US A508-3) is one of their most common representatives. This material is used for the production of pressure vessels or other similar equipment, such as petroleum, gas storage, and transportation [15-17]. The manufacturing processes of these details contain a significant proportion of turning operations, including

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those carried out on lathes with an average service life exceeding 10 years. In this case, when choosing the processing modes for the technological process, it is necessary to take into account a number of errors introduced into the manufacturing process by the processing equipment. In this case, when choosing processing modes for a technological process, it is necessary to take into account a number of errors in the process of manufacturing due to machining equipment. Increased tool wear in combination with high temperature on the contact area "flank surface of the tool – finished surface of the workpiece" and significant fluctuations in the parameters of the cutting system contributes to the deterioration of a number of characteristics of the surface microrelief (average and maximum roughness, statistical parameters of roughness as a random variable) and the surface layer of the material (changes in hardness and gradient of physical and mechanical properties). It is especially important to obtain a high-quality surface when performing finishing turning passes, it reduces the number of operations required to achieve specified roughness values and minimizes cutter wear. In accordance with modern economical and ecological requirements of metalworking industries, it is preferable to process parts with minimal use of cutting fluid or without its use at all [18,19].

The purpose of this research is to study the tribo-vibration parameters of the process of dry finishing turning of heat-resistant steel 20MnMoNi5-5 and to determine the range of processing speeds that ensure minimal vibrations in the cutting system.

2 Materials and Methods

The experiments were carried out when turning workpieces with a diameter $D=120$ mm made of steel 20MnMoNi5-5 with tools with carbide plates T15K6 without cooling. Cutting modes: speed $V=100-220$ m/min, feed $S=0.195$ and $0.26$ mm/rpm, depth of cut $t=0.5$ and $1.0$ mm. The geometry of the cutting part: rake angle $\gamma =10^\circ$, clearance angle $\alpha=10^\circ$, side-cutting edge angle (SCEA) $\varphi=95^\circ$. The vibration characteristics of the turning process were measured by a vibration stand of the following composition: vibration transducer Global Test AP2089-100-3.3-02 B; external ADC/DAC unit L-Card E14-440 to USB for converting data from vibration sensors; signal amplifier Global Test AG01-322005. The sensors were mounted on a lathe cutter in close proximity to the cutting area. During the vibration control, the values of vibration accelerations (mm/sec$^2$) were measured in three directions. The wear of the cutting plates was evaluated using a metallographic inverted microscope LaboMet-I4, the roughness was measured by portable surface roughness tester Surf test SJ-210 (Japan). The lower threshold value of the roughness range of the finished surfaces, for which the operating time of the plate in the test mode is estimated, is $Ra = 1.6 \mu$m. The experimental data were processed in the MathCAD system using methods of analysis of variance [20,21].

3 Discussion of the Results

The dependence of the vibration state of the process on the cutting speed is nonlinear, which indicates the presence of areas of stable cutting and areas with high vibration activity of the tool speed signal and resonance zones (Fig. 1).
Fig. 1. Dependence of the total vibration signal energy $E_{ΔV}$ along three axes on the cutting speed $V$ ($t=0.5$ mm, $S=0.195$ mm/rev).

A trend change from negative to positive is clearly visible with the lowest value at the point corresponding to the velocity $V=190$ m/min for curves $E(V)$ at $t=0.5$ and 1.0 mm and feeds of $S=0.195$ and 0.26 mm/rev. Despite this, the analysis of the characteristics of $E_{ΔV}$ in the directions $x, y, z$ shows that not for all directions this control point is characterized by the lowest value of $E_{ΔV}$ (Fig.2).

Fig. 2. Dependence of the energy of the vibration signal $E_{V'}$ on processing speed $V$ ($t=1$ mm, $S=0.26$ mm/rev).

It is assumed that for the radial and tangential directions ($E_{V'y}$, $E_{V'z}$), the optimum zone is shifted to the right relative to the experimentally studied velocity $V=190$ m/min, since with increasing spindle rotation frequency, the largest deviation of the center displacement trajectory from the origin and the ovality of the trajectory decrease [22, 23], that is, the spindle runout along the $Y$ and $Z$ axes. The position of the local minimum for vibration energy in the range of 190-220 m/min is also indicated by the nature of the dependence of the cutting forces (Fig.3).
Dependence of the average values of the cutting forces $P_{x,y,z}$ on the cutting speed $V$ ($t=1$ mm, $S=0.26$ mm/rev)

The drop in vibration energy $E_{\Delta V}$ is due to a decrease in the deformation displacements of the tool with increasing cutting speed. Analysis of these patterns showed that the optimal range of cutting speeds lies in the area of minimum trajectory trend $E_{\Delta V}$ for a selected set of speed values for all directions of tool movement. In order to establish a correlation between the vibration characteristics of the cutting process under various modes and the wear resistance of the plates, a series of resistance tests were carried out selectively for different cutting speeds. Tool life tests showed that for speeds in the range of 190-220 m/min, the wear process of the plates along the flank surface is significantly minimized in the studied cutting modes. Speeds outside the range of 190-220 m/min are characterized by both lower wear resistance and a shorter operating time of the plates, at which the minimum required roughness value is achieved. So, for example, at $V=180$ m/min and depth of cut $t=0.5$ mm, parameter $Ra 1.6$ is maintained by the cutting system for 19 minutes, at $V=230$ m/min the value of this parameter is 14 minutes. During the durability tests, vibration diagnostics of the process was also carried out during the evolution of the cutting system and wear development. Analysis of the vibration characteristics of the tool motion signal relative to the detail during these tests showed an intensification of vibration energy with increasing tool wear. However, for speeds within the range of 190-220 m/min, the change in vibration energy from the time of the experiment is more regular than for cutting speeds outside of it (Fig. 4)
4 Conclusion

Research was carried out on the process of longitudinal turning of heat-resistant steel 20MnMoNi5-5, the purpose of which was to determine the range of cutting speeds for finishing operations that ensure the required surface quality with minimal wear of the cutting tool. Based on the results of vibration diagnostics of the cutting process, a range of cutting speeds was established, characterized by minimal vibrations, which also implies a reduction in tool wear. Clarifying tool life tests showed that in the speed range of 190-220 m/min, the wear rate of cutting inserts actually decreases significantly. The use of these cutting speeds with finishing values of feeds and allowances when turning 20MnMoNi5-5 steel will make it possible to increase the wear resistance of cutting inserts, as well as maintain a roughness value $Ra$ of less than 1.65 µm for a longer time during the cutting process, without subsequently resorting to additional finishing operations.

References

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