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Structural features of the roughness profile of hardened steel parts after finishing turning

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Abstract. This article presents the results of a study of the structural features of the roughness profile of surfaces that are treated with finishing turning. The processing of hardened high-quality carbon steels is considered as initial data. Standard cutting tools with mechanical plate mounting are used. The profile of the treated surface was analyzed using the theory of random processes and fractal geometry methods. As a result of the research, it was found that with a decrease in the arithmetic mean separation of the Ra profile, the proportion of the random component increases. It can be concluded that the role of vibration processes in the formation of the profile is increasing. This factor makes it possible to implement a processing management strategy with the possibility of improving the quality of the surface layer.

1 Introduction

Initially, an approach was used to describe the process of surface roughness formation during turning, in which it was assumed that the processed profile was a regular curve formed as a result of a combination of kinematic movements during turning. The calculation formula for determining the value of the arithmetic mean deviation of the profile has the form [1]:

$$R_z = \frac{S^2}{8 \times r}, \tag{1}$$

where S– is the value of the longitudinal feed; r - is the radius at the top of the tool.

Later it was found that the process is more complex and it is necessary to take into account not only the geometry and kinematics of the process, but also the characteristics of the cut layer, then in adjusted form expression (1) has the form [1]:

$$R_z = \frac{S}{8 \times r} + \frac{h_{min}}{2\left(1 + \frac{r \times h_{min}}{S^2}()\right)}, \tag{2}$$

where $h_{\min}$ –is the minimum thickness of the cut layer.

Further development of ideas about the process of surface roughness formation has shown that the following set of factors must be taken into account [2,3]:

- breakouts of the treated metal from the surface of the part caused by adhesive friction
- the presence of elastic and plastic deformations;
- the shape of the cutting tool;
- roughness of the cutting edge of the tool;

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- kinematics of the cutting process;
- vibrations of the elements of the technological system.

The dependence, which takes into account the influence of these factors, has the form [2,3]:

$$R_z = h_1 + h_2 + h_3 + h_4, \quad (3)$$

where h_1 – is the height component of the profile of the treated surface, which is generated by the cutting kinematics and geometric parameters of the cutting part of the tool. Analyzing the nature of these factors, we can say that the h1 component is assumed to be conditionally constant (deterministic); h_2–the height component of the profile of the treated surface, which is generated by the oscillatory processes of changing the cutting force due to the unevenness of the cut layer, fluctuations in the hardness of the treated surface, etc. Analyzing the nature of these factors, we can say that the component h_2 is assumed to be variable (stochastic); h_3 – the height component of the profile of the treated surface, which is generated by plastic and elastic deformations of the elements of the technological processing system. Analyzing the nature of these factors, we can say that the h_3 component is assumed to be a variable (stochastic); h_4 – the height component of the profile of the treated surface, which is formed as a result of copying the initial irregularities of the cutting edge of the tool. Based on the experience of studying surface roughness profilograms [4-6], we can say that this factor also refers to constant (deterministic) ones.

Then, taking into account the fact that the final texture of the profile of the treated surface includes both stochastic and deterministic elements, it is possible to represent the profile texture in the form of a diagram (Figure 1), as well as to give a cybernetic scheme for the formation of micro-dimensions (Figure 2).

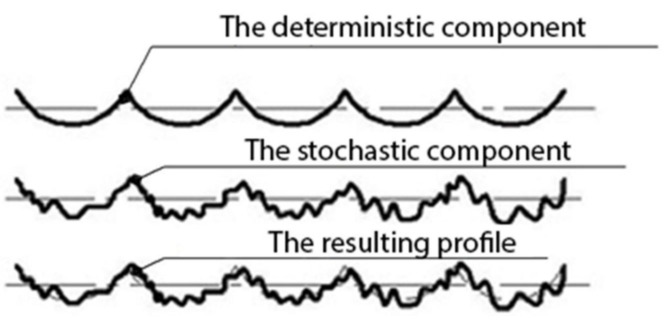

Fig. 1. Diagram of the formation of a surface roughness profile during turning.

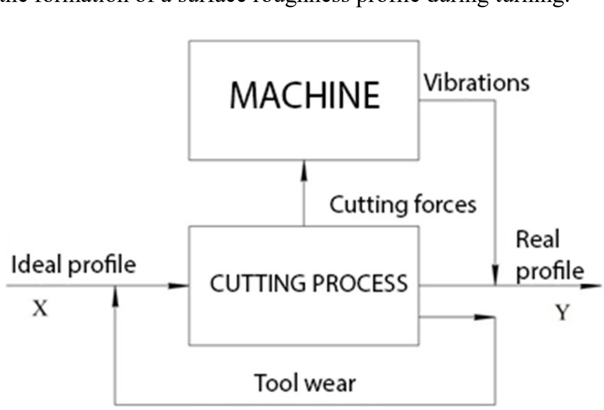

Fig. 2. Cybernetic diagram of the formation of micro-dimensions.

Thus, the application of the approach to identify systematic and random components of the surface roughness profile allows us to identify the factors that have the greatest impact. This is especially important when processing hardened steels. In addition, critical parts are most often made of hardened steels, the executive surfaces of which are subject to increased requirements, including surface roughness. At the same time, the use of grinding for finishing such parts is also not always justified due to the process of caricaturing the treated surface, as well as the random nature of the microrelief of the surfaces treated with grinding.

The purpose of this research is to study the features of the formation of surface roughness during turning of hardened steels based on the quantitative determination of the level of systematic and random components of the profile.

2 Research materials and methods

Profilograms of surfaces treated with finishing turning were used as initial data. The processed material is carbon structural and alloy steels with a hardness of more than 35 HRC: steel 45, 40XH and 45XH.

Experimental studies were carried out on a turning machining center with an inclined bed of the SuperJobber 500.

Test modes:

a) cutting speed limits from 50 to 300 m/min with constant feed.
b) feed limits from 0.01 to 0.2 mm/rev at a constant cutting speed.
c) the cutting depth is from 0.1 to 0.3 mm with constant processing modes.

Standard turning cutters with mechanical fastening of cutting plates from the most common in the production of hard alloys composite 01 (elbor), composite 10 (hexanite), VOC60 were used as cutting tools.

The texture of the processed profiles was studied using the theory of random processes (based on correlation analysis) [4-7], as well as on the basis of fractal geometry [8-9].

In correlation analysis, the studied profilogram is represented as the following transformation:

$$K_{XX}(\tau) = \frac{1}{l-\tau}\sum_{i=0}^{l-\tau} x(t)x(t+\tau), \tag{4}$$

where τ – is parameter along the abscissa axis (physical meaning time delay), takes integer values $\tau = 0,1,2,\ldots,\tau_{max}$;

l – the length of the analyzed profilogram;

$x(t)$ – the value of the ordinates of the analyzed profile.

Then, having a correlation transformation of the profile, it is possible to determine the desired level of the random component as the ratio of the variance of the random component Dγ and the standard deviation of the profile Rq:

$$\gamma = \frac{D_\gamma}{R_q^2}, \tag{5}$$

In turn, the components included in expression (5) can be defined as follows:

$$D\gamma = Rq^2 - 0.5A^2, \tag{6}$$

where $A = \frac{S^2}{8r}$ – is the height of the systematic component of the profile.

The standard deviation of the profile can be defined as the value of the autocorrelation function at the zero point:

$$R_q = K_{XX}(0), \tag{7}$$

Knowing the level of the random component allows you to estimate the proportion of the systematic component β :

$$\beta = 1 - \gamma \tag{8}$$

The use of fractal geometry also makes it possible to obtain information about the degree of randomness in the analyzed curve. It is known that the closer the value of the fractal dimension is to 1.5, the greater the proportion of the random component. In this paper, the fractal dimension of the profilograms of the surfaces of parts made of hardened steels processed by turning was estimated using the Hearst index (H). This indicator is determined by the following formula [9]:

$$H = log\left(\frac{R}{S}\right) = f(log(N)), \tag{9}$$

where R and S are the magnitude of the span and standard deviation of the profile, calculated at different values of the variable t, which varies from 1 to N-1 (N is the length of the profilogram).

The expressions for calculating R and S have the form:

$$R_t = Max(X_{t,N}) - Min(X_{t,N}) \tag{10}$$

$$S = \frac{1}{N} \times \sum_{i=1}^{N}(x_i - M_N)^2 \tag{11}$$

In this case, the Hurst index and the fractal dimension are related by the following ratio:

$$D = 2 - H \tag{12}$$

Considering the above, we can say that the closer the value of H is to 0.5, the higher the level of the random component in the studied profile.

The authors have developed an application software that allows you to determine the values of the level of the random component and the Hurst index. The interface is shown in Figure 3.

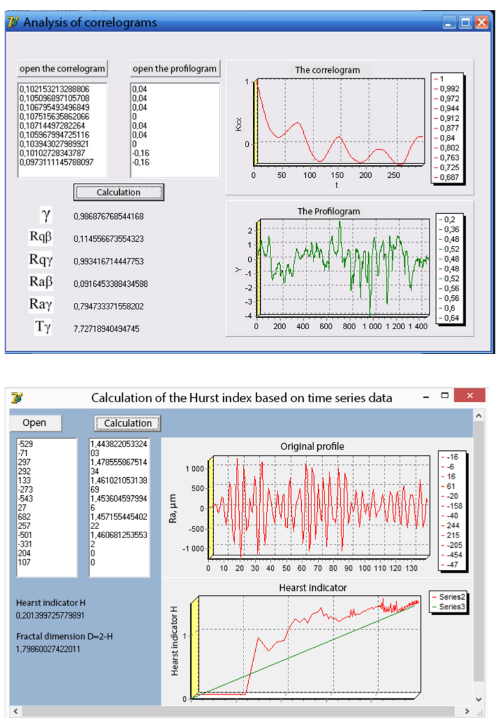

Fig. 3. Application software.

3 The results of the research and their discussion

The dependence of the level of the random component on the arithmetic mean deviation of the profile for surfaces treated with fine turning of workpieces made of hardened steels was obtained (see Figure 4).

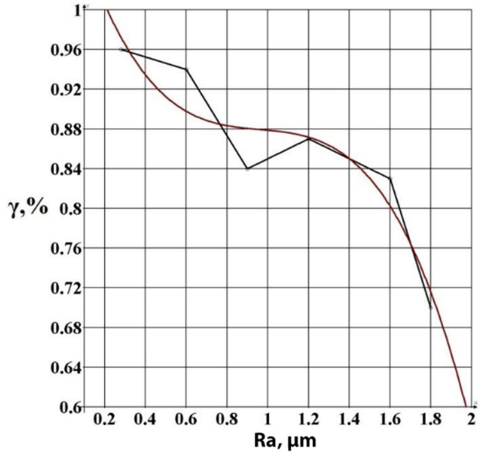

Fig. 4. Dependence of the level of a random component.

Analytically, this dependence is given by an expression of the form:

$$\gamma = 1.12301 - 0.25377 \times Ra^3 + 0.73304 \times Ra^2 - 0.72368 \times Ra \qquad (13)$$

Standard deviation: σ=0.03024

Coefficient of determination: R^2=0.89945.

The value of the coefficient of determination suggests that dependence (13) can be used to describe the relationship between factors.

Figure 5 shows the dependence of the Hearst index on the arithmetic mean deviation of the profile for surfaces treated with fine turning of workpieces made of hardened steels.

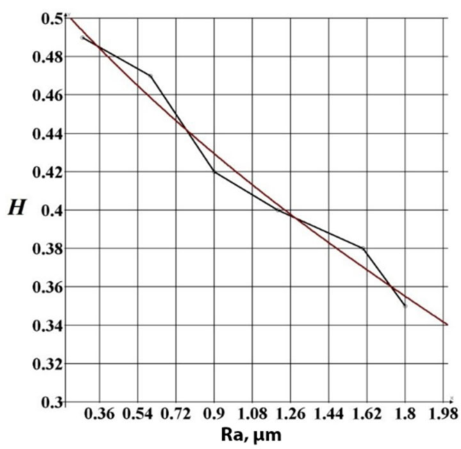

Fig. 5. The dependence of the Hurst index on the arithmetic mean deviation of the profile.

Analytically, the dependence has the following form:

$$H = 0.52733 - 0.0036 \times Ra^3 + 0.02416 \times Ra^2 - 0.12757 \times Ra \qquad (14)$$

Standard deviation: σ=0.00843.

Coefficient of determination: R^2=0.97513.

The value of the coefficient of determination suggests that dependence (14) can be used to describe the relationship between factors.

4 Conclusion

Analyzing the results obtained, it can be concluded that a random component prevails in the texture of the profile of the surfaces of parts that are made of hardened steels and processed by finishing turning. It is important to note that the results obtained are highly consistent, which were obtained using different research methods: the theory of random processes and fractal geometry. This is a confirmation of the correctness of the received data. In general, the nature of the dependencies (13) and (14) is consistent with the dependencies that were obtained for the finishing turning of non-hardened steels in [10]. This is an additional confirmation of the universality of the approach in relation to surfaces with regular microrelief.

An important consequence for practice is that with a decrease in the value of the arithmetic mean deviation of the profile (Ra), an increase in the level of the random component is observed, and for the range that corresponds to finishing and finishing (Ra<1.6 microns), the level of the random component exceeds 75%.

Thus, when solving the problem of ensuring the specified requirements for surface roughness during turning, it is necessary, first of all, to provide such conditions that minimize the influence of vibrations.

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