Generalized Mathematical Model Predicting the Mechanical Processing Topography

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Abstract. We propose a unified approach for the construction of mathematical models for the formation of surface topography and calculation of its roughness parameters for different methods of machining processes. The approach is based on a process of geometric copy tool in the material which superimposes plastico-elastic deformation, oscillatory occurrences in processing and random components of the profile. The unified approach makes it possible to reduce the time for creation of simulated stochastic model for a specific type of processing and guarantee the accuracy of geometric parameters calculation of the surface. We make an application example of generalized model for calculation of roughness density distribution Ra in external sharpening.

Introduction

The surface tool topography has a significant impact on its serviceability and life cycle [1 - 4]. Detail topography allows considering geometric parameters of its surface with different detail levels. It includes the size, form deviations, waviness and roughness of the surface. These indicators and their parameters have a significant effect on the detail serviceability. Having the surface topography it is not difficult to get any parameters of geometric ones. Therefore, when designing the model of the detail, irrespective of the type of processing, it is necessary to focus on its topography – describing the geometry of the surface as a whole.

The measurement process is very laborious, despite there is special equipment for measuring the topography, as well as detail profilograms. Therefore, it is more efficient to predict the topography by means of mathematical modeling for the process of its formation. Due to empirical models are of limited use, and different conditions of machining process have big differences, it is relevant to create a common approach predicting the topography of the finish surface, regardless of the processing type [5].

Theory.

The main events, identifying the topography of the finish surface after the mechanical process, are [1, 6]:
1. geometric copying of the working part of the tool in the material surface of the workpiece;
2. vibrational movement of the tool relative to the workpiece;
3. plastico-elastic deformation of the surface layer of the processed material;
4. random digging of the processed material.

These phenomena are also accompanied by surface damage [7], which affects both size and form of its working parts and the dynamics of the cutting process [8] (cutting force, temperature, etc.). Account must be taken on the sticking of material workpiece surface to the tool (built-up edge) may also change its geometry and dynamics of cutting. Furthermore, the geometry of the tool, the cutting mode settings, hardware settings and devices, physical and mechanical properties of the worked and tool material are not constant and contain both dynamic and random components [5].

In accordance with it, the simulated model of the topography forming machining operation is based on the geometrical copy process of tool profile to the product material. From the theory of sets point of view, the cutting process can be viewed as a process of removing multiple sets of $M_{APTj}$ points, given by the actual profile of the tool, made of workpiece material (set $M_i$). Summary actual profile of the tool may consist of several subsets (e.g. the cutting portion profile of the grinding wheel is determined by the profiles of its constituent grains, and the cutting part of the cutter profile – its teeth). Therefore, union of subsets is used to describe. At every point in time in the original profile (a set of $M_{i-1}$) cut the intersection of this set with a set of the tool actual profile. This process is described in the formation of a new profile $M_i$:

$$M_i = M_{i-1} - \left( \bigcup_j M_{APTj} \right) \cap M_{i-1}$$

In the process of modeling $M_{APTj}$ plurality gradually changes due to, for example, tool wear. The number of elements of this set depends on the mode and the kinematics of the cutting. In the simulation processing blade tool (turning, milling, etc.) set $M_{\Phi\Pi\Phi_i}$ is given in the cutting plane. Profile parameters have stochastic components, and the density of their distribution depends on the accuracy of the instrument and its home base in the device. When simulating abrasion stochastic nature of the process inherent cut: grain instrument have a random distribution of its depth and surface, grains have a random size and shape. But even with the blade, and abrasion processing in the formation of the profile parts there involved copying process of geometric cutting elements (incisor teeth milling, grains of the abrasive tool).

The process of the tool profile copying is accompanied by a process of elastic deformation as processed material, and the instrument. High temperatures in the contact zone of the tool with the workpiece (especially when grinding) lead to smoothing of the resulting profile. When the blade processing the speed factor and the temperature is lower, but high specific cutting force deforms come offroughness ridge by changing its shape. In the actual cutting processes there are two factors: smoothing of the profile, and nonlinear deformation. Fundamental process depends on the specific cutting conditions.

Influence of vibrations during machining is not completely clear. The sources of vibrations are as fluctuation of technological system elements from drives and unbalanced masses (e.g. an imbalance of the grinding wheel or parts), and the cutting process – self-oscillations (regenerative, coordinate communication, nonlinearity, etc.). In the latter case, the analysis requires the study of self-oscillations in the feedback system. Therefore, the output of the model are, in addition topography, and the dynamic characteristics of operation: cutting force, the speed and acceleration of movement of elements of the technological system, etc.

The processes of profile forming and the surface topography are random components related to pickups and pits of the work material. There are instances when the process causes the substantial surface roughness. Therefore, the development of stochastic models supposes taking into consideration the random component of the surface topography.

Fig. 1 shows the structure of a generalized simulation stochastic model of the topography formation. The structure takes into account:

1. The topography formation of the processed surface parameters affects the tool, equipment, devices and cutting conditions.
2. Stochastic parameters of the subsystems are additive.
3. The parameters of the subsystems are defined as dynamic properties of the simulation model (feedback).
4. The surface topography is formed by four phenomena: the geometrical copy, the impact of vibration, plastic-elastic deformation and proper random component.
5. Any geometric parameters of the surface layer are formed by the output function of the surface topography.

According to developed structure we have implemented stochastic simulated models of a number of mechanical processing. For blade machining they are represented by lathe turning and face milling. For abrasion – by circular external and internal grinding, centerless grinding, boned finishing, etc. in spite of different kinematics, unified approach will reduce the time to develop models and to ensure the required simulation fidelity.

**Results and Discussion.**

As an example there are results of systematic and random components of the machined surface roughness when turning. Cutting speed \( V = 1.32 \, \text{m/s} \) (\( n = 630 \, \text{rev/min} \) in workpiece diameter \( d = 40 \, \text{mm} \)). Depth of cut \( t = 0.5 \, \text{mm} \). The feed was changed from \( S = 0.05 \, \text{mm/rev} \) up to \( S = 1 \, \text{mm/rev} \). Processed material – steel 40X as received. Tool – straight-turning tool. Tool material – carbide material T15K6. The geometry of the tool with its spread is shown in Table 1.

| Option                     | Range          | Average value | MSE  |
|----------------------------|----------------|---------------|------|
| The main angle in plan \( \varphi \) | 60 \( \ldots \) 65\( ^\circ \) | 62.5\( ^\circ \) | 0.833 |
| Wedge angle \( \varepsilon \) | 90 \( \pm 1 \, ^\circ \) | 90\( ^\circ \) | 0.167 |
| Nose radius \( r \)       | 0.2 \ldots 0.25 mm | 0.225 mm | 0.00833 |

Fig. 2 shows a graph of systematic component of the roughness parameter Ra depending on the feed, and Fig. 3 - the calculated distribution density of the roughness parameter when \( S = 0.1 \, \text{mm/rev} \).
Figure 2 - The systematic component of Ra parameter (microns)

Figure 3 - The density distribution of the random component of Ra in S = 0.1 mm/rev

For analytical description of the density distribution a combined law was used by the Gaussian distribution:

\[
f(Ra) = \frac{1}{\sqrt{2\pi} \sum_{i=1}^{3} \alpha_i \sigma_i} \exp \left( -\frac{(Ra - Ra_{\text{opt}})^2}{2\sigma_i^2} \right)
\]

(2)

where \( \alpha_i \) weights: \( \sum_{i=1}^{3} \alpha_i = 1 \).

Conclusions

These models will allow solving a wide range of problems associated with the design of mechanical processing. To create the specific models of mechanical processing we need to mathematically describe and define the connection between the model and, primarily, the topography.
formation based on geometrical copy, oscillation deformation, plastic-elastic deformation and a random component.

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