Development of methodology for the purpose of the machining process mode with time-varying parameters in the face of uncertainty of technological information

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Abstract. In recent years, the industry is widely used new structural materials, patterns in the processing area which are not sufficiently studied, which makes it difficult to choose a rational mode of machining, largely determines the performance and quality of parts. A rational method of mode assignment is its calculation using models (dependencies) that link the output and input parameters of the process. However, the inadequacy of the models, the ambiguity of the source data and the influence of unmanaged factors may lead to the fact that the regime calculated with their use will be far from optimal. The scientific significance of the research is to solve the problem of reducing the degree of influence of uncertainty of technological information on the process of assigning machining modes with a variety of input and output parameters. In order to reduce the error in the appointment mode under uncertainty of information for the first time developed mathematical models and algorithms that provide adjustment (correction) of the parameters of the models, linking the input and output parameters of the process, according to the current information about the output parameters. Developed a plan of varying the controllable factors of the technological process, the implementation of which controllable factors closer to the optimal level. The difference between the actual and calculated values of the output parameters of the process, which is obtained during its monitoring, is used as the initial information for model correction. On the basis of models and algorithms the software is developed and efficiency of the developed methodology at appointment and correction of a mode of turning is investigated. The method and algorithm of generation of mathematical models of machining process with time-varying parameters are developed. Models take into account the mutual influence of the tool state parameters and the current processing parameters and their impact on the output parameters and allow you to calculate the output parameters of the process at different times. This makes it possible to create prerequisites for the purpose of machining mode with time-varying parameters in the face of uncertainty of technological information.

1. Introduction

Appointment of a rational mode of machining is an urgent task, the solution of which depends on the processing performance, quality and cost of manufacturing parts. Perspective through the designation of a processing mode is calculated using the dependencies (formulas of the theory of cut). However, mathematical models describing the relationship of the output parameters of the machining process with the input, and used in the calculation of the mode, do not always adequately reflect this
relationship. Many models are obtained using multiple assumptions, do not take into account the influence of a number of controlled and unmanaged factors. In recent years, new tool materials and coolant formulations have emerged; high-speed machining has become increasingly common, with the necessary technological information often lacking. This is the reason that in many cases the difference between the calculated values of the output parameters and their actual values is 20...30 % or more, and the mode calculated using these models will be far from optimal.

The aim of the research is to solve the problem of reducing the degree of influence of uncertainty of technological information associated with the inadequacy of mathematical models and the ambiguity of the initial data for the calculation on the process of setting the machining mode.

To solve the problem, it is proposed to use the variation of controlled factors both for their approximation to the optimal level, and for active study of the process in order to adapt mathematical models. It is also necessary to develop a conceptual model of the machining process, taking into account the mutual influence of the output and current indicators of the machining process and their impact on the output parameters of the process.

2. Development of methods of correction of mathematical models of the technological process and the plan of variation of controlled factors in order to bring them closer to the optimal value

In order to reduce the error in the appointment mode under uncertainty of information developed mathematical models and algorithms that provide for adjustment (correction) of the parameters of the models, linking the input and output parameters of the process, according to the current information about the output parameters [1, 2]. Developed a plan of varying the controllable factors of the technological process, the implementation of which controllable factors closer to the optimal level. The difference between the actual and calculated values of the output parameters of the process, which can be obtained during its monitoring, is used as initial information for model correction.

Mathematical model correction procedures are developed for different variants of relations between the set (limit) values of the output parameters and their actual values: 1) when the limit values of all or part of the output parameters exceed the actual ones; 2) when the limit values of all output parameters are less than the actual ones.

A variation range controllable factors are chosen based on the conditions of the exception appear in the debugging mode of defective parts and the approximation of elements of a regime to the optimum value.

The dependence for the calculation of the variation interval by controlled factors in order to approximate the output parameters to the limit values is obtained. This dependence contains as an argument partial derivatives, showing the degree of influence of the elements of the machining mode on the output parameters of the process. In the first stage, these derivatives are obtained using mathematical relationships that reflect the relationship between the output and input parameters of the process; in the subsequent stages, use data on the actual values of the output parameters obtained in the monitoring process. Recommendations on the choice of the plan of variation of the mode elements depending on the relations of the limit and actual values of the output parameters are given.

For approbation of a technique the software allowing to operate two controlled factors and two output parameters is developed.

As managed input parameters (factors) used, the feed per S revolution and cutting speed V. as output of the monitored parameters were selected arithmetical mean deviation of the profile Ra and the uncertainty of the diametrical dimension of the part ω. Mathematical relationships linking these parameters to the input parameters were selected or obtained.

Previously, the elements of the cutting mode were calculated according to the formulas of the cutting theory and the standards given in the Handbook [3] and adjusted according to the passport data of the machine. The actual values of both output parameters were below their limit values, so it is possible to intensify the values of the mode elements in order to improve performance. Using the developed program, two stages of correction of the assigned mode were performed. The use of the adjusted mode allowed to increase the productivity of processing while ensuring the quality of the
processed part. The developed technique and software can be used in the processing of a small number of blanks, when there is a slight change in the output parameters over time of tool development.

3. Development of methods for determining the interrelated parameters of the process based on the development of its functioning algorithm

When processing a large batch of blanks under the influence of systematic and random factors, there is a change in the output parameters and current indicators of the machining process. There is a shift of mathematical expectation (center of grouping) $\mu(t)$ and change (as a rule, increase) of the instantaneous field of dispersion of parameters (Fig. 1). In order to determine the time of correction of the tool position (adjustment) and (or) correction of the processing mode, it is necessary to know the time during which the output parameters will approach one of the tolerance field boundaries. This requires models of the machining process, focused on its representation as a dynamic system with time-varying output parameters and current performance. However, not all models developed for machining processes meet these conditions.

With the increase in the tool operating time, the parameters characterizing its state (in particular, wear) change, as a result of which the indicators of the processing process (force and temperature) change (Fig. 2). On the other hand, the parameters of the tool state depend on the processing parameters (forces and temperatures). Consequently, the calculation of the output parameters of the known models is associated with a lack of information due to the mutual influence of the process parameters. The status parameters of the instrument and the indicators of the treatment process are functionally related and to determine the parameters of one group, it is necessary to know the parameters of the other. Determination of these interrelated parameters is possible in the process of simulation based on the development of the algorithm of the process.
The operation time of the process should be divided into intervals $\Delta \tau$, and the calculations of the output and current parameters of the process should be performed for periods of time $\tau_0, \tau_1, \ldots, \tau_i, \ldots, \tau_{\text{max}}$, where $\tau_{\text{max}}$ – maximum operation time of the process.

It is known that the cutting forces and contact temperature have a predominant influence on the tool wear process.

Cutting forces and contact temperature are calculated at time $\tau_0 = 0$. It is assumed that the tool wear on the rear surface at this time $h_{w0} = 0$. These forces and temperature are used to determine the wear rate of the tool $U_{0,1}(\mu m/s)$ on the time interval $\tau_0 \ldots \tau_1$, and then calculate the tool wear at the time $\tau_1$ according to the formula

$$h_{w1} = U_{0,1} \cdot \Delta \tau.$$  

Forces and temperature at the time $\tau_1$ is calculated, focusing on tool wear equal to $h_{w1}$. These forces and temperature are used to determine the wear rate of the tool $U_{1,2}$ on the time interval $\tau_1 \ldots \tau_2$, and then the tool wear at the time $\tau_2$ is calculated by the formula

$$h_{w2} = U_{0,1} \cdot \Delta \tau + U_{1,2} \cdot \Delta \tau.$$  

Tool wear at a time $\tau_k$

$$h_{wk} = \sum_{i=k}^{i=k} U_{i,j} \cdot \Delta \tau,$$

where $U_{i,j}$ – tool wear rate at the i-th time interval, $\mu m/s$ ($i = 1, \ldots, k$); $\Delta \tau$ – time interval, sec.

Real technological processes are not deterministic, so the change of quality parameters in time when processing a batch of blanks can be considered as a random (stochastic process). Random processing errors are caused by a set of random factors. These factors include, in particular, fluctuations in the mechanical properties of the workpiece material and the machining allowance, leading to unstable cutting forces and vibrations of the deformation of the technological system. As a result, there is a dispersion of quality parameters, including the size of the parts.

To determine the estimated time of adjustment and the period of resistance of the cutting tool, it is necessary to know the displacement function of the mathematical expectation (grouping center) $\bar{y}(\tau)$ and the boundaries of the instantaneous scattering field output parameters in time. The upper $y_u(\tau)$ and lower $y_n(\tau)$ boundaries of the instantaneous fields of dispersion of parameters can be defined as:

$$y_u(\tau) = \bar{y}(\tau) + \omega_y(\tau)/2; \quad y_n(\tau) = \bar{y}(\tau) - \omega_y(\tau)/2.$$  

Adjustment time $\tau_p$ (life resistances $\tau_s$ tool's) equal to the smaller of the values $\tau_w$ and $\tau_n$: $\tau_p(\tau_s) = \min(\tau_w, \tau_n)$, where values $\tau_w$ and $\tau_n$ determined from the equations:

$$y_{\text{max}} = \bar{y}(\tau) + \omega_y(\tau)/2; \quad y_{\text{min}} = \bar{y}(\tau) - \omega_y(\tau)/2,$$

where $y_{\text{max}}$ and $y_{\text{min}}$ – maximum and minimum limit value of the output parameter (see Fig. 1).

Most of the known models allow us to determine the expectation of the parameters of the processing process and only a few of them – the dispersion of these parameters. To determine the value of the dispersion, you can use a known dependence to increment the function of several variables.

When turning, the size dispersion caused by elastic deformations of the elements of the technological system depends on the elastic movement of the cutter relative to the axis of the centers (cartridge):

$$y = \frac{P_y}{j_y},$$

where $P_y$ – the radial component of the cutting force, N; $j_y$ – stiffness of the process system, N/m.

Having determined the component of $P_y$ by converting the known dependencies [4, 5], we obtain:
\[
y = \frac{1.155 \cdot \sigma_{st} \cdot S \cdot t_{f} \cdot \left[ \left( 1 + \mu_{1} \cdot \left( 1 - \tan \gamma \right) \right) + \frac{(0.5 + \mu)}{2 \cdot k_{C}} \cdot \sin \gamma \right] \cdot \sin \gamma + \frac{l_{2}}{u \cdot h_{1}}}{j_{y}},
\]

where \( \sigma_{st} \) – the average in the area of plastic deformation the yield stress of the processed material, Pa; \( S \) – feed per revolution of the workpiece, mm/rev; \( t_{r} \) – cutting depth, m; \( \mu_{1} \) – is the coefficient of friction of shavings on the front surface of the cutter; \( \mu \) – friction coefficient at the yield stress; \( u \) – is a coefficient having a value of: \( u = 1 \) when \( \gamma \geq 0 \), \( u = 1 - \sin \gamma \) when \( \gamma < 0 \); \( k_{C} \) – coefficient of thickening of the chip; \( \gamma \) – rake angle of cutter, deg.; \( l_{2} \) – the length of contact of the rear surface of the cutter with machined surface of the workpiece, m; \( h_{1} \) – thickness of cutting layer of the workpiece, m.

The dispersion of the parameter \( y \) is affected by the oscillations of all parameters included in the above dependence. Fluctuations (dispersion) of the yield stress \( \Delta \sigma_{st} \) and the cutting depth \( \Delta t_{r} \) can be distinguished as the parameters that have a predominant effect on the dispersion of \( y \). Under constant conditions and processing mode, the parameters \( S, \gamma \) and \( \mu_{1} \) can be considered constant. Parameters \( \Delta \sigma_{st} \) and \( \Delta \mu \) characterize the instability of the mechanical properties of the workpiece material. The choice of values of these parameters should be made, focusing on specifications or standards.

Assuming that the variable parameters in the formula for calculating the movement of the cutter \( y \) are \( \sigma_{st} \) and \( t_{r} \), using the dependence for the increment of the function of several variables, we obtain the dependence for calculating the instantaneous scattering field due to the elastic displacements of the elements of the technological system. Assuming that the variable parameters in the formula for calculating the movement of the cutter \( y \) are \( \sigma_{st} \) and \( t_{r} \), using the dependence for the increment of the function of several variables, we obtain the dependence for calculating the instantaneous scattering field due to the elastic displacements of the elements of the technological system:

\[
\omega_{j} = \frac{\partial f}{\partial \sigma_{st}} \cdot \Delta \sigma_{st} + \frac{\partial f}{\partial t_{r}} \cdot \Delta t_{r},
\]

where \( f \) – a function that describes the dependence of the parameter \( y \) on the arguments.

After performing the transformation, we obtain:

\[
\omega_{j} = \frac{1.155 \cdot S \cdot t_{f} \cdot A_{y} \cdot \Delta \sigma_{st} + 1.155 \cdot \sigma_{st} \cdot S \cdot A_{y} \cdot \Delta t_{r}}{j_{y}},
\]

\[
A_{y} = \left[ 1 + \mu_{1} \cdot \left( 1 - \tan \gamma \right) + \frac{(0.5 + \mu)}{2 \cdot k_{C}} \right] \cdot \sin \gamma + \frac{l_{2}}{u \cdot h_{1}}.
\]

Similar dependencies are obtained for other output parameters of the turning process.

4. Key findings and conclusions

1. The method of correction of the mode of machining, providing variation of controlled factors on a certain plan and adjustment (correction) models, linking the output and input parameters of the process. Software for mode correction has been developed and tested.

2. The structure, technique and algorithm of generation of mathematical models of the machining process presented in the form of a dynamic system are developed. Models take into account the mutual influence of the tool state parameters and the current processing parameters and their impact on the output parameters and allow you to calculate the output parameters of the process at different times. This makes it possible to create prerequisites for the purpose of machining mode with time-varying parameters in the face of uncertainty of technological information.
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