On dynamics and control when finishing body parts

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Abstract. For designing machines, the optimal treatment regimens need to perform dynamic quality of the machine elastic system on the basis of imitating modeling of technological systems during the cutting process. When finishing body parts in some cases, problems arise with a high dynamic quality of the machine elastic system, as the workpiece has, as a rule, sufficiently high rigidity. The simulation modeling allows to obtain reliable qualitative and quantitative characteristics of the process being modeled. In the article the mathematical description of the dynamic model of milling machine is given taking into account the main mechanisms of the excitation process in multi-processing.

1. Introduction

When finishing the body parts there are problems associated with insufficiently high dynamic quality of the elastic system of the machine due to the high rigidity of the workpiece [1, 2, 3, 4, 5]. The quality of the material can be estimated when there is a dependence of the concentration level of a gas on the diagnostic parameter. But this dependence is ambiguous, and it is impossible to directly assess the quality of the material being processed and to make a direct diagnostic conclusion. A change in, for example, the concentration of gaseous compounds formed during mechanical processing is a consequence of variation in physicochemical parameters of the preform, i.e. presence of anomalies. The histograms taken during machining on a planer, indicate the presence of surface hardness anomalies, which indicate the place where it is necessary to check quality of the workpiece, i.e. in this case, the measurement of hardness. Taking into account dependence of the intensity of carbon monoxide formation on hardness, we can assume that its values are the lowest at the minimum values of the measured concentration of carbon oxide and the highest at the maximum values of the concentration in the treatment zone.

In this case, when diagnosing the state of the material, there is no direct conclusion about the parameter being diagnosed, but specific places are indicated where it is necessary to carry out control measurements of the parameter by technological measuring means, thereby significantly reducing the number of such measurements. This is especially true with limited possibilities of the number of technological measurements, when the reliability of the result increases, and in the case of large areas of products, the possibility of volumetric control of its physicochemical properties in principle opens up.
Particularly noteworthy is the continuous monitoring of chemical composition of the material, which is difficult or impossible by other means. Determining the presence of abnormal areas or deviations of the chemical composition of chips is problematic, since in the first case considerable time is required under extreme conditions of the process of plastic deformation and material destruction. The chemical composition of chips is changing, and in the second case it is limited by the number of possible samples for chemical analysis.

Therefore, for a more complete continuous diagnosis of the chemical composition of the material being processed, it is necessary:

– optimally select the gas analyzer that registers the selected and controlled gas, taking into account the chemical composition of the material and the instrument;
– select the optimal modes of machining products;
– use the extensive information obtained from the information output of the gas analyzer, including static, analysis of variance and the calculation of the correlation function.

At constant cutting speed and constant feed, the concentration level of a number of gases in the treatment area is a function of the allowance, hardness, condition of the cutting tool and other factors. Considering that the cutting depth and hardness of the workpiece material require identical and unidirectional actions to optimize the cutting process, you can use information about the intensity of the gases formation as equivalent information about the level of loads on the tool and carry out optimization aimed at reducing the concentration of the formed gases, similar to optimization on the selection of the force (moment) of cutting according to the appropriate algorithm. It should be borne in mind that the effect of tool wear, with the exception of chipping and catastrophic wear, also increases the concentration level of the gases produced and also requires actions of the same direction and character as the effect of changes in the allowance and hardness.

Optimum design of machines and rational technological modes choice can be performed while solving the problem of dynamic simulation of the machine technological system during the cutting process.

2. Results and discussion

Everything that human activity is directed at is called an object (Latin objection is an object). The development of the methodology is aimed at streamlining the receipt and processing of information about objects that exist outside of our consciousness and interact with each other and the external environment.

Replacing one object with another in order to obtain information about the most important properties of the original object with the help of a model object is called modeling. Thus, modeling can be defined as the representation of an object by a model for obtaining information about this object by conducting experiments with its model. The theory of replacing some objects (originals) with other objects (models) and studying the properties of objects on their models is called modeling theory.

It should be noted that from the point of view of philosophy, modeling is an effective means of knowing nature. The modeling process involves the presence of the object of study; the researcher who has been assigned a specific task; model created to obtain information about the object and necessary to solve the problem. Moreover, in relation to the model, the researcher is, in fact, an experimenter, only in this case, the experiment is conducted not with a real object, but with its model. Such an experiment for an engineer is a tool for directly solving organizational and technical problems.

The modeling is based on information processes, since the creation of model M itself is based on information about a real object. In the process of implementing the model, information about this object is obtained, at the same time, during the experiment with the model, control information is entered, the processing of the obtained results, i.e. Information underlies the entire modeling process.

One of the most important aspects of building modeling systems is the problem of goal. Any model is built depending on the goal that the researcher sets for it, therefore one of the main problems in modeling is the problem of target use. The similarity of the process taking place in the model to the real process is not the goal, but the condition for the model to function properly, and therefore the goal should
be to study any aspect of the object's functioning. To develop a simulation model and carry out its simulation of a queuing system with one source of requests, one machine and a queue for the problem of mechanical engineering.

An important point in the study of dynamic cutting processes is their dynamic imitation using specially designed stands and modern computer technology. When bringing the original multidimensional model of a technological system with a blank to a set of simple models, models are formed with the following types of dynamic structure - single or double. Developed measuring and computing complexes that include the following elements: a metal-cutting machine, a stand for full-scale dynamic modeling, primary converters, amplifiers, matching devices, an application package, etc. Such complexes are an effective original full-scale dynamic simulator for a wide class of technological systems for mechanical processing of low-hard blanks with different elastic-dissipative and inertial characteristics. The design features of the stands allow you to simulate the necessary dynamic characteristics of the contours. For more complex machining process systems, the number of contours can be increased to four. The application package provides real-time measurements; filtering, spectral analysis and statistical processing of measurement results.

Mechanical engineering is one of the leading industries, affecting almost all spheres of human activity. The products of the engineering industry are distinguished by complexity, a variety of design solutions and the use of a wide variety of materials with different physical and mechanical properties. The design of the product and the material from which it is made have a significant impact on the choice of shaping methods and technological equipment. For the production of the same parts can be used various methods of shaping and means of technological equipment, which leads to a large variety of production process options. Under these conditions, the most rational method of choosing the optimal variant of the production process is the method of simulation modeling. On the basis of this method, a model has been developed that simulates the production process for processing a given range of parts. The determination of the optimal variant of the production process is based on the analysis of economic indicators and indicators of product quality. The simulation model was based on the modular principle of production organization. In this regard, a classification module was developed.

The simulation model was based on the modular principle of production organization. In this regard, the classification of modules was developed, which were divided into five groups: design modules, procurement modules, process modules, parameter modules and technological base modules. The developed simulation model consists of five stages.

At the first stage, modeling of technological routes for processing individual parts is performed. The objective of this simulation stage is the formation of technological modules of the part, which contain information about the methods and strategies for processing the part, as well as the name of the technological equipment necessary to achieve the specified values of technical parameters at each stage of processing.

At the second stage, an analysis of the machining accuracy is performed. The task of this modeling stage is to form intervals of machining accuracy and to determine allowable values of cutting conditions and machine processing time for each interval of accuracy. Analysis of the machining accuracy is based on the calculation of the total error, which is determined by the formula

$$\Delta = f(\epsilon, \Delta_\gamma, \Delta_{\Delta}, \Delta_N, \Delta_l, \Sigma\Delta)$$

where

- $\epsilon$ is the error associated with the installation of the workpiece on a cutting machine or tool, μm;
- $\Delta_\gamma$ is the error caused by elastic deformations of the technological system, μm;
- $\Delta_{\Delta}$ is the error resulting from dimensional wear of the cutting tool, μm;
- $\Delta_N$ is the error associated with setting the cutting tool, μm;
- $\Delta_l$ is the error caused by thermal deformations of the technological system, μm;
- $\Sigma\Delta$ is the error associated with the geometrical deviations of the equipment, μm.

At the third stage, the formation of all possible variants of the technological process (group technological modules) is carried out.
At the fourth stage, the production process is modeled on the basis of queuing theory. The task of this stage is to determine the parameters of the production system for various variants of the production process. At this stage a closed queuing network will act as a model.

At the fifth stage, the choice of the optimal variant of the production process is made according to three groups of indicators: the machining accuracy, the cost of the investment project and the parameters of the production system.

The definition of the optimal variant can be divided into two stages. At the first stage, a set of optimal solutions is determined based on the Pareto method - Pareto-optimal solutions. At the second stage using the ideal point method, from the set of Pareto-optimal solutions, the choice of the variant of the production process, which has the optimal combination of economic and quality parameters, is made.

To calculate the distance to the ideal point, we chose the weighted Euclidean distance formula:

\[ d_{BE}(x_i, x_j) = \sqrt{\sum_{k=1}^{p} W_k (x_i^{(k)} - x_j^{(k)})^2} \]

where \( d_{BE} \) is the measured Euclidean distance,
\( x_i^{(k)} \) is the value of the k-th property of the object i,
\( x_j^{(k)} \) is the value of the k-th property of the object j,
\( W_k \) is the “weight” of the k-th criterion,
\( p \) is the number of criteria.

The optimal variant of the production process will be considered the variant with the minimum value of the weighted Euclidean distance.

The full dynamic model of a metal-cutting machine tool in simulation tasks is described by the following system.

By cyclic coordinates

\[ J_{jnp} \dot{\phi}_j = M_{gj} - M_{cj} ; j=1,S \]  \( (1) \)

where \( \phi_j \) is the rotation angle of the motor shaft of the j-th drive; \( J_{jnp} \) is the reduced moment of inertia of the j-th drive; \( M_{gj} \) is the driving moment of the j-th engine; \( M_{cj} \) is reduced moment of resistance on the j-th drive; S is the number of concurrent drives.

For elastic deformations of the drives:

\[ \ddot{\theta}_j^* + 2n^*_j \dot{\theta}_j^* + \omega^*_j \theta_j^* = k_{gj}^* M_{gj} - k_{cj}^* M_{cj} \]  \( (2) \)

where \( \theta_j^* \) is the column vector of the normal coordinates of the j-th drive; \( n_j^* \) is the dissipative matrix of the j-th drive, \( n_j^* \) is the diagonal matrix of squares of the natural frequencies of the j-th drive; \( k_{gj}^*, k_{cj}^* \) are Vectors-columns, characterizing the reduction of the engine torque and the moment of resistance to normal coordinates.

According to the spindle assembly:

\[ \ddot{y}_{uw}^* + 2n_{uw}^* \dot{y}_{uw}^* + \omega_{uw}^2 y_{uw}^* = y_p^* P_p^* + k_{uw}^* P_{uw}^* \]  \( (3) \)

where \( y_{uw}^* \) is the vector of normal coordinates, characterizing the transverse oscillations of the spindle; \( n_{uw}^* \) is the dissipative matrix spindle node; \( \omega_{uw}^2 \) is the matrix of squares of the natural frequencies of the spindle assembly; \( P_p^* \) is the cutting forces vector; \( P_{uw}^* \) is the vector of driving forces; \( k_{p}^* \) and \( k_{uw}^* \) are matrices characterizing the reduction of cutting forces or forces driving the spindle assembly to normal coordinates.

By oscillations of the bearing systems:
\[ \dot{n}_0^* + 2n_0^* \dot{n}_0^* + \omega_0^* n_0^* = \kappa_u^* R_{u0}^* + \kappa_p^* P_p^* + \sum_{i=1}^{k} (k_{ii}^* Q_i + k_{Ri}^* R_{ni}^* + k_{g0}^* M_{gi}^*), \]

where \( \dot{n}_0^* \) is the vector of the normal coordinates of the carrier system; \( n_0^* \) is the diagonal dissipative matrix, \( \omega_0^* \) is the diagonal matrix of squares of natural frequencies; \( k_{ii}^*, \kappa_u^*, k_{Ri}^*, k_{Ri}^*, k_{g0}^* \) are matrices of reducing the reaction vectors of the corresponding subsystems to the normal coordinates of the carrier system, namely: \( \kappa_u^* R_{u0}^* \) is the spindle head; \( k_{Ri}^*, Q_i \) is for the effort of supplying the i-th operating drive; \( k_{Ri}^*, R_{ni}^* \) is for support reactions of the i-th operating drive; \( k_{g0}^*, P_p^* \) is for cutting forces; \( k_{g0}^*, M_{gi}^* \) is for the moment of the i-th engine.

We proceed to the description of the dynamic processes in the drives. It is convenient to use the description of structural schemes through transfer functions.

The electromagnetic moment of the j-th engine is determined by the ratio

\[ M_{gj} = C_{Mj} I_{gj} \Phi_j, \]

where \( C_{Mj} \) is the moment constant of the j-th engine; \( I_{gj} \) is the armature current j-th engine; \( \Phi_j \) is the magnetic flux of the j-th engine. For typical block diagrams of drives for heavy drives of heavy machine tools, we write the formulas for current and flux in Laplace images:

\[ I_{gj} = W_{gj}^{(s)} (P) \bar{U}_{3aj} + W_{ogj}^{(v)} (P) \bar{Y}_{ogj} + \]
\[ + W_{ogj}^{(w)} (P) \bar{Y}_{ogj} + f_{gj} (P, \bar{I}_{gj}, \bar{\Phi}_j, \bar{Y}_{ojj} \ldots). \]

\[ \bar{\Phi}_j = W_{\Phi j}^{(s)} (P) \bar{U}_{3aj} + W_{o\phi j}^{(v)} (P) \bar{Y}_{o\phi j} + W_{o\phi j}^{(w)} (P) \bar{Y}_{o\phi j} + \]
\[ + W_{o\phi j}^{(w)} (P) \bar{Y}_{o\phi j} + f_{\phi j} (P, \bar{\Phi}_j, \bar{Y}_{o\phi j} \ldots), \]

where \( I_{gj} \) is the image of the armature current of the j-th motor; \( \bar{U}_{3aj} \) is the image of the voltage setting at the j-th drive armature; \( \bar{Y}_{ogj}, \bar{Y}_{ogj}, \bar{Y}_{ogj} \) are images of feedback signals in the armature circuit of the j-th drive, respectively, in position, speed, acceleration; \( W_{gj}^{(s)} (P) \) is the transfer function of the armature contour of j-th drive; \( W_{ogj}^{(s)} (P), W_{ogj}^{(v)} (P), W_{ogj}^{(w)} (P) \) are transfer functions of the armature chain of the j-th drive in position, speed, acceleration, respectively; \( f_{gj} \) is the function characterizing the nonlinearity in the armature circuit of the j-th drive; \( \bar{\Phi}_j \) is the image of the excitation flow of the j-th drive.

The feedback sensor signal is:

\[ \bar{Y}_{ogj} = \phi_j + \sum d_{ij} \eta_i. \]

To close the mathematical description of the system, it is necessary to introduce a dynamic characteristic of cutting force into the model. Restricting ourselves to the case of fine milling and introducing a spatial nonstationary model of the milling process, we give the dynamic characteristic in the form

\[ T(\omega t) \dot{P}_p^* + \left[ K_{p0}^* (\omega t) + \sum_{i=1}^{M} \delta_i K_{pi}^* (\omega t) \right] P_p^* = -k^* E^* (\omega t) \Delta, \]
where $\omega$ is the angular velocity of the spindle; $T$ is the square matrix of the third order, which elements characterize the delay of the corresponding vector components, $P^*_p; \delta_i$ is the delta function, which characterizes the impact when the tooth enters or leaves the cutting zone; $M$ is the number of teeth cutters; $\Delta$ is the vector of deformations; $k_*$ is the cutting coefficient characterizing the properties of the material being processed and the size of the cutting zone.

3. Conclusion

Relation (9) takes into account all the main mechanisms of excitation in the process of multi-blade processing, namely: quasi-static perturbation associated with a change in the thickness of the cut layer; shock external disturbance associated with the entrance and exit of teeth from the cutting zone; the delay of the cutting force relative to the change in the thickness of the cutting layer; trail disturbance; the impact nature of the formation conditions of the dynamic cutting force. All ratios form a closed mathematical model of the machine control system in the process of cutting, and their analysis at the design stage allows us to predict bringing the object under real working conditions.

The developed simulation model allows to:

1) Identify all possible options for the production process of processing parts and the structure of the production system.

2) Assess the accuracy of manufacturing parts at each stage of processing for different methods and strategies of shaping.

3) Determine the list of technological equipment necessary for parts processing and their number.

4) Determine the costs required for the implementation of each variant of the production process.

5) Assess the effectiveness of the structure of the production system.

6) Determine the optimal variant of the production process, taking into account economic indicators and indicators of product quality.

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