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Honing process optimization algorithms

Ramil R. Kadyrov[1], Pavel N. Charikov[1] and Valeria V. Pryanichnikova[1]

[1]Branch of Federal State of Ufa State Petroleum Technological University in Sterlitamak City,
Pr. Oktyabrya, 2, Sterlitamak, 453118, Bashkortostan, Russia

E-mail: r_kadyrov@mail.ru

Abstract. This article considers the relevance of honing processes for creating high-quality mechanical engineering products. The features of the honing process are revealed and such important concepts as the task for optimization of honing operations, the optimal structure of the honing working cycles, stepped and stepless honing cycles, simulation of processing and its purpose are emphasized. It is noted that the reliability of the mathematical model determines the quality parameters of the honing process control. An algorithm for continuous control of the honing process is proposed. The process model reliably describes the machining of a workpiece in a sufficiently wide area and can be used to operate the CNC machine CC743.

1. Introduction

There are many mechanical engineering objects, which are subject to stringent requirements for the quality of a hole being processed. The operational and economic characteristics of a product, its life cycle depend on the compliance to these requirements. Each hole of the critical products requires fine-tuning to achieve high accuracy of shape and quality. Here, the honing process with a properly organized and optimized work cycle can help. For example, it is possible to vary the pressure of honing stones in such way that the required quality, shape accuracy and productivity are achieved. Therefore, it is important to find the optimal structure of the honing working cycle. This can be done empirically or by creating a process model and its further researching. Undoubtedly, the second approach is preferable since it saves time, allows one to study the patterns and clearly see the features of operations during honing. In addition, nowadays methods of computer simulation of processes in parallel design systems are widely used, which is rational and economically reasonable. The presence of feedback between the manufacture of a product and its design allows one to make adjustments to the process model, increasing its reliability.

In order to understand the optimization of the honing process, it is important to clearly understand such concepts as the task for optimizing the honing operations, the optimal structure of honing working cycles, stepped and stepless honing cycles, simulation of the processing and its purpose mean.

During honing, it is very difficult to consider at once the whole set of the factors influencing parameters of hole processing. It can be noted that the selection of the mathematical model is determined by the actual conditions for optimizing the structure of the working cycle, and the accuracy of the model and the speed of calculation of its parameters determine the quality of the honing processing.

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The optimal structure of the honing working cycles should be considered in the law of control of a parameter (in particular, the pressure of honing stones) during the processing of a workpiece. That is, it is necessary to synthesize a control system that ensures the stability of the process and corresponds to a certain objective function (qualitative index) [1].

When processing holes by honing, it is necessary to analyze the optimization task in order to find the process conditions that will ensure the best value of one of the performance parameters (accuracy, productivity) with the restriction of the remaining ones or allow one to synchronously achieve a set of performance parameters with a priori preset values. Consequently, the effectiveness of optimization algorithms determines how far the extreme performance parameters are achievable.

2. Features of the honing process

In the honing process, some elements of the cycle structure can be identified.

The machine starts operation by inserting a honing head into a hole being machined. At the same time, coolant must be supplied immediately (cutting cooling fluid) in order not to reduce the quality of the treated surface. Then automatically there is a radial routing of the stones - "by pressure" or dosed. Thus, a new cycle of pressure change or displacement of the stones begins.

For the simplest cycle, the constant pressure of the stones or their dosed movement after turning the spindle on is typical. The completion of the cycle is checked by the system of continuous monitoring of a hole size or by the counter of the number of double strokes. Drop and clamping of the stones take place in less than 2 seconds. The described cycle structure is used for honing of hardened steels and cast irons.

In cases where processing of crude alloy steels and of viscous materials takes place, wear of the tool can occur. Therefore, at the beginning of processing, a low pressure or a small dosed movement is applied, which helps to remove the ridges of the initial roughness, then honing is carried out with high pressure (or with a large dosed feed) of the stones and the main stock removal takes place.

Only specific conditions determine the choice of the structure of the processing cycle. For example, for a maximum metal removal, a cycle can be used that maintains a given intensity of a metal removal constant, but the achievement of a given value of the roughness index will be longer [1].

In the most critical cases, when higher quality is required, the honing process is divided into a number of operations. Another organization of the honing cycle is possible. For example, when working with very rough surfaces, it is practical to first apply a low stone pressure to reduce the wear of the stones. The further increase in pressure increases the metal removal, and then it decreases again to reduce the roughness of the treated surface. The main reason for the increased wear of the stones is the high initial roughness of the treated surface in combination with the high pressure of the stones. Decrease in pressure of stones at the beginning of the cycle leads to a decrease in the roughness of the honed surface, which reduces the wear of the stones during the initial stage of honing [2].

The pressure of the stones significantly affects the honing time, which is explained by the achievement of a given accuracy in size of the treated surface.

3. Process model

As it has been already noted, the reliability of the mathematical model determines the quality parameters of the honing process control. Therefore, it is important to identify in the model all the significant parameters. This is a rather complex task, requiring theoretical constructions and research of the real process. It is the complex consideration of all aspects of honing that allows us to approach this problem.

The study of honing operations shows that a dynamic mathematical model that takes into account the accuracy of geometric shape, metal removal and roughness can be represented as follows:

$$\frac{\delta Q}{\delta t} = a_1 p + a_2 t + a_3 \varepsilon + a_4 R_a ,$$
$$\frac{\delta R_a}{\delta t} = b_1 p + b_2 Q + b_3 t ,$$
$$\frac{\delta \varepsilon}{\delta t} = c_1 p + c_2 Q + c_3 t ,$$

where p – honing stones radial pressure;
t – operation duration;
ε – workpiece geometrical shape accuracy factor;
R_a – treated surface roughness value;
Q – amount of removed metal;
a_i, b_i, c_i – parameters of mathematical model.

The advantage of the above-described model is that it can be used to optimize the honing cycle with variable pressure of stones. These formulas imply the existence of factors that are not explicitly considered.

4. Optimization algorithms

For the process of honing, it is necessary to know the patterns of variation in the radial pressure of honing stones, in which process performance parameters are achieved within a specified time. Such algorithm can be described as follows:

$$u_0 = u\, sign\left[\sum_{i=1}^{n}\left[(y_{10} - y_i)^2 \prod_{i=1}^{n}(\frac{\delta y_i}{\delta t})^2\right] - G(T;t)\right], \qquad (1)$$

where y_i – current value of controlled axis;
y_{i0} – set value of controlled axis;
G (T; t) – valuation function;
m – number of controlled axes;
u_0 – controlling action.

The application of this search algorithm to express the dependence of honing stones pressure on time at which a predetermined amount of metal removal Q_0 for the duration of the operating cycle T is achieved allows us to write the following expression:

$$p(t) = \left(\frac{a_2 A_3}{c_1 A_1} - \frac{A_2}{A_1^2}\right) e^{-A_1 - 1} + A_2\left(\frac{1}{A_1^2} - \frac{t}{A_1}\right) - \frac{d_2 A_3}{c_1 A_1} ,$$

where $A_1 = \frac{1}{a_1}(a_3 c_1 + a_4 b_1);$

$$A_2 = \frac{1}{a_1}\left[(a_3 c_2 + a_4 b_2)\frac{Q_0}{T} + (a_3 c_3 + a_4 b_3)\right];$$

$$A_3 = \frac{a_2}{a_1}.$$

If one assumes that the roughness of the material has little effect on process performance of the workpiece treatment (a_4=0), then previous expression can be simplified:

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$$p(t) = \psi(e^{-A_1 t} - 1) + \frac{A_2}{A_1} t\,, \qquad (2)$$

where $\psi = \left(\frac{c_2 A_3}{c_1 A_1} - \frac{A_1}{A_1^2} \right)$.

Using algorithm (1), it is possible to describe dependence p(t) for controlling the radial pressure of the honing stones during the honing working cycle to obtain a predetermined value of hole geometrical shape accuracy factor ε_0:

$$p(t) = \varphi(e^{-B_1 t} - 1) - \frac{B_2}{B_1} t, \qquad (3)$$

where $\varphi = \frac{B_3}{B_1} - \frac{B_2}{B_1};$

$$B_1 = \frac{1}{c_1}(a_1 c_2 + a_4 b_1 c_2);$$

$$B_2 = \frac{1}{c_1}\left(a_2 c_2 + a_4 b_3 c_2 + a_3 c_2 \frac{\varepsilon_0}{T} \right);$$

$$B_3 = \frac{c}{c_1}.$$

The study of the algorithm made it possible to determine that it is applicable for finding the dependences of p(t) and for the continuous control of the honing process [3].

The peculiarity of this algorithm is that the necessary quality parameters are obtained by controlling only the pressure of the honing stones. If the number of parameters in the structure of the working cycle increases, then the algorithm is greatly complicated and requires the use of feedback sensors and computing devices.

The mathematical model of product treatment by honing determines the choice of searching a method for optimal conditions. The most important factors are the reliability of the mathematical model of the honing process and the ability to quickly find the values of the model parameters.

The study of different types of mathematical models of the honing process made it possible to describe the treatment process in a rather wide way.

The relationship between the controlling action and the output of the model is determined by the following equation:

$$k_{u1} k_{u2} \int_0^t \int_0^t x(t) dt + k_{u1} \int_0^t x(t) dt + k_0 x(t) + k_{\partial 1} \frac{\partial x(t)}{dt} + k_{\partial 1} k_{\partial 2} \frac{d_2 x(t)}{\partial t^2} = y(t), \qquad (4)$$

where $k_{иi}$ – transfer coefficient of an i integrating element;

$k_{\partial i}$ – transfer coefficient of an i differentiating element;

k_0 – transfer coefficient of scaling amplifier;

x(t) –pressure of honing stones p(t);

y(t) – controller process parameter.

It is reasonable to use the following equation for empirical controlling action:

$$x(t)=a_0+a_1t+a_2t^2+\ldots+a_nt^n.$$

When choosing a function of type y(t) based on experimental data, it is necessary to take into account that the more complex the structure of the controlling action, the more properties of the object are noticeable in the nature of the change in the controlled process parameter.

When used in respect to real processes, the model (4) can be adapted by increasing the number of differentiating and integrating elements.

Summary

The results of research in the field of creating systems for automatic control of the honing process show that the reasonability of their application is determined by specific process conditions. However, the most important thing in the development of such systems is the development of highly reliable actuators - systems for stones drop-off and obtaining reliable information on the process progress. The solution of these problems is a necessary condition for automation of honing control and creation of honing machine-tools built in automatic lines.

The models of workpiece processing and pressure pattern changes of the honing stones for the purpose to improve the process performance shown in the article can be used in real processes on machines. The presented algorithms for optimizing the structure of honing cycles can be included in production process control systems. There is an experience of using such algorithms on CNC machine CC743 [3, 4].

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