Decomposition of milling operation

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Abstract The article deals with the problem of improving the stability of quality parameters in the milling of molds, which provides for minimizing deviations from the set values that meet the requirements of the product drawing. For this purpose, a block diagram of the milling operation was developed and decomposition was carried out, which allowed to identify such subsystems, "workpiece", "machine – tool", "tool", "contact zone". The factors that lead to a decrease in the parameters of the quality of the surfaces of the workpiece are determined. The developed block diagram allowed to establish the relationship between the main components of the technological system and the characteristics of the machining process.

1 Introduction

During operation, the molds for polymer materials are subjected to significant pressures (up to 4903 MPa), periodic heating to a temperature of more than 200°C, chemical and abrasion effects of the pressed components [7]. The most responsible and expensive (17...70 thousand rubles) parts of the molds are punches and dies that form the product. The quality of the resulting product and the service life of the mold largely depend on the quality of their thermal and mechanical treatment [1]. One of the actual requirements for mechanical processing of the mold parts is to ensure the stability of the quality parameters of the forming surfaces, which allows to minimize deviations from the values specified in the drawing.

The roughness of the forming surfaces of the mold parts must be within Ra 0,025 ... 0,02 microns, and the machining accuracy-6 ... 7 quality [1, 19]. The forming parts is made of steel 40X13 grades, 4H5MFS, 1.2343, THYROPLAST2316 etc. [12,16].. Production of mold parts is a multi-stage technological process of modifying the initial properties of the material and the shape of the workpiece in the resulting characteristics of the finished product. This change in properties and quality parameters is performed in the technological system (TS). This structure includes the object of modification (blank) and elements, they carry out a given change in properties (tools, equipment, etc.) [2, 17, etc.]. The problem of stabilization of quality parameters, especially at the stage of final processing, is relevant. Deviations of quality parameters are sometimes observed within one treated surface (which is typical for a long cutting path when processing large complex profile parts), within the tool life, the replacement of the lubricating-cooling technological means (LCTM), the operation of the machine before maintenance [3,4]. When using products, the spread of

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quality parameters has a more significant impact on reliability, performance and efficiency than the value of the parameter itself.

Processing of complex surfaces of the mold parts is performed by the milling cutters, the conditions of contact with the workpiece largely determines the probability of trouble in the operation. Therefore, stabilization of quality parameters on operations of fine milling of the complex-profile surfaces is an urgent task.

2 Materials and methods of research

One of the main technological operations of processing of complex profile surfaces of parts of the mold (Figure 1, a) is the operation of fine milling. Forming of complex surfaces in this operation is performed by means of integral (or with replaceable cutting plates) end mills (figure 1, b) [8, 20]. For milling of such parts it is recommended to use, as a rule, specially designed for this operation the cutters, such as the end mills TDB50X-CN, LaserMill / GBE / BRE (Figure 1, b), etc. The carbide inserts with PVD coating, CN or CBN are often used as cutting plates for these cutters whishing treatment.

Fig. 1. Milling of complex profile surfaces of the mold: (a) – the mold; (b) – the milling process and the cutter for the profile fine milling.

In the process of milling the complex surfaces, the parameters of the cutting inserts are not stable - the cutting properties of the plates deteriorate, the cutting forces increase, vibrations occur, the accuracy of processing decreases and the roughness of the surface increases. The length of the process of fine milling of a workpiece on a CNC machine is from 90 ... 150 minutes [14, 15], which leads to a change in the state of its cutting inserts, the edges of the cutting blades become dulled.

All these factors lead to a decrease in the parameters of the quality of the surfaces of the workpiece, that is, the quality of processing a complex surface in different areas is not the same.

Milling operation, as a technological system, can be divided into subsystems (Figure 2): tools, workpieces, machine tools and technological equipment, LCTM. Each of the subsystems includes a set of parameters of the state, properties, the vector of input and output variables, as well as a vector of disturbing effects [5,6, etc.].

Fig. 2. Block diagram of milling process.

The degree of influence of each of the subsystems of the milling operation on the characteristics of the analyzed process is different:

- Subsystem "workpiece". The whole milling process is influenced by such physical and mechanical characteristics of the workpiece as material, hardness, strength, structure of the surface layer (bond 3 – 16 – 10). The higher the physical and mechanical properties of the processed material and the content of carbon, chromium, molybdenum, tungsten and silicon, the more intense the wear of the cutting edges of the tool. The surface temperature of the workpiece (link 2 – 10 – 14 – 23 – 30) and as a consequence, the possibility of formation of surface defects on it, depends on the physico-mechanical properties of the workpiece material, machining modes and geometric parameters of inserts [11]. The higher the strength and hardness of the workpiece material, the higher the temperature in the contact zone of the cutting tool plates, which according to [9,10], can reach 600...1200 °C (depending on the type and processing conditions). The released heat is absorbed by the cutting plates of the cutter, the material of the workpiece and the LCTM, resulting in an instantaneous temperature at the time of chip removal in the cutting zone. Due to the high heating of the surface, the pre-hardened steel (the mold blank after roughing and semi – finishing is heat-treated) in the surface layer is subjected to secondary hardening and high tempering (bond 23-30) [12] under this surface layer. The structure "troostite " is formed which it the part has the structure of the starting material of the workpiece.
- Subsystem "machine-device". The equipment and devices that implement the milling process have a direct impact on the productivity, accuracy and quality of the machined surfaces (communication 4 – 20 – 25 – 27). Depending on the characteristics of the machine, namely: structural, kinematic, power and speed, a certain level of processing performance is achieved, taking into account the limitations that depend on the physical and mechanical characteristics of the workpiece and the characteristics of the cutter (link 4 – 19

– 9 – 10). The degree of accuracy of the processing (communication 4 – 18 – 25 – 27) depends on the accuracy class of the machine. In the process of processing, the accuracy of movement of actuators and their rigidity are changed. Due to the wear of the contact friction surfaces, the gaps in the mates increase. As a result, when foreign particles get into the conjugation nodes, random deviations of the shape of the contact friction surfaces occur (bond 3 – 9 – 12 – 18 – 25 – 27). Basing and fastening of the workpiece is provided by, tooling, which has an impact only on the accuracy of processing. Changing the state of the technical system in the process of performing technological operations depicted in the diagram links: 2 – 10 – 13 – 22 – 18 – 25 – 27; 2 – 10 – 13 – 22 – 20 – 25 – 27; 3 – 16 – 19 – 9 – 10 – 13 – 22 – 28 (the influence of cutting forces and, consequently, the magnitude of the deformation of its elements) and connections: 2 – 9 – 10 – 14 – 18 – 23 – 30; 2 – 9 – 10 – 14 – 20 – 25 – 27 (the effect of heat released during processing).

- Subsystem "tool". As a rule, for fine milling the end mill with replaceable cutting plates is used. Characteristics of the cutter (design and dimensions of the cutter, dimensions, geometry and material of the cutting plates, the way they are fixed and adjusted, the accuracy of the cutter height and diameter) affect the quality of the workpiece surface (connection 1 – 5 – 9 – 10 – 15 – 24 – 31). Of the above characteristics, the process of fine milling is most influenced by: the material of the cutting plates, the material of the cutter body, the number and condition of the cutting plates after their reinstallation and adjustment [12].

The state of the working surface of the cutting plates during the milling operation changes (bond 11 – 21 – 6 – 5). Plates wear out (bond 10 – 11 – 21), resulting in a violation of processing accuracy (communication 10 – 9 – 8 – 9). Due to the violation of processing accuracy there are vibrations (communication 10 – 11 – 7 – 8). Cutting plates are exposed to LCTM (bond 17-10). All of the mentioned above factors worsen the quality of the cutting plates and lead to an increase in cutting forces, the appearance of deviations of the surface shape of the part and increase its roughness.

- Subsystem "contact zone". The contact zone is the area of penetration of the cutter inserts into the processed material, in which complex stochastic processes occur. When moving, each of the edges of the cutting plates outlines its cutting surfaces in the space of the workpiece. When processing the workpiece in the contact zone plastic, elastic, thermal deformation, chemical interaction of the processed material and components of the LCTM occur. Wear on the back surface of the inserts occurs evenly over the entire length of the cutting edge as the working material wears out or blunts the cutting edge of the insert. In some cases, the metal from the workpiece is layered on the cutting edge, visually masking the true size of the wear trace on the plate [13].

As a result, the dimensions of the previously formed surface irregularities (bond 3 – 9 – 10 – 15 – 24 – 31). Scratches, craters, protrusions are formed on the surface. Processes of plastic, elastic deformations, blunting of cutting edges depend on their geometry, kinematics and dynamics of motion and therefore they belong to the secondary processes of shaping. It should also be noted that the uneven removal of the material by the cutting plates has an additional effect on the beating of the machine spindle. When milling, there is almost always a non-uniformity of the material removal process caused by fluctuations in the circumferential cutting force [18, 21]. It is noted that the smaller the number of simultaneously working cutter teeth and the smaller the ratio of the milling width B to the cutter diameter d , the greater the amplitude of the circumferential cutting force and, accordingly, the unevenness of the milling process

The dimensions of the contact zone are in direct connection with the size and spatial arrangement of the tool, workpiece, the impact of LCTM (communication 3 – 9 – 10 – 17 –

14– 23 – 30). In the process of chip formation, the tool contact with the workpiece is associated with the appearance of cutting forces (communication 2 – 9 – 10 -12 – 15 – 22 – 28) and the release of a large amount of heat (communication 2 – 9 – 10 -14 – 23 – 30). Cutting forces and heat flow cause elastic and thermal deformation of the tool, the workpiece, machine components, tooling (communication 23 – 16 – 9 – 10; 14 – 18– 9 – 10; 14 – 20 – 9 – 10), which leads to a change in the size and shape of the contact zone. The wear of the cutting edges leads to a change in their shape, which affects the parameters of the cutting surfaces, the chip formation process (bond 11 – 12) and the microgeometry of the workpiece surface (bond 11 – 15).

In the developed structural scheme, the features of the milling process are reflected by direct and backward linkages, without which, qualitative and quantitative assessment of the process is often impossible. Each of the subsystems: *MD* - "machine-devicel", and *T* - "tool", *W* - "workpiece"; *CZ* - "contact zone"; has its own set of properties, state parameters, vector input and output variables. Mathematically, they are represented by sets (vectors) of state parameters. For example, for the subsystem "machine-tool" Z_{MD} : a vector of input variables – X_{MD}^M ; the vectors of input variables – $Y_T^{MD}, Y_{LCTM}^{MD}, Y_W^{MD}, Y_{CZ}^{MD}$, a vector of output variables – Y_{MD} [4].

The behavior of the subsystems involved in the technological operation can be represented by a system of the equations characterizing the state of the technological system:

$$\left. \begin{aligned} Z_{MD} &= \Phi_{MD}(X_{MD}^M, Y_T^{MD}, Y_{LCTM}^{MD}, Y_W^{MD}, Y_{CZ}^{MD}, \tau\tau) \\ Z_T &= \Phi_T(X_T^M, Y_{TF}^T, Y_{MD}^T, Y_{CZ}^T, Y_{LCTM}^T, \tau\tau) \\ Z_W &= \Phi_3(X_W^C, Y_{MD}^W, Y_{MD}^W, Y_{LCTM}^W, \tau\tau) \\ Z_{CZ} &= \Phi_{CZ}(Y_W^{CZ}, Y_T^{CZ}, Y_{LCTM}^{CZ}, \tau\tau) \end{aligned} \right\} \begin{aligned} Y_{MD} &= F_{MD}(Z_{MD}, X_{MD}^*, \tau\tau) \\ Y_T &= F_T(Z_T, X_T^*, \tau\tau) \\ Y_W &= F_W(Z_W, X_W^*, \tau\tau) \\ Y_{CZ} &= F_{CZ}(Z_{CZ}, X_{CZ}^*, \tau\tau) \end{aligned}$$

where - the vector of input variables that has a direct impact on the output parameters; - the operator that displays the influence of many input variables and the parameters of the initial state on the set of parameters of the MD subsystem state at the time τ ; - the operator that displays the set of values of input variables and parameters of the state.

Analysis of initial data, communications, and interconnections between, the list of structural parameters to be determined, as well as the system of interrelations between these parameters will allow us to design the sequence of calculation of the optimal values of surface roughness for quality parameters stabilization of geometrically-complex details. This can be done by using mathematical models that describe the dependence of the output parameters of the milling process on the characteristics of the cutting tool, the processing mode, taking into account the necessary restrictions due to by the conditions of the operation.

3 Conclusion

The developed block diagram of the milling process allowed to establish the relationship between the main components of the technological system and the characteristics of the processing process, to form the structure of the model that determines the quality characteristics of the finished product. The basis of which is based on the principles of establishing relationships between the main components of the technological system and the characteristics of the processing process based on the requirements for milling operations. It also allows you to select expressions that describe the state of individual subsystems, taking into account input and output variables and perturbing effects.

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