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Simulation Modeling of Formation of Geometric Parameters of Surface Quality at Milling

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ABSTRACT: The article covers the use of high-speed milling when machining bores, the trajectory of the cutter teeth with the calculation of the envelope is determined. An algorithm for calculating the profile of the machined surface has been developed, which allows to calculate the circular plot and profile diagram of the surface of bore depending on the number of teeth, the angle of inclination and diameter

KEYWORDS: technological system, personal computer, machining center, milling process with a milling cutter with one cutting tooth, trajectories of motion of cutter tooth, waviness, high-speed milling.

1. INTRODUCTION

Now, in view of the increased requirements for the productivity of machining, on the one hand, and with the widespread introduction of personal computers (PCs) into the industry, on the other, the matter of revising the methods for finding the most effective schemes for forming the surfaces of a part has been raised.

Modern personal computers allow with the utmost speed and accuracy to solve the most complex analytical problems, to analyze the results obtained, to find the optimal parameters for the design, and, ultimately, to fully automate the design process. The theoretical foundations for such methods should contain solutions to the issues of shaping surfaces with tools, calculating cutting patterns, manufacturability, etc.

Based on analysis of modern machine-building production, it can be noted that the principle of concentration of operations is increasingly used in the design of modern technological processes. Where earlier operating machines were used with the maximum differentiation of the processing process into separate operations, now they concentrate more operations on one machine in order to reduce the production area and the number of equipment used. This is especially evident when using CNC machines such as a machining center (MC).

II. MATERIALS AND METHODS

Technological facilities of processing on machines of the MC type are extremely wide. In particular, on such machines, all kinds of milling work with various designs of cutters are successfully performed: milling planes with end mills, milling grooves with end mills; milling with disc cutters; milling along the contour of flat or shaped surfaces, milling of internal rafts, beads and bores.

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The technological capabilities of the bore milling increase dramatically with the use of carbide end mills and mills with replaceable inserts. In this case, it is possible to milling stepped bores without changing the tool, trimming the ends, milling face grooves, undercuts and other surfaces.

In terms of accuracy, most machines of the MC type are close to coordinate boring machines; therefore, fine boring of bores is performed on them. The part positioning accuracy is ±0.005mm, and the re-positioning accuracy is ±0.0025mm.

The most widespread are machines of the MC type of vertical layout. This group of machines usually has a vertical spindle and a horizontal table, which makes them suitable for machining parts in which the tool can approach the work-piece from one side. Such parts include casings such as plates and covers with parallel bores. On machines of this type, equipped with a three or five coordinate system CNC, curved surfaces of a convex or concave shape are processed. If such a machine is equipped with a rotary table of the type of a globe table used on jig boring machines, it will be possible to process work-pieces that require a tool approach from many sides. However, in this case, the working volume of the machine is reduced by 3-4 times, which sharply reduces the dimensions of the processed parts. In addition, a rotary device with a horizontal axis of rotation can be installed on a standard table. It also significantly increases the technological capabilities of the machine.

In modern machine-building production, among the machining processes, insufficient attention is paid to the processes of milling work-pieces. It must be admitted that interest in improving systems for controlling machining processes on machine tools is focused on turning or on some specific technological processes, such as drilling deep bores of small diameter, threading, drilling blind bores of small diameter in difficult-to-machine materials, etc. 48% of the total machine park in the world are milling machines.

In general, the efficiency of the milling process is determined by a set of components, in particular, the state of the machine tool, the quality of the tool, the size and properties of the work-piece material, cutting modes, etc.

All errors arising during processing on CNC machines and affecting the processing accuracy can be divided into three groups according to the main sources of their occurrence: errors arising at the stages of preparation and transformation of the initial information; errors introduced by the feed drives of the working bodies of the machine; errors of the technological system.

Errors arising because of elastic deformations of a technological system during contour milling are caused by the instability of the cutting force and rigidity of the technological system in its various sections. The experience of operating CNC milling machines shows that processing errors due to elastic deformations of the vehicle are 0.15-0.4 mm in areas with a smoothly changing allowance and reach 0.5-1.2 mm or more at marks with sharp change of stock.

The least rigid link in a process system for contour milling with end mills is the tool.

The cutting force arising from milling with end mills creates elastic deformations of the technological system, affecting the accuracy of the resulting dimensions and the wind resistance of the system [1, 2]. The most significant (in comparison with other elements) the tool is deformed by the end mill due to its lowest rigidity. Since the fastening of the cutter is cantilever and the cutting force acts on the cutter not along its entire length, but in the section corresponding to the milling width, the elastic deformation of the cutter axis is significantly uneven along its length.

The problem of compensating for elastic deformations is quite relevant, especially when machining with end mills for parts with a rather complex geometry, characterized by complex laws of distribution of cut allowances, and high requirements for the quality of manufacturing of parts, including their surface layer.

Knowing the magnitude of the elastic deformation of the cutter allows predicting the theoretical trajectory of its movement and increasing the processing accuracy.

Formation of the surface profile when machining with a milling cutter with one cutting tooth. The spatial shape of the part is determined by the combination of various surfaces. To ensure processing, the designer strives to use simple geometric surfaces: flat, circular cylindrical and conical, spherical, end, hypoid. For example, to form a circular cylindrical surface, a straight line (generatrix) is moved along a circle (guide). Generating and guiding lines may well be replaced with one another. In addition, any surface can be defined by another line (for example, an Archimedean spiral), which determines the existence of the above two.

The center of the mill moves in a circle:

$$\begin{cases} x_c = Rsin\omega_1\tau \\ yc = Rcos\omega_1\tau \end{cases} \quad (1)$$

The teeth also move around the center in a circle. Joint equation of motion:

$$\begin{cases} x_c = Rsin\omega_1\tau + rsin\omega_2\tau \\ yc = Rcos\omega_1\tau + rcos\omega_2\tau \end{cases} \quad (2)$$

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Where R is the radius of the trajectory of the center of the cutter; r is the radius of the cutter; ω_1 is angular speed of the cutter along the contour; ω_2 is angular speed of rotation of the cutter.

Fig 1 shows an example of the constructed trajectory. In this case, the radius of the resulting bore makes R + r.

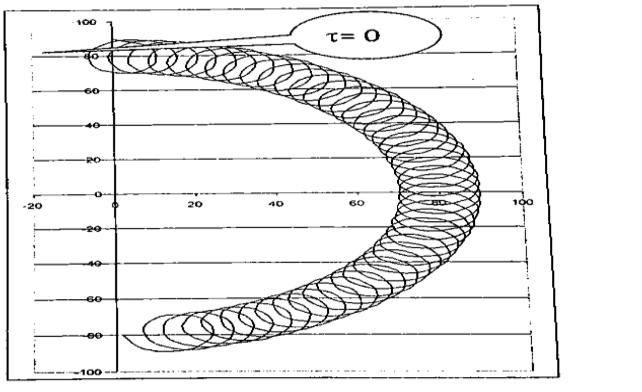

Fig. 1 Example of constructing a trajectory of movement of mill tooth

To find the envelope - the profile of the bore - we find the time value τ, corresponding to the given angle of the tooth position φ. In this case, the coordinates of the tooth vertex coincide with the coordinates of the machined surface

$$\begin{cases} R_d sin\varphi = Rsin\omega_1\tau + sin\omega_2\tau \\ R_d cos\varphi = Rcos\omega_1\tau + cos\omega_2\tau \end{cases} \quad (3)$$

For a given φ, this equation has several solutions - values of R_d. It is necessary to choose the maximum of them. Eliminating R_d from the equation, we obtain the equation for determiningτ.

$$\begin{cases} R_d = \frac{Rsin\omega_1\tau + rsin\omega_2\tau}{sin\varphi} \\ R_d \frac{Rcos\omega_1\tau + rcos\omega_2\tau}{cos\varphi} \end{cases} \quad (4)$$

$$\frac{Rsin\omega_1\tau + rsin\omega_2\tau}{sin\varphi} = \frac{Rcos\omega_1\tau + rcos\omega_2\tau}{cos\varphi} \quad (5)$$

$$(Rsin\omega_1\tau + rsin\omega_2\tau)\, cos\varphi = (Rcos\omega_1\tau + rcos\omega_2\tau)\, sin\varphi \quad (6)$$

Figure 2 shows an example of solving equation (6) for a specific φ value, and Table 1 shows the values of the found roots

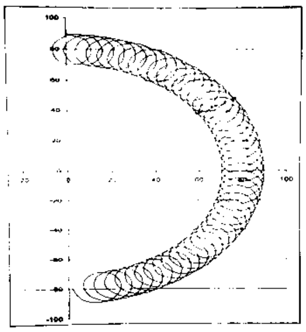

Fig. 2 Example of solving an equation

For the calculation example, the following values are taken: R = 80 mm; r = 10 mm; ω_1 = 0.1 rad/s; ω_2 = 10 rad/s; φ = 1 radian = $57,3^0$

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The value of $\tau$is found from equation (4), and then $R_d$is calculated by the formula

$$R_d \frac{Rsin\omega_1\tau + rsin\omega_2\tau}{sin\varphi}$$

Equation (4) contains imaginary solutions with negative values of R_d. These decisions (N 10……16) must be excluded from consideration.

Of all the solutions, the solution with the maximum $R_d$value is selected. In this case, R_d= 64.121 mm is selected. Performing these calculations in a cycle onφ, we get the envelope of the contour.

Fig 3 shows an example of obtaining an envelope (highlighted in bold). For clarity, the rotational speed of the cutter is increased: ω_1 = 0.2 rad/s.

Fig 4 shows the dependence of the radius of the machined surface on the angle of rotation in Cartesian coordinates. The presence of waviness of the treated surface is clearly visible, which depends on the modes and geometric parameters during the operation.

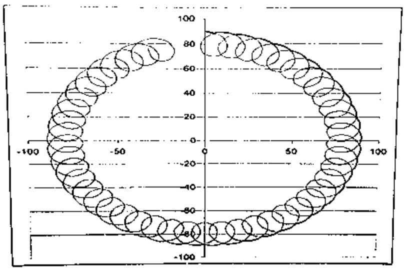

Fig. 3. Getting an envelope contour

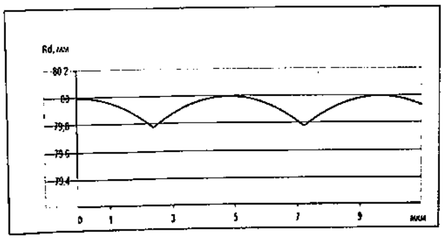

Fig. 4. Formation of geometric parameters of machined surface

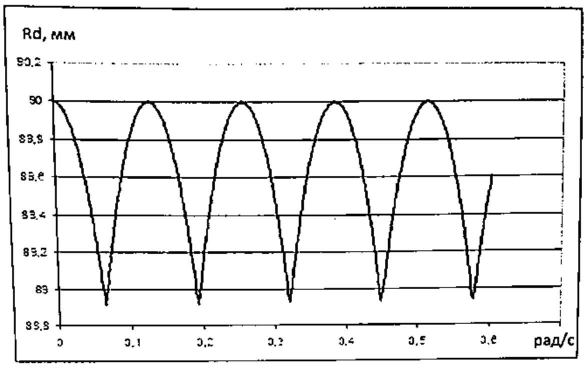

Fig. 5. Formation of geometric parameters of the machined surface during high-speed milling

Formation the surface profile when machining with a multi-toothmill with straight teeth

Let the cutter have N teeth. The first of them moves along a trajectory, the construction of which is described in the previous paragraph. Each subsequent tooth lags behind the previous one by an angle$2\pi/N$:

$$\begin{cases} x_i = Rsin\omega_1\tau + rsin(\omega_2\tau - 2\pi(i-1)/N) \\ y_i = Rcos\omega_1\tau + rcos(\omega_2\tau - 2\pi(i-1)/N) \end{cases} \qquad (6)$$

i = 1,2,….N

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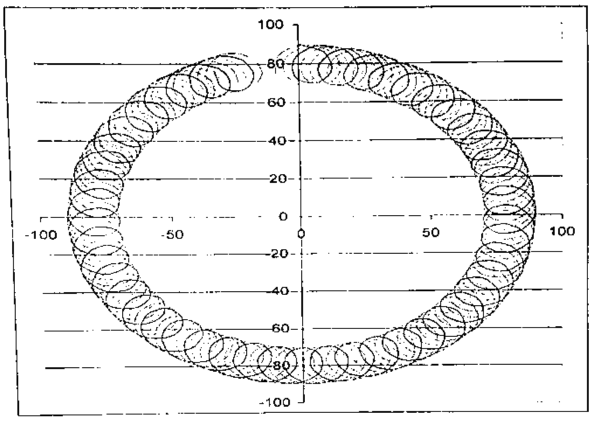

Fig. 6 shows an example of overlapping the trajectories of 3 teeth of the mill.

To construct the envelope, an algorithm similar to the analysis of the operation of a single-tooth mill can be used, adding a cycle of teeth search in it. The block diagram of the algorithm is shown in Fig 8.

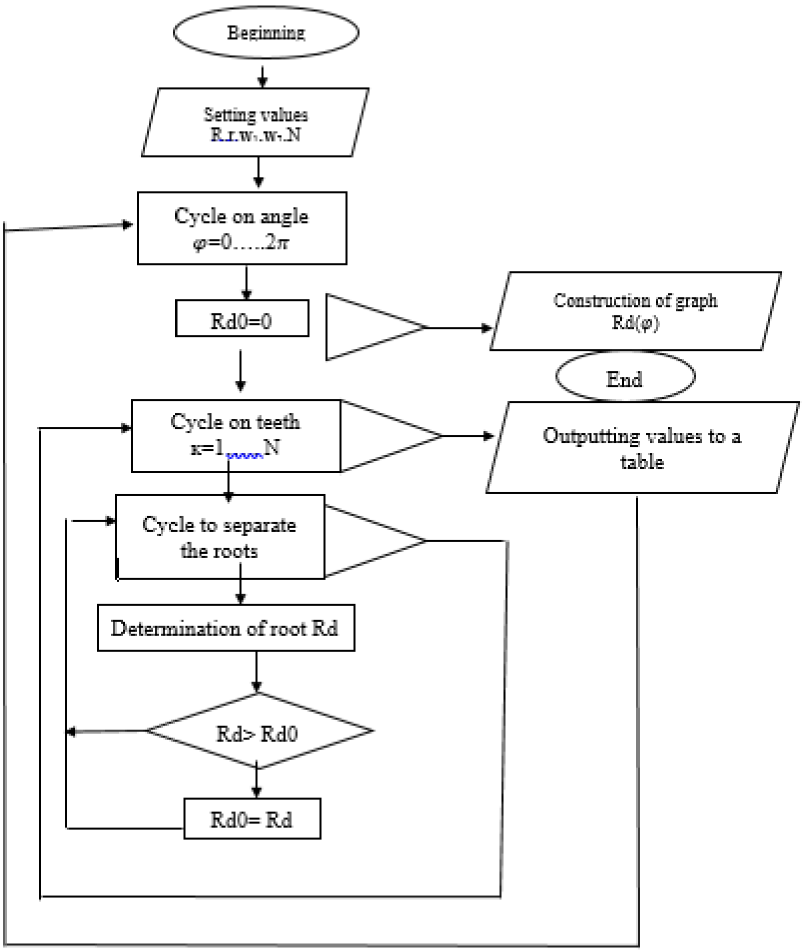

Fig. 7 - Algorithm for calculating the profile of the machined surface

The essence of the algorithm is to solve the equations

$$[\![Rsin\omega_1\tau + rsin(\omega_2\tau - 2\pi(i-1)/N)]\!]cos\varphi =$$
$$= [\![Rcos\omega_1\tau + rcos(\omega_2\tau - 2\pi(i-1)/N)]\!]sin\varphi \quad (7)$$

Regarding τ for different teeth of the mill, calculation of the radius of the part according to the formula

$$R_d = \frac{[\![Rsin\omega_1\tau + rsin(\omega_2\tau - 2\pi(i-1)/N)}{sin\varphi} \quad (8)$$

and choosing from them the greatest for each value of φ. Fig 8 shows examples of such graphs for single-tooth and three-tooth cutters. It is clearly seen that the height of the waviness is significantly reduced for a three-tooth cutter.

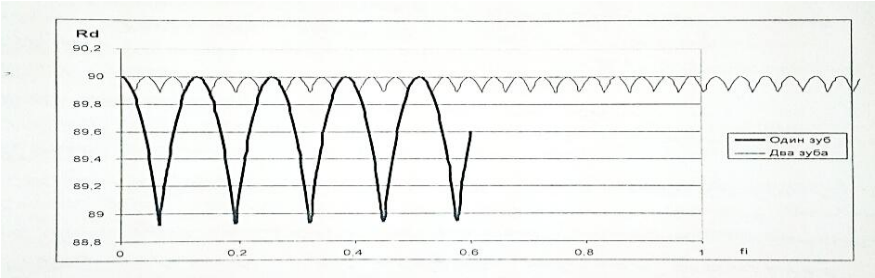

Fig.8 Examples of dependence $R_d(\varphi)$

Fig 9 shows the dependence of the waviness of the machined surface on the number of cutter teeth. Analysis of the graph shows that this dependence is close to power-law dependence with value equal to -2.

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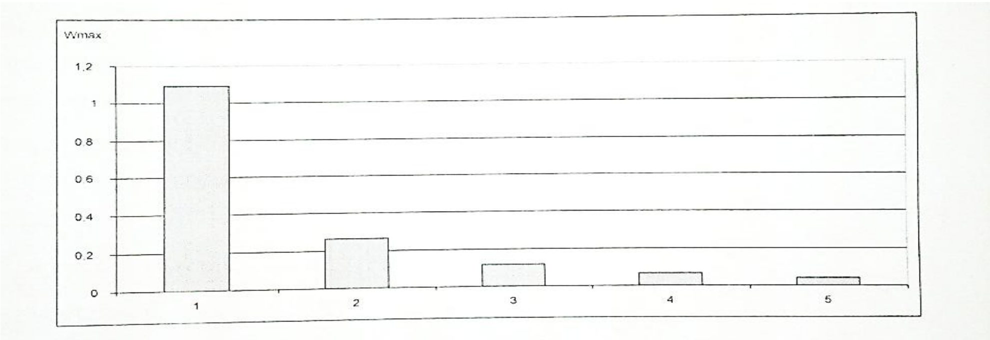

Fig 9. Dependence of the waviness height on the number of teeth

III.CONCLUSIONS

The formation of surface waviness is determined by the kinematics of the milling processes, elastic deflections of the technological system and vibrations. The last two factors are practically absent in high-speed milling. To determine the waviness of the bore surface, it is necessary to calculate the trajectory of the cutter teeth and compute the envelope. The developed algorithm for calculating the profile of the machined surface allowscalculating the circular diagram and profile diagramof bore surface depending on number of teeth and the angle of inclination and diameter.

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