Automatically search of a rational cutting mode for milling non-rigid blanks with the specified quality parameters

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Abstract. The work is devoted to the question of lowering the cost of production engineering products by reducing the costs of technological training. The possibility of cutting mode selection based on the quality of the processed parts using the proposed methodology for determining the roughness, elastic deformation of the item in the process of mechanical machining non-rigid parts of machines and technological level of residual stresses. The algorithm search automation rational cutting mode a brute-force attack all possible combinations of milling with calculation mode settings for each of the required quality parameters. Shows his work in appointing cutting mode for accommodative wall milling on aluminum alloy billet D16T.

1. Introduction
At the present stage of development of metal-cutting equipment (3-5 axial CNC machines and machining centers) and tools (ultrafine hard alloy, mineral ceramics, increased rigidity of tooling), more and more often there are situations when the processing of the workpiece is less lengthy than the process of its technological preparation. Thus, the key to reducing the cost of engineering products is to reduce the cost of engineering work by automating a number of processes that require repeated repetition. One of these processes is the assignment of the processing mode for each planned transition in such a way that the process engineer must choose a rational combination of cutting mode elements, in which all the quality parameters specified by the drawing and technical requirements will be maintained. Starting with the tolerance of the element being processed and the surface roughness, ending with the state of the surface layer (SL), for example, the level of technological residual stresses (TRS). The complexity of this process lies in the absence of recommendations from manufacturers of cutting tools (CT) for processing, above all, the most difficult to manufacture - non-rigid blanks, in the relationship of quality parameters with elements of cutting mode [1-8].

2. Description of theoretical research
Employees of the Volgograd State Technical University [9] proposed a technique for determining the roughness parameter Ra when milling on CNC machines, which allows calculating the expected microroughness of the surface based on a given cutting mode.
\[ R_a = C_{Ra} \times \left[ \frac{z \times \arccos \left( 1 - 2 \times \left( \frac{B}{D} \right)^2 \right)}{360} + 1 \right]^{K_1} \times \frac{E^{k_2} \times t^{k_1} \times S^{k_3}}{V^{k_4}} \]  

(1)

\( C_{Ra} \) - coefficient taking into account the type of processing (for semi-finishing \( C_{Ra} = 2.75 \), for finishing \( C_{Ra} = 73.5 \));

\( E \) - arithmetic average value of thermo-EMF, mV;

\( V \) - cutting speed, m / min;

\( S \) - feed per tooth, mm / tooth;

\( t \) - depth of cut, mm;

\( z \) - number of cutting edges of the multiblade carbide tools;

\( B \) - milling width, mm;

\( D \) - diameter of the tool, mm;

\( K_1 \) - coefficient that determines the degree of influence of the number of cutting edges \( z \) of a multiblade carbide cutting tool per milling width \( B \) for a given cutter diameter \( D \) on roughness parameter \( Ra \), (for semi-finishing, \( K_1 = 1 \), for finishing - \( K_1 = 0.833 \));

\( K_2 \) - coefficient determining the degree of influence of the arithmetic average value of thermo-EMF on the roughness parameter \( Ra \), (for semi-finishing processing \( K_2 = 0.732 \), for finishing \( K_2 = 0.727 \));

\( K_3 \) - coefficient determining the degree of influence of the depth of cut \( t \) on the roughness parameter \( Ra \), (for semi-finishing, \( K_3 = 0.51 \), for finishing - \( K_3 = 0.264 \));

\( K_4 \) - coefficient that determines the degree of influence of the feed on the tooth of the precast multi-useful carbide tool \( S \) on the roughness parameter \( Ra \), (for semi-finished machining \( K_4 = 0.5 \), for finishing - \( K_4 = 0.313 \));

\( K_5 \) - coefficient that determines the degree of influence of cutting speed \( V \) on the roughness parameter \( Ra \), (for semi-finishing \( K_5 = 0.284 \), for finishing \( K_5 = 0.997 \)).

Employees of the Regional Technological Center for Industrial Internet in Mechanical Engineering of Ulyanovsk State Technical University proposed techniques for determining the level of technological residual stresses in the surface layer of thin-walled parts made of aluminum and titanium alloys [10].

The value of technological residual stresses in blanks of aluminum alloys at a depth of 150 microns:

\[ \sigma_{150} = -170.334 + 0.934V - 0.519S + 26t, \text{MPa}; \]  

(2)

at a depth of 80 microns:

\[ \sigma_{80} = 109.496 - 0.678V + 0.038S + 25.75t, \text{MPa}; \]  

(3)

To determine the magnitude of residual stresses at a depth of 8 \( \mu \)m in the surface layer of titanium alloys, the following dependence was proposed:

\[ \sigma = -66.08 - 49.58S - 26.42t - 32.83V/5 - 13.17Vt - 71.155St - 94.83VSt, \text{MPa} \]  

(4)

\( V \) – cutting speed, m / min; \( t \) – milling depth, mm; \( S \) – feed per tooth, mm / tooth;

The authors have developed a method for calculating the magnitude of elastic squeezing of non-rigid walls during machining, which allows, at the design stage of the machining program for a CNC machine, to correct the trajectory of the cutting tool to ensure that the size of the processed element falls within the tolerance field specified by the drawing. [11]

The magnitude of the elastic squeezing of a separate wall is determined by:

\[ C = \frac{P_y l}{24EI} \left( 3 - 4 \frac{a^3}{l^3} + \frac{a^4}{l^4} \right), \text{mm}; \]  

(5)

\( P_y \) – the radial component of the cutting force, H; \( l \) – wall height, mm; \( E \) – modulus of elasticity, MPa; \( I \) – moment of inertia of the wall section, mm\(^4\); \( a \) – distance from the base of the wall to the area where \( Py \) acts, mm.

For a wall adjacent to other structural elements, the magnitude of the elastic squeezing determined by the following dependency:
\[ C = k_w \times \frac{P_y \times h^2}{\pi D}, \text{mm}; \]  

(6)

\( k_w \) – coefficient, for the middle of the wall equal to 0.527; \( P_y \) – radial component of the cutting force, N; \( h \) - wall height, mm; \( D \) – cylindrical wall stiffness, kg\( \cdot \)cm.

3. Results

Using the above dependencies make possible to select the cutting mode, in which all selected limiting factors will be within the specified limits.

The first stage of automation is the formation of the source database. The data are generated in a table (see table 1) which containing data about the cutting tool: diameter \( D \); the maximum cutting speed \( V \); the length of the cutting teeth \( L_T \); the minimum and maximum value of the cutting depth \( T_{\text{min}}, T_{\text{max}} \); the minimum and maximum value of the width of the milling \( B_{\text{min}}, B_{\text{max}} \); data on the range of the additional feed to the tooth \( S_{z_{\text{max}}}, S_{z_{\text{min}}} \); the steps to vary the data of the parameters.

| D   | 3    | 4    | 6    | 8    | 10   | 12   |
|-----|------|------|------|------|------|------|
| V   | 610  | 610  | 610  | 610  | 610  | 610  |
| LT  | 8    | 11   | 13   | 19   | 22   | 26   |
| T_{\text{min}} | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| T_{\text{max}} | 8   | 11   | 13   | 19   | 22   | 26   |
| B_{\text{min}} | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| B_{\text{max}} | 1.5 | 2    | 3    | 4    | 5    | 6    |
| S_{z_{\text{min}}} | 0.015 | 0.015 | 0.02 | 0.03 | 0.04 | 0.04 |
| S_{z_{\text{max}}} | 0.05 | 0.06 | 0.13 | 0.13 | 0.14 | 0.144 |

The formation of the table carried out in manual or automatic mode based on the data presented in the corresponding catalogues. For clarity, the data on monolithic carbide mills of the company YG-1 series Alu Power, designed for processing aluminum alloys, are considered.

As an example, we consider the use of the algorithm of selection of the cutting mode when limiting the maximum permissible elastic pressing of the wall. Workpiece with a separate wall height of 30 mm, thickness of 3 mm and a length of 100 mm. Workpiece material aluminum alloy D16T. Rational mode considered to provide maximum performance at the value of elastic deformation within a given value.

The choice of rational cutting mode carried out by the method of search possible with the calculation of the value of the elastic pressing and the value of the productivity of removal of the material per minute during milling.

Varied by the following cutting conditions: cutting width \( B \), the cutting depth \( T \), the feed per tooth \( S_z \). The range of variation determined by the source database, in which the maximum and minimum values of the variable parameters were selected. The variation step for each parameter remained unchanged: for milling width \( B \) - 0.05 mm, for milling depth \( T \) - 0.1 mm, for feeding to the tooth \( S_z \) - 0.002 mm/tooth. The step value determined empirically. Data search carried out according to the scheme given in Table 2.

| Table 2. | Brute force scheme |
|----------|-------------------|
| 1 | B_{\text{min}} | T_{\text{min}} | S_{z_{\text{min}}} | C_1 | Q_1 |
| 2 | ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... | ... |
| ... | B_{\text{min}} | T_{\text{min}} | S_{z_{\text{min}}} | C_2 | Q_2 |
| ... | B_{\text{max}} | T_{\text{min}} | S_{z_{\text{min}}} | C_2 | Q_2 |
| ... | B_{\text{max}} | T_{\text{max}} | S_{z_{\text{max}}} | ... | ... |
| ... | ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... | ... |
| ... | B_{\text{min}} | T_{\text{min}} | S_{z_{\text{min}}} | C_{n} | Q_{n} |
The number of sets of elements of the cutting mode determined by the following formula:

\[ N_n = \frac{B_{\text{max}} - B_{\text{min}}}{0.05} \times \frac{T_{\text{max}} - T_{\text{min}}}{0.1} \times \frac{S_z_{\text{max}} - S_z_{\text{min}}}{0.002}; \]

For the considered example of machining with an end mill with a diameter of 6 mm, the number of possible sets of cutting mode parameters will be 411510.

All calculated sets form the output database, which presented in the form of a table (table. 3):

| №  | B   | T   | S_z | Z   | C            | Q               |
|----|-----|-----|-----|-----|--------------|-----------------|
| 1  | 0.10| 0.1 | 0.020|     | 1,025*10^{-6}| 0.0018          |
| 2  | 0.10| 0.1 | 0.022|     | 1,107*10^{-6}| 0.0019          |
| ...| ... | ... | ... | ... | ...          | ...             |
| 411510 | 3,00| 13,0| 0,130|     | 1,3789*10^{-6}| 45,63           |

The algorithm of operation of the parameters of the cutting mode shown in figure 1.

![Figure 1. Brute force scheme](image)

After forming the output table, it is necessary to filter out the sets of elements of the cutting mode, the use of which is unacceptable. Filtering is based on the condition \( C \leq C_{\text{max}} \). This removes all the sets the calculated deflection exceeds the allowable.
For the considered example, the value of the maximum pressing $C_{\text{max}}$ is 0.01 mm. The data set after filtering is as follows (table. 4).

Table 4. Search for rational cutting mode

| №  | B  | T     | Sz   | C    | Q       |
|----|----|-------|------|------|---------|
| 1  | 0,1| 10    | 0,048| 0,0098| 0,432   |
| 2047| 0,2| 6,3   | 0,046| 0,0098| 0,544   |
| 75232 | 0,5| 3     | 0,040| 0,0062| 0,540   |
| 75233 | 0,5| 3     | 0,050| 0,0074| 0,675   |
| 75234 | 0,5| 3     | 0,072| 0,0099| 0,972   |
| n  | 2,95| 1,8   | 0,02 | 0,0099| 0,956   |

Among the remaining sets of parameters of the cutting mode, the search is carried out for the most productive, the value of which $Q$ is the maximum. Such a set in the presented sample is the set №75234, the value of the removed material per minute at which is 0.972 cm³/min.

The resulting set transmitted to the CAM system. When generating the path of the cutting tool used the milling depth 3 mm, width of cut 0.5 mm, feed per tooth 0.072 mm/tooth.

Thus, replacing or adding limiting elements, we can automatically search for a rational cutting mode, ensuring the fulfillment of all specified requirements.

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