Milling of Thin Walled Components from Aluminum Alloys by Considering the Conditions of Rigidity and Automation Assignment Elements of a Cutting Mode on CNC Machines

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Abstract. The work is devoted to the problems of manufacturing thin-walled parts of the aviation industry and instrument engineering on modern numerical control machines. The main reason of defects of such products - loss of dimensional accuracy is revealed. The reason for this is the elastic deformation of the workpiece during milling. A mathematical model for calculating the elastic pressing of a thin wall during milling is proposed. The method of checking the adequacy of the developed model with the help of engineering analysis system is presented. The minimum set of geometrical parameters of the processed element and the cutting tool necessary for search of the rational cutting mode was defined. A new approach to automation of this process present through the evaluation of all possible solutions. The calculation of the rational cutting mode was made taking into account the conditions of rigidity of the workpiece. Conclusions on the efficiency of the developed technique are made.

1 Introduction

Currently, in the aviation industry and instrumentation a large number of parts are used, which are a complex combination of non-rigid elements (thin walls, panels). Their separate processing causes significant difficulties, and in combination with similar no rigid elements, makes this technology in accordance with the requirements of the drawing very costly and time-consuming.

Fig. 1. Part consisting of a series of adjacent non-rigid elements.

The main problem in the processing is the elastic deformation of the walls in the milling process, which leads to vibration, shape deviation and going beyond of tolerance of the geometric dimensions of the processed element. The reason for this is the lack of recommendations from the manufacturer of the cutting tool for the processing of non-rigid blanks. Engineers and technologists can only access information about the maximum permissible milling modes, which are presented for an ideal, absolutely rigid technological system. [1, 2, 3, 4, 5]

The aim of this work is to develop an automated system assignment of the cutting conditions during milling of non-rigid workpieces of machine parts. To achieve the goal, it is necessary to solve the following tasks: to develop a mathematical model for determining the value of elastic deformations of the processed element in the milling process; to develop a technique for finding the most productive cutting mode that ensures the fulfillment of the requirements specified in the drawing.

2 The description of the theoretical studies

To implement this process, it is necessary to present the processed wall in the form of a plate length l , height h and thickness s fixed on three sides, which acts concentrated force P_y . The radial component of the cutting force leads to a mutual elastic deformation of the workpiece and the cutting tool. Mills made of hard alloy have a much greater stiffness in comparison with thin walls of aluminum and titanium alloys used in the aviation industry. In this regard, the deformation of the tool is neglected.

Fig. 2. Representation of the processed wall in the form of a plate.

Fig. 3. Processed item.

The maximum deviation of the wall C from the specified position will be observed at the point as far as possible from all fixes, which is located in the middle of the processed element and at a distance h from its base.

The calculation of the maximum elastic deformation of the wall is made according to the following formula:

$$C = k_w \times \frac{P_y \times h^2}{\pi D}; \quad (1)$$

k_w – coefficient for the middle of the wall is equal to 0.527;

P_y – radial component of cutting force, N;

h – height of the wall, mm;

D – cylindrical wall stiffness, kg*cm.

To check the efficiency of the given method, we will make a calculation. Consider the case: milled wall to which the sides adjacent to other structural elements. The billet of aluminum alloy D16T, the length of the wall $l = 100$ mm, height $h = 30$ mm, thickness $s = 3$ mm. Cutting tool – solid carbide mill of diameter $D = 10$ mm, rotation speed $n = 3000$ Rev/min, feed per tooth $S_z = 0.03$ mm/tooth, cutting depth $T = 5$ mm, width of cut $B = 0.5$ mm. Radial component of cutting force is equal to:

$$P_y = 0.3 \times \frac{10 \times C_p \times t^{2P} \times S_z^{YP} \times B^{UP}}{D^{QP} \times n^{WP}} \times K_p; \quad (2)$$

$$P_y = 0.3 \times \frac{10 \times 261 \times 5^{0.5} \times 0.03^{0.8} \times 0.5^{1.1}}{10^{1.1} \times 3000^{0.45}} \times 1.05 = 2.777 \text{ N}; \quad (3)$$

Using this value in the calculation of the Siemens NX CAE engineering analysis package, the following results were obtained: the maximum deviation C of the wall was 0.0023 mm.

Fig. 4. Design model of the wall with adjacent structural elements.

Calculate the value of C analytically:

$$C = 0.527 \frac{2.777 \times 30^2}{3.14 \times 174222.87} = 0.0024 \text{ mm}; \quad (4)$$

The difference between analytical and CAE calculations was 4%. Thus, it can be concluded that the proposed mathematical model adequately reflects the research process.

2.1 Calculation of cutting mode.

To make a decision on the admissibility of the use of a milling mode, it is necessary to determine a number of restrictions: the maximum spindle speed, the maximum allowable elastic deformation of the workpiece, the highest performance.

The recommendations of the cutting tools manufacturers of a cutting speed are not always valid. Each machine has a value of the maximum spindle speed, which imposes restrictions on the maximum allowable cutting speed. In this regard, the speed values recommended by the cutting tools manufacturer are checked for applicability.

$$n = \frac{1000 \times V}{\pi D} \leq n_{MAX}; \quad (5)$$

n – recommended frequency of rotation mill, rpm;

n_{max} – maximum permissible speed, rpm.

If the condition is not met, the maximum permissible value of the cutting speed V_{max} is recalculated, which is used in further calculations.

$$V_{max} = \frac{\pi \times D \times n_{MAX}}{1000}, \text{ m/min}; \quad (6)$$

Consider the use of YG-1 Alu-Power cutter with a diameter of 10 mm when milling a workpiece is made of aluminum alloy D16T on the machining center DMG DMU 50 ecoline. Recommended cutting conditions for this mill: cutting speed $V = 610$ m/min, maximum feed per tooth $S_z = 0.13$ mm. the Maximum spindle speed of the selected machine $n_{max} = 12\,000$ rpm.

$$n = \frac{1000 \times 610}{3.14 \times 10} = 19427 \text{ rpm}; \quad (7)$$

Recommended speed 19427 rpm greater than the maximum permissible frequency of 12000 rpm. Determine the maximum cutting speed the permissible from machine characteristics.

$$V_{max} = \frac{3.14 \times 10 \times 12000}{1000} = 376 \text{ m/min}; \quad (8)$$

For further calculations we accept V_{max} 376 m/min.

The following limiting condition is the maximum allowable elastic deformation of the wall C_{max} [6]:

$$C_{max} = \frac{dop}{2} \times 0.8 \text{ mm}; \quad (9)$$

dop – the maximum allowable deviation of the linear size of the processed element, mm;

0.8 – factor, providing a margin of 20%.

When processing the wall height 30h14 mm, thickness 3h9_(-0.025) mm determine the maximum permissible value of the wall elastic deformation:

$$C_{max} = \frac{0.025}{2} \times 0.8 = 0.01 \text{ mm}; \quad (10)$$

The table of input data for finding a rational cutting mode is as follows:

Table 1. Input data for calculation

Cp	D	n	Kp	HB	zp	yp	up	qp	wp	h	E	I	np
261	10	12000	1.053	200	0.9	0.8	1.1	1.1	0.13	30	69000	520.8	1

D – mill diameter, mm; N – cutter speed, rpm; Cp – coefficient, reference data; zp , yp , up , qp , wp – exponents, reference data; h – wall height, mm; E – modulus of elasticity, MPa; I – moment of inertia of the section, mm⁴.

The determination of the above conditions is followed by the calculation of all possible combinations of cutting parameters. For each set of parameters, the value of the radial component of the cutting force Py , the value of deformation C , as well as the amount of material removal per minute Q is calculated.

$$Q = \frac{T \times B \times S_z \times n \times N_z}{1000}, \text{ cm}^3/\text{min}; \quad (11)$$

N_z – the number teeth of mill.

At this stage we vary the depth of milling T , the width of milling B , and the feed to the tooth S_z . These parameters vary within the limits recommended by the mill manufacturer. Step variation for S_z – 0.002 mm/tooth, for T and B – 0.1 mm.

For each step, the calculated wall deformation C is compared with the allowable C_{max} . If the condition $C \leq C_{max}$ is not met, the data set is excluded from further calculation.

3 Results and discussion

The next step in determining the rational cutting mode is finding the most productive set of parameters. Table 2 shows an example of the calculated sets of elements of the cutting mode.

Table 2. The result of the calculation (sampling)

№	B, mm	T, mm	Sz, mm/tooth	C, mm	Q, cm ³ /min
1	1.0	10.0	0.015	0.0099	3.6
2	1.0	7.8	0.027	0.0099	4.86
3	1.0	5.4	0.054	0.0098	6.99
4	1.0	3.8	0.120	0.0100	10.94

Based on the calculation result, we obtain a set of elements of the most productive cutting mode: $V=376$ m/min, $S_z = 0.12$ mm/tooth, $T = 3.8$ mm, $B = 1$ mm, for which the value of the probable elastic wall deformation $C = 0.01$ is known.

Thus, already at the stage of technological preparation of production, it is possible to adjust a tool path, which provides obtaining the dimensions of the processed element within the tolerance field specified by the drawing. In this example, it is recommended when using the found cutting mode to shift the trajectory by 0.01 mm to the treated surface (set a negative value of allowance), which will allow to obtain the thickness of the treated wall within 3-0.02 mm, which eliminates the additional finishing pass required to remove the allowance remaining on the surface due to elastic deformations, the value of which exceeds the permissible values.

4 Conclusion

The method of determining the value of the machined element elastic deviation in the milling process is developed, as well as the method of using the calculation results in the appointment of a rational cutting mode.

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