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Feed speed control to assure accuracy of complex profile surfaces processing

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Abstract

This document describes how cutting force components influence the accuracy of processing complex profile surfaces of parts on CNC machines. It demonstrates how changing cutting zone geometrical parameters influences cutting force components. The article includes dependences for determining cutting force components. We propose a mathematical model to identify dynamic size-setting errors for 2D machining of complex profile surfaces. We suggest a processing method to reduce error occurrence rate by controlling feed speed. This document includes a method of setting feed motion speed depending on the geometrical parameters of the machined surface. We recommend changing feed motion speed depending on machined surface pitch against the feed motion vector. We demonstrate that feed motion speed control allows to increase machining efficiency while assuring the set accuracy of the shape and dimensions of the components' complex profile surfaces.

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Keywords: Processing accuracy, complex profile surfaces, cutting forces, feed speed control, cutting modes, CNC machines.

1. Introduction

Machine building industry has a task of increasing parts producing accuracy. We are talking about 10 times accuracy increasing and assuring roughness of up to *Rz* = 0.001 mm. Same time, approaches to designing technological processes of manufacturing parts on metal cutting machines mostly remain traditional. Process designing mainly uses reference data for evaluating processing accuracy per process steps. Cutting modes choosing reference books don't demonstrate full relation to all parameters of processing accuracy [1, 2, and 3]. Often cutting

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modes are determined by cutting tool strength and resistance. Lac of reference data on complex relation of all processing accuracy parameters with cutting modes, tool, fittings, and equipment parameters, leads to significant role of subjective decisions on designing technological processes. This leads to moving accuracy assuring tasks to technological process adjusting stage, leading to significant increase in its labor intense and cost. Taking into account small-scale of modern production with high concentrated process operations, accuracy becomes very critical. Processing of complex profile surfaces is the most difficult task if considering assuring accuracy.

2. Cutting forces influence on processing errors

Due to process non-stationary, main part of errors is due to dynamic setting size errors. In order to predict these errors it is necessary to evaluate cut forces and process system condition. Cutting forces can be determined with practical degree of accuracy on the basis of reviewing elementary components of cutting force, acting at infinitesimally small area of the tool cutting edge [4].

This approach allows creating universal mathematics model of the cutting force, invariant to different processing types.

According to forces and stresses on elementary area of the tool forward and rear surfaces, cutting forces components during sharpening are determined by:

$$dP_{xy} = \frac{\sigma_i a_i db}{\sqrt{3}\sin\beta_1 \cos(\beta+\beta_1)}\sin\beta + 0{,}16\sigma_i l_w db;$$
$$dP_z = \frac{\sigma_i a_i db}{\sqrt{3}\sin\beta_1 \cos(\beta+\beta_1)}\cos\beta + 0{,}16\mu\sigma_i l_w db, \tag{1}$$

where: dP_{xy} – component of cutting force in main plain; dP_z – cutting force main component; a_i - cut-off layer thickness on tool cutting edge elementary area; db - cutting edge elementary area; β_1 – reference shear plane pitch. Most often it is determined by chip thickening coefficient; σ_i – intensity of stresses in shear area; β - angle between shear line and resultant force direction; l_w – worn face length; μ – friction coefficient.

When knowing the force, acting on elementary areas of the tool cutting edge active zones, we can determine (by integration) cutting force components for any processing conditions as for simple surfaces, with generator lines, parallel to machine coordinate axes, as for complex profile surfaces, randomly located in the machine coordinates system.

We shall discuss design accuracy prognosis on the example of 2D machining of complex profile surfaces in one stage [5].

We talk about 2D machining when performing contour turning, bore machining, and contour milling with core mills. This type of processing is characterized by the fact, that two cutting force components influence process system elastic displacements error and its changing. P_x, P_y for turning and P_z, P_y for contour milling.

Lets discuss analytical model of contour processing error forming $y = \phi(x)$ (Fig. 1). Resulting from joint acting of components P_x and P_y (for turning) and some extend of process system flexibility, point A, being a part of tool cutting edge with coordinates (x_i, y_i), will move to point B with coordinates $(x_i + \Delta x, y_i + \Delta y)$. Where Δx and Δy are amounts of the tool elastic moving along appropriate coordinates. Part contour tangent line in point A is as follows:

$$y - y_i = \frac{\partial y}{\partial x}(x - x_i). \tag{2}$$

In order to find size error in point A along normal line in this point we'll modify coordinate axes XOY by relocating there beginning point to point A. In new coordinates system point B is determined by coordinates (Δx, Δy), and equation (2) can be read as follows: $Ax + By = 0$, where $A = \frac{\partial y}{\partial x}$, $B = -1$.

Distance Δ_N from point B to tangent line in point A is determined according to known equation: $\Delta_N = \dfrac{A\Delta x + B\Delta y}{\sqrt{A^2 + B^2}}$ [6].

Taking previously determined designations into account, we'll have to following:

$$\Delta_N = \frac{\Delta y - \frac{\partial y}{\partial x}\Delta x}{\sqrt{1 + \left(\frac{\partial y}{\partial x}\right)^2}}. \tag{3}$$

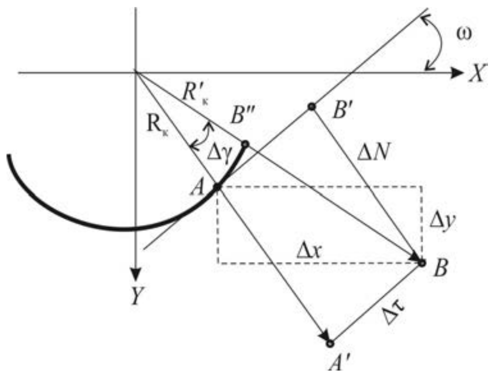

Fig. 1. Analytical model of determining errors for 2D machining.

Considering instrument displacement along X axis, actually this moment of machining forms part profile error in point B'', where error Δ_f along normal line is equal to jog BB''. Its size is determined from a triangle:

$$\Delta_f = \frac{R_k + \Delta_N}{\cos\left(\operatorname{arctg}\frac{\Delta_\tau}{R_k \pm \Delta_N}\right)} - R'_k, \tag{4}$$

where R_k – machined contour curve radius in point A; R'_k – machined contour curve radius in point B''; Δ_τ – elastic relative tool movement to tangent line in point A.

Taking into account that $\Delta_\tau = \Delta y \sin\omega + \Delta x \cos\omega$, and using value Δ_N from relation (3), we'll obtain formula for determining dynamic setting size error for 2D contour machining:

$$\Delta_f = R_k + \frac{\Delta y - \frac{\partial y}{\partial x}\Delta x}{\sqrt{1 + \left(\frac{\partial y}{\partial x}\right)^2}} \cdot \cos\left[\operatorname{arctg}\frac{\frac{\partial y}{\partial x}\Delta y + \Delta x}{R_k\sqrt{1 + \left(\frac{\partial y}{\partial x}\right)^2} \pm \Delta y \mp \frac{\partial y}{\partial x}\Delta x}\right] - R'_k. \tag{5}$$

In formulas (4) and (5) (+) signs are used for external turning and contour milling of contour convex areas, (−) signs – for bore machining and concave areas milling. Δ_x and Δ_y values are determined by dividing appropriate cutting force component by process system stiffness along machine coordinate axes directions. Stiffness can be determined by testing the process system [7].

Obtained relation demonstrates that kinematic angles changing in plan influence on machining error under all else being equal is as larger, as lower the machined part area curve radius is.

Calculations demonstrate that changing cutting forces, depending on part machined surface tangent line pitch, lead to errors of dynamic setting size, changing on different machined surface areas 4 and more times. This leads to machined part shape errors that, due to variability of their values within one surface, can't be compensated by introducing simple correction of static setting size.

Non-stationary machining parameters influence on accuracy can be decreased at technological process design stage by directed control over feed speed, set in control program.

3. Feed speed control

Having error value Δ_f as a target and solving equitation (5) relative to feed S, we can determine law of feed control, assuring stabilization of pushing out the technological system elements. Graphs of feed changing for assuring dynamic setting size error constancy are presented in Fig. 2.

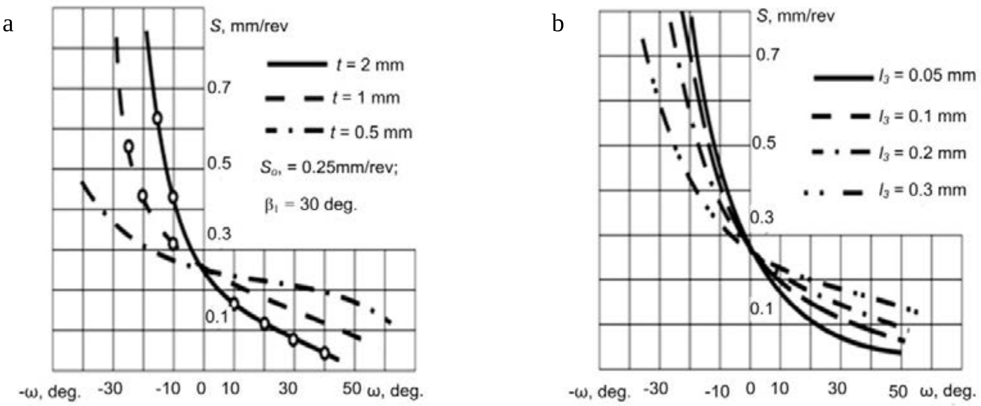

Fig. 2. Graphs of changing feed for assuring error constancy depending on (a) cutting depth (b) cutter wear.

Calculations and presented graphs demonstrate, that, when preparing control programs for complex profile surfaces machining, it is necessary to set different feed speeds for surface areas with different pitches of machined surface tangent line against machine spindle axis.

Practical experience in cylinder parts machining modes setting is quite enough. Usually parts, machined on CNC machines, have combinations of cylinder and profiled surfaces. Due to this fact it seems reasonable to determine law of setting feed change at profiled surface, taking into account feed speed for cylinder part. In this case speed change law should assure same machining error for all part sections, or different with regulating feed for each section. Method of determining such law is as follows:

- feed for cylinder surface is set on the basis of regulatory recommendations;
- based on set feed and implementing relation (5) dynamic setting error for cylinder surface is determined;
- values of cylinder part predicted error are introduced into formula for determining law of changing feed depending on shape of the machined profiled surface.

4. Conclusions

Software control over feed speed allows assuring necessary accuracy of machined surfaces shape and improves machining effectiveness.

In order to improve technological processes effectiveness on the stage of their implementation, it is reasonable to use machine computer for determining specific technological system status and to perform software customizing their parameters.

In this case it is reasonable to divide between designing and producing systems functions of assuring parts quality and assuring reliability of process operation performing.

Following can be taken as the basis for software-customizing designing of technological operations: analytical dependences, determining relations between main machining process parameters (cutting mode, tool geometry and its wear rate, physical-mechanical parameters of machined material, work pieces errors, and technological system stiffness) and assured parts sizes and shape accuracy, as well, as dependences, taking into account physical condition of the technological system. Testing of the technological system allows not only determining transfer factors for calculating designed operation accuracy balance, but also specifying technological process model according to calculated machining stages quantity and their content for each part surface. Necessary tests, allowing determining actual technological system status, are chosen for specified model. Transfer functions of dominant effects at each machining stage are also determined. Initial technological operation parameters are corrected by means of mathematical models, functionally linking produced component output parameters (accuracy and degree of roughness) with current operation parameters (5). Feed speed software control, taking into account actual technological system stiffness, allows decreasing machining cycle duration for complex profile surfaces 1.5 times by means of decreasing time period, spent for adjusting CNC machine control program.

Analyzed method allows controlling feed speed for 3D machining on CNC milling machines, taking into account three components of the cutting force influence on machining errors.

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