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Procedia Engineering 206 (2017) 1127–1132

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2017

Modeling the Influence of Geometric Errors of Turning Machine for Accuracy Machinable Surface

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Abstract

The actual problem of modeling machine tools geometrical errors influence on machined surfaces precision is considered in the paper. The turning as an example of the treatment type is considered because it has the highest prevalence. The mathematical model of the machined surfaces accuracy is set and the model takes into account the influence of machine tools geometrical errors. The basis for the mathematical model creation was the application of the variational method development for calculating of the metal cutting machines accuracy. The mathematical model of the cylindrical and end surfaces turning precision is proposed in this work. The lathe processing accuracy is simulated at constant values of the turning machine geometrical errors for presented typical surfaces. The direction of future research of the processing accuracy simulation is identified for the values of geometric errors which are associated with the coordinate motion of the machine components. The directions for further studies of the turning accuracy at variable geometric errors of the turning machine are suggested. The work is useful for scientists involved in the study of the metalworking accuracy.

Peer-review under responsibility of the scientific committee of the International Conference on Industrial Engineering

Keywords: turning machine; geometric accuracy; precision; treaded surface; real surface.

1. Introduction

The study of the influence of machines geometrical errors on the treated surfaces accuracy was initiated by the professor Schlesinger [1]. Since that time a large number of studies have been carried out in this direction [2] which are associated with ever-increasing demands to the products quality provided by increasing the accuracy of

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Peer-review under responsibility of the scientific committee of the International Conference on Industrial Engineering.
10.1016/j.proeng.2017.10.605

manufacturing its parts and components. The cutting processing is the main way to produce parts despite the rapid development of additive technology and nanotechnology. The research in this area are actual since turning is very significant part among the various types of processing.

2. General mathematical model of machining precision

The basis of this work is the variational method for calculating the accuracy of machine tools [3]. The method was developed in [4] and it was proposed to abandon the notion of a "basic surface" and to make estimates of the accuracy of processing only on the basis of a "real" treated surface.

The equation of the nominal treated surface is of the form:

$$r_0 = r_0(u, v, q_0) \tag{1}$$

where u, v - curved surface coordinates; q_0 – vector dimensional parameters of the surface; $q_0 = (q_{01}, \ldots, q_{0m1})^{\mathrm{T}}$; $m1$ – the number of the vector q_0 components.

Shaping function (SF) reflects the relationship between the coordinates of the tool cutting edge points in the system S_l of cutting tool and the same points coordinates of the treated work piece in the system S_0:

$$r_0 = A_{0,l} r_l \tag{2}$$

where $A_{0,l} = \prod_{i=1}^{l} A_{i-1,i}^{jl}$; l – the number of the forming machine system moving parts, where the matrices A entering in the product correspond to one of the six generalized displacements performed by the joint; r_l – radius-vector of the cutting tool edge; and also links (diffraction, hidden and functional) between generalized displacements so the *SF* (2) can be represented as follows:

$$r_0 = r_0(u, v, q_{\mathrm{st}}) \tag{3}$$

where q_{st} – vector machine communications; $q_{st} = (q_{st1}, ..., q_{stL})^{\mathrm{T}}$; L – number of vector q_{st} components (number of links), $L = n + m - 2$; n – the number of links carrying shaping motion; m – number of independent variables in the model of the cutting tool.

Equality expressions (1) and (3) provides a formalized description of the service purpose of the machine. The total variation vector *SF* represents the vector balance of accuracy [3]. The authors proposed a new definition of the vector balance of accuracy considering in this balance only those errors that affect on the accuracy parameters of the treated surface and also the nature of this influence

$$\Delta r_0^{**} = \varepsilon_0 r_0 + \delta r_0 + d r_0 \tag{4}$$

where ε_0 – matrix of the work piece error position relative to the technological base at the surface r_0 treatment.

The essential difference between the definitions of vector precision balances is the following. Vector Δr_0 balance [3] considers all geometrical machine errors that affect on the accuracy at the processing of all machined surfaces with given instrument. Vector balance Δr_0^{**} [4] considers all geometric machine errors that affect the accuracy at the processing of a given treated surface only..

Taking into account (1) and (4), the equation of the real treated surface has the following form:

$$r = r_0 + \Delta r_0^{**} \tag{5}$$

It follows from (4) and (5) that the errors of the real treated surface are divided into size errors (dr_0), shape errors (δr_0) and position errors ($\varepsilon_0 r_0$). The position error ($\varepsilon_0 r_0$) is determined with respect to the technological base used for processing of this surface.

To determine the relationship between of the geometric accuracy parameters of machine units and the processed surfaces of details the following equation is used:

$$\Delta r_0\left(u,v,\Delta q_0\right)=\Delta r_0^{**}\left(u,v,\Delta q_{st}\right) \tag{6}$$

In (6) member Δr_0 (u, v, Δq_0) is the total variation of the expression (1), the member of $\Delta r_0^{**}\left(u,v,\Delta q_{st}\right)$ is the total variation of the expressions (2) and (3).

The adequacy between the total differentials is employed when using the relation (6)

$$dr_0\left(u,v,dq_0\right)=\Delta r_0\left(u,v,dq_{st}\right) \tag{7}$$

and between private variations

$$\delta r_0\left(u,v,\delta q_0\right)=\delta r_0\left(u,v,\delta q_{st}\right) \tag{8}$$

since the following expression is an identity

$$\varepsilon_0 r_0\left(u,v,q_0\right)\equiv\varepsilon_0 r_0\left(u,v,q_{st}\right) \tag{9}$$

Thus the mathematical model of machined surfaces precision considering the influence of the machine tools geometrical errors is fully defined.

3. Mathematical model of precision turning

At the present time the shaping function (2) of machine tools is known [3]:

$$r_0=A^6\left(\phi\right)A^3\left(z\right)A^1\left(x\right)e^4=\left(x\cdot\cos\phi;x\cdot\sin\phi;z;1\right)^{\mathrm{T}} \tag{10}$$

where $A^6(\varphi)$ – rotation matrix about the Z axis; $A^3(z)$ и $A^1(x)$ – are displacement matrices along the axes Z and X, respectively; e^4 – radius vector of the origin, $e^4=(0,0,0,1)^{\mathrm{T}}$, i.e. a pointing tool is used for processing $r_l=e^4$.

When the treatment of cylindrical surfaces with a radius R takes place the communication equation is $x=R$. The nominal treated surface equation (1) is $r_0=\left(R\cdot\cos\phi;R\cdot\sin\phi;z;1\right)^{\mathrm{T}}$.

Vector balance Δr_0^{**} and its components are

$$\Delta r_0^{**}=\begin{pmatrix}\delta x_0+z\beta_0+z\beta_1\cdot\cos\phi+\sum_{i=1}^{3}\delta x_i\cdot\cos\phi\\ \delta y_0-z\alpha_0+z\beta_1\cdot\sin\phi+\sum_{i=1}^{3}\delta x_i\cdot\sin\phi\\ R\alpha_0\cdot\sin\phi-R\beta_0\cdot\cos\phi-R\beta_1\\ 0\end{pmatrix}, \tag{11}$$

$$\delta r_0=\left(z\beta_1\cos\phi;\,z\beta_1\sin\phi;\,-R\beta_1;\,0\right)^T, \tag{12}$$

$$\varepsilon_0 r_0 = \begin{pmatrix} 0 & 0 & \beta_0 & \delta_{x0} \\ 0 & 0 & -\alpha_0 & \delta_{y0} \\ -\beta_0 & \alpha_0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} R\cdot\cos\phi \\ R\cdot\sin\phi \\ z \\ 1 \end{pmatrix}, \quad (13)$$

$$dr_0 = \left(\left(\sum_{i=1}^{3} \delta x_i \right) \cos\phi; \left(\sum_{i=1}^{3} \delta x_i \right) \sin\phi; 0; 0 \right)^T . \quad (14)$$

When processing of the end surface takes place the communication equation is $z = c$ – the distance from the end surface to the coordinate system S_0 beginning. The nominal treated surface equation (1) is $r_0 = (x\cdot\cos\phi; x\cdot\sin\phi; c; 1)^{\mathrm{T}}$.

There Δr_0^{**} and its components are

$$\Delta r_0^{**} = \begin{pmatrix} c(\beta_0 + \beta_1 \cdot\cos\phi) \\ c(\beta_1 \cdot\sin\phi - \alpha_0) \\ \alpha_0 x\cdot\sin\phi - \beta_0 x\cdot\cos\phi - (\beta_1+\beta_2)x + \sum_{i=0}^{3}\delta z_i \\ 0 \end{pmatrix}, \quad (15)$$

$$\varepsilon_0 r_0 = \begin{pmatrix} 0 & 0 & \beta_0 & 0 \\ 0 & 0 & -\alpha_0 & 0 \\ -\beta_0 & \alpha_0 & 0 & \delta z_0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} x\cdot\cos\phi \\ x\cdot\sin\phi \\ c \\ 1 \end{pmatrix}, \quad (16)$$

$$\delta r_0 = \left(c\beta_1 \cos\phi; c\beta_1 \sin\phi; -(\beta_1+\beta_2)x; 0 \right)^T , \quad (17)$$

$$dr_0 = \left(0; 0; \sum_{i=1}^{3} \delta z_i; 0 \right)^T . \quad (18)$$

The above expressions (11) - (14) and (15) - (18) are the mathematical model of accuracy at turning of two typical surfaces such as cylindrical and end surface.

4. Modeling of turning precision when geometric machine errors are constant

The influence of the machine tool geometrical errors on precision of cylindrical and end surfaces machining on condition $q_{st} \neq q_{st}(u, v)$ is considered in this section of the paper.

The effect of geometric machine errors on the position error, size error and shape error at turning of the cylindrical surface is shown in fig. 1. The effect of geometric machine errors on the position error, size error and shape error at turning of the end surface is shown in fig. 2.

The error α_0 is the component of the matrix ε_0 and affects only on the position of the real surface relative to the nominal machining surface (or its technological base) rotated around the axis X_0. This follows from an analysis of the data presented in fig. 1(b) and fig. 2(b). The error β_0 has identical influence like the error α_0 and only leads to an additional rotation of the real surface around the axis Y_0. The shape errors during the processing of the cylindrical and end surfaces are identical in the form of conicity. These errors are caused by the same geometric error of the machine such as the spindle guide nonparallelism with respect to the axis of rotation (β_1). This follows from an analysis of the data presented in fig. 1(c) and fig. 2(c).

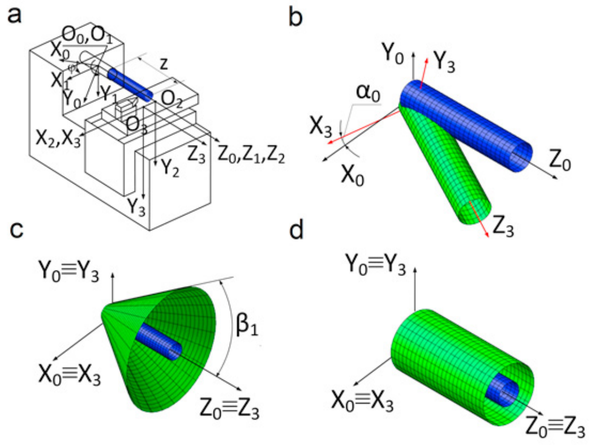

Fig. 1. Influence of the machine geometric errors on the faults of cylindrical surface treatment: (a) machine forming system and nominal processed surface (cylinder); (b) formation of the real surface position error; (c) formation of the real surface shape error; (d) formation of the surface size error

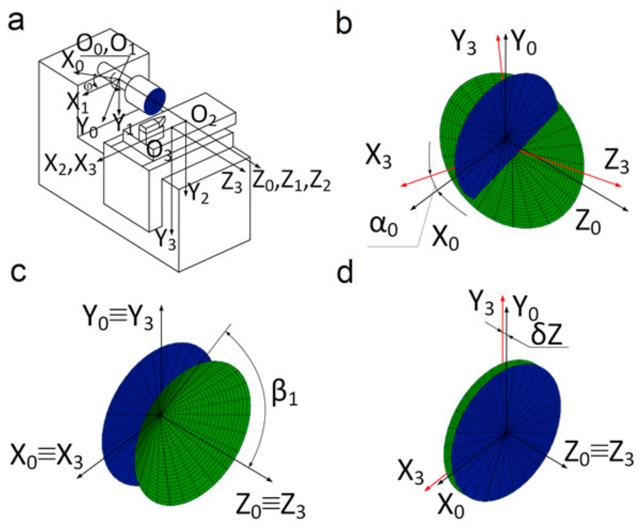

Fig. 2. Influence of the machine geometric errors on the faults of end surface treatment: (a) machine forming system and nominal processed surface (cylinder); (b) formation of the real surface position error; (c) formation of the real surface shape error; (d) formation of the surface size error

The size error at processing of the cylindrical surface is $dr_0(dR) = \delta x_1+\delta x_2+\delta x_3$ and at processing the end surface the error is $dr_0(dc) = \delta z_1+\delta z_2+\delta z_3$. This follows from an analysis of the data presented in fig. 1(d) and fig. 2(d).

5. The direction of future research of turning precision simulation at variable values of the machine geometrical errors

The simulation results presented in the previous section are fairly obvious but their importance is due to consistency with the results of previous research in this area [3,5,6]. The condition $q_{st} = q_{st}(u, v)$, accounting when the treatment of simple surfaces such as cylindrical and the end is considering requires additional operations of transformation and analysis of the structure of relationships between expressions (11) – (13, 14) and (15) – (16, 18). The priority in the analysis of these relations is precisely the correspondence to the structure (11) and (15).

For example, the presence of the rotation axis beating $\delta x0 = a \cdot \cos(\varphi)$, $\delta y0 = b \cdot \sin(\varphi)$, $(a \neq b)$, caused by errors in the manufacture and assembly of the spindle unit bearings leads not only to the real surface position error relative to the nominal surface but also to errors in shape and size (fig.3). Here the position error relative technological base (for two coaxial cylindrical surfaces such as nominal and real) is $\sqrt{a^2+b^2}$, and the ratio between the shape errors and size errors will depend on the ratio between R, a and b values.

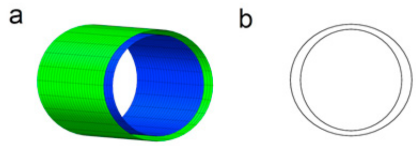

Fig. 3. Influence of variable components ε0 on the cylindrical surface size and shape errors forming: (a) position of the nominal and real surfaces; (b) cross section of the nominal and real and surfaces

So the further research direction of the processing accuracy modeling including turning is revealed for the values of the geometrical errors related with coordinates movements of the machine units.

6. Conclusions

The new general mathematical model of the machine tools processing precision for the first time is systematically presented in this work and one is the base of precision turning model. The processing accuracy modeling for treatment of the cylindrical and the end surfaces had made and the results obtained are consistent with previous studies. The principal difference between the effect of fixed and variable machine errors on the accuracy of the position, size and shape of the machined surfaces is established. The directions of future research of turning precision simulation at variable values of the machine geometrical errors are developed.

Acknowledgements

The work is executed with financial support of RFBR (the Project № 16-38-60049).

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