ATLANTIS PRESS
Advances in Engineering Research (AER), volume 157
International Conference "Actual Issues of Mechanical Engineering" (AIME 2018)

Accuracy estimation of mill pin machining with desk-side tools

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***Abstract*—Building materials equipment repair and reconstruction are a challenge as this equipment has large overall dimensions and masses. Requirements to desk side tools precision are expressed in the following: basing surface accuracy of the restored workpiece by the tools; accuracy of working tools movement; basing surface position relative to the guiding support; kinematic chains accuracy; locating accuracy.**

Keywords—accuracy, machine-tool, form, deviation, parameters, model, system.

I. INTRODUCTION

Desk-side tools machining and reconstruction processes are different from that ones by common machine-tools standing on the base. Desk-side tools are put on to the machined detail or near it but placing is done while the tool is put onto the detail, which is a crucial difference between stationary tools and desk-side ones [14-16].

II. INFORMATIVEPART

To estimate the accuracy of a large-dimensional detail machining with desk side tools, if deviations in position of nodes and desk-side tools elements, caused by different reasons, are considered as input data, and output parameters are sizing errors, position and form, received during surface machining, then the mathematical model of desk-side tool formation can be represented as follows [9, 10]:

- formation layer, including list of numbers, generalized coordinates of shape-generating system links movements and information about a shape-generating structure. If matrix of these data multiplies by a radius-vector of the cutting tool, then we get a vector equation of the shape formatting;

- shape-generating function flows out of a shape-generating code, this function relates with tool accuracy balance, which follows from error source and errors in shape-generating system links position;

- tool accuracy balance in its turn is related to the machined surface, which is formed basing on the specified machined surface;

- Machined surface forms the base surface, which gives size and position errors (deviations);

- form deviation will appear from the base surface data and tool accuracy balance.

If we know system disturbance values their direction and the shape-generating function we can identify desk-side tool accuracy balance. Tool accuracy balance serves as a base to characterize machining accuracy. The base is drawn according to the points of the machined surface; it should coincide with the true surface prescribed by the draw. In such a way, tool output accuracy model is based on calculations and further approximation of the machined surface to the prescribed base surface. Base surface deviations from the nominal ones characterize size and position errors. Desk-side tool form-generating system contains elements providing mutual position and translation of mechanisms, which go along the prescribed trajectory of the cutting tool relative to the reconstructed detail. Hence, the desk-side tool should have the system of supports for every link to provide the prescribed accuracy. The characteristic of the desk-side tools is that during machining only one tool is applied. As the result, amount of tool shape-generating points is an input signal and the machined surface is an output signal of the shape-generating accuracy.

During mill pins machining it is necessary to estimate tool output accuracy. Determining of tool accuracy balance is a general problem which can be solved having all information about tool input errors.

But during manufacture and utilization of desk-side tools, it is impossible to receive precise information. So the best way here is to estimate the tool according to the output deviations (errors) of the machined detail.

To do this it is necessary to determine known functions, determine their number and estimate the parameters, it is necessary to measure many times, on the condition that ( ), that is the number of measurements should be more than the number of components, and function deviation rate should be not less than in *m* in different points. This problem can be reduced to parameters estimation by linear regression equation [12]:

$$\Delta_1 = \Delta(u_1, v_1) = a_{11}\delta q_1 + a_{12}\delta q_2 + ...a_{1m}\delta q_m$$
$$\Delta_2 = \Delta(u_2, v_1) = a_{21}\delta q_1 + a_{22}\delta q_2 + ...a_{2m}\delta q_m \quad (1)$$
$$\Delta_n = \Delta(u_n, v_{n1}) = a_{n1}\delta q_1 + a_{n2}\delta q_2 + ...a_{nm}\delta q_m$$

After estimation δq_j the position of a shape-generating system is changed into δq_i, compensating real machining deviations. If a sporadic error occurs $m = 1$, then it is easy to determine its reason and eliminate it. In this case, the inverse problem gives the best tool accuracy estimation.

To estimate size, position accuracy and accuracy of the machined pin surface it is necessary to create a metrological base, that is, to create a base surface. Sizes and base surface position depend on point of deviation of the machined surface from nominal on the type of base surface.

Base surface should be the same as the nominal one, determined by points of the machined surface so that the volume included between the base and the real surfaces should be minimal, all the point of the real surface should be on the same side of the adjoining, that is the nominal surface is determined by the machined surface equation [12].

In this case, a cylindrical pin is machined. All cylindrical surfaces as initial values have radius deviation Δr_n that is deviation from the nominal radius in the given point.

The equation r0 of a straight circular cylinder is written:

$$r_0 = \begin{pmatrix} R\cos\varphi \\ R\sin\varphi \\ z \end{pmatrix} \quad (2)$$

These cylinder radius deviations, as projections Δr_0 onto normal to cylindrical surface:

$$\Delta r_0 = \begin{pmatrix} \Delta_1 \cos\varphi - \Delta_2 \sin\varphi + \Delta_3 \\ \Delta_1 \sin\varphi + \Delta_2 s\cos\varphi + \Delta_4 \\ \Delta_5 \\ 0 \end{pmatrix} \quad (3)$$

where $\Delta_1, \Delta_2, \Delta_3, \Delta_4, \Delta_5$ are individual errors of links positions.

The mean square cylinder equation has five parameters: diameter Dsqc and four minor values, they characterize eccentricity and translation of a mean square cylinder relative to X and Y coordinate system connected with the nominal cylinder.

Base surface equation is based on nominal

$$r_0 = r_0(u_1 v_1 q_0) \quad (4)$$

and real

$$r_0 = r_0 + \Delta r_0 = r(u_1 v_1 q_0) \quad (5)$$

Basing on these equations the base surface equation is done:

$$r_b = r_0(u_1 v_1 q) \quad (6)$$

where q is a parameter vector of the base surface;

$$q = (q_1, q_2, ..., q_p)^t \quad (7)$$

As base surface deviations are little to nominal the base surface equation can be written as [12]:

$$r_b = r_0 + \Delta r_b \quad (8)$$

where Δr_b is determined as the total of position and size deviation vectors:

$$\Delta r_b = \varepsilon_b r_0 + dr_0 \quad (9)$$

where ε_b is coordinate system position deviation matrix (4x4), connected with base surface, relative to the system of the prescribed equation (5). As these deviations are small dr_0 there is a total differential of the radius-vector r0, drawn on all vector components q0. As deviation Δr_b is small, there is total differential rb drawn on vector components q so we can write [12, 13]:

$$\Delta r_b = G\Delta q \quad (10)$$

Where G is matrix 4x4, composed of partial derivatives of column vectors $\partial r_b / \partial q_i = \partial \Delta r_b / \partial \Delta q_i$; Δq is a p-sized column vector composed of position and size deviations Δq_i.

The parameters for the mean square base surface are drawn from the condition of minimal sum of squared deviations of the real surface to base one rb, then we can write [1,12, 13]:

$$H\Delta q = d \tag{11}$$

where H is matrix pxp with elements $h_{ki} = \int_s f_k f_i ds$, d is a vector of order p with elements: $d_i = \int_s f_i \Delta r_n ds$, where fk, fi are k[th] and i[th] coordinate f of normal coefficients (k, i=1, 2,… , p) ;f= Gtn; n is a unit normal vector to the surface r0 .

To construct base cylindrical surface let's determine elements of formula 9.

By the equation of the quadric cylinder (1) vector q0 consists of one element q01 –cylinder radius value x=R, as φ and z are independent variables [1, 12, 13].

So, m=1, q0=q01=R, then:

$$dr_0 = \frac{dr_0}{dR}\Delta R = \begin{pmatrix} \cos\varphi\Delta R \\ \sin\varphi\Delta R \\ o \\ o \end{pmatrix} \tag{12}$$

As φ and z are independent variables, then in the matrix (4x4) ε_b coordinate system position deviation, connected with the base surface, relative to the system specified by the equation (5):

$$\varepsilon_b = \begin{pmatrix} 0 & -\gamma_b & \beta_b & \delta_{xb} \\ \gamma_b & 0 & -\alpha_b & \delta_{yb} \\ -\beta_b & \alpha_b & 0 & \delta_{zb} \\ 0 & 0 & 0 & 0 \end{pmatrix} \tag{13}$$

As deviations along coordinates φ are little and z can be $\delta_{zb} = \gamma_b = 0$, hence, n=4 and then:

$$\varepsilon_b = \begin{pmatrix} 0 & 0 & \beta_b & \delta_{xb} \\ 0 & 0 & -\alpha_b & \delta_{yb} \\ -\beta_b & \alpha_b & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \tag{14}$$

Let's substitute the formula data 9 and 11 in 12 and receive:

$$\Delta r_b = \varepsilon_b r_0 + dr_0 = \begin{pmatrix} \delta_{xb} + \beta_b z + \cos\varphi\Delta R \\ \delta_{yb} - \alpha_b z + \sin\varphi\Delta R \\ -\beta_b R\cos\varphi + \alpha_b R\sin\varphi \\ 0 \end{pmatrix} \tag{15}$$

Hence, function Δr_b is the function of two independent φ and z and five small deviations $\delta_{xb}, \delta_{yb}, \alpha_b, \beta_b, \Delta R$. To receive formulas for calculation $\Delta r_b(r_b)$ and if the expression Δr_0 is known through individual errors by formula (3) and literal expression (14) for rb. For this, we should find 25 matrix elements H and 5 vector elements d, calculate Δq after that from the system of equations (11).

Matrix components H are determined by formula:

$$h_{11} = \int_s (f_1)^2 ds = \int_0^{2\pi}\int_0^{L} R\cos^2\varphi dz d\varphi = \pi LR, \tag{16}$$

$$h_{12} = h_{21} = \int_s f_1 f_2 ds = \int_0^{2\pi}\int_0^{L} R\cos\varphi\sin\varphi dz d\varphi = 0, \tag{17}$$

Where L is the cylinder length.

$$H = \frac{1}{6}\pi LR \begin{pmatrix} 6 & 0 & 0 & 3L & 0 \\ 0 & 6 & -3L & 0 & 0 \\ 0 & -3L & 2L^2 & 0 & 0 \\ 3L & 0 & 0 & 2L^2 & 0 \\ 0 & 0 & 0 & 0 & 12 \end{pmatrix}$$

Components di of the vector d in the equation 11 are calculated by formula:

$$d_i = \int_0^{2\pi}\int_0^{L} Rf_i \Delta r_n dz d\varphi, \quad i = 1,2,...,5 \tag{18}$$

Solving the system 11, we receive [12]:

$$\delta_{xb} = \frac{2}{\pi LR}\left(2d_1 - \frac{3}{L}d_4\right)$$

$$\delta_{yb} = \frac{2}{\pi LR}\left(2d_2 + \frac{3}{L}d_3\right)$$

$$\alpha_b = \frac{2}{\pi L^3 R}\left(\frac{2}{L}d_3 + d_2\right) \qquad (19)$$

$$\beta_b = \frac{6}{\pi L^3 R}\left(\frac{2}{L}d_4 - d_1\right)$$

$$\Delta R = \frac{d_3}{2\pi LR}$$

III. CONCLUSION

The received formulas allow determining size and position deviations, appearing due constant displacement of the cutting tool end in the surface plane.

Shape-generation analysis has proved that a desk-side tool can be placed in any suitable position on the condition that detail axis of rotation coincides with the cutting tool motion line. In this case, shape-generation can be shown as the rotation of curve line segments around machined surfaces axes.

The tests revealed factors appearing during utilization, which influence rotating surfaces shape-generation, their numerical impact on the detail rotation axis displacement and methods of mathematical calculation and numerical impact on the detail rotation axis displacement have been developed.

Acknowledgement

The article was prepared within development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shoukhov, using equipment of High Technology Center at BSTU named after V.G. Shoukhov.

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