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FIXTURING ERRORS ASSESMENT FOR ADAPTIVE DIMENSIONAL CONTROL

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ABSTRACT

In machining, the workpiece fixturing is an essential task which often affects the quality of the final product. The actual approach of the fixturing error control is based on the correlation of the workpiece position with respect to the tool position and tool programmed trajectory. In this paper, a method for fixturing errors identification is proposed. This method is using input data which consist in the coordinates of points belonging to the reference surfaces. Using on-machine measuring system this input data is acquired and the position parameters of the references surfaces are determined. Data obtained from identification can be used for compensation of the fixturing errors. As a case study, a longitudinal turning process was considered. For the validation of the proposed method a numerical simulation program was conducted.

KEYWORDS: fixtures, machine tool, dimensional control, on machine measurement.

1. INTRODUCTION

Enhancing the precision of the mechanical parts obtained through cutting processes is often required in order to respect the tolerances imposed by the technical specifications.

A number of factors influence the accuracy of the final product. The precision of machined surfaces is affected by errors which can be classified in two categories as follows: process errors and system error.

In the case of machining operations, one of the most important sources of system errors is caused by the fixturing device inaccuracy. Typically, the fixturing error determines the modification of the workpiece reference system, which can be programmed on CNC systems using frames.

In literature, in order to limit the fixturing errors, many authors suggest using more precise fixturing devices [1], while others [3, 5] proposed methods for predicting the deviations caused by fixturing errors. Some authors used Computer Aided Fixture Design in order to select and to model the most appropriate fixturing design [4]. Salisbury et al observed [2] that the fixturing errors are also determined by the errors of the contact surfaces, so in the case of batch manufacturing the variability of fixturing errors is important even if the workpieces are almost similar.

In this paper we will analyze the case of fixturing errors that appears during the turning operations. In this case using the transformation of the workpiece reference system is feasible not a solution.

2. PROBLEM FORMULATION

If the machined surface position is specified in relation to one or more reference surfaces, then the inaccuracy of fixturing device may induce deviations as regard machined surface dimensions, shape and position. In order to minimize these deviations the parameters that characterize the reference surfaces have to be determined. Using the reference surfaces parameters, the corrected parameters of the machined surface have to be determined in order to compensate the fixturing errors.

3. PROBLEM SOLUTION

3.1. Key ideas

The problem solution is based on the following key ideas:

1. Before the machining process, the machine will explore the reference surfaces using an on-machine measurement system. During the measurement stage, the tool will be replaced by a measurement device which will be used for measuring the distance between the tool support and the workpiece reference surfaces. This measurement

device can be a length gauge or better a non contact displacement laser sensor. These devices can achieve submicron resolution while measuring range can be grater than 50 mm. The measuring device will trace a path for reference surface exploration. The data obtained during the measurement stage will be recorded in a data set.

2. The equation of each reference surface should be determined. Each reference surface is characterized by their nominal position, shape and dimensions. Each real reference surface dimensions are different from their nominal values. Moreover, the position of each reference surface is different from the nominal position. So in order to determine the real position and the real dimensions of each reference surface, the equation describing each real surface in the condition in which the fixturing error appears must be known.

3. The data set obtained during the measurement stage, the equations describing the position and the dimension of the reference surfaces will be used by a regression algorithm that will determine the real values of the parameters of each reference surface.

4. The position of the surface, which will be obtained by machining, will be determined so the surface position error with respect to the reference surfaces to be minimum.

Let us consider the case of a longitudinal turning operation (Fig. 1). The position of machined surface is specified in relation with a reference surface, which in this case is a cylindrical surface. The reference surface was machined in different machining operation. The spindle axis and the axis of the reference surface are agonic lines. In this case the parameters of the reference surface are parameters which describe the position of the reference surface axis and the value of the surface diameter.

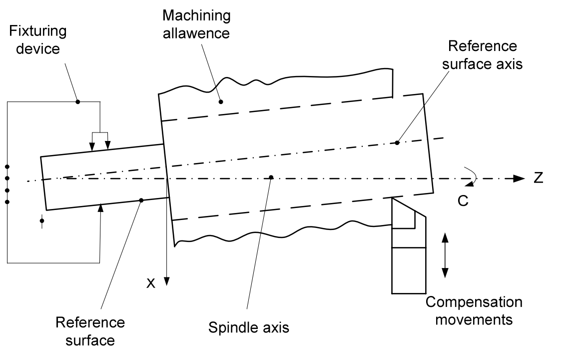

Fig. 1. The fixturing errors that appears in the case of turned parts

3.2. Identification of the surface parameters for a conical reference surface

Let us consider a line δ whose position in respect with a coordinate system (x,y,z) can be expressed using the following equations:

$$\begin{cases} x = x_0 + \lambda l \\ y = y_0 + \lambda m \\ z = \lambda n \end{cases} \quad (1)$$

$$\bar{r} = \bar{r}_0 + \lambda \bar{u} \text{ , with } \|\bar{u}\| = 1 \Rightarrow \sqrt{l^2 + m^2 + n^2} = 1 \quad (2)$$

The cone surface parameters to be determined by the identification algorithm must describe the following:

- the opening angle of the cone;

-the position of the cone apex

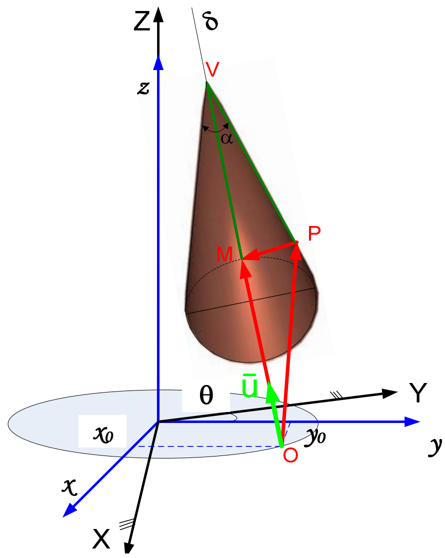

Fig. 2. The coordinates systems used for determination of equation of a conical reference surface

In Fig. 2 we considered a cone for which the line δ is the cone axis. The cone apex is the point V. The cone opening angle is α. The position of the cone apex is defined by a parameter *k* defined as follows:

$$\begin{cases} x_v = x_0 + kl \\ y_v = y_0 + km \\ z_v = kn \end{cases} \quad (3)$$

If we consider a point P defined by its coordinates (x,y,z) which belongs to the cone, then the distance between this point and the cone axis can be expressed as following:

$$r = D(P,\delta) = \frac{\| \overline{OM} \times \overline{OP} \|}{\| \overline{OM} \|} = \| \bar{u} \times \overline{OP} \| \quad (4)$$

Also, consider ΔVMP right triangle, the MVP angle is equal with $\alpha/2$.

$$r = \|\overline{VP}\| \cdot \sin(\frac{\alpha}{2}) \quad (5)$$

$$\|\overline{VP}\| = \sqrt{(x - x_0 - kl)^2 + (y - y_0 - km)^2 + (z - kl)^2} \quad (6)$$

By combining (4), (5) and (6) results:

$$\sqrt{(x-x_0-kl)^2+(y-y_0-km)^2+(z-k\sqrt{1-m^2-l^2})^2}\,\sin(\frac{\alpha}{2})=\sqrt{\left[\sqrt{1-m^2-l^2}(y-y_0)-mz\right]^2+\left[lz-\sqrt{1-m^2-l^2}(x-x_0)\right]^2+\left[m(x-x_0)-l(y-y_0)\right]^2} \quad (7)$$

The coordinate system xyz is rotated with an angle θ relative to a fixed coordinate system (X,Y,Z):

$$\begin{cases} x = X\cdot\cos(\theta) - Y\cdot\sin(\theta) \\ y = X\cdot\sin(\theta)+Y\cdot\cos(\theta) \\ z = Z \end{cases} \quad (8)$$

The measurement is performed in the machine coordinates, and the measuring device is positioned parallel to the direction of X axis.

The coordinates of the points explored by the measurement system are characterized by Y = 0. So we can write:

$$\begin{cases} x = X\cdot\cos(\theta) \\ y = X\cdot\sin(\theta) \\ z = Z \end{cases} \quad (9)$$

By replacing (9) in equation (7) we will obtain the equation (10) where X is the unknown and l, m, x_0, y_0, k and α are parameters of the reference surface. Also in this equation Z and θ are the coordinates which describes the position of point measured by the measuring system:

$$aX^2+bX+c=0 \quad (10)$$

By resolving this equation we usually obtain two solutions. These solutions represent the points of intersection between the conical surface and the line which describes the position of the measuring device. So, we must retain only one of these solutions depending on the position of the measuring device. If the measuring device is positioned like a cutting tool then the biggest of these solutions must be selected.

$$X_c(l,m,x_0,y_0,k,\alpha,\theta,Z)=\frac{-b+\sqrt{b^2-4ac}}{2a} \quad (11)$$

In order to determine the parameters values l, m, x_0, y_0, k *and* α, we propose the following method:

1. The measurement device will be positioned parallel to X axis;

2. A measurement cycle will be performed during which the workpiece will be rotated and measurement device will be moved in Z axis direction to complete the reference surface exploration;

3. The values measured using the measurement device will be recorded in a data set, which will contain, for each record, the value measured by the measurement device X_M, the corresponding value of Z axis and the C angle of rotation of the spindle.

4. The following optimization problem is solved: Giving the list of values $X_M(i)$, $C(i)$, $Z(i)$ with i from 1 to n, where n is the number of measurements to determine l, m, x_0, y_0, k, α such that the sum (12) to be minimized.

$$S=\sum_{i=1}^{n}\left(Xm(i)-X_c\left(l,m,x_0,y_0,k,\alpha,C(i),Z(i)\right)\right)^2 \quad (12)$$

This optimization problem is a non-linear regression problem which can be solved using classical optimization algorithms such as Gauss-Newton algorithm and Levenberg-Marquardt algorithm.

3.3. Compensation of the fixturing errors

After identifying the position parameters corresponding reference surfaces it is necessary to determine the position of points of the machined surface so the machined errors to be minimum. For example, if there is only one reference surface then the axis of the surface to be machined must be identical with the axis of the reference surface.

To machine the surface such that the position errors with respect to the reference surface to be minimized, it is necessary to apply compensation movements to the cutting tool. These corrective movements must be made along the X axis and must be correlated with the rotation of the spindle. Obviously, the magnitude of these movements is reduced, but their frequency is high.

These compensation movements cannot be accomplished by the transversal saddle of a lathe because its high inertia.

But a piezoelectric actuator, which can operate at high frequencies up to 600Hz and travel up to 600 microns can be used for actuation of a fast tool servo.

4. NUMERICAL EXPERIMENTS

In order to test the proposed method for adaptive control of system errors we have used synthetic data generated using known values the position parameters corresponding reference surfaces.

These synthetic data are composed of successive values that would have C and Z axes of the machine during the measuring cycle, completed with values obtained by simulation of the values that would be obtained from the measuring device which explores the workpiece.

We preferred to use data obtained from numerical simulations so that we can validate the algorithm for identification of the reference surface parameters by comparing the real values of the parameters with the value determined by the identification algorithm.

To validate the proposed identification algorithm, in this paper we used simulation data in order to identify the parameters of a conical reference surface. The nominal parameters which describe the parameters of the conical reference surface are:

- the direction cosines for x and y axes are zero- $l=0$, $m=0$;
- the parameters which describes the eccentricity in the *xy* plane x_0 and y_0 are also zero;
- the parameter which describes the position of the cone apex is $k=400$ [mm],
- the nominal cone opening is $\alpha=30^0$.

The virtual process of measuring the reference surface was similar to the actual situation, we considered that the workpiece fixed in the fixturing device and is rotated by the machine spindle. We considered that for each rotation of the workpiece, only ten measurements are made. Also, concomitant with the workpiece rotation, the Z axis is moved with a feed equal to 0.2 mm /rev.

In table 1 we examined the influence of the measurement length on the accuracy of the identification method. We considered that the uncertainty of the measurement device was 10 μm. The results were good even for small measuring lengths.

In table 2 we examined the influence of the precision of the measurement device on the accuracy of the identification method. The measurement length was set to 30 mm.

Table 1. The influence of the measurement length on the accuracy of the identification method

Parameters Values		Model	Measurement length [mm]				
Nominal	Real	parameters	10	20	30	40	50
0	0.05	x_0^*[mm]	0.0507	0.0518	0.0501	0.0501	0.0501
0	0.1	y_0^*[mm]	0.099	0.1015	0.1001	0.0998	0.0998
0	0.0002	l^*	0.0002	0.0002	0.0002	0.0002	0.0002
0	0.0009	m*	0.0009	0.0009	0.0009	0.0009	0.0009
400	402	k*[mm]	402.036	401.991	401.994	401.998	401.998
15	15.5	a*[grade]	15.498	15.5006	15.5004	15.5001	15.5001

Table 2. The influence of the measurement device errors on the accuracy of the identification method

Parameters Values		Model	Measurement device precision [μm]			
Nominal	Real	parameters	2	10	2	50
0	0.01	x_0^*[mm]	0.0101	0.0095	0.0099	0.0107
0	0.01	y_0^*[mm]	0.0101	0.0094	0.0102	0.0123
0	0.0026	l^*	0.0026	0.0026	0.0026	0.0026
0	0.0026	m*	0.0026	0.0026	0.0026	0.0027
400	402	k*[mm]	401,9953	401,994	402,0039	402,0326
15	15.5	a*[grade]	15,5003	15,5004	15,4997	15,4977

6. CONCLUSIONS

In this paper we described a method for correction and identification of fixturing errors which is mainly based on regression techniques.

We analyzed in detail the case of fixturing errors which appears in the case of the turning operations for conical reference surfaces. Similarly, the case of other reference surfaces can be analyzed.

To validate the proposed method, numerical simulations were performed. These simulations revealed that the proposed method can be used even for small measuring lengths. Also the proposed method is robust so it can determine the correct values for the reference surface parameters.

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