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A model-free machining error compensation method for symmetric free form component

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Abstract

In this study, a machining error compensation method, not involving comprehensive error modelling, for symmetric free form components was proposed. First, the coordinate values of the generatrix were calculated according to the paraboloid equation in order to establish a 3D model. After the machining process was completed, the coordinate values of the paraboloid were measured by an ultra-precision coordinate measuring machine (CMM). Next, the coordinate values of the contour points on the generatrix of the machined surface were measured, and the corresponding machining errors were extracted. The compensation process was conducted in the normal direction, and the machining error compensation values were decomposed into two respective coordinate directions. Then, the coordinate values of the new generatrix were generated. This was followed by programming a new machining process according to the newly refactored 3D model. The finishing processes were repeated again under the same clamping conditions, tool paths, and machining parameters. Finally, the coordinate values of the paraboloid were measured again. The results indicated that the form error could be reduced to 4.5 µm from 44.4 µm after just one compensation cycle, which validated the effectiveness of the comprehensive machining error compensation method.

Comprehensive error compensation, model reconstruction, free form, form error

1. Introduction

Comprehensive errors in machining centers include geometric errors, thermal errors, and cutting tool wear induced errors. Each of these has negative effects on the machined part, and establishment of an integrated model to represent the errors is difficult. In practical applications, it has been found that the norm of the error vector is simply a comprehensive conception of the cutting tool posture [1]. More attention has been paid to volumetric error modelling for the purpose of improving the precision [2]. However, the volumetric error model accuracy strongly depends on the error propagation scheme and correctness of the geometric error measurement and identification [3]. It should be noted that thermal-induced errors are very complex, and pose significant challenges to volumetric error modelling [4]. Normally, machining accuracy can be effectively improved off-line by means of modifying the machining programs according to the nominal or refactored 3D model based on the measurement data [5]. This study proposes a method to reduce machining errors for symmetric free form components using a simple compensation process. A single iteration of the compensation process resulted in a significant reduction in machining error. The proposed method has the potential to save fabricators significant time and expense by reducing the need to re-machine components with larger errors.

2. Description of the symmetric free form component

The symmetric free form component was made of K9 glass using the following paraboloid function:

$$Z = \frac{cr^2}{1+\sqrt{1-(1+K)c^2r^2}} + Ar^4 + Br^6 + Cr^8 + Dr^{10} + Er^{12} \tag{1}$$

where, $r^2 = x^2 + y^2$; c is the curvature; and A, B, C, D, and E are the coefficients of the polynomials. K is the conicity coefficient. The 3D model is shown in Figure 1.

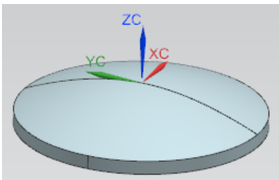


Figure 1. 3D model of the symmetric free from component

3. Form error compensation processes

The model-free form error compensation processes were performed as follows.

Step 1: Calculate the profile points on the original generatrix using Eq. (1), and establish a 3D model of the symmetric free form component.

Step 2: Write the machining programs and complete the finish machining processes.

Step 3: Obtain the coordinate values of the profile by using an ultra-precision CMM, and calculate the optimum coordinate values by using a fitting algorithm. (The measured values contain geometric errors, thermal errors, and grinding wheel wear induced errors in the machining center.)

Step 4: Calculate the coordinate values of the generatrix from the fitted profile of the free form component as well as the comprehensive machining error. Decompose the machining error in the norm direction of the profile and conduct the error compensation. Then, obtain the new generatrix coordinate values.

Step 5: Generate a new 3D model using the compensated generatrix, which contains the comprehenseive machining error represented on the machined symmetric free form component.

Step 6: Conduct the machining processes again. Write new machining programs according to the compensated 3D model, and finish the machining processes with the same clamping position, tool path, and machining parameters at the same room temperature (20±1°C).

Step 7: Measure the symmetric free form component again, and obtain the form error to validate the effectiveness of the proposed error compensation method.

The blue line shown in Figure 2 represents the original generatrix of the symmetric free form component. After the form error measurement, the machining error was decomposed in the norm direction shown by the arrows in the figure. Then, the new generatrix, which included all the arrow endpoints, was derived.

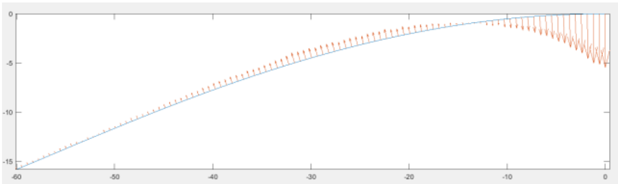


Figure 2. Schematic of the error compensation direction

4. Machining, measurement, and compensation results

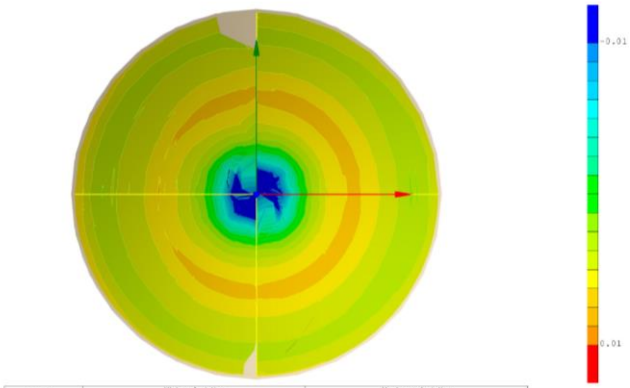
The free form component was machined by a five-axis precision machining center (DMG HSC75 Linear). The stroke range along the x-, y-, and z-axes was 750 mm, 600 mm, and 560 mm, respectively. The rotational range of the C-axis was 360°, and the rotational range of the B-axis was −10°–110°. The repositioning accuracy for the three linear axes and two rotational axes was 3 µm and 5 arcsec, respectively. The form error of the free form component was measured by an ultra-precise CMM (Leitz Infinite 12.10.7), for which the measurement error in any position of the measurement range was within (0.3 + L/1000) µm by using the contacted scanning method. The form error measurement is shown in Figure 3.

Figure 3. Form error measurement and evaluation

It can be seen that the form error reached 44.4 µm prior to machining error compensation. The measurement result is shown in Figure 4. The accuracy was not acceptable; hence, the proposed model-free machining error compensation processes described in Section 3 were employed. The form error reached to 4.5 µm after only one error compensation cycle, as shown in Figure 5, and it is anticipated that this value may become even better after two or more iterations of the compensation process.

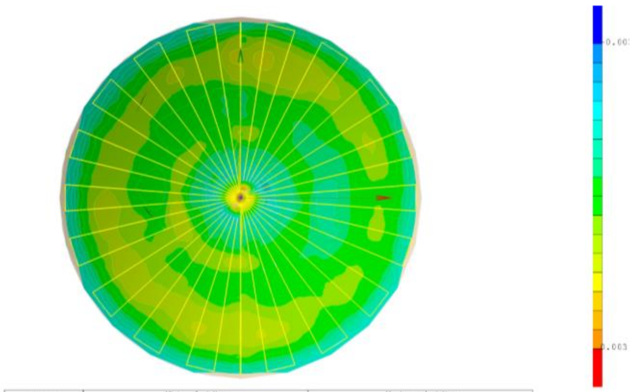
5. Conclusions

In this study, a machining error compensation method, not involving comprehensive error modelling, for symmetric free form components was proposed. The machining error compensation values were decomposed into two respective coordinate directions after form error measurement. Then the coordinate values of the new generatrix were generated to refactor a new 3D model. The form error was reduced to 4.5 µm from 44.4 µm after only one compensation cycle, which verified the effectiveness of the proposed method. Future work will be focus on machining error compensation of asymmetric free form component with this method.



Element :	Minium deviation					Maximum deviation				
	No.	Dev.	- X -	- Y -	- Z -	No.	Dev.	- X -	- Y -	- Z -
SRF_ACN1	400	-0.0367	1.2506	0.0000	-0.0081	249	0.0077	0.0525	31.6642	-4.9993

Figure 4. Form error without compensation



Element :	Minium deviation					Maximum deviation				
	No.	Dev.	- X -	- Y -	- Z -	No.	Dev.	- X -	- Y -	- Z -
SRF_ACN1	301	-0.0022	-58.1023	4.4039	-15.1186	110	0.0023	1.8704	-0.1418	-0.0183

Figure 5. Form error after one cycle of compensation

Acknowledgement

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