Study on the direct relation between machine error and machined form accuracy

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Abstract

This paper mainly focuses on form error prediction based on machine tool errors, aiming at constructing a direct mathematic correlation between the form error of the workpiece and the error components of the machine. A case study about side surface machining of a concave circular truncated cone is carried out on a five-axis machine tool (RTTTR) with 37 error components. Both theoretical modeling and experimental verification were conducted. The eperimental result verifies the effectiveness of the proposed method.

1 Introduction

The volumetric error of a machine tool directly influences the machining accuracy, although the machining process- and tool-related factors also play an important role. Recently, many publications are devoted to volumetric error modeling, identification, measurement and compensation for improving machining accuracy[1-2]. Error reduction or compensation is usually aimed either at decreasing the high frequency surface error of the workpiece such as surface roughness or the low frequency surface error such as form error. The reported research usually focused on directly and indirectly reducing the volumetric errors at cutting point for enhancing the machining accuracy. However, little attention has been paid to the direct relationship between the part form accuracy and the machine error components, which constitutes an improtant research issue related to part form accuracy prediction. The studies on surface error prediction were usually based on several special factors such as the cutting force[3], motion errors[4] and tool-related errors[5]. However, there is still insufficient consideration on the form accuracy predction based on machine tool errors in multi-axis machining. It will be the focus of this work.

2 Form error prediction method based on machine tool errors

The modeling method in this paper uses actual tool contact points by calculating the tool motion and geometry. Figure 1 shows the flowchart for form error prediction. The volumetric error of each discretization point is intergrated with each corresponding point coordinate value in the tool motion path.

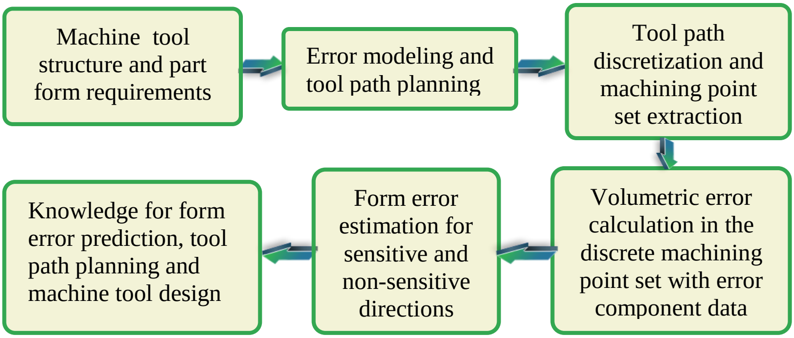

Figure 1: Flowchart of form error prediction

3 Case study on form error prediction in a five-axis machine

Form error prediction is realized by constructing the direct mathematical correlation between the form error of the workpiece and the error components of the machine error. The error analysis was carried out on a five-axis machine tool with a RTTTR configuration, which can be described as Bed-X-Y-C-Tool-B-Z-Bed. Figure 2 shows the machine structure. The side surface machining of concave circular truncated cone was selected as an example to illustrate this correlation. Here, the volumetric error at the cutting point is used as the bridge between the error components of the machine tool and the form error of the workpiece. The purpose machining can be conducted by the motions of the X, Z and C axes. The single point diamond tool on the B axes travels along a straight line with the simultaneous motion of the X and Z axes. The workpiece is fixed on the C axis. The volumetric error was modeled based on the rigid body kinematics and homogeneous transformation matrix method. In the error model, 37 error components were considered, which contained 30 position dependent errors and 7 position independent errors. All errors already exist at the beginnig of machining because of the tool setting motion. When the volumetric error at the cutting point was obtained, it was used to construct the error map under specific machining path. The form error in the modeling was obtained by analyzing the volumetric errors at the different discrete cutting points along the tool path, which can be calculated in each direction.

This paper focused on the form error in the Z direction, and used 2D cross profile errors to predict the form error. The values of the machine error components used in the simulation were obtained through measurements and analysis, and they were supposed to be constant in the machining. Figure 3 shows the simulated volumetric errors in the Z direction, which indicates that the predicted maximum form error in the Z direction for this machining case is 2.39 µm.

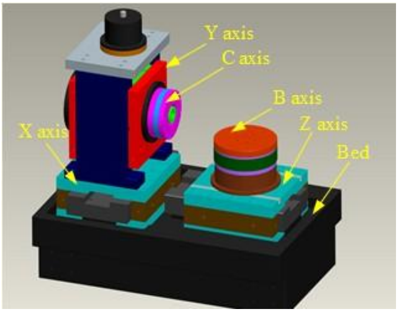

Figure 2: Five-axis machine structure

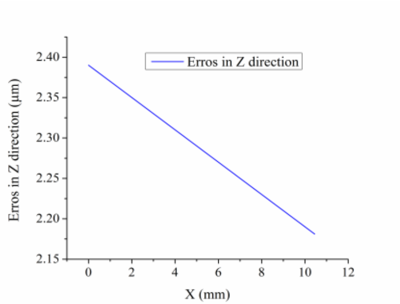

Figure 3: Simulated errors in Z direction

The experimental verification was also carried out. The cross profile of the machined surface was compared to the theoretical profile shown in Figure 4. The two profiles agree with each other very well. Figure 5 illustrates the form errors in the Z direction after the comparison of the experimental and theoretical profiles, which indicates that the maximal form errors of profile A and profile B is 2.72 µm and 2.89 µm. Therefore, the maximal form error from the machining experiments can be considered as 2.89 µm, which is close to the simulated result (2.39 µm). Therefore, this study shows that the proposed method can be used to predict maximum form error effectively.

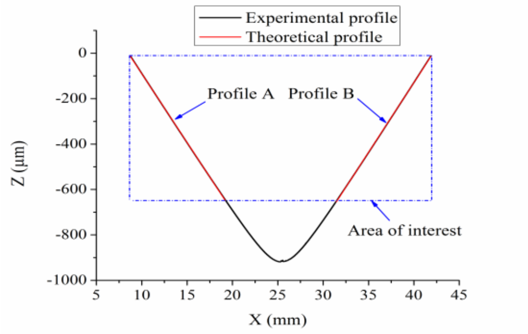

Figure 4: Profiles comparison

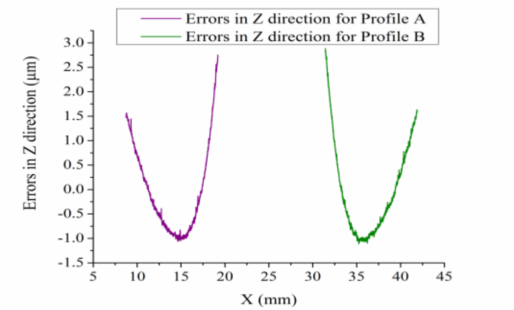

Figure 5: Experimental errors in Z direction

4 Conclusion

The good comparison results between the experimental and predicted form error shows the effectiveness of the proposed form error prediction method. It also shows that it is feasible to study the direct relation between the form errors and machine tool errors. The result of this study can be applied to predict the achievable form accuracy of the workpiece based on known machine errors. Also, it can be used in the design and manufacture of a machine tool or control the main error components to satisfy the form accuracy requirement of the workpiece.

Acknowledgement

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