An Industrial Feasible Approach for Assessing the Performance of a 5-axis Ultraprecision Micromilling Machine

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Abstract

5-axis micromilling machines are ever more demanded in industries, such as optics, automotive, medical aerospace and defence industry, to machine high precision 3D components and microstrcutures from an extensive range of engineering materials. Compared to 3-axis machining, simultaneous 5-axis machining has more complex configuration which likely leads to higher volumetric errors. This paper presents an industrial feasible approach in determining the volumetric errors of a 5-axis micromilling machine and the associated 5-axis ultraprecision micromilling.

1 Introduction

The demands for ultraprecision machines have increased due to the demands to meet the machining accuracy, surface finish and geometrical complexity of components and parts. Typical micromanufacturing requirements are high dimensional accuracy being better than 1 micron, flatness and roundness better than 50 nm and surface finish ranging between 10 and 50 nm. Determining the volumetric errors is necessary so as to produce products with high precision and complex features, increase productivity and compensate the errors through software compensation. Literatures on machine tool testing mainly concentrate on the test codes for conventional sized machine tools. Test codes for micromilling machines still require to be addressed.

2 Performance Assessment Approach

This paper proposes an industrial approach to assessing a 5-axis ulraprecision micromilling machine. The approach taken includes determining the error components of each linear and rotary axis, squareness error components between axes, formulation of the volumetric error matrix using Homogeneous Transformation Matrix (HTM), identifying type of artefacts to be machined and measured for assessment purposes and modelling for software compensation to the volumetric errors. The approach involves theoretical understanding and actual machining and measurement of artefacts.

As stated in [1], the performance of volumetric machining accuracy is the ability of a machine tool to perform the intended multi-axes functions anywhere within the working volume or a smaller volume. The 3D volumetric positioning error is defined as the root mean square of the three linear axes displacement error. This however is used in conventional sized machines. Existing setting up or calibration equipment used for the conventional machines is unsuitable for micromilling machines as the setup or equipment is too big or heavy to be mounted on the micromilling machine. The performance assessment approach is as follows:

(1) **Determination of Error Components:** There are six error components for each linear and rotary axis respectively. The squareness error components between axes are six as well. These errors will be enhanced further if there are many assembly errors or manufacturing faults.

(2) **Volumetric Error Matrix:** The Homogenous Transformation Matrices (HTM) is adopted to derive the relative position of a rigid body in 3D space relative to designated coordinate system. Determining the geometrical errors of a machine tool, the relationship of the tooltip to the workpiece surface should be defined in a common reference coordinate system [2]. Figure 1 illustrates the schematic and a diagrammatic sketch of a 5-axis micromilling machine (Ultra-Mill) for error analysis. The matrix derivation is too extensive to be covered in this paper [3, 4].

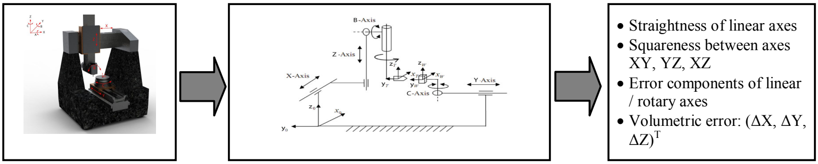
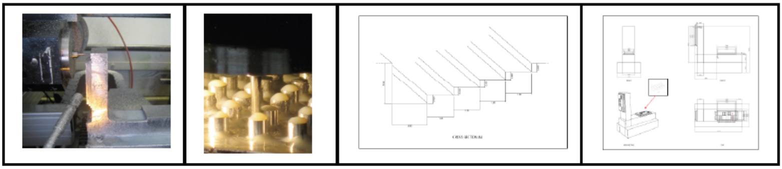


Figure 1: Schematic of the 5-axis Ultra-Mill and its machining errors

(3) **Machined Artefacts:** The design of artefacts to be machined should fulfil several criteria. These criteria include the artefact size, shape, features in relation to the machine performance and machining complexity, etc. Artefacts are machined through complex simultaneous multi-axis motion and tool trajectory. At the artefacts, error relationships between axis planes, tool and machine base kinematic chain, workpiece and machine base kinematic chain, straightness, squareness, parallelism and circularity errors of the axes can be determined. Figure 2 shows two machined artefacts.

(4) **Modelling:** The modelling uses the derived volumetric error matrices so as to develop a software compensation method. The modelling is undertaken using Matlab. The CAM generated toolpath is input into the model to obtain the real toolpath trajectory. Comparison between ideal and actual toolpaths is carried out and software compensation of the toolpath can be achieved [5].



(a) (b) (c) (d)

Figure 2: (a) L-shape artefact (b) artefact with 64 circular upstands (c) microsteps on the artefact (d) detailed drawing of an artefact

3 Performance Assessments

The artefacts machining is conducted as illustrated in Figure 2. The machined artefacts are measured on a micro-CMM, F25 by Karl Zeiss, so as to determine the straightness, squareness, parallelism and circularity errors of the axes which are directly embodied on the artefacts. The measurements are able to provide the machine performance information such as:

- The surface roughness Ra obtained lies in the range of 10 to 70 nm.
- The measurement data shown in Table 1 provides clear indication that Ultra-Mill is working robust with the repeatability and machining accuracy as design specification specified.

The next step is to input these data into the error model for software compensation. In this paper the results obtained from software compensation are not covered as this part of the work is still in further development.

Table 1: Measurement data on the machined artefact using the F25

	Slideway Straightness			**Squareness**			**Volumetric Measurement**
	X	**Y**	**Z**	**X-Y**	**Y-Z**	**X-Z**	
Errors	1.4 µm 57 mm	1.07 µm 32 mm	0.78 µm 57 mm	0.00023°	0.000239°	n/a	**Design Specification:** 7276 mm^3 **Actual:** 7248 mm^3

4 Conclusions

The proposed approach used to assess the performance of the 5-axis ultraprecision micromilling, Ultra-Mill, is industrial feasible because of its practicality and simplicity. This method illustrates that this is a reverse engineering method whereby machining of artefacts is required to trace the actual toolpath trajectory and to validate the derive error matrices. Observing commercially available calibration equipment being unsuitable for micromilling machines, the proposed method fulfils the requirements to develop a more scientific approach to evaluate the machining accuracy and volumetric errors, i.e. the machining performance, of multi-axis micromilling machines.

References:

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