A NEW APPROACH TO ASSESS GEOMETRIC ERROR COMPONENTS OF A MICRO-MACHINE-TOOL BASED ON MEASURING SPATIAL COORDINATES OF TWO SPECIAL POINTS

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1 Introduction

To achieve the purpose of saving energy and resource, Miniaturization of machine tools has become a trend in the manufacturing domain [1]. It has multiple advantages to minimize the scale of a machine tool. Firstly, the power to drive a machine tool will be proportionally decreased with its scale. More important, the power to maintain the condition of a workshop will be drastically brought down, as its dimension is very small. According to the result of a survey by N. Kawahara, the power to drive machine tools only consumed 8 percent of all the power of a work-plant and the power consumed by air-conditions and illuminations are some 80 percent of all the power consumed by a workshop. Thus, miniaturized scale of machine tools will bring great benefits to a factory. In addition, miniature machine tools will take advantage of constructing a portable manufacturing system. Finally, to satisfy the requirement of flexible manufacturing system (FMS), a miniature machine tool is feasible because of its convenient reconfigurable. A typical model of micro machining tool is displayed in Fig. 1.

In the research of miniature machine tool, accuracy enhancement of machine tools is also one of the most critical concerns, which is primarily affected by geometric errors, thermal errors, cutting-force induced errors, etc. For a conventional precision machine tool, the thermal error is testified as a main error source because of the geometric errors was been well controlled by means of various methods. However, the thermal errors are relatively easy to be reduced because of small size of a miniature machine tool. Hence the geometric error becomes a major contributor to the work-piece errors in error sources mentioned above. And how to calibrate the geometric errors is one of the most important affairs to design a micro-machine-tool.

For a three-axis machine tool, however, the complete measurement of 21 geometric error components is very time consuming. Thus, Zhang [2] developed a displacement method to assess the 21 geometric

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errors through linear displacement measurement along 22 lines. Further, Chen [3] improved a new approach based on Zhang’s, which only needs 15 lines to be detected. Park, et al. [4] earlier presented a geometrical table error measurement system to measure translational and angular errors. Later, a Multi-Degree-of-Freedom measurement (MDFM) system to identify five geometric error components simultaneously was developed by Ni [5]. Huang [6] used the retro-reflector instead of the mirror reflector in the MDFM system to achieve the on-line error compensation of CMMs. To measure up to six geometric error components at a time, a six-degree-of-freedom measurement system has shown good results compatible with the HP 5528A interferometer calibration [7].

However, all the aforementioned methods with an interferometer system have few problems such as laser beam pointing instability, set-up errors, etc. and also the system with an interferometer is costly. At the same time, for a micro-machine-tool, the system with an interferometer and reflectors is excessively large and is very difficult to be mounted on the drive stage. In most recent, Jae-Ha Lee presented a measurement system formed by five capacitance probes and a linear encoder to detect five error components of a miniature machine tool simultaneously [8]. Yet this method could produce mounting errors of measurement system.

Corresponding to the special characteristic of micro-machine-tool, mainly indicate its small size and compact configuration, this paper proposed a new approach to assess the geometric error components based on measuring spatial coordinates of two special points by means of capacitance sensors mentioned above.

2 Experimental configuration and algorithm

The Configuration of X-axis stage error components measurement system is depicted in Fig. 3. It is made up of two components, one is a moving platform mounted on the X-axis stage, and six tiny sensors are mounted on this platform. The other one is a precise-made platform mounted on the machine tool base and used as a measure gauge.

Three of these sensors are mounted at one end of the moving platform and their central-lines intersect at a special point, which marked as point A in Fig. 3. The other three are mounted at another end of the moving platform and their central-lines intersect at a special point, which marked as point B in Fig. 3. A line formed by Point A and point B, AB, is parallel to XY plane at initial position.

When the X-stage is moving forward to a certain position, the actual spatial position of point A and point B can be determined by means of the capacitance sensors. Thus the actual position and stance of line AB can be made certain.

Assuming a motion frame attached at the moving stage, as showed in Fig. 3, point O is the origin of the frame. When the X-stage is moving, the frame moves and rotates accompany with it. So its stance is changing with the stage.
With the known coordinates of point $A$ and point $B$, we can solve all the three translational error components.

\[
\delta_{xx} = \frac{(x_{Be} - x_{Ai}) + (x_{Be} - x_{Bi})}{2} = \frac{\Delta x_A + \Delta x_B}{2} \tag{1}
\]

\[
\delta_{yx} = \frac{(y_{Be} - y_{Ai}) + (y_{Be} - y_{Bi})}{2} = \frac{\Delta y_A + \Delta y_B}{2} \tag{2}
\]

\[
\delta_{zx} = \frac{(z_{Be} - z_{Ai}) + (z_{Be} - z_{Bi})}{2} = \frac{\Delta z_A + \Delta z_B}{2} \tag{3}
\]

Furthermore, we can get all the three rotary errors by means of a comprehensive algorithm in terms of projective geometry.

\[
\epsilon_{xz} = \frac{[(x_{Be} - x_{Ac}) \cdot W_1 - (y_{Be} - y_{Ac}) \cdot L]}{\sqrt{(x_{Be} - x_{Ac})^2 + (y_{Be} - y_{Ac})^2 \cdot L^2} + W_1^2} \tag{4}
\]

\[
\epsilon_{yx} = \frac{(z_{Be} - z_{Ac}) \cdot L}{\sqrt{(x_{Be} - x_{Ac})^2 + (z_{Be} - z_{Ac})^2 \cdot L^2}} = \frac{(z_{Be} - z_{Ac})}{\sqrt{(x_{Be} - x_{Ac})^2 + (z_{Be} - z_{Ac})^2}} \tag{5}
\]

\[
\epsilon_{zx} = \frac{(z_{Ac} - z_{Be}) \cdot W_1}{\sqrt{(y_{Be} - y_{Ac})^2 + (z_{Be} - z_{Ac})^2 \cdot W_1^2}} = \frac{(z_{Ac} - z_{Be})}{\sqrt{(y_{Be} - y_{Ac})^2 + (z_{Be} - z_{Ac})^2}} \tag{6}
\]

### 3 Simulation and discussion

In order to validate availability of the decomposition model inferred above, we performed a simulation to find out the results of its identification by means of MATLAB. As an example, one of the three translational error components and one of the three rotary errors are presented in Fig. 3 and Fig. 4 as follows.

![Fig. 3 simulation of translational error ($\delta_{xx}$)](image1)

![Fig. 4 simulation of rotary error ($\epsilon_{xx}$)](image2)

Although the approach presented as above exhibits many advantages in measuring the motion errors of a micro-machine-tool, such as compact structure, simple algorithm and cost-effective, etc,
is necessary to admit some possible problems of this specific apparatus. One of those possible problems is that this instrument needs to be mounted carefully in order to avoid mounting errors of those sensors, which were used to measure the position error along with X-axis.

4 Conclusions

In comparison with the conventional machine tools, the micro-machine-tools get hold of many advantages such as power saving, portable and re-configurable conveniently due to their small size. But it also meets many problems since it is very difficult to be calibrated, monitored and operated etc. Although valid detecting range of a capacitance sensor is normally restricted, it just adapts to measuring the motion errors of a micro-stage due to its limited travel distance. This paper presented a new method by utilizing a set of measurement device with six micro-capacitance probes to detect the spatial coordinates of two special points. By means of projective transform and vector calculation, this paper produced a simple model to extract out all six error components of a motion stage based on the known values. Results of simulation indicated that this calculating model is feasible for identifying the error components of a motion stage. The developed system is simple in principle and extraordinary fit to a miniaturized machine tool with extremely confined operating room.

References