Real-time correction of nonlinear error of u ltra-precision form measuring system

Jingzhi Huang [1,2,#], **Jiubin Tan** [1], **Wei Gu** [1] and **Tao Sun** [2]

1 Center of Ultra-precision Optoelectronic Instrument, Harbin Institute of Technology, Harbin 150001,China
2 Postdoctoral Research Station of Mechanical Engineering, Harbin Institute of Technology, Harbin 150001,China
Corresponding Author / E-mail: jzhuang@hit.edu.cn, TEL: +86-451-86412041, FAX: +86-451-86402258

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It is proposed that a method on nonlinear error correction of inductance displacement sensor system used in ultra-precision form measuring instrument. Firstly, the nonlinear characteristic of sensor system is obtained through static calibration with piezo nanopositioning stage, which is traced to the laser wavelength. Secondly, the nonlinear characteristic is stored in a computer connected to the sensor in the form of error correction function, and when the sensor system works, according to the established error correction function, corrected value of nonlinear error that correspond to the measured point is to be taken out automatically, and the actual measurement data is corrected by real-time. Especially, if the correction data point position is not the same as that pre-stored in computer, corrected value will be obtained using linear interpolation. Experimental results indicate that the nonlinearity of sensor system can be within 0.2% in the range of 6μm after correction, it could meet the demand of ultra-precision form measurement.

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1. Introduction

With the rapid development of ultra-precision manufacturing technology, workpieces with sub-micron/nano machining precision have been widely used in industry and research. For example, aerostatic bearing spindles are used in ultra-precision turning machine and lithography machine etc., and the roundness departure of spindle is within 0.05μm after precision grinding[1]. It is required that the measurement accuracy of measuring instruments should increase as machining quality of workpieces increase. Especially, as the variation of workpiece surface profile is reflected directly through sensor which acts as measuring datum, measurement error of sensor itself is one of the main error source, such as nonlinearity. So it is very critical to correct the nonlinear error of inductance displacement sensor system that used in ultra-precision form measuring instrument[2,3].

2. Principle

Firstly, the nonlinear characteristic of sensor system is obtained through static calibration with piezo nanopositioning stage, which is traced to the laser wavelength. Secondly, the nonlinear characteristic is stored in a computer connected to the sensor in the form of error correction function, and when the sensor system works, according to the established error correction function, corrected value of nonlinear error that correspond to the measured point position is to be taken out automatically, and the measurement data is corrected by real-time. Especially, when the correction data point position is not the same as that pre-stored in computer, corrected value will be obtained using linear interpolation.

3. Acquisition and correction of nonlinear error

Acquisition of nonlinear error for sensor system is performed with piezo nanopositioning stage as shown in Fig.1. Here, piezo nanopositioning stage acts as the standard measurement system of static calibration, and the subject of calibration is inductance displacement sensor and related data acquisition system used in ultra-precision form measuring instrument. During the calibration process, stylus of sensor contacts to micro-displacement stage stably, when the stage provides a micro-displacement, the displacement signal is picked up by sensor system, and then all this information is feed in computer through conversion and amplification circuit and A/D conversion.

According to the correction curve and ideal characteristic $y = kx$, as shown in Fig. 2, correction data $\{e_i\}$ can be obtained,

$$e_i = y_i - y_{oi} \qquad i = 0, \pm 1, \pm 2, \cdots \pm (N-1) \tag{1}$$

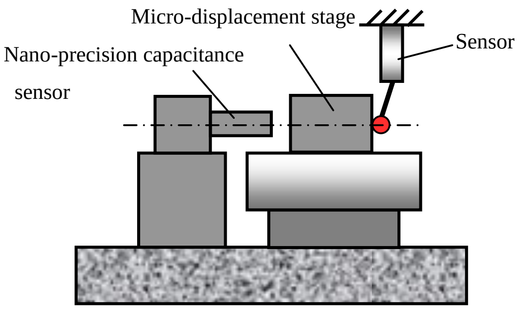

Fig. 1 Sketch of static calibration system

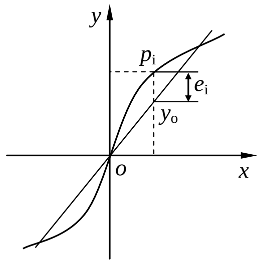

Fig. 2 Principle of nonlinear error correction

Then the correction point can be determined according to the actual correction error data point, and the error correction data table can be established and stored in computer. When the sensor system works, error correction program automatically compare and adjust corrected point position, and the corresponding corrected value is to be searched or calculated, and the correction can be performed in measurement process by real-time.

To Suppose there is 2N data point $P_i(x_i, e_i), i = 0, \pm1, \pm2, \cdots \pm(N-1)$, and the error correction function table $\{x_i, -e_i\}$ can be established. During the realtime correction, error corrected value of nonlinear error is $-e_i$ if the correction point could be searched in the correction function table, namely x=x_i . But if the correction point could not be searched in the correction function table, namely $x \neq x_i$, the error correction value $-e(x)$ will be obtained using linear interpolation.

$$e(x) = \begin{cases} -e_i & x = x_i \\ \dfrac{x - x_{i+1}}{x_i - x_{i+1}} e_i + \dfrac{x - x_i}{x_{i+1} - x_i} e_i & i = 0, \pm1, \cdots \pm(N-1) \\ x \in (x_i, x_{i+1}) \end{cases} \tag{2}$$

Correction experiment of nonlinear error was performed with piezo nano-precision actuator/positioning stage P-753, as shown in Fig.3. The displacement resolution of the actuator/positioning stage is 0.05nm, and nonlinearity within 0.03% in the range of 12μm. Inductance sensor system of ultra-precision form measuring instrument is calibrated with a step size of 0.2μm in the range of 6μm, and the curve of nonlinearity error of the sensor system as shown in Fig. 4 after correction, it can be seen that the nonlinearity error is less than 0.2%.

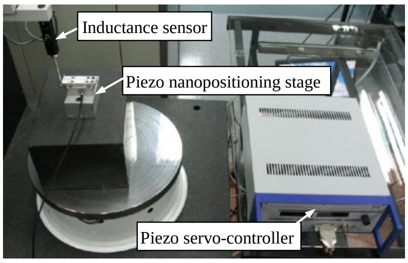

Fig. 3 Experimental system for static calibration

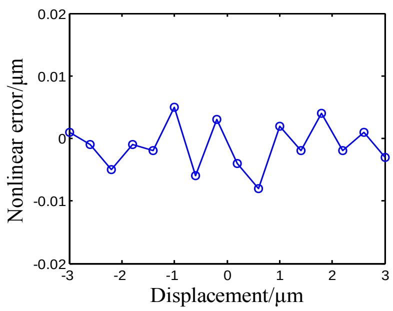

Fig. 4 Curve of nonlinear error of sensor system after correction

4. Conclusions

We used static calibration to correct the nonlinear error of sensor system of ultra-precision form measuring instrument, piezo nano-precision actuator/positioning stage P-753 was used as the standard device to generate micro-displacement. Experimental results indicate that after correction the nonlinear error is less than 0.2% in the range of 6μm, and it could meet the demand of ultra-precision form measurement. The method we proposed can be used to improve the measuring accuracy of ultra-precision form measuring instrument.

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