Sub-Nanometer Positioning with a High Resolution Laser Interferometer

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Abstract

Demands for fabricating high precision products such as semiconductor have increased in industrial fields. In order to realize sub-nanometer positioning, an laser interferometer with high resolution is newly developed in this study. The interferometer developed is modified both optically and electrically. The performance evaluation results confirm that the developed system is available for realizing the sub-nanometer positioning.

1 Introduction

The demands for realizing high accurate positioning systems have increased in many industrial and advanced scientific fields. In particular, machine systems for production of semiconductors or precise parts require higher positioning performance to their positioning systems. A lot of researches on precision positioning have been reported, hardware and software of positioning systems have progressed. Characteristics of a sensing system for feedback generally limit positioning performance such as a moving stroke, a positioning resolution, driving speed, accuracy and repeatability. Therefore it is important to develop a high performance displacement measuring system for nano positioning systems.

This paper presents a newly developed laser interferometer with picometer resolution for ultraprecision positioning system. Performance evaluation results confirm that the developed laser interferometer is available for sub-nanometer order positioning system.

2 Basic concept of high resolution laser interferometer

Figure 1 shows a basic concept of proposed high resolution laser interferometer. A commercial homodyne type laser interferometer is used as a base system, and modified optically and electrically. Laser paths for measurement were increased from double to quad by replacing a plane mirror to a retro reflector on a moving table and an additional plane mirror fixed on a base. This optical modification reduces the measuring resolution of an original system to half. In addition, outputs of sine and cosine signal according to movement x from homodyne laser interferometer are used as input signals to an additional analog circuit for getting higher resolution by following equations;

$$\begin{aligned} \sin(2x) &= \sin(x)\cos(x) \\ \cos(2x) &= 1 - 2\sin^2(x) \end{aligned} \tag{1}$$

Because these equations convert sinusoidal signals according to x into signals according to $2x$, the interpolator can output position data with half resolution.
These modifications provide a quarter measuring resolution (9.7pm) in comparison with a commercial system one (38.6pm).

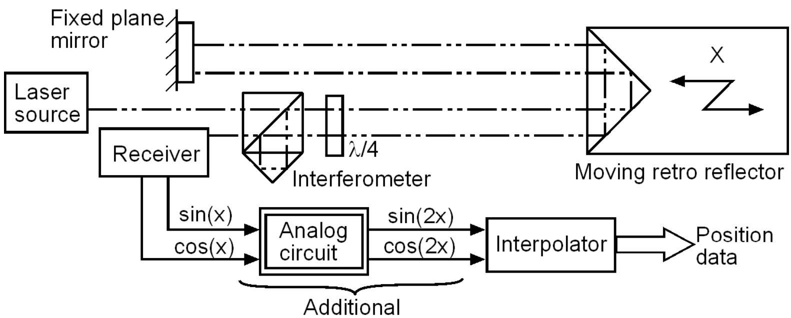


Fig.1 : Concept of proposed high resolution laser interferometer

3 Performance evaluation

In order to evaluate performance of the developed high resolution laer interferometer, some experiments were performed. Figure 2 shows the configuration of cross-check of measurement. A linearmotor-driven aerostatic table system[1] was used for positioning experiments. The developed laser interferometer and a heterodyne laser interferometer which has 309pm measuring resolution were arranged opposite sides of the positioning table, and table position was measured by two interferometers simultaneously.

Figure 3 shows a relationship between input and ouput signal of the additional analog circuit. As shown in this figure, the circuite can convert sin(x) and cos(x) into sin($2x$)

and cos(2*x*). This result confirms that the proposed circuit can convert the frequency of the sinusoidal signals.

Figure 4 shows the relationship between measured position with the heterodyne interferometer and one with the developed interferometer. In this experiment the moving table was controlled by using measured position with the heterodyne interferometer. This result shows that the developed interferometer can measure a table position lineally. The sensitivity to displacement is 1.03×10^2 count/nm, and thus the measuring resolution of the developed interferometer is equal to 9.7pm.

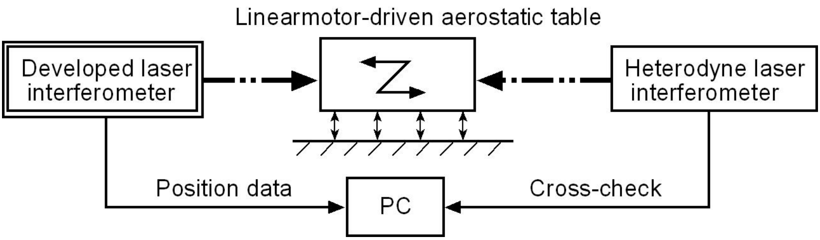
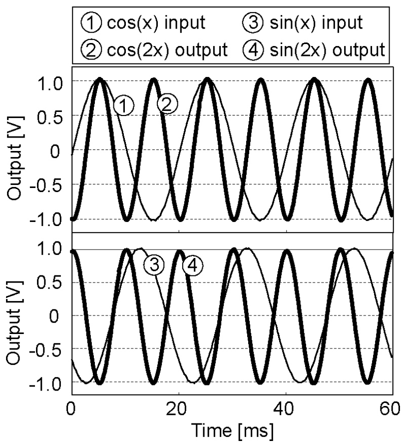


Fig.2 : Configuration of cross-check



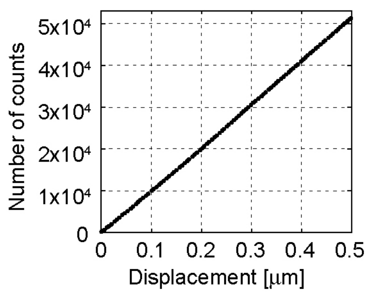


Fig.3: Input and output signal of original electric circuit Fig.4: Calibration results

Figure 5 shows the sub-nanometer positioning results using laser interferometers with different resolutions. Sampling frequency of a position controller was 20kHz and these measured results were not filtered. As shown in this figure, higher resolution

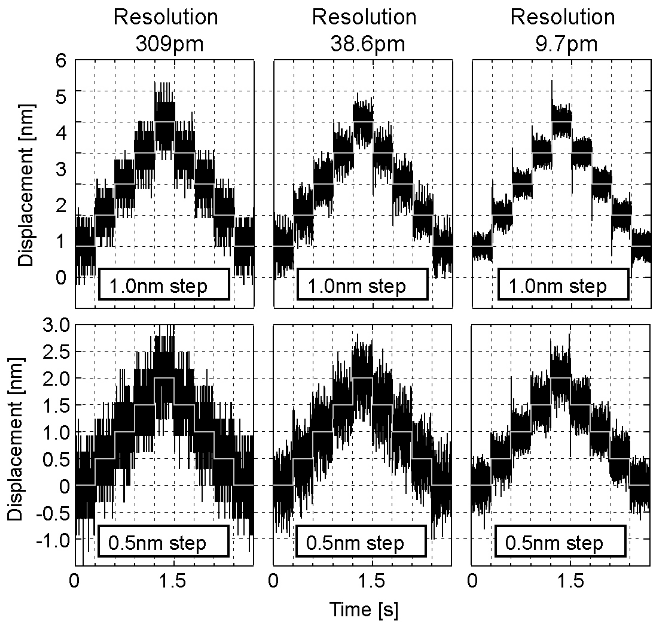


Fig.5 : Sub-nanometer stepwise responses

interferometer enables higher positioning resolution. In particular, the response with the developed interferometer was clear at 0.5nm stepwise.

4 Conclusion

In order to realize sub-nanometer positioning, a laser interferometer system with picometer resolution was newly developed. The performance evaluation results confirmed that the developed laser interferometer system is available for sub-nanometer positioning as a feedback sensor.

References:

[1] Shinno, H., Hashizume, H., Sato, C., Nanometer positioning of a linear motor-driven ultraprecision aerostatic table system with electrorheological fluid dampers, CIRP Annals - Manufacturing Technology, Vol.48, No.1, 1999, pp.289-292.