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NOVEL OPTICAL DESIGN OF FOLDED FABRY-PEROT DISPLACEMENT MEASUREMENT INTERFEROMETER

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Abstract: *Due to its high resolution and the large measuring range, laser interferometer has been applied widely to the precision industrial measurement and calibration. Fabry-Perot interferometry was often used for the micro-displacement, because of its common optical path structure being insensitive to the environmental disturbances. In the past researches, some kinds of modified Fabry-Perot interferometers with corner-cube reflector have been proposed to enhance the measuring range. With such new optical structure, the Fabry-Perot interferometer can be used in the purpose of hundred milometer displacement measurement. This will be beneficial to realize the high precision displacement in the large measuring range and under the ordinary measuring environment. In this investigation, a novel folded Fabry-Perot interferometer has been proposed. With the optical design, the optical resolution is about 158.2 nm and the measurement range of the Fabry-Perot interferometer can be enhanced up to 200 mm without any tilt angle compensation system.*
Keywords: *Fabry-Perot interferometer, corner cube reflector, displacement measurement, optical structure design*

INTRODUCTION

Laser interferometers have demonstrated outstanding measuring performances for high precision positioning or dimensional measurements in the precision industry [1, 2], especially in the length measurement. For the mechanical displacement measurements, it provides the traceable definition of length by the Laser wavelength. The major advantage of interferometers is their coexisting characteristics of large measuring range and high resolution. Te two-beam interferometers such as the Michelson interferometer are the major equipment for the linear positioning measurement. But these kinds of interferometers are sensitive to environmental disturbances, because of the different environmental variations between the measurement arm and reference arm. Contrarily, multi-interferometric interferometers such as the Fabry-Perot interferometer are a kind of interferometer with the common-optical-path where the displacement measured is precisely defined by the distance in the optical cavity, independent of an external reference interferometer arm and not involved with a beam splitter in the optical path [3-5]. For this reason, the environmental effect will be obviously minimized. Hence the displacement measurement by Fabry-Perot interferometers is more insensitivity to environmental disturbances. But conventional Fabry-Perot interferometers have a critical problem of the limited measuring range due to the tilt angle of the measuring mirror during the displacement motion. Therefore, conventional Fabry-Perot interferometers are hardly for the dynamic displacement measurement.

In 1961, the folded Fabry-Perot interferometer is proposed by P. Rabinowitz et al.. Because of the tilt-angle-insensitive characteristics of the corner cube reflector, the limitation of the measuring range can be eliminated. For enhancing the applications of common-optical-path interferometric system, the serial researches about the multi-interferometric displacement measurement system has been described in this investigation.

MEASUREMENT PRINCIPLE

The previous research is shown in the Fig. 1 [6]. This modified optical structure design with corner-cube prism (CCR) has been proposed to resolve the problem of limitation of the measurement range of the multi-interferometric interferometer. The measuring range has been enlarged to 160 mm without any tilt angle compensation system. Nevertheless, in this stage, the position of the transmitted interference laser beams will be influenced by the tilt angle of the measuring mirror. For this reason, the unestimable phase shift of the signal will occur during the measurement processing.

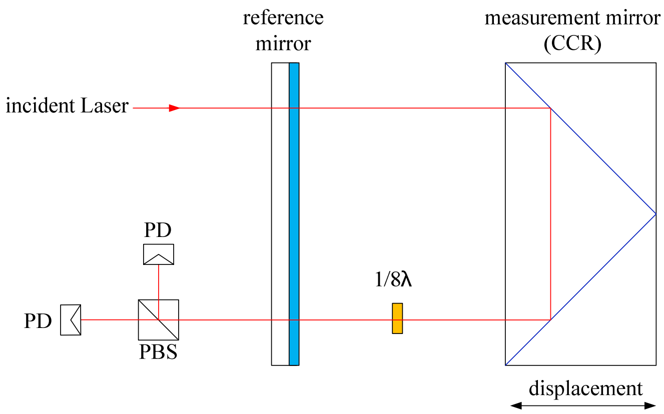

Figure 1 – Optical structure of the previous research [6]

In this research, the reflected beams will be the sensing signal of the interferometric system. By this way, the unestimable phase shift must be eliminated. The optical design of the proposed interferometer is shown in Fig. 1. The Laser light source passes through the BS into the optical cavity. The one eighth waveplate in the cavity is employed to form interference signals with the orthogonal phase shift. And the polarization axis of the waveplate must be the same as that of PBS. By this arrangement, the orthogonal signal can be acquired by two photodiodes (PDs) and then transmitted to the signal processing module.

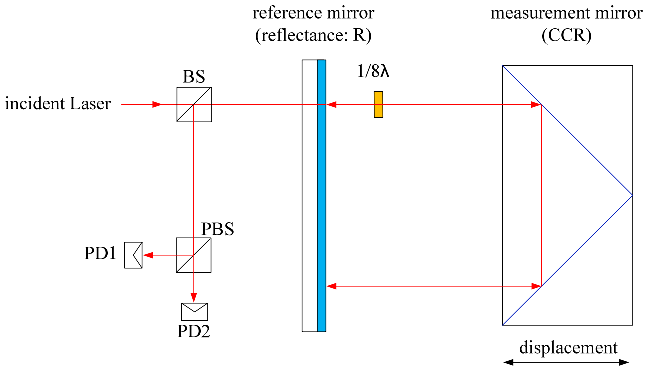

Figure 2 – Proposed interferometer

The corresponding equation of intensity distribution can be expressed as equation (1) and (2). Where A_0 is the amplitude of Laser source, R is the reflectance of the coated mirror and phase difference (δ) is equal to 8πd/λ. Fig. 3 is the interferometric intensity simulations when R is 25%. This orthogonal signal can be easily counted by a commercial encoder counter. It is convenient for the signal processing. With this aid, the resolution about 40 nm can be achieved.

For s-type (PD1) intensity,

$$I_s = \frac{1}{8} A_0^2 \times [\frac{2R\times[1-\cos(\delta+\frac{\pi}{4})]}{1+R^2-2R\times\cos(\delta+\frac{\pi}{4})}] \quad (1)$$

For p-type (PD2) intensity:

$$I_p = \frac{1}{8} A_0^2 \times [\frac{2R\times[1-\cos(\delta-\frac{\pi}{4})]}{1+R^2-2R\times\cos(\delta-\frac{\pi}{4})}]] \quad (2)$$

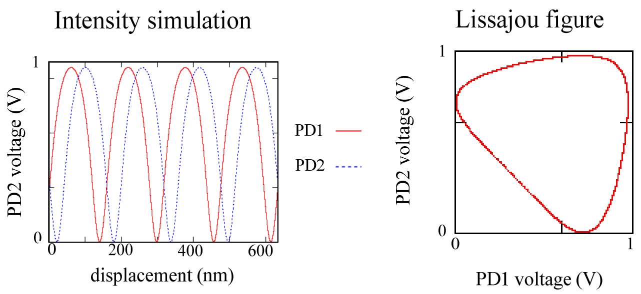

Figure 3 – Simulation of the interferometric intensity distribution

OPTICAL STRUCTURE DESIGN

For the modified multi-interferometric interferometer, its optical structure arrangement is shown in Fig. 4. The Laser source with the fiber coupler is fixed on the fiber mount. The BS and the

PBS are set on the BS set. The reference mirror mount is the place where is the coated mirror fixed on. The waveplate mount for the one-eighth waveplate is able to be regulated rotationally. The complete volume of this sensor head is less than 100 mm³. The compact sensor head will be desirable to reduce the thermal expansion error during longer measuring period.

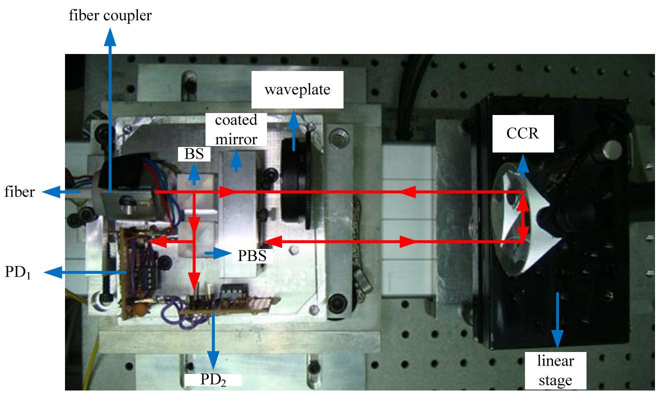

Figure 4 – Experiment setup

EXPERIMENTAL RESULT AND ANALYSES

To verify the measurement performances of the proposed interferometric system, comparison measurements with a commercial interferometer as reference standard have been carried out. The experimental scheme of the comparison measurements is arranged as Fig. 5. The proposed interferometric system and the reference standard are installed opposite and the linear stage and involving measurement mirrors are located between them. For minimizing the Abbe offset, the optical axes of two measurement systems are aligned as coaxially as possible and the distance of the two CCRs is as short as possible.

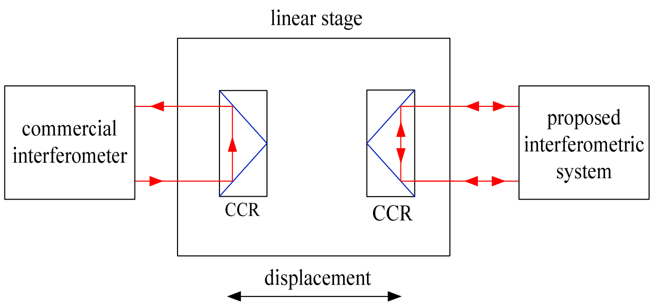

Figure 5 – Optical structure design

The comparison experimental measurements between the proposed interferometer and the above-mentioned reference standard have been performed in the measuring ranges of 200 mm. These two interferometric systems are arranged in same linear stage and measure displacements of a liner stage simultaneously whose measuring intervals are 20 mm in the range of 200 mm. Forward displacement experiments have been repeated five times.

The displacement differences between both systems have been analyzed and demonstrated in Fig. 6. The maximum standard deviation is 0.1459 µm. The detailed analysis values have been listed in the table 1. According to the results, there should be some systematic errors in this experimental mechanical structure. The major error sources for comparison measurements between two systems are the tilt angle and the straightness of the stage. Although the optical axes of two measurement systems are aligned as collinear as possibly, there are still some geometric offsets between two measurement mirrors. Because the measurement mirrors are corner cube reflectors, the result will be influenced by the straightness. These systematic errors will be repeatable and can be observed in the experiment results.

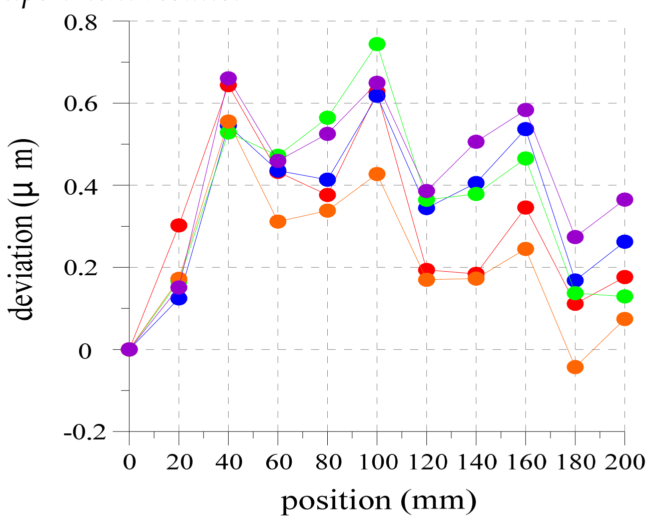

Figure 6 – Comparison measurements in the range of 200 mm

Table 1 – Standard deviation of the measurement results

position (mm)	STD (□m)	position (mm)	STD (□m)
20	0.0691	120	0.1018
40	0.0607	140	0.1459
60	0.0640	160	0.1391
80	0.0973	180	0.1145
100	0.1153	200	0.1146

CONCLUSIONS

A self-developed interferometric displacement measurement system with common-optical-path has been proposed and its measurement features have been verified experimentally. The experimental results demonstrate that this proposed interferometer is feasible for the precision industrial measurement. Hence the modified optical structure has the potential of high precision displacement measurements in the large traveling range. From the comparison experiments it has revealed that the maximum standard deviation is 0.1459 μm in the measuring range of 200 mm. It yields that the proposed interferometer can be realized for the aim of submicrometer order measurement in ordinary environment with the compact structure and convenient signal processing.

In the future work, the advanced signal interpolation algorithm for the folded multi-interferometric interferometer should be designed for the better resolution. With the enhanced measuring precision and the enlarged range, that multi-interferometric interferometer would be more available for the contribution in the application of nanometrology.

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REFERENCES

[1] Jaeger, G.: Measurement, "Limitations of precision length measurements based on interferometers, MEKO XIX World Congress Part 1 – Advances in Fundamental and Applied Metrology, 43(2010)5, 652-658.

[2] Manske, E., Hausotte, T., Mastylo, R., Machleidt, T., Franke K-H., Jaeger, G.: New applications of the nanopositioning and nanomeasuring machine by using advanced tactile and non-tactile probes, Measurements Science and Technology, 18(2007)2, 520-527, 2007.

[3] Qu, X. H., Wang, L. H., Fu, Y. X.: Common-path laser interferometer, Optics Letters, 34(2009)24, 3809-3011.

[4] Wang, Y. C., Shyu, L. H., Chang, C. P.: The Comparison of Environmental Effects on Michelson and Fabry-Perot Interferometers Utilized for the Displacement Measurement, Sensors, 10(2010) 2577-2586.

[5] Lawall,J. R.: Fabry–Perot metrology for displacements up to 50 mm, J. Opt. Soc. Am. A, 22(2005)12.

[6] Shyu, L. H., Wang Y. C.; Chang, C. P.: Tung, P. C. Manske, E.: Investigation on Displacement Measurements in the Large Measuring Range by Utilizing Multibeam Interference, Sensor Letters, 10(2012)5-6, 1109-1112.

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