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Fabry–Perot displacement interferometer for the measuring range up to 100 mm

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ABSTRACT

Current commercial laser interferometers have demonstrated outstanding measuring performances for high precision measurements, but they are very sensitive to environmental or mechanical effects. Owing to the fact that the most laser interferometers are based on the structure of Michelson interferometer, the above-mentioned influences from measuring arms will undisputedly lead to significant errors. To realize the high precision measurement, the environmental conditions must be strictly demanded. As a result of that limit, it's inconvenient for industrial applications. In comparison with such non-common optical path structure, conventional Fabry–Perot interferometer with common optical path can effectively reduce the measuring errors resulting from environmental disturbances.

To minimize the environmental and mechanical effects, a new interferometric displacement system with the structure of common optical path is proposed. By the optical interference principle and the corner cube reflector, the novel system with the common optical path can be designed. Hence, the novel interferometer can hold the advantage of large measurement range, and the signal pattern is nearly the same with that of Michelson interferometer. Because of the folded optical cavity, the resolution of the multi-interference interferometer with corner-cube can be enhanced to $\lambda/16$.

Through this development, a high accurate interferometric displacement measurement system can be available under ordinary environmental conditions without the compensation requirement of the tilt angles and its prominent measurement characterizations have been proven. It will be demonstrated that measurement range is larger than 100 mm and the standard deviation of the comparison experiment is about 0.211 μm (within half wavelength) in the whole measuring range.

1. Introduction

The laser interferometer is one of the important measurement equipments for the precision mechanical industry [1]. Simultaneous features of the large measuring range and the high resolution reveal the major measuring advantage of a laser interferometer utilized for displacement measurements. Nevertheless, the reference arm of the two-beam interferometer being out of the expect measurement area, most of the commercial laser interferometers are sensitive to environmental disturbances. Contrarily, Fabry–Perot interferometer is a kind of interferometer with the common optical path which can be free from the effect of the reference arm. For this reason, the ef-

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fect of environmental disturbances will be obviously minimized. Hence the displacement measurement by Fabry–Perot interferometers is more insensitivity to environmental disturbances [2–4]. For this reason, the high accurate measurement purpose can be easy achieved by Fabry–Perot interferometic technology [4–7]. However, the conventional Fabry–Perot interferometers have the limited measuring range due to the tilt angle of the measuring mirror during the displacement motion. Therefore, conventional Fabry–Perot interferometers are not feasible for the hundred millimeters displacement measurements purpose.

In this investigation, a modified folded Fabry–Perot interferometer for large measuring range has been proposed. The original idea of this folded Fabry–Perot interferometer comes from Rabinowitz in 1961 [8]. Nevertheless, because of the particular signal pattern, the folded Fabry–Perot interferometer is seldom mentioned by other research in displacement measurement field. Followings are some previous researches about the length measurement and the optical design.

1.1. Conventional Fabry–Perot interferometer

Fabry–Perot interferometer has been proposed by A. Fabry and Ch. Perot in 1897 [9]. As the Fig. 1 shown, the incident light beam is split into many individual beams which all interfere with each other. Such interferometer is therefore known as a multi-interference interferometer or common optical path interferometer. Incident beam (Ai) with the tiny incident angle (α) spreads into the cavity which is composed of the measurement and reference mirror. In the cavity, the incident beam travelling forwards and backwards is divided into numerous transmitted beams (At1, At2, etc.). The electric field equation of each transmitted beam can be described in formula (1). And the intensity distribution of interference beam can be derived by interference principles and is denoted as Eq. (2). The simulation of the intensity distribution is shown in Fig. 1 (λ = 632.8 nm, $\alpha \approx 0$, R = 90%).

$$E_N = At_N \times e^{i(\omega t - kx - (n-1)\delta_F)} \quad (1)$$

$$I = I_0 \frac{(1-R)^2}{1 + R^2 - 2 \times R \times \cos(\delta_F)} \quad (2)$$

1.2. Folded Fabry–Perot interferometer

Although the Fabry–Perot interferometer is possessed of the beneficial features of the common optical path, there has been still a critical problem about the displacing mechanism, i.e. the parallelism of the two mirrors during the measurement mirror travelling. Hence, the Fabry–Perot interferometer suffers from realizing displacement measurements in the large range. In 1961, Rabinowitz et al. [8] proposed to use the corner cube reflector (CCR) as the measurement mirror of the Fabry–Perot interferometer. By this way, the decline of the interferometer pattern resulting from the tilt angle of the measurement mirror can be avoided (Fig. 2). The intensity distribution of the interference beam is similar to that of the conventional Fabry–Perot interferometer, but the phase difference will be double that of the conventional Fabry–Perot interferometer. With this structure, not only the mechanism problem has been solved, but also the resolution of Fabry–Perot interferometer has been enhanced. In Ref. [8], the prototype illustration of a folded cavity has been proposed, but the signal processing and the application for displacement measurements have not been expressed.

The sketch of our previous investigation is shown in Fig. 3 [10]. The key point of this optical structure design is the one-eighth wave plate. By using the waveplate, the orthogonal signal can be obtained. And it is an advantage for the signal processing. Its concrete result reveals that the measuring range can be enhanced up to 160 mm. And the standard deviation of the comparison experiment is about 0.255 μm in the full measuring range. In this case, the intensity of the interference signal will be varied by the optical and mechanical parameters all the time [11]. Hence the signal processing must include the DC drift compensator and Auto Gain Controller (AGC). For this reason, the signal processing will become complicated.

1.3. Multi-pass folded Fabry–Perot interferometer

The multi-pass folded Fabry–Perot interferometer is proposed by Ki-Nam Joo and the optical structure as shown in Fig. 4 [12]. The innovative variation of this study is utilization of the quarter waveplate. By the quarter waveplate, the optical resolution can be enhanced to quarter wavelength.

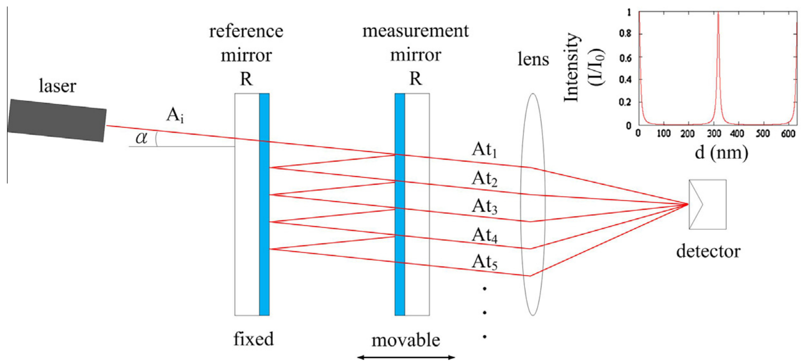

Fig. 1. Conventional Fabry–Perot interferometer.