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A novel Interferometer for Measuring Small Distance

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ABSTRACT

A novel wavelength scanning optical fiber dual-interferometer for measuring small distance has been developed in this paper. A wavelength-scanning source is used to simultaneously illuminate two Fabry-Perot (F-P) cavities. One is as the sensing cavity, the other is as the reference cavity. If the length of the reference cavity is pre-calibrated and maintain constant, and the scanning wavelength is taken as an inter-converter to compare the gap length of the sensing cavity with the reference cavity length, using the frequency spectrum separator, absolute measurement can be obtained.

Key words   Wavelength-scanning , Optical fiber interferometer , Absolute distance measurement

1. INTRODUCTION

F-P interferometer is applied to analyze the spectrum with narrow rang and simple spectrum. But since 1980's many researches have indicate that F-P interferometer for measuring has many advantage compared with other interferometers [1]-[5]. A.Kersey was first to demostate the use of optical fiber F-P interferometer (FPI)[1] for measuring small distance in 1983. Due to its unique characters of simple structure and single-end operation, and has common characters of fiber sensors, the FPI has been extensively utilized in various practical applications since then. In 1991 K.Murphy suggested a bi-directional fringe counting FPI system[2]. This FPI system may improve the dynamic character in perturbation environment, but it still has a differential technique. In order to realize the absolute measurement for small distance, a novel wavelength scanning optical dual-interferometer has been developed in this paper. A wavelength-scanning source is used to simultaneously illuminate two F-P cavities: One is as the sensing cavity, the other is as the reference cavity. If the length of the reference cavity is pre-calibrated and maintain constant, and the scanning wavelength is taken as inter-converter to compare the gap length of the sensing cavity with the reference cavity length, absolute measurement for the sensing cavity length can be obtained.

2. WAVELENGTH SCANNING OPTICAL FIBER F-P INTERFEROMETER (FPI)

2.1 The Decision of Harmonic Cavity Length

In the standard FPI, the two beams which reflected from the two fiber ends in FPI are interfered each other and the signal received from the detector can be expressed as (1) and (2):

$$I_{(\lambda,L)} = I_{0(\lambda)} \cos(\phi_s + \phi_0) \tag{1}$$

$$\phi_s = 2KL = (4\pi Ln)/\lambda \tag{2}$$

Where λ is the wavelength ,L is the harmonic cavity's length, $I_{(\lambda,L)}$ is the intensith received at the detector (this intersity is the function of λ and L), $I_{0(\lambda)}$ is the spectrum intensity of the source , ϕ_s is the phase difference between the two beams that was introduced by L and λ , ϕ_0 is the initial phase, n is the

referctive index in F-P cavity and $K = 2\pi / \lambda$ 。

If the wavelength is scanned from λ_1 to λ_2 while the cavity length remains constant, the phase change can be obtained.

$$\Delta\phi_s = \int_{\lambda_1}^{\lambda_2} d\phi_s = 4\pi L \int_{\lambda_1}^{\lambda_2} (-n/\lambda^2) d\lambda = 4\pi L\Delta(n\lambda)/(\lambda_1\lambda_2) - 4\pi L_n \Delta\lambda / \lambda_1\lambda_2 \tag{3}$$

The harmonic cavity length L can be decided from Equation (3), which is valid for the accuracy required by most applications.

2.2 Wavelength Scanning Optical Fiber Dual Interferometer(DFPI)

The experimental configuration of the DFPI is shown in fig.1. Two FPIs are connected to the output ports of couplers C_2 and C_3 respectively. Each FPI is constructed with two carefully prepared fiber ends inserted in
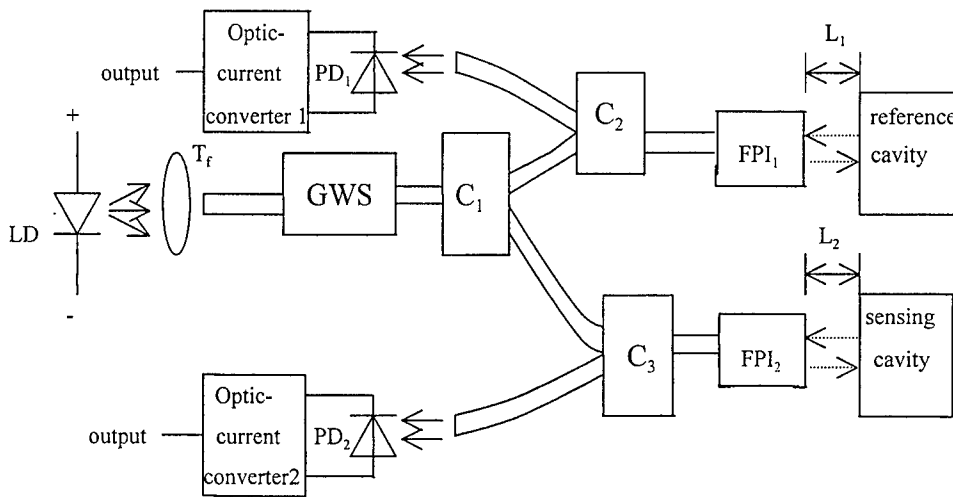

Figure 1. Experimental setup of DFPI

the silica fiber in the sensing FPI_2 is epoxied to the hollow tube end to provide accurate distance for the experiments and for the self-calibration of the reference cavity length. For the reference FPI_1, the input and output were epoxied to the hollow tube to construct a stable cavity. The Fresnel reflections from the fiber/air interface and from the air/fiber interface in each FPI are interfered. The light from the tunable LD-grating-scanner is split into two beams in coupler C_1 to illuminate FPI_1 and FPI_2 through C_2 and C_3 respectively. The structure of LD grating-wavelength-scanner (GWS) is shown in fig.2. The light source is a 1300nm edge-emitting LD. As dispersion element the diffraction grating G is mounted on the shaft of scanner. Thus the GWS is constituted. The broad spectrum light from the LD is collimated in lens T_1 and diffracted by the grating. Part of the refracted light is collected into the coupler C_1 by the second lens T_2 . When a triangle driving current is applied to the GWS, it rotates the grating and the wavelength launched into the coupler C_1 is correspondingly scanned.

According to equation (1)~(3), each FPI can produces a group of fringes when the wavelength is scanned from λ_1 to λ_2. Using subscript 1 and 2 to denote the reference and sensing FPIs, the phase changes of these two independent FPIs can be obtained from Equation (3).

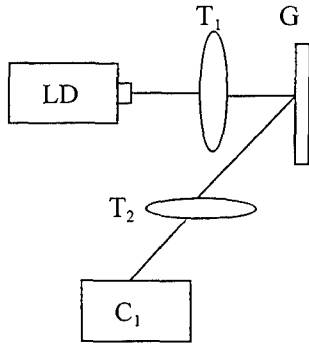$$\Delta\phi_{s_1} / \Delta\phi_{s_1} = L_1 / L_2 \tag{4}$$
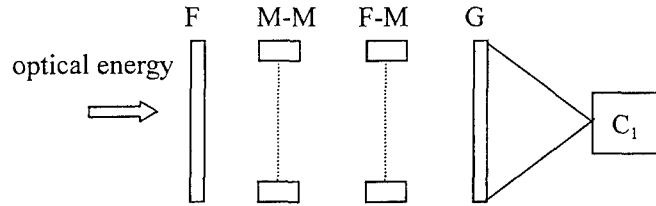

Figure 2. Grating wavelength scanner

Figure 3.   Frequency spectrum separator

Equation (4) indicates that the measurement of sensing cavity length L_2 relative to reference length L_1 is independent of other factors. This means we don't need the light source to be tuned accurately nor repeatedly. The only requirement for the wavelength scanning is smoothness. This is much easier to achieve.

In practice the phase information can be obtained from an analysis of the corresponding interference fringes. The fringe number produced during one optical tuning cycle in each cavity can be expressed as[2]-[3]:

$$m_i = \Delta\phi_{s_i} / 2\pi = \varepsilon_i + f_{i,1} + f_{i,2} \tag{5}$$

Where m_i is the number of the fringes (i=1 for the reference cavity and i=2 for the sensing cavity) . ε_i is the integer of m_i. $f_{i,1}$ and $f_{i,2}$ are the fraction before the first fringe peak and the fraction after the last peak respectively. The absolute gap length L_2 of the sensing FPI is:

$$L_2 = L_1 m_2 / m_1 = L_1(\varepsilon_2 + f_{2,1} + f_{2,2})/(\varepsilon_1 + f_{1,1} + f_{1,2}) \tag{6}$$

Equation (6) indicates that $\Delta\phi_{s_1}$ and $\Delta\phi_{s_2}$ are medium values. The measurement of L_2 is decided by the number of fringes. We can obtain a high measuring precision by adjust L_1.

3. THE IMPLEMENT OF SYSTEM CHARACTER

The theory and method of optical scanning interferometer for measuring small distance has been concrete indicated in the conferences. But how to improve the characters of measuring system hasn't been satisfactory solved[4]. The problem of wavelength rang from λ_1 to λ_2 is solved by using frequency spectrum separator. This method can improve the character of system effectively.

In fig.3 the optical energy should pass a preposition wave filter F to separate suitable frequency spectrum rang before it enters GWS. This rang is decided by standard detecting plate which is composed with moving mirror (M-M) and fixing mirror (F-M). In order to avoid hot noise, F, M-M, and F-M are sealed in a vacuum bottle. The function of standard detecting plate is act as multi-band filter. A lower resolution frequency is operated when scanning begin. The spectrum's resolution is improved when M-M is moved to a property distance, and the higher frequency part in the spectrum can be resoluted. This distance is decided by the expecting resolution. M-M must parallel to F-M exactly when M-M is moving. The output of scanning interferometer can be described as:

$$N_i = \frac{A_0\Omega_i}{4\pi} Q_c T_{0i} \int_0^\infty T_f(\upsilon,t)B_{atmos}(\upsilon)d\upsilon \tag{7}$$

The transmission coefficient of standard detecting plate can be described with array as [5]:

$$T_{et}(\upsilon,t) = \frac{1-R}{1+R}\left\{1+2\sum_{n=1}^{\infty}R^n\upsilon_n\ \cos[4\pi N\mu t\upsilon\cos(\theta)]\right\} \tag{8}$$

In equation (7) and (8), υ is optical wavelength, N_i is the transmission energy which is obtained from the coupler. A_0 is the hole's area of M-M. Ω_i is the stereoscopic angle facing with the couple. Q_c is the coupling efficiency of the coupler C_1. T_{0i} is the transmission coefficient except standard plate and filter. T_f is the filter's transmission coefficient. R is the reflection coefficient of the standard plate. n is the exponential function being related to internal reflection of cavity. D_n is the coupling function (when $D_n=1.0$ the state is ideal coupling state). μt is the distance between the two plates. θ is the beam angle when optic is passing the two plates. N is the numbers of optical wave in the cavity. We can obtain a small dimensional angle when radiation beams are passing these plates. If the brightness $B_{atmos}(\upsilon)$ is given, the radiation can be measurement by these plates. So the spectrum rang from λ_1 to λ_2 can be decided by the filter and the standard detecting plates.

4. EXPERIMENTAL RESULTS

The experimental results from optical scanning DFPI are shown in fig.4. The operation wavelength is
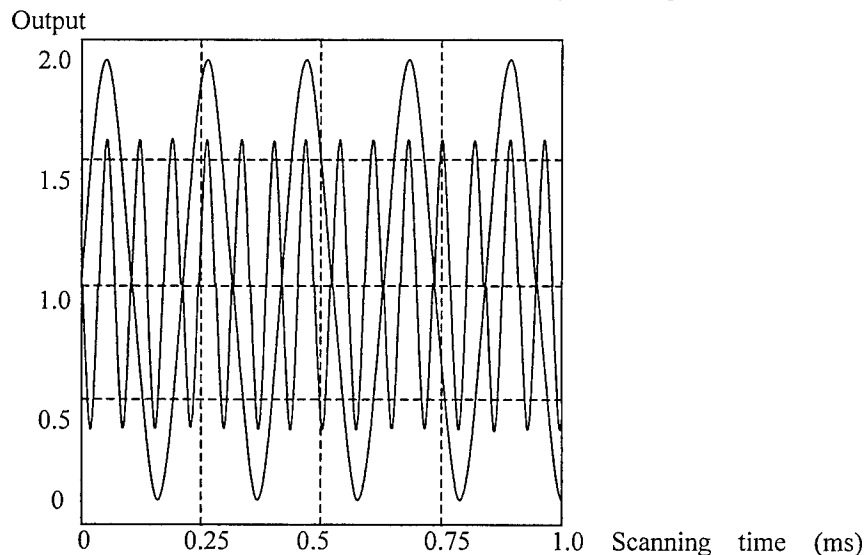

Figure 4. The experimental results

1300nm. The upper trace is the fringes of reference cavity; the lower one is the fringes of sensing cavity. The linear scanning rang is about 40nm. The reference cavity length is 0.2mm. It's seen that the amplitude of out put will decrease when sensing cavity length increased. The reference cavity and sensing cavity length are 0.20 mm and 0.65mm respectively. From the fig4, We know that the two group of fringe numbers are 4.745 and 15.383. So we can obtain that the sensing cavity length is 0.6498mm from calculation. The relative error is 0.03%. The measurement accuracy is 0.2 μm. The resolution is 0.03 μm.

5.CONCLUSION

In this paper using DFPI, the absolute measurement is realized. But the demands on the source, such as stability of frequency, repetition of scanning, stability of source power are reduced. The experimental results show that the accuracy of $0.2\,\mu m$ and resolution of $0.03\,\mu m$ are achieved, in the rang of 0~3mm. This technique can be easily applied in the absolute measurement of pressure, strain and so on.

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