Measurement 42 (2009) 1335–1340

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

# Stabilisation of an optical fiber Michelson interferometer measurement system using a simple feedback circuit

Fang Xie *, Zhimin Chen, Junyu Ren

*Optical Science and Technology Laboratory, Department of Physics, School of Science, Beijing Jiaotong University, Beijing 100044, PR China*

ARTICLE INFO

*Article history:*
Received 8 February 2009
Received in revised form 20 April 2009
Accepted 24 April 2009
Available online 5 May 2009

*Keywords:*
Fiber optics
Interferometry
Feedback control
Stabilisation

ABSTRACT

Single-mode optical fiber interferometers used with fiber measurement systems must be stabilised to achieve high measurement accuracy and linearity in the presence of differential phase drift in their arms resulting from temperature fluctuations and other types of the environmental disturbances. By employing fiber Bragg gratings (FBGs) as in-fiber reflective mirrors, two interleaved fiber Michelson interferometers which share the common-interferometric-optical path are configurated. One of the fiber interferometers is used to stabilise the system while the other one is used to perform the measurement task. A simple electronic feedback loop for compensating the influences resulting from environmental disturbances is designed and the measurement system is stabilised. This makes the system suitable for on-line precision measurement.



## 1. Introduction

Optical fiber interferometers have been widely used in metrology due to their prominent advantages such as non-contacting measurement mode, compactness, light weight, immunity to electromagnetic interference, wide bandwidth, multiplexing capability, high resolution, low cost. As the components that configurate the optical fiber interferometers are connected together, there is no need for adjusting and keeping the components in correct positions which is necessary for separate optical components that configurate the normal optical interferometers. Hence there is a great amount of interest to exploit optical fiber interferometers for the measurement of a large variety of parameters such as displacement, vibration, acceleration, velocity, strain and temperature [1–10].

For a fiber interferometer measurement system, the fiber should be used just for transmitting the light and the phase change in the interferometric signal should be induced only by the measurand. However, as the length of the fiber that used in the interferometric arms will change randomly because of the temperature fluctuations and other types of the environmental disturbance, low frequency random phase drifts would be induced in the interferometric signal. The random phase drifts will decrease the measurement accuracy, and in the worst circumstances, will even make the fiber interferometer unfunctioning. With the need for ultra high precision measurement, the random phase drifts induced by the environmental disturbances must be eliminated [3–5].

Although techniques such as common-path interferometric arms [1] and feedback compensating loop [3] are able to compensate the random phase drifts in interferometric signals, the measurement range of Ref. [1] is very small because of being limited by the interferometric visibility and Ref. [3] cannot continue the measurement function if a reset voltage action takes place.

We propose an interleaved fiber Michelson interferometer measurement system which is able to self-compensate effectively the influences resulting from the environmental disturbances and offers high stability for on-line precision measurement. By employing fiber Bragg gratings (FBGs) as in-fiber reflective mirrors, the measurement system includes two fiber Michelson interferometers which are interleaved together and share the common-

* Corresponding author. Tel.: +86 10 51688200; fax: +86 10 51840433.
*E-mail address:* fxie@bjtu.edu.cn (F. Xie).

0263-2241/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.measurement.2009.04.009

interferometric-optical path. In this system, one of the fiber Michelson interferometers is used to compensate the differential phase drifts in the interferometer arms resulting from the environmental disturbances, while the other one is used to perform the measurement task. A simple electronic feedback loop drives a piezoelectric cylinder wound with the fiber used in the reference arm, and the piezoelectric cylinder tunes the length of the reference arm and keeps the interferometer in quadrature position (keeping the phase difference of the two arms at $\pi/2$ rad). By this way, the influences resulting from the environmental disturbances has been compensated. Therefore, the system is stabilised and is suitable for on-line precision measurement and sensing.

## 2. The principle of the systems

### 2.1. The proposed interleaved fiber interferometer system

The proposed interleaved fiber interferometer measurement system is shown in Fig. 1. The system is configured with two fiber Michelson interferometers which share the common-interferometric-optical path by employing four FBGs as in-fiber reflective mirrors. Two temperature-stabilised DFB laser sources with center wavelengths at 1557.32 nm and 1558.52 nm are used in the system. Both lasers give output power 2.5 mW with spectral bandwidth 0.2 nm at 20 dB. Three FBGs – FBG1, FBG2 and FBG3 – used in the system have the same Bragg wavelength at 1557.32 nm with bandwidth 0.3 nm at 3 dB. The fourth FBG – FBG4 – has a Bragg wavelength at 1558.52 nm with bandwidth 0.3 nm at 3 dB. Because the bandwidth of the DFBs is much narrower than the bandwidth of the FBGs and the sensitivity of the Bragg wavelength shifts of FBGs to temperature variation is 13 pm/°C, so under ordinary temperature fluctuation, the fiber Bragg gratings will always be able to reflect the DFB lasers wavelength.

The first fiber Michelson interferometer, which employs FBG1 and FBG2 as reflective mirrors that are placed just behind the two Grin lenses, is used to monitor and compensate for the differential phase drifts in the two arms resulting from the environmental disturbances. Light emitted from the 1557.32 nm DFB passes through 3 dB-coupler 1, circulator 1, 3 dB-coupler 2, and is divided into two beams which are then reflected back by FBG1 and FBG2, respectively. The two reflected beams are combined again at 3 dB-coupler 2 and interfere with each other. The interferometric signal from one output of 3 dB-coupler 2 passes through circulator 1, circulator 2, and FBG4 and is received by photodetector 1 (PD1), while the interferometric signal from the other output of 3 dB-coupler 2 goes through circulator 3, is reflected by FBG3 (so it will not reach PD3), and is received by PD2. The two interferometric signals detected by PD1 and PD2 are electrically processed by the electronic feedback loop and an information derived from this processing is used as a correction signal which is applied on the piezoelectric cylinder PZT (length 35 mm, outer diameter 3.5 cm, thickness 2 mm). Eleven meters of the fiber used in the reference arm is wound on the piezoelectric cylinder PZT. The feedback signal drives PZT to tune the fiber length of the reference arm to keep the interferometer at quadrature position. By means of this, the differential phase drifts in the two arms is effectively compensated and therefore the interferometer is stabilised.

The second fiber Michelson interferometer shares the common-interferometric-optical path with the first one and is prevented from the environmental disturbances when the first Michelson interferometer is stabilised. The second fiber Michelson interferometer is probed by the light from the 1558.52 nm DFB and is used to obtain information from the measurement mirror. The light from the DFB is transmitted through 3 dB-coupler 1, circulator 1, 3 dB-coupler 2 and is divided into two beams. The two beams pass through FBG1, FBG2 and are collimated by the two Grin lenses, respectively. The two collimated beams are projected onto the measurement mirror and the reference mirror, and are reflected back by the two mirrors into the system again. The two beams are combined at 3 dB-coupler 2 and interfere with each other. The interferometric signal from one output of 3 dB-coupler 2 passes through circulator 3 and FBG3, and is received by PD3. The interferometric signal from the other output of 3 dB-coupler 2 goes through circulator 1 and 2 and is reflected back by FBG4, so it does not reach PD1.

By probed with two DFB laser sources, respectively, and employing the characteristics of FBGs, the two interleaved fiber Michelson interferometers are actually independent. One interferometer is used to stabilise the measurement system while the other one is used for perform the measurement or sensing task.

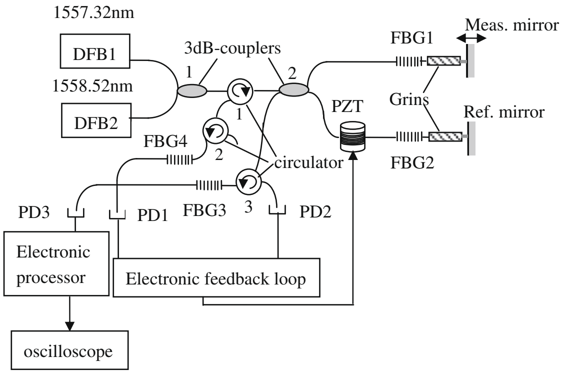


**Fig. 1.** The proposed interleaved fiber interferometer system.

### 2.2. The feedback loop system

The schematic diagram of the feedback stabilisation circuit is shown in Fig. 2. The interferometric signals detected by PD1 and PD2 are 180° out of phase because of 3 dB-coupler 2. The currents from PD1 and PD2, $i_1$ and $i_2$, which are linearly proportional to the optical signals detected by PD1 and PD2, will therefore have the following forms

$$i_1 = i_0[1 - k\cos(\phi_d + \phi_s)] \quad (1)$$

$$i_2 = i_0[1 + k\cos(\phi_d + \phi_s)] \quad (2)$$

where $i_0$ is related to the input optical power, $k$ is a function of the interferometric fringe visibility, $\phi_d$ is the static