Optics Communications 311 (2013) 140–143

Contents lists available at ScienceDirect

Optics Communications

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

Power-compensated displacement sensing based on single mode-multimode fiber Bragg grating structure

An Sun*, Zhishen Wu, Huang Huang

International Institute for Urban Systems Engineering, Southeast University, 2 Sipailou, Nanjing, 210096 Jiangsu, China

ARTICLE INFO

Article history:
Received 2 June 2013
Received in revised form
23 July 2013
Accepted 11 August 2013
Available online 28 August 2013

Keywords:
Optical fiber sensor
Multimode fiber Bragg grating
Multimode interference
Displacement

ABSTRACT

In this paper, power-compensated displacement sensing is proposed and investigated experimentally based on single mode-multimode fiber Bragg grating (FBG) structure, which is fabricated by a single mode fiber and an FBG written on 105/125 μm graded-index multimode fiber (MMF). Experimental results verify that the reflected peak power of multiple wavelengths in single mode-multimode fiber Bragg grating structure shows different response to displacement induced bending of transmitting multimode fiber as the result of multimode interference (MMI). By employing different bending responses between multiple wavelengths of multimode FBG, ratiometric detection based high sensitive displacement measurement can be achieved, which provides a simple and practical method for displacement sensing and meanwhile a potential solution for multi-parameter measurement.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

FBG in multimode fiber [1–6] has received intensive attention for both telecom and sensing application because it shows unique characteristics compared with FBG in single mode fiber (SMF), for instance large core and multiple peaks, which can be used for telecom such as comb filter [7] or sensing application. In recent years, various types of multimode FBG based sensing methods have been reported for the measurement of strain [8], bending [9], refractive index [10], or multi-parameter discrimination [11]. For most of the previously reported multimode FBG sensing schemes, FBG are employed as sensing element which means that usually a costly spectrum analyzer is needed to analyze the corresponding spectrum changes of multimode FBG caused by measurand. As well-known, when light passes from SMF to MMF, interference between different modes occurs along the MMF due to the different group velocities of modes [12–14], that exhibits excellent sensing potential [15–17]. Therefore, MMI [15,18] and other losses such as bending loss [19] based displacement sensors have also been explored in recent years. The shortcoming of these schemes, however, lies in that fiber loop configuration is needed for the detection of forward transmission light. Moreover, usually additional reference light path is also needed in these schemes in order to compensate the fluctuation of light source. In this paper, we propose a simple and cost-effective displacement sensor based on single mode-multimode fiber Bragg grating structure. Similar SMS FBG [20] sensor has been reported, in which the strain and temperature responses of reflected multi-wavelengths are investigated. Its potential application for refractive index measurement by employing a thinned cladding layer fiber structure has also been studied. But so far, there are few investigations of MMI in a multimode FBG and its potential application for sensing. Additionally, compared with other fiber grating based sensors, the transmitting fiber instead of FBG in the proposed structure is employed as the sensing element. By utilizing the different power response of multiple wavelengths of multimode FBG toward displacement, because of multimode interference effect, ratiometrical power detection based displacement measurement can be achieved meanwhile the fluctuation of light source can be compensated. This provides a simple displacement sensing technique and meanwhile a potential solution for multi-parameter measurement.

2. Sensor fabrication and sensing principle

The sensor structure is shown as in Fig. 1, which is fabricated by a single mode fiber SMF28 that is spliced with an FBG written on 105/125 μm graded-index MMF. Between SMF 28 and multimode FBG is a piece of 105/125 μm MMF that acts as the sensing element.

When forward broadband sensing light passes from SMF to MMF, because of the large core radius of MMF, high-order eigen modes of the MMF are excited and interference among different modes occurs while the light propagates along the MMF.

At grating section, the modes that satisfy phase matching conditions of multimode FBG will be reflected. As a result, several peaks in the reflected spectra can be excited that correspond to

* Corresponding author. Tel.: +86 25 83794567; fax: +86 25 83793232.
E-mail address: ansun_iiuse@163.com (A. Sun).

0030-4018/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.optcom.2013.08.033

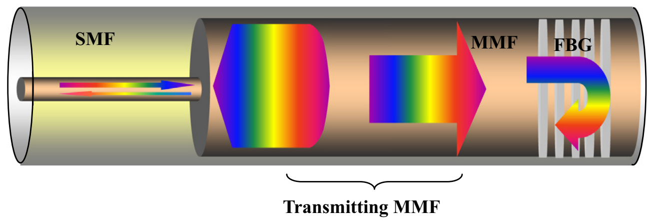

Fig. 1. Configuration of single mode-multimode FBG for displacement measurement.

different propagation constants and then recoupled into SMF through transmitting MMF.

The propagation constant for the *N*th principal mode can be approximately described by Eq. [3]:

$$\beta = \frac{2\pi n_1}{\lambda}\sqrt{1 - \frac{4\Delta(N+1)}{V}} \tag{1}$$

where β is the propagation constant at phase-matching condition $\beta = \pi/\Lambda$, Λ the grating period, n_1 is the refractive index of core, Δ the maximum relative index difference between core and cladding of the fiber, $V = 2\pi\alpha NA/\lambda$ the normalized frequency, α the core radius, and *NA* the numerical aperture.

If the transmitting MMF between SMF and multimode FBG is bent because of displacement, the reflected spectra of single mode-multimode FBG is modulated from two aspects. In multimode FBG section, firstly, the mode population of forward transmitting light is redistributed and the corresponding peak modal reflectivity of multimode FBG is changed due to bending of transmitting MMF. Second, when the reflected modes pass through the bent MMF again, the recoupling efficiency of reflected modes from the core of MMF to the core of SMF is also changed since the multimode interference in the bent MMF becomes irregular. For the proposed sensor structure, it is similar to a SMS fiber structure (single mode-multimode-single mode structure), which has been confirmed that the bent of MMF induce the mode population distribution changes as well as the recoupling efficiency due to multimode interference (MMI), so both the spectral shape and intensity of MMI are modulated by displacement induced bending of MMF. The difference between multimode FBG scheme and SMS structure lies in that only limited modes that satisfy the phase match condition of multimode FBG can be reflected. Considering that the reflected grating wavelength is unchanged, the overlapped changes of MMI spectral and the recoupling efficiency modulate the intensity of reflected modes. Because displacement induced bending radius is small, the radiation loss of fiber can be neglected. So the spectra changes of multimode FBG is the overlapped effect of recoupling efficiency change of reflected modes from MMF to SMF induced by multimode interference, and the reflected spectra changes of multimode FBG caused by mode population redistribution and related peak modal reflectivity changes of FBG. Because both effects modulated by the bent of MMF are wavelength dependent, it can be expected that the reflected intensities of these modes at different wavelengths exhibit different responses towards displacement.

3. Experimental result and analysis

First, the reflected spectra response of a straight single mode-multimode FBG structure was measured for the purpose of comparison and illustrated as shown in Fig. 2.

The grating used in the scheme is fabricated on hydrogen-loaded graded-index MMF with a core diameter of 105 μm through phase mask method. The length of FBG is about 1 cm. The multimode FBG is spliced with single mode fiber SMF 28 and the length of transmitting MMF between SMF and FBG is about 50 cm. Light

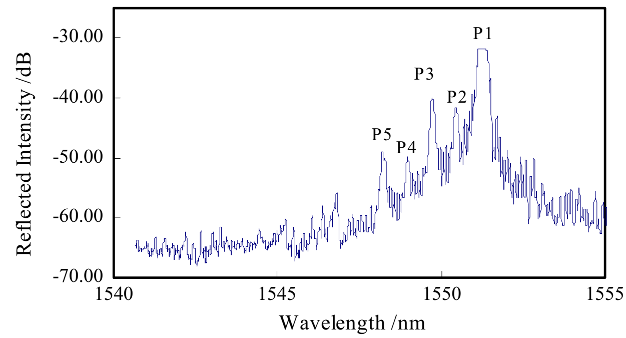

Fig. 2. Reflected spectra of single mode-multimode FBG.

from a C+L broadband source is launched into single mode-multimode FBG through a 2 × 1 single mode fiber coupler and the reflected light of sensor is detected by a spectrum analyzer MS 9740A with a wavelength resolution of 0.03 nm. It can be seen from Fig. 2 that several reflected modes can be observed in which the main mode of multimode FBG is about 1551.3 nm that is defined as *P*1, meanwhile several comparatively weak modes distribute at the shorter wavelength side of main peak with a wavelength of 1550.46 nm, 1549.73 nm, 1548.99 nm and 1548.22 nm, respectively, which are defined as *P*2, *P*3, *P*4 and *P*5 subsequently. Because of the weak intensity of *P*4 and *P*5, they are neglected for sensing application. It can also be seen from Fig. 2 that the initial reflected intensity of these peaks totally show decreasing trend with irregular fluctuation toward shorter wavelength side when MMF is kept at straight state. It is decided by both peak modal reflectivity of FBG as well as the length of transmitting MMF which affect the initial mode distribution conditions. It can also be seen from the reflected spectrum as indicated in Fig. 2. that there are still other modal peaks which can be neglected due to their weak intensities.

Experiment was carried out to evaluate the performance of single mode-multimode FBG for displacement measurement. The experimental setup is as shown in Fig. 3. One piece of transmitting MMF with a length of 2 cm was selected as sensing fiber. One side of sensing fiber was fixed at displacement mount while another side was glued to a fixed mount. The launch section of MMF was kept straight and fixed on experimental platform during experiment to avoid any inaccuracy caused by the bent of launch MMF The displacement change between two fixed points caused the bending of sensing MMF, and the corresponding spectra changes were measured and recorded through optical spectrum analyzer. During the experiment, the multimode FBG was free from any stress and the room temperature was kept around 24 °C in order to avoid any interference from surrounding condition changes.

The displacement changes from 0 mm to 3.9 mm, and the corresponding reflected intensity changes of multimode FBG is as illustrated in Fig. 4.

As shown in Fig. 4, following with the increasing of displacement, the power of three reflected modes as *P*1, *P*2 and *P*3 show obviously different response trends. Generally, the reflected intensities of *P*1 and *P*2 indicate similar responses to displacement change, which can be divided into two parts. When displacement increases from 0 mm to 1 mm, the intensities of *P*1 and *P*2 increase gradually. When displacement exceeds 1 mm, the reflected intensity of *P*1 and *P*2 decrease monotonic followed by the further increasing of displacement from 1 mm to 3.9 mm. The power of *P*3, however, exhibits quite a different trend toward displacement changes compared with that of *P*1 and *P*2. When displacement increase within the range from 0 mm to 0.5 mm and from 3 mm to 3.9 mm, the power of *P*3 decreases. But within the range of 0.5–3 mm, the power of *P*3 shows negative trend toward the increasing of displacement. Although it is hard to build theoretical modeling between displacement and

Download English Version:

https://daneshyari.com/en/article/7932273

Download Persian Version:

https://daneshyari.com/article/7932273

Daneshyari.com