Measurement 46 (2013) 4108–4113

Contents lists available at ScienceDirect

Measurement

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

Novel approach to indirect measurements of alternating current based on the interrogation of an all-fiber laser

J.L. Camas-Anzueto [a,*], J.B. Roblero-Galdámez [a], R. Vázquez-Sánchez [b], C. García-Lara [b], G. Anzueto-Sánchez [c], M. Pérez-Patricio [a], S. Mendoza-Vázquez [d], A. Medina-Santiago [a]

[a] Maestría en Ciencias en Ingeniería Mecatrónica, ITTG, Tuxtla Gutiérrez, Chiapas, Mexico
[b] Facultad de Ingeniería Ambiental, UNICACH, Tuxtla Gutiérrez, Chiapas, Mexico
[c] Centro de Investigación en Ingeniería y Ciencias Aplicadas (CIICAp), UAEM, Mexico
[d] CEFYMAP, UNACH, Tuxtla Gutiérrez, Chiapas, Mexico

ARTICLE INFO

Article history:
Received 29 August 2012
Received in revised form 14 June 2013
Accepted 2 August 2013
Available online 12 August 2013

Keywords:
Fiber sensor
Fiber laser
Fiber Bragg gratings
Heat transfer

ABSTRACT

This paper proposes and demonstrates a novel alternative to measure alternating current (AC) in an indirect manner, based on the interrogation of an Erbium-doped all-fiber laser. The principle of operation is based on sensing the temperature of an electrical wire AWG-22 caused by Joule effect. The heat transfer between a sensing Fiber Bragg Grating and the electrical wire modulates the intensity of the optical output power of the fiber laser. The intensity variation of the fiber laser is caused by the wavelength overlapping process into the fiber laser. The advantage of the proposed alternative is measuring AC current through the optical power from the fiber laser. The linear increment of optical output power as a function of temperature allows for the measurement of the AC current, which is an advantage over other methods.

1. Introduction

One of the most important devices in fiber sensor systems is the Fiber Bragg Grating (FBG) [1]. A common and interesting application of the FBGs is temperature sensing taking advantage of its thermal tuning capabilities. In connection with this, multiple proposals for measurement of electrical energy with optical fiber sensors have been investigated, using the heat interchange in an electrical wire with a FBG. For instance, Cavaleiro et al., proposed a current sensor device based on the temperature sensitivity of a FBG. The temperature induced Bragg wavelength shift is accomplished by passing electric current through a thin conductive coating on the surface of a short length of the fiber where the FBG is located. Measurements of the RMS current of power lines at 50 Hz from 0 to 1.6 A with resolution of 2 mA was demonstrated [2]. In addition, Mora et al., proposed a magnetostrictive sensor head with temperature compensation developed for measurement of static magnetic fields. The device consists of two different alloys with similar thermal expansion coefficient, one of which has giant magnetostriction. The expansion of both materials produced by heat and magnetism is detected by two optical fiber gratings [3,4]. A demonstration of an optical fiber sensor using a superstructure fiber grating (SFG) to measure AC current was reported recently [5]. The FBGs have also been used to develop fiber optic sensors for electric field and magnetic field measurements [6]. In other interesting works, a high accuracy electrical current sensor with no need of temperature compensation procedures for high value electric current measurements was proposed by Nikolay et al. This sensor has accuracy of 0.5% in the range of measured current from 15 to 250 kA [7]. A fiber-optic interferometric voltage sensor with a high sensitivity was investigated by Kim et al. The fiber-optic voltage sensor is composed of an in-line Michelson interferometer bonded to a piezoelectric

* Corresponding author.
E-mail address: jcamas@ittg.edu.mx (J.L. Camas-Anzueto).

0263-2241/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.measurement.2013.08.001

transducer (PZT) [8]. An hybrid optical current sensor employing a fiber Bragg grating, multilayer piezoelectric stack and a specially designed current transformer was demonstrated by Dziuda et al. [9]. Additionally, the measurement of AC current has been related to a magnetic force, providing a reliable indirect measuring of the AC current [10–12]. Also, an experimental setup for current measurement and a novel signal detection method for demodulation of fiber Bragg grating wavelength shift were developed with accuracy of ±1 mA in the current range from 0 to 400 mA [13], and a fiber-optic current sensor based on the Faraday rotation effect capable to sense up to 600 A rms with accuracy of ±1.3 mA rms/$\sqrt{Hz}$ was proposed by Lee et al. [14]. Most of the above mentioned approaches based on fiber Bragg gratings utilize an optical spectrum analyzer (OSA) to monitor the wavelength shift in response to the temperature or other parameter [15]. However, the performance of the sensor could be limited by the resolution of the OSA, and it is an expensive demodulation method as well. Therefore, new approaches are required for such measurements. Compared with those fiber optic sensors described above, this paper proposes and demonstrates a novel approach to indirect measurements of AC current based on identifying an optical parameter of a fiber laser related with the increasing temperature produced by the heat interchange between an electrical wire AWG-22 and a fiber Bragg grating. When a sensitive FBG is locally heated, its Bragg wavelength shifts to a longer wavelength. The wavelength shift from the FBG undergoes overlapping with the reflections from the cavity laser. The output optical power of the fiber laser presents a linear dependence according to the temperature in the electrical wire that ranges from 35 °C to 55 °C. The linearity shows that the optical power increases 0.23117 μW/°C. It is important to mention that our proposed approach is independent of both magnetic force and wavelength shift measurement, which is a novelty compared to the other works reported in the literature.

2. Experimental setup

Fig. 1 shows the scheme of the experimental setup of the proposed system. It consists on all-fiber Erbium-doped fiber laser in a linear configuration. The laser cavity is formed by two FBGs as reflectors, and an Erbium-doped fiber (EDF) as active gain medium. The reference wavelength was provided by a fiber Bragg Grating (FBG1), and a second fiber Bragg grating (FBG2) is the sensitive element that is in contact with the electrical wire AWG-22. The wavelength shift was induced in FBG2 by the increasing temperature when an AC current passes through the electrical wire. The characteristics of the FBGs are as follows: the Bragg central wavelength of FBG1 was 1550.074 nm, with 99% of reflectivity, and the FBG2 1549.557 nm with 94% of reflectivity. The Full Width Half Maximum (FWHM) values of each FBG were 0.2 nm and 0.15 nm respectively. The sensing system was insulated against the room temperature using a thermodynamic system that provides effectively constant temperature. The active gain medium consists of 10-m in length of Erbium Doped Fiber (EDF), with 100 ppm Er^{3+} ion concentration. The EDF was fusion spliced with 1-km of single mode fiber (Corning smf-28) to demonstrate the capacity of the system to perform remote measurements. The 980 nm Laser diode (QFBGLD-980-150 model, QPHOTONICS, LLC) was used to pump the EDF, and a Wavelength Division multiplexer (WDM) coupler multiplexes the light of the laser pumping and the fluorescence signal (around 1550 nm). The laser output is 10% out-coupled from the laser cavity through a 90:10 splitting ratio optical fiber coupler, and a photo-detector (S155C InGaAs model, Thorlabs) was used to monitor the optical output power.

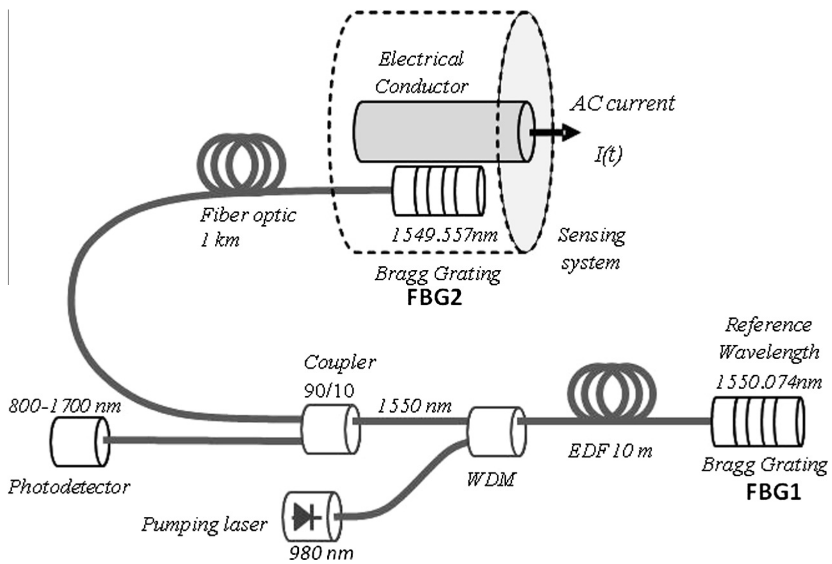

Fig. 1. Fiber laser with the sensing system.