Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 168 (2016) 1317 – 1320

Procedia Engineering

www.elsevier.com/locate/procedia

30th Eurosensors Conference, EUROSENSORS 2016

Fibre Grating-based sensor design for humidity measurement in chemically harsh environment

Lourdes S. M. Alwis[a,*], Tong Sun[b] and Kenneth T.V. Grattan[b]

[a]*School of Engineering and Built Environment, Edinburgh Napier University, Edinburgh, UK*
[b]*School of Mathematics, Computer Science and Engineering, City University London, London, UK*

Abstract

A temperature compensated Relative Humidity (RH) sensor incorporating Fibre Bragg Gratings (FBGs) has been developed to be tested in extremely harsh gaseous acidic environment. One FBG is coated with moisture sensitive polymer while the other was used for temperature compensation. The resonance wavelengths were chosen to be within suitable spectral bandwidths for efficient interpretation of both RH and temperature. The performance of the sensor was evaluated for use in challenging environment by trialing the sensors for over a month in a waste sewerage tank with highly acidic gaseous environment. The sensitivity of the sensor to RH/temperature is calculated to be 5 pm/%RH and 9 pm/ºC respectively.

Peer-review under responsibility of the organizing committee of the 30th Eurosensors Conference

Keywords: Fibre Bragg Grating sensor, Humidity sensor

---

1. Introduction

Accelerated corrosion results in large operational costs for mitigation and significant capital outlays for rehabilitation and repair. Measurement of RH is important in order to predict corrosion rates of infrastructure assets, such as sewerage pipes, so that appropriate repair strategies can be planned. The motivation for this test rises from the fact that most electrical sensors used for RH measurement in aggressive environment have limited life span and fails within a matter of weeks, making them unsuitable for long term monitoring of RH. Both the sensor element as well as

---

* Corresponding author. Tel.: +44 (0) 131 455 2423
E-mail address: l.alwis@napier.ac.uk

Peer-review under responsibility of the organizing committee of the 30th Eurosensors Conference
doi:10.1016/j.proeng.2016.11.359

the packaging in this work were therefore carefully designed to be suitable for high humidity measurement as well as to withstand aggressive environmental conditions i.e. high gaseous acid and pressure.

1.1. Fibre Grating-based sensors

Optical fibre grating based sensors are widely utilised due to various advantages they possess over conventional systems [1]. They represent a class of intrinsic devices that has gained widespread popularity in recent years. It has found use in many applications in industry due to its inherent sensitivity to temperature, strain and refractive index change [2–4]. The grating structure within the fibre sensor is created by UV-induced periodic refractive index modulation of the fibre core and can be generally classified into two main categories depending on the grating period, namely the fibre Bragg grating (FBG) [2] and long period grating (LPG) [3].

Previous work by the authors [5] have demonstrated that a hybrid grating sensor design, containing both a Long Period Grating (LPG) and a FBG, can be utilised for simultaneous measurement of NaCl concentration and temperature. The work presented here involves the design of a temperature compensated RH sensor incorporating only FBGs and is subjected to RH variations in chemically harsh environment, i.e. in a waste sewerage tank.

1.2. Humidity sensing mechanism

The concept of in-fibre grating devices for humidity sensing is still fairly new. In sensors of this type, the fibre grating acts as the basis of the device and the humidity sensing concept used in this sensor exploits the strain effect induced in an in-fibre grating through the swelling of a thin layer of applied polymer coating. The swelling of the polymer coating, arising from the absorption of moisture, changes the wavelength associated with the grating and this can be calibrated to give a direct indication of the humidity level. Thus in the case of an in-fibre Bragg grating, the ratio of the wavelength shift to the Bragg wavelength for a polymer-coated and stretched FBG can be represented as follows.

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - P_e)\alpha_{RH}.\Delta RH + [(1 - P_e)\alpha_T + \zeta]\Delta T$$

where Pe is the photo-elastic constant of the fibre, ξ is the fibre thermo-optic coefficient, α_{RH} and α_T are the moisture and thermal expansion coefficients of the coated FBG respectively. A detailed discussions of the fabrication of the FBGs used for humidity measurement have been reported by some of the authors elsewhere [6,7].

2. Sensor probe design and fabrication

2.1. Sensor probe and packaging

The sensor element contains 2 FBGs, as can be seen from Fig. 1, one coated with moisture sensitive Polyimide (PI) and the other left bare for temperature compensation.

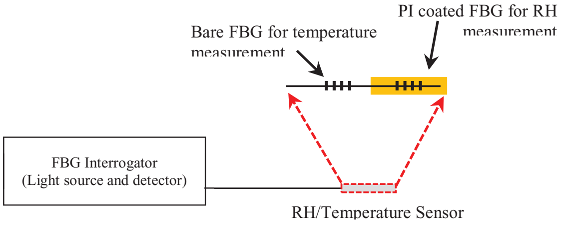

Fig. 1. The sensor element containing two FBGs.

A 3D printed epoxy sensor packaging was then used where the sensor was carefully inserted in and protected by a perforated cap. This approach was chosen as it was inexpensive, quick to fabricate and could be done ‘in-house’. The design comprised a printed epoxy rod, with a small hole in the middle into which the fibers could be inserted. The region of the fiber containing the sensing elements was exposed to air on one end which is protected with a 3D-printed perforated cap, which could easily be removed for inspection (or indeed redesigned and replaced if it became contaminated). This sensor packaging is illustrated in Fig. 2 where a comparison to the commercial electrical sensor can also be seen, (as used for in the in-sewer evaluation tests). The target of the test is to evaluate not only the performance of the sensor but also whether the newly designed packaging was suitable to be used in such conditions.

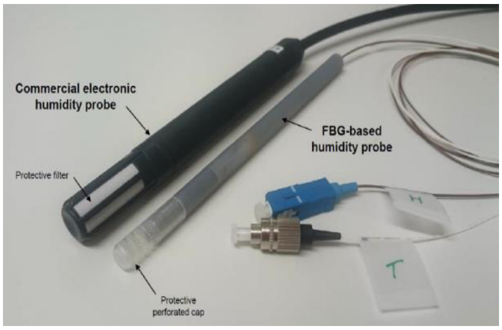

Fig. 2. Sensor designed using 3D-printed epoxy packaging and for comparison a conventional commercial electronic humidity probe (left).

2.2. Sensor fabrication

The fibre gratings used in this work were fabricated using phase masks illuminated by light from a 248 nm KrF excimer laser with pulse energy of 12 mJ and a pulse frequency of 200 Hz. Upon fabrication, all gratings were annealed at 185 °C for 3 hours prior to the rest of the procedure in order to achieve good thermal stability.

Upon annealing, the grating was first treated with 3-aminopropyltriethoxysilane (3-APTS) in order to obtain good bonding between the fiber surface and the moisture sensitive polymer, i.e. polyimide (PI) liquid. This was achieved by preparing a 0.1% 3-APTS solution which was dip-coated on the grating surface at a speed of 13 mm/min following which the grating was placed in the oven at 130 °C for 5 minutes and the PI solution was used to coat multiple layers of PI on the fiber at 13 mm/min until the desired thickness is achieved. The coated fibre was placed in the oven at 150 °C for 5 minutes for each layer and upon the final layer, the PI coating was cured in the oven at 180 °C for an hour.

3. Sensor calibration and results

The sensor was then calibrated under laboratory conditions before and after the trial period to evaluate whether the prolonged sewerage exposure has had any effect in terms of the sensor performance, i.e. hysteresis, sensitivity. The sensor performance after the trial period in response to RH variations can be seen from Fig. 3.

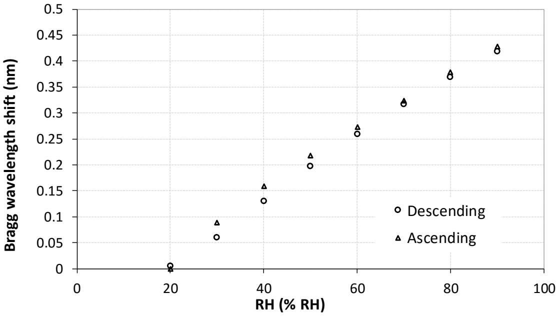

Fig. 3. Recalibration results (average over 7 repeated cycles) of the probe to both ascending and then descending levels of RH.

A comparison between the performance between the electrical sensor and the design proposed was made, as can be seen from Fig. 4, when both sensors were subjected to the same but chemically harsh environment.

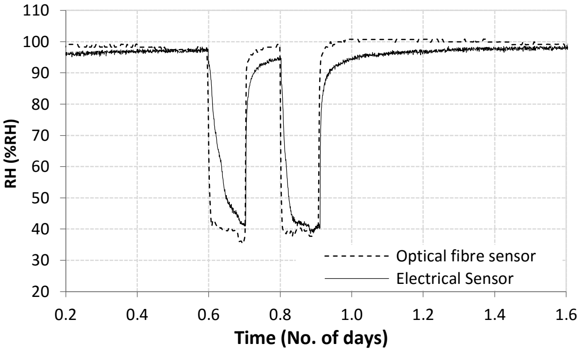

Fig. 4. Comparison between the responses of the optical and electrical sensors.

4. Discussion

The results obtained have shown clearly that the fiber optic sensor system designed and developed for use in the very high humidity, chemically harsh sewer environment have performed satisfactorily and highly reliably over a significant test period. This recalibration showed that the humidity sensitivity remained essentially unchanged at ~5 pm/%RH (depending on the design and fabrication parameters), with the temperature sensitivity again being consistent at ~9 pm/°C (again depending on the design and fabrication parameters).

The strength of the approach that can be seen from the results is building on both the appropriate sensitivity of the design of the sensor element as well as of suitable packaging that will enable optical fibre sensors to be deployed in environmentally and chemically challenging conditions. In light of the results obtained from the study, it can be concluded that the use of optical fiber sensor systems for the target application of humidity and temperature measurement in chemically harsh environment can be successfully achieved.

Acknowledgements

The authors would like to acknowledge the support from Edinburgh Napier University Early Career Researcher's fund, the Royal Academy of Engineering and the George Daniels Educational Trust.

References

[1] L. Alwis, T. Sun, K.T.V. Grattan (April 2016): Developments in optical fibre sensors for industrial applications, Journal of Optics and Laser technology 78, 62-66.
[2] R. Kashyap, "Fiber Bragg Gratings", Academic Press, 1999.
[3] Bhatia V, "Properties and sensing applications of long period gratings", PhD Thesis, Virginia Polytechnic Institute and State University, Virginia, 1996.
[4] A. Othonos, K. Kali, Fiber Bragg Gratings Fundamentals and Applications in Telecommunications and Sensing, Artech House, 1999.
[5] L. Alwis, T. Sun, K.T.V. Grattan (2015): Optical Fibre Refractive Index Sensor in a Hybrid Fibre Grating Configuration, Proc. Eurosensors XXIX 120, 11-14.
[6] T.L. Yeo, T. Sun, K.T.V. Grattan, D. Parry, R. Lade, B.D. Powell, "Polymer-Coated Fiber Bragg Grating for Relative Humidity Sensing", IEEE Sensors 5, pp 1082-1089, 2005.
[7] T.L. Yeo, T. Sun, K.T.V. Grattan, "Fibre-optic sensor technologies for humidity and moisture measurement", Sensors and Actuators A 144, pp 280–295, 2008.