Fiber Bragg Grating Tilt Meter

Sharath Umesh, Shikha Ambastha and Asokan Sundarrajan*
Department of Instrumentation and Applied Physics,
*Robert Bosch Centre for Cyber Physical Systems,
Indian Institute of Science, Bangalore 560012, India

***Abstract*— In this paper, we propose a novel methodology of real time dynamic tilt monitoring through the designed and developed Fiber Bragg Grating Tilt Meter (FBGTM). Based on the volumetric water pressure exerted from inside the chamber on the diaphragm over which the FBG sensor is bonded, the tilt angle of FBGTM can be estimated. An inclination platform is constructed to test the designed FBGTM in conjunction with a commercial inclinometer. The results obtained from both sensor methodologies are in good agreement with each other.**

Keywords- Fiber Bragg grating sensor, tilt angle measurement

I. INTRODUCTION

Fiber Bragg Gratings (FBGs) have attracted much research interest in the area of optical sensors as well as communications. FBGs have distinct advantages over other types of sensors, such as being inherently self-referencing, multiplexing capability, electrically passive operation, high sensitivity, ultra-fast response, compact dimensions, insensitivity to radio frequency interference and electromagnetic interference. Other than being utilized to sense primary measurands of strain [1] and temperature [2], FBGs are also employed in packages which operate as transducers to measure parameters like pressure [3], acceleration [4], flow rate [5], force [6], torsion [7] and tilt angle [8-11], etc.

Measurement of tilt angle is of great importance in many fields [12-13]. In the medical field, tilt sensors are used to analyze the gait [14] and pelvic tilt of a person [15]. In the aerospace field, real-time tilt attitude monitoring [16] for the aircraft is vital. In civil engineering, tilt sensors are employed to measure parameters like surface levelling, road gradient etc. Several FBG-based tilt meters with different configurations are reported [17-20]. Fiber Bragg Grating Tilt Meters (FBGTMs) based on pendulum suspension mechanism [8], cantilever mechanism [9] and intensity modulation mechanism [10] have been realized with varying choices in tilt angle measurement range, accuracy, sensitivity and resolution. In this paper, a novel and simple tilt sensor structure using a pair of FBGs is proposed and demonstrated. The proposed FBGTM does not employ any mechanical joint for strain transduction, thus reducing greatly mechanical errors during tilt measurement.

II. DEVICE DESIGN AND FABRICATION:

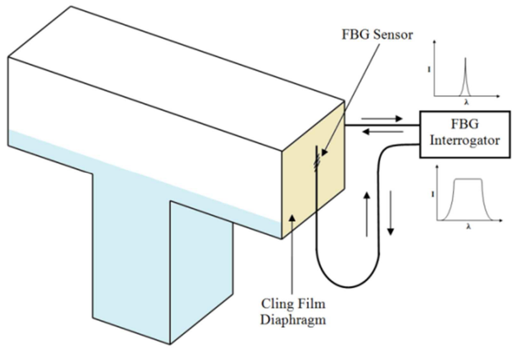

Figure 1. Schematic of FBGTM.

In this work, the Fiber Bragg Gratings are photo-inscribed [21, 22], by exposing the core of a photosensitive, single-mode, germano-silicate fiber to an interference pattern created by passing of a 248 nm UV laser beam through a phase mask [23]. This exposure results in a periodic modulation of the refractive index along the core of the photosensitive fiber. When a broad band light is launched into a FBG sensor, one particular wavelength (λ_B) which satisfies the f Bragg condition (1) is reflected and other wavelengths are transmitted through the fiber. The wavelength of reflected light from the grating structure is given by

$$\lambda_B = 2 n_{eff} \Lambda \quad (1)$$

Here, the Bragg wavelength λ_B is the centre wavelength of the input light that will be back-reflected from the grating, n_{eff} is the effective refractive index of the fiber core at the centre wavelength and Λ is the spacing between the gratings.

Figure 1 shows the schematic of the novel and simple FBGTM developed to measure the tilt angle, based on dynamic strain measurement. It consists of a 'T'-shaped perspex box with specific dimensions of 25 mm x 25 mm x 25 mm in all three chambers. The bottom chamber is enclosed with perspex and the side chambers are enclosed with a cling film diaphragm. Water of volume 25 cc is filled into the package before enclosing the side chambers. FBGs are bonded on the exterior facade of cling film diaphragms on both of the side chambers.

When the FBGTM experiences any tilt, the water from other chambers starts accumulating in the corresponding tilt chamber side, increasing the pressure on the cling film diaphragm. With increase in tilt angle, waterl starts flowing from the bottom chamber to the corresponding tilt side chamber due to the action of the gravitational force which further enhances the pressure over the cling film diaphragm. This increase in pressure creates strain variations over the cling film diaphragm, which are sensed by the FBG sensor bonded over it. The strain variation on the cling film diaphragm indicates the tilt angle of the FBGTM.

III. Experimental Setup and Results

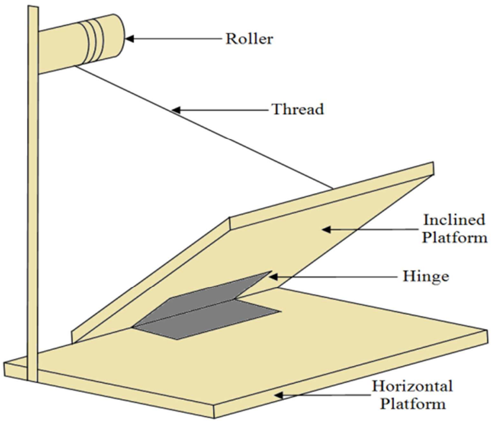

Figure 2. Schematic of tilt platform used in the experiment.

Two platforms made of wood are adjoined by a hinge as shown in the Fig. 2, in which one platform is stationary (the horizontal platform) and the other platform is movable (tilt platform). A roller thread assembly is tied to the tilt platform. Both the FBGTM and the inclinometer (Wyler Clinometer Plus) are placed over the tilt platform, as shown in Fig. 3. As the roller is rotated, the thread pulls the tilt platform providing the inclination angle required. Data from both the sensor technologies are acquired simultaneously for one full cycle of the tilt platform movement from 0^0 to 45^0. Similarly the response of the other chamber is also acquired, by interchanging the direction of the FBGTM, i.e., the water flow direction.

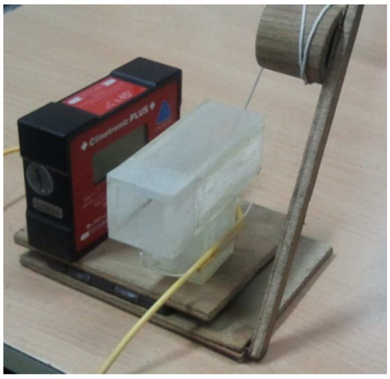

Figure 3. Experimental setup with FBGTM and inclinometer.

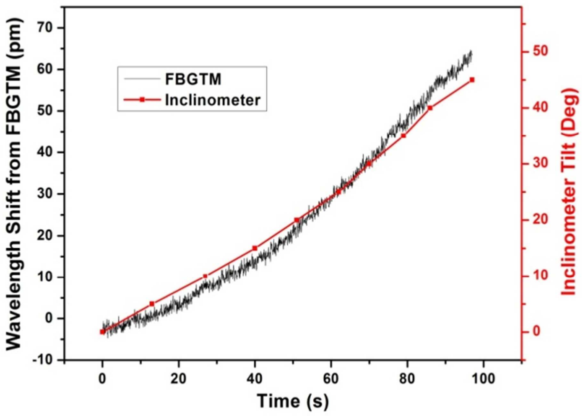

Figure 4. Comparison of FBGTM response with inclinometer response during calibration.

Experiments were conducted in the laboratory under controlled environmental conditions. The tilt platform was raised from 0^0 to 45^0 methodically which provided the inclination required for the calibration of the proposed FBGTM. Data from both the FBGTM in the form of Bragg wavelength shift and inclinometer in the form of tilt angle were recorded simultaneously, as shown in Fig. 4. It is observed that the response of both FBGTM and inclinometer are linear and for a tilt angle increase of 45^0 in the inclinometer corresponding Bragg wavelength shift of 61 pm is acquired in the FBGTM. The tilt angle sensitivity achieved by the proposed FBGTM is 0.73^0/pm; similar tests are conducted to obtain response of FBG sensor in the other chamber of the FBGTM. The responses of the FBG sensors from both the chambers are found to be close, with negligible differences, which may arise from different strain on the cling film diaphragm or the positional offset of the bonded FBG sensor.

IV. Conclusion

A remote sensing, stand alone, compact and light-weight Fiber Bragg Grating Tilt Meter (FBGTM) has been developed for real time dynamic tilt angle measurements. The proposed FBGTM has been compared against a commercial inclinometer for validation. The results obtained are found to be in good agreement, which proves the efficiency of FBGTM. The optimization of the FBG sensor positioning combined with a suitable choice of material for diaphragm and the density of the liquid used, have to be further investigated for optimal device performance.

References

[1] I. C. Song, S. K. Lee, S. H. Jeong and B. H. Lee, "Absolute Strain Measurements Made with Fiber Bragg Grating Sensors", vol. 43, no. 6, pp. 1337-1341, 2004.

[2] Z. Zhou and J. Ou, "Techniques of temperature compensation for FBG strain sensors used in long-term structural monitoring", APCOM 2004, Khabarovsk, Russia, pp. 465-471, September 2004.

[3] M. G. Xu, L. Reekie, Y. T. Chow, and J. P. Dakin, “Optical in-fiber grating high pressure sensor,” *Electron. Lett.*, vol. 29, no. 4, pp. 398–399, 1993.

[4] T. A. Berkoff and A. D. Kersey, “Experimental demonstration of a fiber Bragg grating accelerometer,” *IEEE Photon. Technol. Lett.*, vol. 8, pp. 1677–1679, December 1996.

[5] J. Lim, Q. P. Yang, B. E. Jones, and P. R. Jackson, “DP flow sensor using optical fiber Bragg grating,” *Sens. Actuators A Phys.*, vol. 92, no. 1–3, pp. 102–108, 2001.

[6] W. Zhang, X. Dong, Q. Zhao, G. Kai, and S. Yuan, “FBG-type sensor for simultaneous measurement of force (or displacement) and temperature based on bilateral cantilever beam,” *IEEE Photon. Technol. Lett.*, vol. 13, no. 12, pp. 1340–1342, December 2001.

[7] X. G. Tian and X. M. Tao, “Torsion measurement using fiber Bragg grating sensors,” *Appl. Opt.*, vol. 41, no. 3, pp. 248–253, 2001.

[8] B. O. Guan, H. Y. Tam, and S. Y. Liu, “Temperature independent fiber Bragg grating tilt sensor,” *IEEE Photon. Technol. Lett.*, vol. 16, no. 1, pp. 224–226, January 2004.

[9] B. Peng, Y. Zhao, Y. Zhao, and J. Yang, “Tilt sensor with FBG technology and matched FBG demodulating method,” *IEEE Sensors J.*, vol. 6, no. 1, pp. 63–66, February 2006.

[10] X. Dong, C. Zhan, K. Hu, P. Shum, and C. C. Chan, “Temperature insensitive tilt sensor with strain-chirped fiber Bragg gratings,” *IEEE Photon. Technol. Lett.*, vol. 17, no. 11, pp. 2394–2396, Nov. 2005.

[11] P. Ferdinand and S. Rougeault, “Optical fiber Bragg grating inclinometry for SMART civil engineering and public works,” in *Proc. OFS*, Venice, 2000, vol. 4185, pp. 13–16, SPIE.

[12] M. Rehman, W. Ahmed, T. Ajmal, “A fiber optic tiltmeter. IEEE instrumentation and measurement technology conference.” Brussels, Belgium, June 1996.

[13] R. Olaru and C. Cotae, “Tilt sensor with magnetic liquid.” *Sensor Actuator A*, vol. 59, pp 133-135, 1997.

[14] R. Dai, R. B. Stein, B. J. Andrews, K.B. James, and M. Wieler, “Application of tilt sensors in Functional Electrical Stimulation”, *IEEE Trans Rehabil Eng*, vol. 4, no. 2, pp. 63–72, 1996.

[15] K. Coleman, S. Reinecke, and T. Bendix, “A measurement technique to monitor pelvic tilt,” Proceedings of the 1991 IEEE seventeenth annual northeast bioengineering conference, pp. 156–57 April 1991.

[16] T. Kirubarajan, P. R. P Hoole, “An electromagnetic inverse problem solver for rafar: aircraft rotation and tilt measurements,” *IEEE Transactions Magnetics* 1993, vol. 29, no. 2, pp. 1767–70.

[17] S. Mangan, J. Wang and Q. H. Wu, “Measurement of the road gradient using an inclinometer mounted on a moving vehicle.” IEEE International symposium on computer aided control system design proceedings, Glasgow, Scotland, UK, September 2002, pp. 80–85.

[18] P. Ferdinand, S. Rougeault, “Optical fiber Bragg grating inclinometry for smart civil engineering and public works”, OFS’2000, International conference on optical fiber sensors, Venice, October 2000.

[19] H. Y. Au, Sunil K. Khijwania, H. Y. Fu, W. H. Chung, and H. Y. Tam, “Temperature-Insensitive Fiber Bragg Grating Based Tilt Sensor With Large Dynamic Range”, *J. Lightwave Technol.*, vol. 29, no. 11, pp. 1714-20, 2011.

[20] Yong Zhaoa, Jian Yanga, Bao-Jin Pengb and Shi-Yuan Yanga, “Experimental research on a novel fiber-optic cantilever-type inclinometer”, *Optics & Laser Technology*, vol 37., pp. 555-559, 2005.

[21] K. O. Hill and G. Meltz ,“Fiber Bragg Grating Technology Fundamentals and Overview”, *J. Lightwave Technol.*, vol. 15, pp. 1263–1276, 1997.

[22] G. Meltz, W.W. Morey, and W. H. Glam, “Formation of Bragg Grating in Optical Fibers by a Transverse Holographic Method”, *Opt. Lett.*, vol. 14, pp. 823–825, 1989.

[23] K.O. Hill, B. Malo, F. Bi lodeau, D.C. Johnson and J. Alber, “Bragg Gratings Fabricated in Monomode Photosensitive Optical Fibers by UV Exposure Through a Phase Mask”, *Appl. Phys. Lett.*, vol. 62, pp. 1035–1037, 1993.