Optical Fibre Sensors for Structural Health Monitoring

Jinwu Li
School of Computer Science and Electronic Engineering

Objectives

- To investigate the fibre Bragg grating (FBG) and its working principle.
- To learn how FBG can be used for strain and temperature sensing and how to compensate the cross sensing.
- To study how to develop FBG sensors for real-time structural health monitoring (e.g. bridge).
- To gain soft skills including paper searching and reading, oral/poster presentations, report writing, time management, self-study ability.

Background

- Optical fibre has a various of advantageous, such as low loss, small size, light weight, and free from environmental dust.
- FBG easy coupling with optical fibre, compatible with other optical devices, It is mainly used in the field of optical sensing and optical communications.
- This project presents the FBG-based sensing technology for real-time bridge structrual health monitoring.

Principle & Methodology

When FBG is illuminated by a broadband light source, a set of beams are reflected from a set of partially reflecting planes formed by the periodic refractive index modulation interfere with each other. The interference is destructive unless each beam is in phase with all the others.
According to phase matching condition, the Bragg wavelength is given by:

$$\lambda_B = 2n_{eff}\Lambda$$

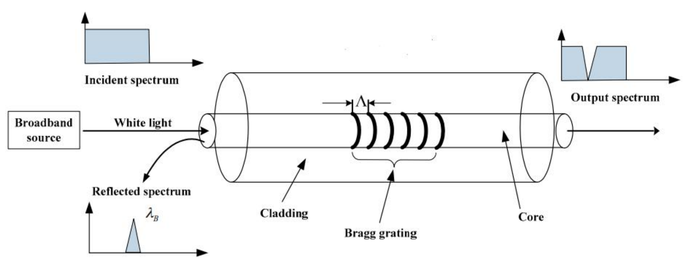

Figure 1. A fibre Bragg grating [1]

- **Sensing principles:**

  When a FBG experiences the external parameter changes (e.g. strain, temperature), the FBG central wavelength will change corresponding to the external variations.

  i) For strain measurement:

$$\Delta\lambda_{BS} = \lambda_B(1-\rho_\alpha)\Delta\varepsilon$$

  ii) For temperature sensing:

$$\Delta\lambda_{BT} = \lambda_B(1+\xi)\ \Delta T$$

- **Dual-wavelength superimposed FBGs method**

Since both strain and temperature affect the λ_B, we need a method which can measure strain and temperature simultaneously, it is called temperature compensation [2] [3].

$$\Delta\lambda_B = K_\varepsilon\Delta\varepsilon + K_T\Delta T$$

$$\begin{pmatrix}\Delta\lambda_{B1}\\ \Delta\lambda_{B2}\end{pmatrix} = \begin{pmatrix}K_{\varepsilon1}K_{T1}\\ K_{\varepsilon2}K_{T2}\end{pmatrix}\begin{pmatrix}\Delta\varepsilon\\ \Delta T\end{pmatrix}$$

Bridge Structural Monitoring

Figure 2. Tsing Ma bridge [4]

- Hong Kong's landmark -- Tsing Ma bridge (TMB) is the world longest suspension bridge (1377 m) that carries both railway and regular road traffic.

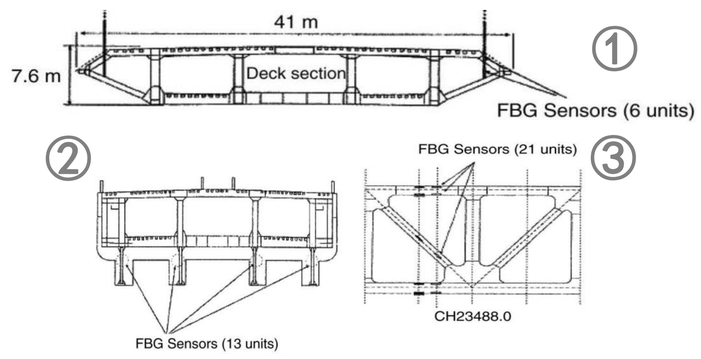

Figure 3. 40 FBGs were installed on the TMB to measure temperature and strain at (1) hanger cable, (2) rocker bearing, and (3) truss girders of section Chainage.

- 40 FBG sensors divided into three arrays were installed on the hanger cable, rocker bearing and truss girders of the TMB.
- Via monitoring the strain of different parts of the TMB under both the railway and highway loads as well as comparing the FBG sensors' performance with the conventional structural health monitoring system.

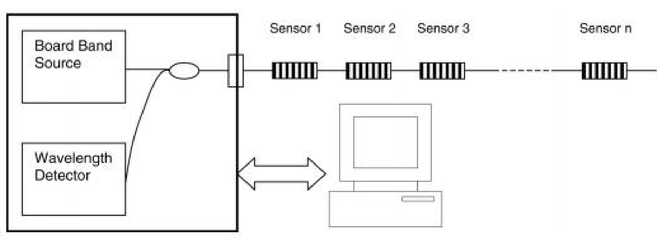

Figure 4. Experimental setup of FBG interrogation system

- In this study the interrogation system was switched on continuously for 24 h to monitor the structure and temperature change of the bridge.
- The results were assessed and compared with the conventional strain gauges obtained from the WASHMS.

Results

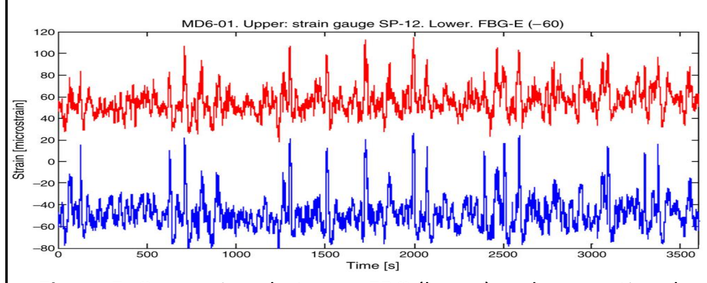

Figure 5. Comparison between FBG (lower) and conventional strain gauges (upper) installed on rocker bearings [4]

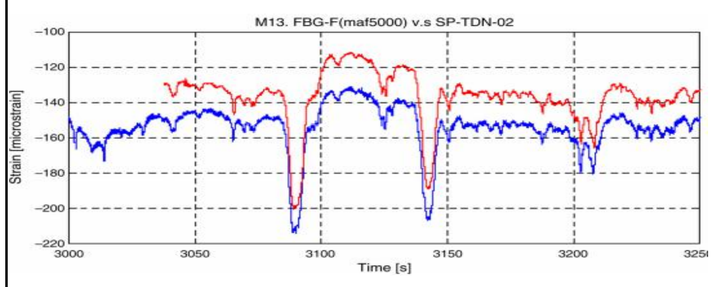

Figure 6. Comparison between FBG (upper) and conventional strain gauge (lower) installed on a truss girder [4]

- FBG sensors show more sensitive. The curve of FBG changes even more dramatically than that of conventional strain gauge under the same conditions.
- The measurement result of the interrogation system was in excellent agreement with those obtained by resistive strain gauges.

Conclusions

- FBG technique was proposed to apply for structural health monitoring applications. It can clearly and correctly detect the dynamic strain responses of the bridge induced by the passage of trains on the bridge.
- FBG sensor system offers many advantages over traditional resistive strain gauges. These include remote sensing, ease of installation, non-corrosive and lower maintenance cost.
- FBG technology has been demonstrated as a good alternative for civil and structural dynamic strain monitoring.

Acknowledgements

I acknowledge support from my supervisor Dr X Chen and the School of Computer Science and Electronic Engineering at Bangor University.

Contact

<Jinwu Li>
Email: jnl18ztk@bangor.ac.uk

References

1. X.W Ye, Y.H Su and P.S Xi. 'Statistical analysis of stress signals from bridge monitoring by FBG system', Sensors (2018) 18, 491.
2. S.W. James, M.L. Dockney and R.P. Tatam, 'Simultaneous independent temperature and strain measurement using in-fibre Bragg grating sensors', Electronics Lett. (1996) 32, 12.
3. Y. J Rao, 'In-fibre Bragg grating sensors ', Meas. Sci. Technol. (1997) 8, 355–375.
4. T. Chan, L. Yu, H.Y. Tam, Y.Q. Ni, S.Y. Liu, W.H. Chung, L.K. Cheng 'Fiber Bragg grating sensors for structural health monitoring of Tsing Ma bridge', Engineering structures , (2006) 8, 648–659.