Jurnal Kejuruteraan 36(2) 2024: 793–799
https://doi.org/10.17576/jkukm-2024-36(2)-36

Monitoring For Strain-Based Railway Structure Assessment Approach Using Optical Fibre Sensor

Agus Danish Hakim AgosMustaram[a], Meor Iqram Meor Ahmad[a*], Nur Shufinah Suhaimi[a], Mohd Zaki Nuawi[a], Mohd Hafizi Zohari[b], Ahmad Kamal Ariffin[a] & Aidie Zeid Muhammad Abdullah[c]

[a]*Department of Mechanical & Manufacturing Engineering, Faculty of Engineering and Built Environments, Universiti Kebangsaan Malaysia, 43600, UKM Bangi, Selangor, Malaysia*

[b]*Advanced Structural Integrity and Vibration Research (ASIVR), Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600, Pekan, Pahang, Malaysia*

[c]*Rail Engineering Department, Track Network Maintenance Ampang Line, 5th Mile Jalan Ampang, 68000, Ampang, Selangor, Malaysia*

[*]*Corresponding author: meoriqram@ukm.edu.my*

Received 30 July 2022, Received in revised form 14 October 2023
Accepted 24 November 2023, Available online 30 March 2024

ABSTRACT

Railway transportation is essential and continually evolving with new technologies to achieve high efficiency and passenger safety. Monitoring railways can be challenging, especially when dealing with delicate equipment. This study outlines a basic guideline and real-time monitoring process for railway tracks, serving as precautionary measures. The research employs Fiber Bragg Grating (FBG) sensors directly attached to the railway track's web surface, which have the potential to cause failures. Before sensor installation, several critical steps were taken to ensure the fragile FBG sensors remained intact. These steps involved preparing sensor arrangements and positioning them before installation. Additionally, a calibration test for FBG is performed using the Universal Tensile Machine (UTM) with a mild steel sample, achieving a measurement of almost 1.2 picometers/micro-strain. As a result, a shift in wavelength was successfully measured and collected, enabling the calculation of strain-stress data for the rail structure during operation. The collected data exhibited no irregularities or anomalies data, indicating the success of the monitoring process. The data obtained from a well-prepared installation greatly differs from that of an underprepared one. This study underscores the necessity of thorough preparation when handling delicate equipment like FBG sensor. Therefore, the FBG sensor has the capability to measure the strain-stress behavior of rail structures, allowing for more accurate predictive assessments to prevent rail failures.

Keyword: Railway Transportation; Structural Monitoring; Fibre Bragg Grating (FBG); Strain-Stress

INTRODUCTION

Monitoring is essential for predictive maintenance to prevent casualties and accidents. It also enhances quality and reliability while avoiding the costly reengineering of older structures and machines (Hesser & Markert 2019). With the advancements in transportation over generations, there has been a significant increase in traffic volume, necessitating the development of new structures to mitigate vibrations and forces caused by vehicle travel (Hesser et al. 2022). However, due to various factors, not all infrastructure can be rebuilt. Therefore, a highly reliable monitoring system is required to ensure that the structure can withstand heavy traffic loads and harsh conditions. This monitoring system can detect sudden changes in the structural integrity of the infrastructure, allowing for timely countermeasures to maintain it based on its estimated health state (O'Brien et al. 2017).

In the last decade, fibre optic sensors have demonstrated significant potential for applications in the engineering field due to their prominent advantages, including their small size, chemical inertness, immunity to electromagnetic interference (EMI), and multiplexing capability (Dennison C. R. et al. 2008). The fibre optic sensors also represent a high-performance alternative compared to standard technologies such as electrical strain gauges (ESG), piezoelectric, resistive, or other solid-state sensing methods, whether for measuring physical parameters or conducting high-sensitivity biochemical analysis (Udd & Jr. 2011).

Fibre optic sensors based on the Fibre Bragg Grating (FBG) type have gained a significant market share due to several advantages: a small form factor, lightweight design, lack of need for electrical connections, and compatibility with non-invasive remote sensing. The characteristics of FBGs, such as high sensitivity, high resolution, a wide dynamic range, intrinsic immunity to radio frequency interference (RFI) and electromagnetic interference (EMI), and their ability to interface with data communication systems, contribute to their widespread use in many sensing applications. Due to FBGs' high sensitivity to various environmental parameters, including physical, chemical, biomedical, and electrical parameters, they are employed for structural health monitoring in civil infrastructure, aerospace, energy, and maritime sectors. In these applications, measurement-related information is typically encoded by the wave crest displacement of the FBG (Campanella et al. 2018).

A railway monitoring system was developed to enhance safety and proactively assess the condition of the railway track (N.S. Shuhaimi et al. 2022). This system involves the installation of an on-board sensing device integrated with an in-service train, which monitors the track condition by measuring the car body acceleration (Tsunashima et al. 2015). Another study, conducted by N.S. Shuhaimi et al. investigates the strain-stress behaviour of railway welded rail joints for structural condition assessment using rosette FBG sensors (N.S. Shuhaimi et al. 2023). Additionally, other types of monitoring, such as Hirokata Mori's research, involve the use of in-service vehicles with sensors and devices installed inside moving trains to detect the vertical and lateral acceleration of the train car body (Mori et al. 2010). The development of a portable and easily installable railway monitoring system is necessary, as it enables real-time data reading and collection. Furthermore, another research effort by Tsunashima et al. involves monitoring car-body vibrations using time-frequency analysis (Tsunashima & Hirose 2020).

In this study, the monitoring process is performed using FBG sensors placed on the web of the railway track to detect strain-stress behavior. Before the sensors are installed, several procedures must be undertaken to ensure the fragile FBG sensors remain intact, including preparing sensor arrangements and positioning them appropriately. Monitoring is conducted in real-time to collect wavelength data from the device. The process consists of three major steps: before, during, and after the installation of the FBG sensors in order to make sure that the data measured is accurate and precise.

FBG THEORY AND WORKING PRINCIPAL

The FBG sensor is delicate and fragile; it can easily break and requires a precise workflow for handling. If the fiber optic breaks, it can be spliced together using a splicer machine. The cladding of the fiber optic needs to be stripped to expose the core. The core part of the fiber optic is then spliced and connected to form a strong, lossless connection. Furthermore, the data acquisition system used in this research consists of an interrogator, a light source, a circulator, and fiber optic cables. The mechanisms of the FBG system and the path of the light source are illustrated in Figure 1. All the connections are made using an FC/APC patch cord to minimize losses and ensure secure connections, as depicted in Figure 2. APC stands for angled physical contact, which features an 8° slant at the tip of the connector. This design ensures that reflected light does not travel back to the light source, as explained in Figure 3.

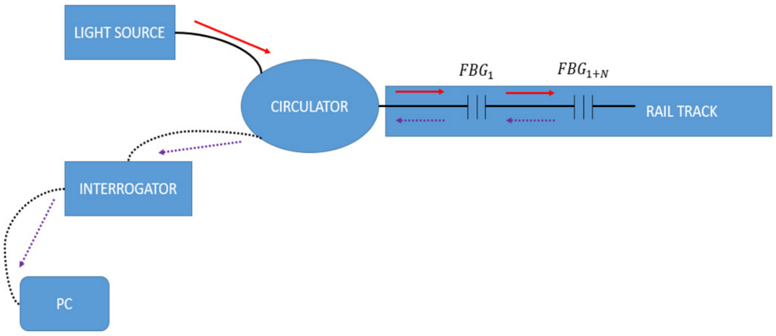

FIGURE 1. The mechanisms of data acquisition for FBG system and light path

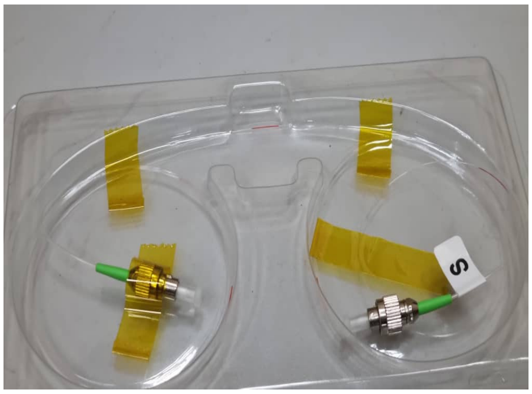

FIGURE 2. The patch cord type connector

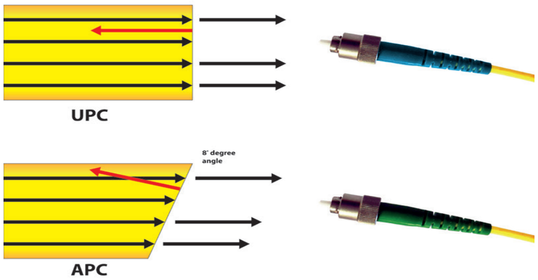

FIGURE 3. The light path for APC type connector

Grating-based sensors detect the effect of gratings in the core of optical fibers. As light, frequency, or wavelength propagates through an optical fiber, the grating serves as a narrow-band filter or mirror, modulating a range of wavelengths, commonly referred to as Bragg wavelengths (Du et al. 2020). The system structure of the FBG sensor is depicted in Figure 4.

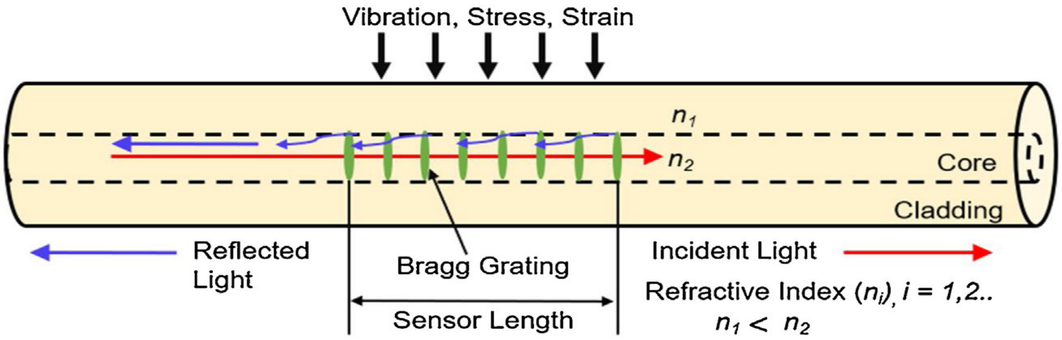

FIGURE 4. Working principle of the FBG sensor

METHODOLOGY

THE CALIBRATION TEST FOR FBG SYSTEM

The calibration test is conducted using a Universal Tensile Machine (UTM) as shown in Figure 5. The FBG is attached to a sample, which is mild steel, and is subjected to tension within a specific timeframe to collect wavelength and shifting data. The test is repeated multiple times to obtain average results and ensure ideal FBG calibration.

FIGURE 5. The samples set up in the UTM

THE INSTALLATION AND MONITORING OF FBG ON RAIL TRACK

The installation is carried out on two types of railway tracks: one with minimal deformation and a potential for failure, and the other in normal condition. This is done to highlight the differences in strain-stress data. The selected location is approximately 600 meters from the station platform due to the minimal deformation on the surface of the railway track. The installation can only be performed during engineering hours, which are from 12:00 am to 4:00 am, as shown in Figures 6 and 7. The sensor is installed on the web of the railway track, a location that does not disrupt train operations, and allows for easy data collection. The FBG sensors are attached using UV glue and arranged in a rectangular rosette configuration at 0°, 45°, and 90°. The positions of the FBG sensors attached to the web of the railway track are illustrated in Figure 8.

FIGURE 6. The FBG sensors installation on the railway track

FIGURE 7. The FBG sensors are attached to the web of the railway track

FIGURE 8. The FBG sensors configuration after installation

Finally, the monitoring process involves gathering wavelength data from the FBG using the I-MON 256 Evaluation Software. Data collection occurs during two time periods: from 8:00 am to 9:00 am and from 4:00 pm to 5:00 pm. These time frames are selected to coincide with peak LRT train times when passengers are traveling to and from work. During each period, 10 data points are collected in real-time to establish patterns and consistency in the FBG data. Data collection takes place at the train station platform for safety purpose as depicted in Figure 9. A long fibre optic cable is used to connect the FBG to the train platform, allowing for the collection of wavelength data. The complete configuration of the setup for the FBG sensor monitoring system is illustrated in Figure 10.

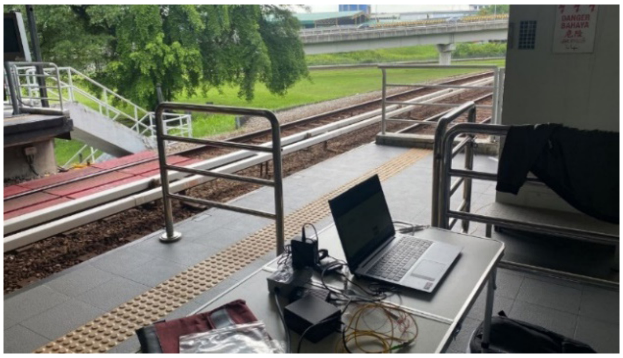

FIGURE 9. The platform location for the data collection

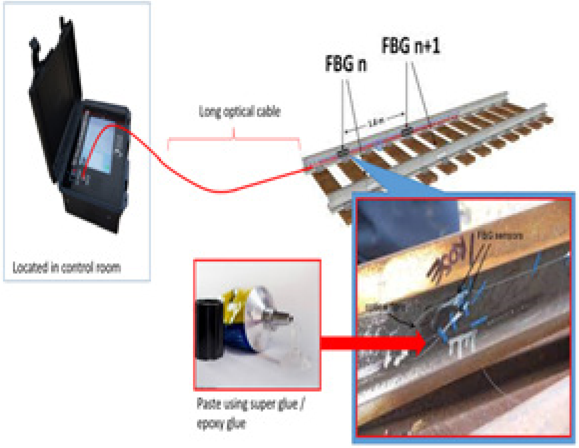

FIGURE 10. Complete setup for the structural monitoring for rail track

Several steps must be taken to ensure a disturbance-free and smooth monitoring process. Firstly, certain settings need to be configured in the software to collect the necessary data. Secondly, the light source must be adjusted to optimize the light's transmission through the fiber optic sensor without any loss. When monitoring the FBG sensor, various data points, in addition to wavelength, are collected to serve as references when comparing the data.

RESULTS AND DISCUSSION

The strain applied to the specimen was plotted against the change in wavelength detected by the FBG sensor. The R value is estimated to be 0.99, indicating that the value is within acceptable bounds. The slope displays the sensitivity of the FBG sensor, which is found to be 1.2 pm/micro strain (W. Balarabe et al. 2018). As shown in Figure 11 where the displayed sensitivity rating shows that the FBG sensor is suitable for use.

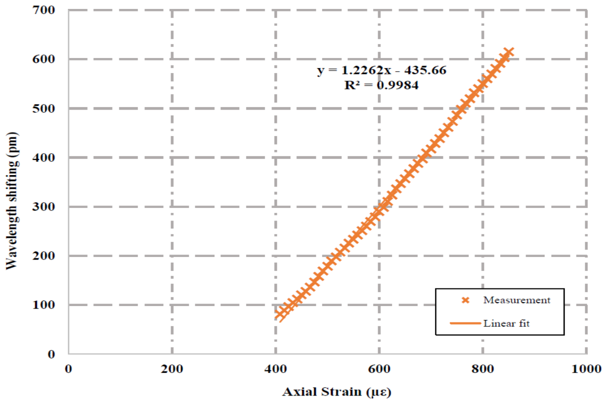

FIGURE 11. Calibration test result for tensile test

The data is collected each time a train travels over the location where the FBG sensor is attached, as illustrated in Figure 12. A long fibre optic cable is used to transmit the data from the FBG to the data acquisition system, where it is stored on a computer. When monitoring the FBG sensor, data is collected after the train has completely passed through the location in a time of 7 seconds, and this data is recorded in wavelength form. A total of 9 peaks are used as references to confirm that the train has passed over the sensor. Each peak corresponds to a set of 18 train wheels passing through the point. Figure 13 below displays the strain values (micro-strain) for each of the 18 wheels, with each peak representing a set of wheels passing over the FBG sensor.

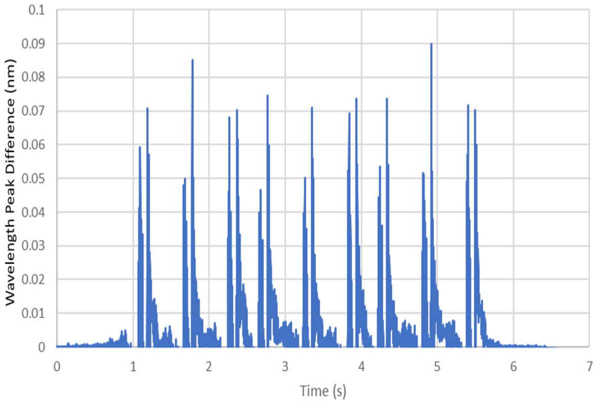

FIGURE 12. Wavelength peak difference data

When a train travels on a rail, the rail is subjected to various force components, categorized into three main directions: vertical, lateral, and longitudinal. These forces, originating from different directions, affect the material behaviour of the rail in distinct ways. The behaviour can be inferred from the strain, which is detected and determined using wavelength data from the FBG sensor.

Therefore, the strain graph exhibits different patterns due to vertical, lateral, and longitudinal forces acting on the rail. The highest forces originate from the vertical direction, as they result from the weight of the train being transmitted to the rail. These vertical pressures compress the rail, leading to a negative strain value, indicating that the rails undergo deformation due to compression forces. Lateral forces on the rail are generated by the loading of the wheels and the dynamic loads caused by wheel movement. These lateral forces result in bending and twisting of the rail, influencing its behaviour. The instability of the vertical FBG sensor pattern is caused by the lateral instability of the wheel-rail interface.

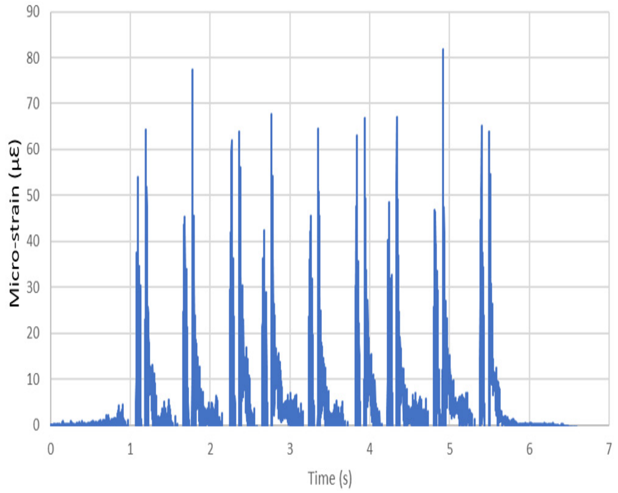

FIGURE 13. Microstrain data

CONCLUSION

The FBG sensor proves reliable for accurately monitoring strain data on the rail track. This strain data is valuable for researching and analysing the microstructure of the rail track. The pattern of strain data displayed in the graph shows significant variances between different positions. These variations in strain data result from the dynamic contact between the wheel and the rail. The specific variances in data values depend on factors such as the number of passengers or the mass of the train on the rail. Furthermore, it is essential to conduct the monitoring process in compliance with rules, regulations, and safety protocols to prevent any issues or injuries. The monitoring process yields results without complications, and the collected data is promising. With the use of the fibre optic system, data collection can occur remotely, reducing the need to monitor the rail track in close proximity, thereby mitigating the risk of injuries and accidents. In conclusion, this work has been successfully accomplished, utilizing the FBG sensor to measure direct strain in the web section of a rail. Through these measurements, the wavelength signal pattern can be analysed to study strain-stress and the components of forces occurring in a rail track application.

ACKNOWLEDGENT

The research has been funded by the Ministry of Higher Education (MOHE) Malaysia under the Fundamental Research Grant Scheme with grant number FRGS/1/2020/TK02/UKM/03/1.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Campanella, C., Cuccovillo, A., Campanella, C., Yurt, A., & Passaro, V. 2018. Fibre Bragg Grating Based Strain Sensors: Review of Technology and Applications. *Sensors*, *18*(9), 3115.

Dennison, C. R., Wild, P. M., Wilson, D. R., & Cripton, P. A. 2008. A minimally invasive in-fiber Bragg grating sensor for intervertebral disc pressure measurements. *Measurement Science and Technology*, *19*(8), 085201.

Du, C., Dutta, S., Kurup, P., Yu, T., & Wang, X. 2020. A review of railway infrastructure monitoring using fiber optic sensors. *Sensors and Actuators A: Physical*, *303*, 111728.

Hesser, D. F., Altun, K., & Markert, B. 2022. Monitoring and tracking of a suspension railway based on data-driven methods applied to inertial measurements. *Mechanical Systems and Signal Processing*, *164*, 108298.

Hesser, D. F., & Markert, B. 2019. Tool wear monitoring of a retrofitted CNC milling machine using artificial neural networks. *Manufacturing Letters*, *19*, 1–4. https://doi.org/10.1016/j.mfglet.2018.11.001

Mori, H., Tsunashima, H., Kojima, T., Matsumoto, A., & Mizuma, T. 2010. Condition Monitoring of Railway Track Using In-service Vehicle. *Journal of Mechanical Systems for Transportation and Logistics*, *3*(1), 154–165.

OBrien, E. J., Quirke, P., Bowe, C., & Cantero, D. 2017. Determination of railway track longitudinal profile using measured inertial response of an in-service railway vehicle. *Structural Health Monitoring*, *17*(6), 1425–1440.

Suhaimi, N. S., M. I.M. Ahmad, M. Z. Nuawi, A. K. Ariffin, and A. Z.M. Abdullah. 2023. "Structural Condition Assessment Based Strain-Stress Behaviour for Railway Welded Rail Joint Using Rosette Fibre Bragg Grating Optical Sensor." Results in *Engineering 19* (July): 101300. https://doi.org/10.1016/j.rineng.2023.101300.

Suhaimi, Nur Shufinah, Meor Iqram, Meor Ahmad, Mohd Zaki Nuawi, Ahmad Kamal, and Nur Azam Abdullah. 2022. "A Review on Modes of Failure of Rail Tracks Structure in Railway Transportation." ASEAN *Journal of Engineering and Technology 2* (1): 1–7. https://doi.org/10.26666/rmp.ajte.2022.1.2.

Tsunashima, H., & Hirose, R. 2020. Condition monitoring of railway track from car-body vibration using time–frequency analysis. *Vehicle System Dynamics*, *60*(4), 1170–1187.

Tsunashima, H., Mori, H., Ogino, M., & Asano, A. 2015. Development of Track Condition Monitoring System Using Onboard Sensing Device. *Railway Research - Selected Topics on Development, Safety and Technology*.

Udd, E., & Jr., W. S. B. 2011. *Fiber Optic Sensors: An Introduction for Engineers and Scientists* (2nd ed.). Wiley.

W. Balarabe, M. Hisham, A. R. Niraku, and I. S. H. Harahap, "Preliminary View of a Smart Technique for Materials Testing in the Laboratory using FBG Sensor," *MATEC Web Conf.*, vol. 203, 2018.

Yasukuni, Tanaka, M., & Ichikawa, K. 2001. High-Speed Track Inspection Car in New Dr. Yellow.