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Structural Health Monitoring of Gantry Girder using Fibre Bragg Grating Sensors

Pradeep Kumar. S, Beenamol. M

***Abstract:** Most of the industries have an in-build overhead crane that helps in lifting and transportation of heavy loads from one location of work place to another. Gantry girders are provided to support the loads transmitted through the moving wheels of the overhead cranes. The paper presents the structural health monitoring (SHM) practices that can be implemented for damage detection of gantry girder using Fiber Bragg Grating (FBG) sensors that are positioned on the key parts of the crane. The sensor is designed for monitoring the stress and strain of the girder. The alternating stress was determined based on distributed fiber bragg grating strain sensors. The analysis of the signals based on finite element (FE) models helps to determine the safety condition of the crane.*

***Keywords:** Gantry girders, structural health monitoring, Fiber Bragg Grating sensors, finite element models.*

I. INTRODUCTION

The gantry crane is widely used machinery in industries for loading and unloading of various heavy loads (Carlo et al., 2014). The critical asset gantry crane must be carefully monitored to ensure a reliable and safe operation. The fatigue loading of the machine causes major impact on the metal structures that degrades the quality of the entire machines and leads to numerous safety risks (Teti et al., 2010).It directly affects the main components of the structures. The gantry girder section of the crane suffers an extreme range of strain and stress due to maximum loading. The potential structure changes like fracture, corrosion, cracking occurs possibly within the structure. Gantry girder undergoes stress due to loads force acting longitudinally along the crane runway, Lateral Forces which act in a direction perpendicular to the gantry girder due to operation of the trolley, the stresses produced by the impact factor and the fatigue effect. The different load force exerted on the gantry girder is shown in figure 1. These create a serious problem on the work fulfillment and handling efficiency. Monitoring the safety and functionality of the gantry crane is critical to minimizing the cost associated with its repair. The SHM provides the means for assessing the condition of the structures. The information from an SHM system allows accurate prediction of the response due to extreme loading conditions. Most research has focused on assessing the damage detection mechanism. To generate the date necessary for the SHM various sensing methodologies have been adopted.

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* Correspondence Author
Pradeep Kumar. S, Research Scholar.at Noorul Islam Centre for Higher, Kumaracoil, Kanyakumari District, Tamilnadu, INDIA.
Dr. M. Beenamol, Associate Professor in the Department of Civil Engineering at Noorul Islam Centre for Higher, Kumaracoil, Kanyakumari District, Tamilnadu, INDIA.

The SHM based on vibration is utilized to monitor the dynamic response of the system by using random inputs (Doebling and Hemez, 2001). The SHM based on strain measurements is utilized to monitor the stress-strain response of the system by using conventional strain gauges.

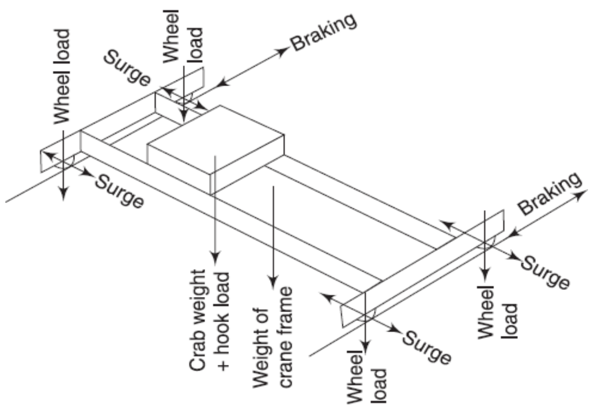


Figure 1: Loads on Gantry Girder

An optical fiber Bragg grating-strain sensor is used particularly for the strain-based SHM measurement (Takeda et al., 2013). The complex structures make use of advanced wireless sensor networks to mitigate the complications caused by the wired networks (Lynch and Loh, 2006). The most established techniques for SHM is Ultrasonic Guided Waves (UGW) testing that is carried out using transducers that transforms applied voltages to strain waves (Shull, 2002). These waves are sensed to measure the response. To capture the changes resulting from the damage the sensors must be in proximity. A low cost FBG sensor is used in this work for structural monitoring of gantry girder. The factors obtained from the sensors are subjected to finite element modal analysis that provides better information on the structural condition.

II. LITERATURE REVIEW

Steel structures have a lot of benefits, they are simple to install and have a less construction period so they are commonly used in construction projects. Research indicates that the number of steel constructions is increasing by around 5% to 8% annually. When the steel structures develop quickly, there are many diplomas of accidents (Han and Jin, 2003), particularly crash accidents, such as the roof rack of steel structures collapsed during the construction activity. Even though steel structures have outstanding seismic performance, the damage is probably initiated by extreme loads. The steel structural integrity must, therefore, be monitored. For engineering infrastructure, the process of adopting a damage identification strategy is referred to as SHM. Furthermore, SHM for steel constructions could decrease the effect of such disasters. As a result, SHM is becoming increasingly essential for steel buildings. Current techniques for detecting damage are either visual inspection or experimental techniques such as acoustic emission, ultrasonic techniques, etc. It requires that the damage proximity is already recognized and the part of the inspected structure is easily available. The present practice issue is because of the shortage of skilled inspectors and the inevitable delay in time created by in-depth structural analysis. As a consequence, there has been a need for extra techniques to detect worldwide damage that can be implemented for complicated buildings. Techniques for identifying global damage can be categorized as "method based on response" or "method based on model." The response-based technique relies only on structural experimental response information; while the model-based technique assumes that for damage detection, a specific mathematical design model is accessible (Fan, 2011). The response-based technique of damage detection includes the structural system's static tests from which the answers are measured owing to internal excitations. Because the structural parameters are functions of the dynamic and static reactions of a structural system, these parameters can be recognized using the dynamic and static characteristics adjustments. It is worth mentioning that using the above techniques in SHM is not compulsory. Some scientists combined modal as well as static damage recognition reactions (Lee et al., 2010). Health monitoring has indeed expanded due to advances in microprocessors.

III. PROPOSED METHODOLOGY

The SHM in the proposed system make use of FBG sensors that is embedded on the gantry girder section of the crane for inspection. Sensor is optimally positioned on the hotspot areas that are probable to initiate damage. Sensors are subjected to various factors such as load, temperature and electromagnetic field. Strain signal is collected by sensors and transmitted to the data processing unit. Static strain measurements are defined from distributed sensors and are discussed about data processing and extraction of features. Based on the extracted characteristics, SHM research is implemented for evaluation based on models of finite element (FE) and structural behaviour assessment.

IV. DESIGN OF HARDWARE SYSTEM

The structure employs the fibre grating strain sensor with the self-compensation temperature. The sensor is designed to monitor the gantry girder strain. The sensor has greater measurement resolution and precision, outstanding temperature compensation capacity, due to the use of strain sensitizing technique (Yong, 2007). Table 1 shows its technical parameters of the sensors.

Table 1: Parameters of Fibre Grating Strain Sensors

Parameter	values
Range	± 1300 με
Strain measurement coefficient	0.93 με/pm

For the data signal acquisition from the fiber grating sensors a signal demodulator is used and its parameters are tabulated in table 2.

Table 2: Parameters of signal demodulator

Parameter	values
Dynamic range detection	Output power： 0 to −30dB detected for the input power of up to -
	80dB
Strain resolution	0.2με

V. EXPERIMENTAL INVESTIGATIONS

The paper is intended to analyze the damage detection in the girder section of the gantry crane using FBG sensor array based on static testing. FE model analysis is performed from the observational measurements based on the data recorded by different sensors as shown in figure 1. The structural parameters are estimated using the FBG sensor series static macro-strain distribution by means of strain gauges.

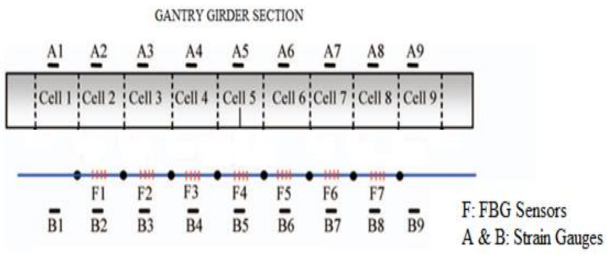


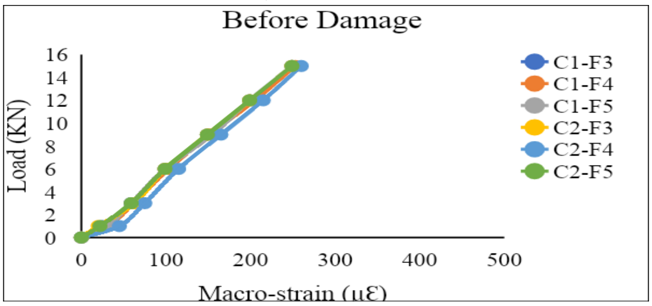
Figure 2: Sensor placement on the girder section

The FBG sensors are positioned in girder from cell 1 to cell 9. The FBG sensors F3, F4 and F5 are installed in the most susceptible bending sections. The load and macro-strain from F3, F4 and F5 for the beams before and after damage identification is made from a comparative analysis. If no damage occurs, the data from these three sensors should be the same and should increase as the damage extent increases.

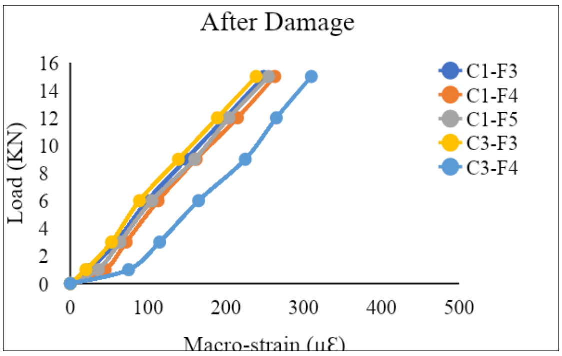
Table 3: Correlation coefficients measurements

Sensor	F1	F2	F3	F4	F5	F6	F7
C1	0.99 9402	0.99 9965	0.99 9952	0.99 9910	0.99 9887	0.99 995	0.99 9825
C2	0.99 9896	0.99 9861	0.99 9969	0.99 9973	0.99 9961	0.99 9974	0.99 9793
C3	0.99 9864	0.99 9899	0.99 9876	0.99 9881	0.99 9781	0.99 9634	0.99 9885

The figure 3 shows that the F3, F4 and F5 measurements for the intact beam agree well, while those from F4 show an apparent departure from the F3 and F5 information for the damaged beams. The correlation coefficients of the macro-strain measurements are calculated for various load steps and shown in the table 3.



(a)



(b)

Figure 3: Load versus macro-strain comparisons (a) Before Damage (b) After Damage

VI. CONCLUSION

The strain analysis has a high potential in assessing the dynamic performance of the gantry cranes since the strain measurements are directly obtained from the FBG sensors. The use of strain sensitizing technique provides an excellent measurement resolution owing to temperature compensation. In this paper, the experimental analysis of girder section of the gantry crane is carried out using arrays of FBG sensors. Relations achieved between load and static macro-strain distributions using the features from the FBG sensors helps to identify structural damage. An enhanced SHM approach on steel structures is made based on static macro-strain distribution, including detection of structural damage.

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AUTHORS PROFILE

Pradeep Kumar. S, is currently a Research Scholar.at Noorul Islam Centre for Higher, Kumaracoil, Kanyakumari District, Tamilnadu, INDIA.

Dr. M. Beenamol is an Associate Professor in the Department of Civil Engineering at Noorul Islam Centre for Higher, Kumaracoil, Kanyakumari District, Tamilnadu, INDIA. She has published over fourteen national and international journals and her research in focused on Wavelet Based Seismic Analysis of Structures