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Application of Fiber Bragg Grating Sensors for Dynamic Tests in Wind Tunnels

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Abstract | This paper presents an introduction to Fiber Bragg Grating (FBG) sensors and a typical application for dynamic tests in wind tunnels. Bench tests were carried out to measure the dynamic response of a cross-flexure pivot using FBG sensor and a conventional strain gage sensor simultaneously. The results suggest that FBG sensors, which are much easy to handle as compared to strain gages, can be effectively used for measurement of dynamic derivatives in a wind tunnel.

Keywords: *Damping derivatives, Dynamic testing, Wind tunnels, Forced oscillation, FBG sensors*

Nomenclature

f	Frequency of oscillation, Hz
n	Index of refraction
λ	Wavelength of light, meter
Λ	Period of n variation of FBG sensor
ζ	Damping ratio

1 Introduction

Many researchers have demonstrated that FBG sensors can be used to measure strain of a structure under static as well as dynamic loading conditions. High resolution of FBG sensors provides reliable data while comparing with the traditional Resistance Strain Gage (RSG) sensors. Application of FBG sensors to assess dynamic response is well established in civil structures[1–3], but is not popular in wind tunnel applications. One of the main advantages of FBG sensors is that they can be deployed in large numbers without wiring problems associated with strain gages. FBG sensors have the advantage of sequential measurement, which makes it possible to obtain large amount of data from a single fiber, making real time measurement of large amount of data feasible. FBG technology has a number of advantages over the conventional strain gauges, e.g., small size, immune to electromagnetic interference, intrinsically passive (no power supply required) and long term stability. FBG works on the principle of change of wavelength of reflected light. The central wavelength of the reflected component satisfies the Bragg relation: $\lambda_{refl} = 2n\Lambda$, where n the index of refraction and Λ the period of the index of refraction variation. Due to temperature and strain dependence of the parameters n and Λ, the wavelength of reflected component change as a function of temperature and/or strain. This dependency is well known and allows determination of temperature or strain from the reflected FBG wavelength. FBG sensors have been used for force measurements in wind tunnels in place of conventional strain gauge balances, but the main disadvantage seems to be routing of cables inside the balance.

2 FBG Sensors

A sensor based on Fiber Bragg Grating is an optical fiber where the refractive index in the fiber's core has an induced period variation so as to produce a 'grating' on which the light undergoes the Bragg diffraction.[4] In this way, the reflected spectrum has a peak centred on a wavelength λB that is a function of Λ, the period of the refraction index changing. With more details, if the period of refraction changes due to an external strain ε and/or a temperature variation ΔT, the Bragg wavelength changes according to the law[5]:

$$\Delta\lambda_B = k_\varepsilon \varepsilon + k_T \Delta T$$
$$K_\varepsilon \approx 1.2\ pm/\mu\varepsilon$$
$$K_T \approx 10\ pm/K^0$$

FBG used in sensors mostly rely on the spectral analyses of reflected light wavelengths.

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Bragg resonant wavelength is determined by various factors applied on the FBG, which affect effectively refractive index or grating periodic variation; therefore, it is an indirect measurement resulting from modifying physical or geometrical properties of the FBG. Among the affected factors are temperature, mechanical deformation (e.g., stretching, pushing, bending, and applying shear stress) to the fiber Bragg grating. In real applications, it is difficult to separate the effects of measured and parasitic variables that affect the same parameter (e.g., when the fiber Bragg grating deformation is measured, temperature also affects reflected light wavelengths). Applied stress on the fiber Bragg grating in the direction of the fiber axis results in the extension of its physical dimensions and in the change of the periodic variation; however, the influence of temperature also affects physical dimensions due to thermal expansion.

3 Features of FBG Sensor

FBG sensors measure strain directly, whereas metal foil gages measure displacement and converting to strain; this direct measurement provides advantage over RSG while measuring strain. FBG performance is already evaluated in case of material like glass and carbon fiber reinforced composite, and concluded its better suitability. In the present study, efforts have been made to characterize its performance in case of material like steel and aluminium. FBG provides some superior qualities making them very useful for wind tunnel environment: As space is a major constrain while testing models in wind tunnel, FBG find great advantage due to its very small size and lightweight. FBG are completely immune to electromagnetic interference, perform similar to strain gages with the additional advantage that multiple sensors can be installed on the same fiber and can be read out at once. These sensors have a wide use in many fields such as industry, space technology, health care, civil nuclear industry. They can be distributed over a long distances up to few tens of kilometres. Figs. 1 and 2 show schematics of a FBG sensor and FBG system.

4 Experimental Set-up

Experiments were performed on a Cross-Flexure Pivot (CFP) in a rigid rig designed for the measurement of dynamic derivatives using forced oscillation technique in the 1.2 m wind tunnel at the National Aerospace Laboratories, Bangalore. Fig. 3 shows a photograph of the CFP equipped with RSG on one side and FBG sensor on the other side.

5 FBG Installation

FBG sensor was installed on the adjacent arm of the CFP where resistance strain gage was already in place. This provides one to one comparison of strain data measured by both the sensors. Placing of FBG sensor was much easier compared to fixing of the strain gage, required less time and provided ease of cabling. FBG needed more attention while

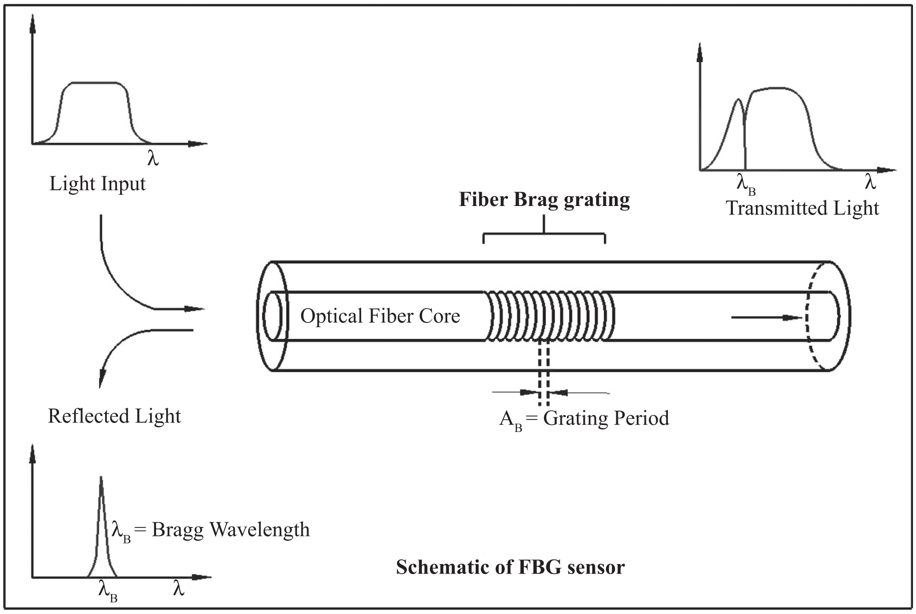

Figure 1: Schematic of FBG sensor.

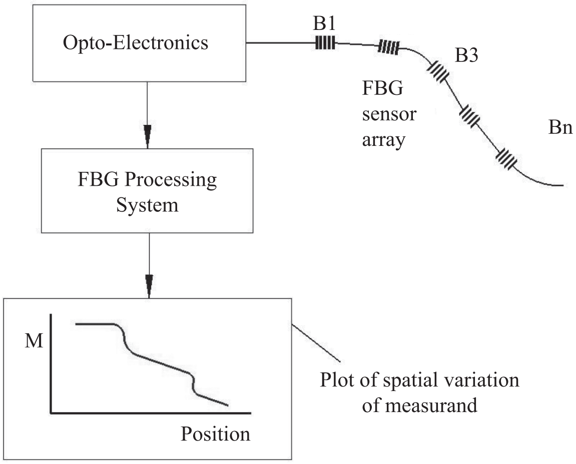

Figure 2: Schematic of FBG system.

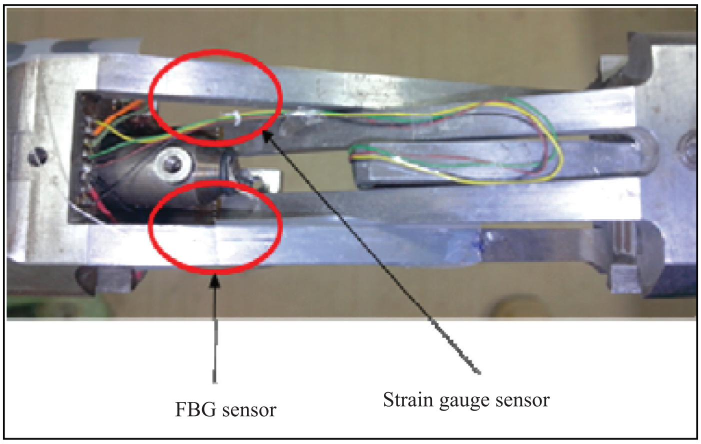

Figure 3: Photograph of Cross Flexure Pivot with installed FBG and RSG.

routing fiber cable at sharp bends to preserve internal reflection of light.

6 Data Acquisition

The FBG data acquisition system consisted of an optical interrogator (4 channels, 1 kHz) to measure the Bragg sensor signal [6]. The fiber was illuminated with laser light at central wavelength 1547 nm and the light reflected back from the sensor to the interrogator stored in the system for analyses. The RSG data acquisition system uses a National instrument card with appropriate signal conditioning. Strain gage data were obtained using National Instrument analog voltage measuring card (NI 9239) with pre-amplifier of gain 1000 and 50 Hz low pass filter. Impulse response data were obtained using a high-speed 4-channel interrogation system for FBG sensor arrays (DC to ~1 kHz) for all channels simultaneously.

7 Results

Fig. 4 shows typical complete data (unfiltered) from the FBG when the flexure was instantaneously released after a static deflection of about 1°.

Figs. 5–7 show zoomed-in data from both sensors. The results are identical, but for phase difference of 180°. This phase difference arises essentially because of the way of mounting the FBG on the flexure: when the RSG is in tension, FBG is in compression and vice versa. During free-oscillation tests, since the ratio of successive amplitudes alone is used for determining the logarithmic decrement, time to half-amplitude and damping derivatives, data from FBG can be considered as identical to that from RSG. Detailed analyses of the signals yielded identical results: for example, natural frequency of the CFP was found to be 11.6108 and 11.6107 Hz respectively from FBG and RSG sensors respectively, thereby

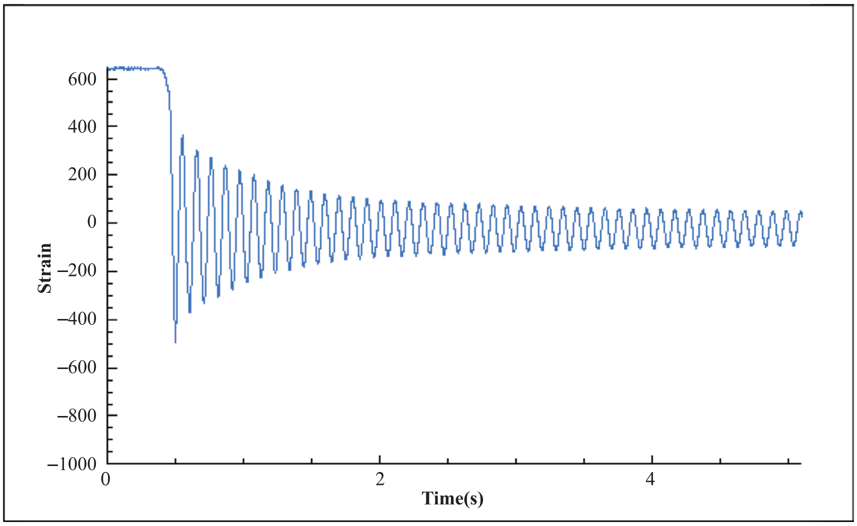

Figure 4: Typical unfiltered data from the FBG sensor.

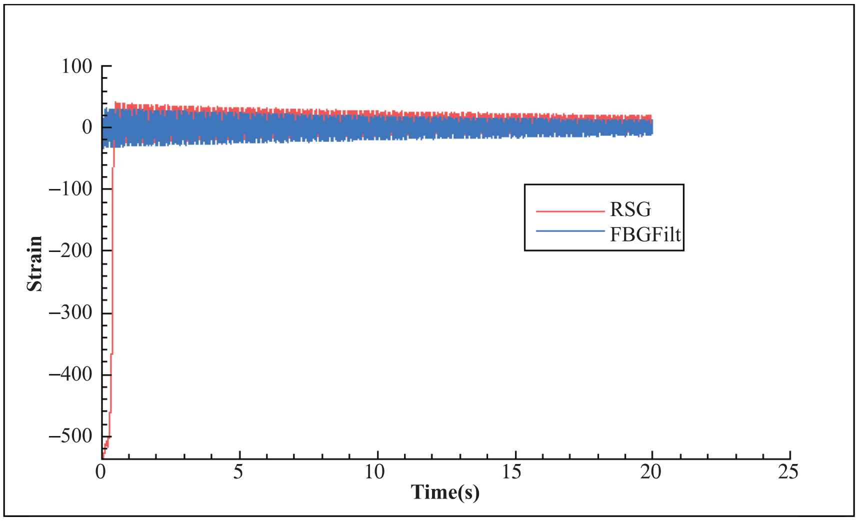

Figure 5: Comparison of data from FBG and RSG sensors.

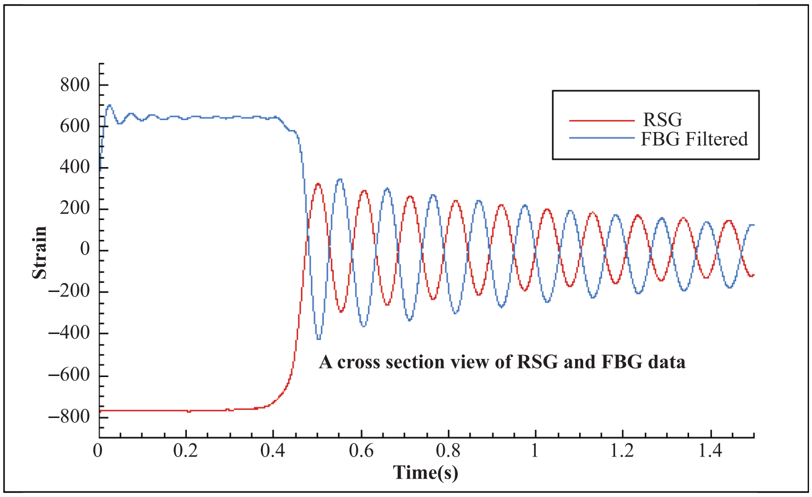

Figure 6: Close-up of data from both the sensors after instantaneous release.

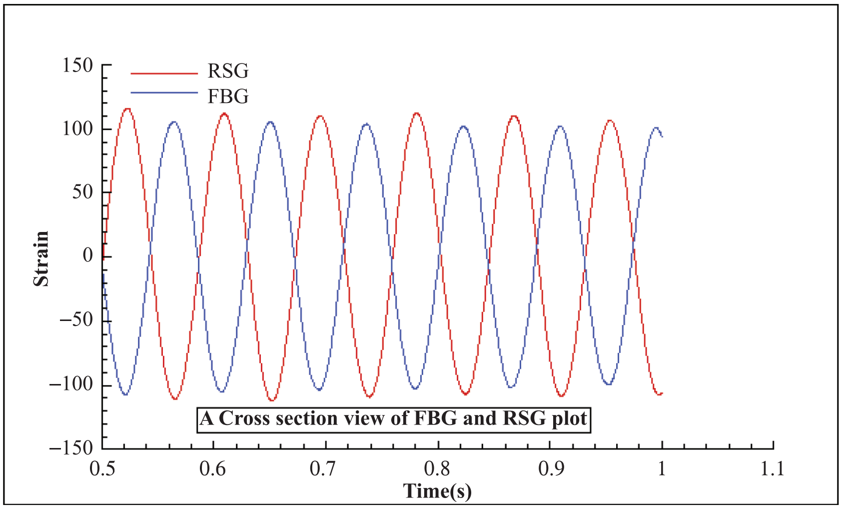

Figure 7: Close-up of data from both sensors indicating damped oscillations.

establishing that FBG sensors are as accurate as strain gages for dynamic measurements using free-oscillation technique.

8 Possible Application of FBG in Forced-Oscillation Technique

In forced oscillation technique for determining pitch/yaw damping derivatives, it is essential to maintain small amplitude oscillations of the model at phase-resonance conditions in the wind tunnel. Hence, the phase difference between the model excitation (which can be achieved using an electrodynamic shaker) and the response of the model must be maintained close to 90°. Since the FBG has a much higher frequency response, signals from the FBG can be used to provide faster feedback to the control system to obtain the appropriate command signal to modify the excitation frequency to achieve resonance condition. This may be expected to achieve faster convergence to resonance compared to feedback from RSG sensors and hence advantageous in short-duration test facilities such as blowdown type wind tunnels.

9 Conclusions

The performance of Fiber Bragg Grating sensors in dynamic strain measurements was compared against that of conventional Resistance Strain Gages. Tests were carried out by acquiring data simultaneously by mounting both the sensors on opposite sides of a Cross Flexure Pivot spring designed for measurement of dynamic derivatives in the NAL 1.2 m wind tunnel. Impulse response from both the sensors were studied and found that the frequency of oscillations measured from FBG sensor was almost the same as that from the RSG sensor.

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