Advanced Fiber Optic Sensors
Capable of Multiparameter Sensing

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ABSTRACT

This paper outlines improvements that have been made in a multiaxis fiber grating strain sensor that can also be used in certain cases to measure temperature. The current status and future prospects for these sensors are outlined.

Keywords: fiber gratings, multiaxis strain, health monitoring

1. INTRODUCTION

Early efforts to implement fiber gratings as sensors were usually confined to the measurement of a single axis of longitudinal strain or temperature. However for many manufacturing, process control functions and structural health management systems it would be highly desirable to be able to measure more than one axis of strain. In particular it would be highly desirable to measure transverse as well as axial strain. One of the first papers to address this problem was written by Valis and Measures where a multiaxis strain sensor was implemented by forming a strain rosette formed by three separate fiber etalon sensors [1]. This provided one of the first demonstrations of multiaxis strain sensors. Its major limitations were that it involved three separate sensors and a design that was practically limited in terms of cost effectiveness. Singh and Sirkis [2] and Sirkis and Lo [3] also began to look at multiple components of strain using combinations of intrinsic and in line fiber etalons.

Ideally in many structures one would like a fiber sensor that could measure both transverse axes of strain, axial strain and temperature while being easily multiplexed. An approach to solving this problem is to use dual overlaid fiber gratings at different wavelengths written onto polarization preserving fiber [4-5]. When a fiber grating is written onto birefringent optical fiber that may be polarization preserving two fiber gratings result one along each of the polarization axes because of the difference in index of refraction. Thus by writing two fiber grating effective four fiber gratings result and one can obtain four equations in four unknowns.

When transverse load is applied along one of the axes it induces strain causing the effective index of refraction to change resulting in a spectral shift. The net transverse strain is indicated by the relative peak to peak spectral difference.

When longitudinal strain or temperature is applied each set of dual peaks corresponding to each fiber grating act in a manner that is very similar to an ordinary single fiber grating.

2. SENSING APPLICATIONS OF THE TRANSVERSE FIBER GRATING STRAIN SENSOR

The transverse fiber grating sensor can be used to measure a host of different environmental parameters. For example corrosion could be measured by placing a jacketing material inducing transverse stress over the sensor. As corrosion caused the jacket to weaken transverse strain would be reduced and the extent of corrosion measured. A similar approach could be used to measure hydrogen. Basically the idea is to coat the fiber with palladium or another hydrogen sensitive material and look at changes in transverse strain with exposure to hydrogen. Jim Sirkis at the University of Maryland is using this approach for hydrogen sensors using axial strain in single fiber gratings.
Blue Road Research is also looking at transverse strain sensors to measure ice formation and transverse loading in composite parts as is recorded in another paper in this proceedings.

All of these transverse fiber grating sensors may be multiplexed using a series of commercial demodulation systems as shown in Figure 1. Here different types of transverse fiber grating sensors have been multiplexed in line using wavelength

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division multiplexing. Blue Road Research is working with a number of companies to interface their commercial fiber grating demodulation systems with Blue Road Research transverse fiber grating sensor products. Typical requirements are to separate spectral peaks with separation on the order of 0.3 nm with better than one picometer resolution. In particular Research International is upgrading their commercial Ferret II scanning etalon system to the Ferret III to be able to demodulate transverse fiber grating sensors by measuring peak to peak separation to less than a picometer. Micron Optics is also developing a system with improved resolution that also can meet this requirement. Traditional optical spectrometers may also be used to measure peak to peak separation and Blue Road Research is working with Ando optical spectrometers to develop interface software and attain the necessary measurement accuracy. This software may also eventually be ported to support Hewlett-Packard and Anritsu optical spectrometers as well.

These sensors and demodulators could then be deployed to support structural health monitoring for a variety of aerospace and civil structure platforms. Figure 2 shows an example of how these sensors might be configured to support health monitoring of a launch gantry as well as the launch vehicle itself.

In some case the number of fiber sensors used to support such a health monitoring system could be quite large, perhaps involving thousands of fiber grating sensors. In this case a modular architecture similar to that shown in Figure 3 could be employed. Many strings that could consist of tens of sensors each could be supported by a single demodulation system operating in concert with an optical switch. In a quiescent mode of operation all of the fiber grating sensors could be sequentially scanned on a low resolution mode. When damage started to occur in any specific region, detailed assessments could be made by switching to a higher resolution mode. On an aircraft or spacecraft a Pave Pillar architecture similar to that of Figure 4 may be used where the outputs of these modules could be fed into a vehicle health management bus. The information would then be processed and distributed throughout the vehicle as needed.

3. COMMERCIALIZATION EFFORTS

Blue Road Research has undertaken a series of efforts to improve the multiaxis fiber grating strain sensor to allow its introduction as a commercial products suitable for embedding in composite materials. Near term application areas that are being pursued by Blue Road Research customers include monitoring the manufacturing process and structural health monitoring.

To enable these applications Blue Road Research multiaxis fiber grating use a polyimide coated, bend resistant polarization preserving fiber that has been shown to be highly compatible with writing dual overlaid fiber gratings. Fiber gratings are written onto these fibers, their position marked to within a mm and the region of polyimide stripped for fiber grating fabrication is then recoated with polyimide. Efforts have been made to mark the orientation of the fiber during the fabrication process. Transverse load testing established that the initial process used was not accurate enough for transverse strain measurement purposes. While additional efforts are underway to improve this process and alternative technique has been developed by Blue Road Research that involves physically loading the polyimide fiber transversely to establish the axis orientation to less than 5 degrees. A removable soft epoxy tab is then placed on the fiber which provides the end user with an easy means of orientation prior to installation into a composite part.

Blue Road Research has fabricated 60 commercial multiaxis fiber grating sensor and has sold approximately 50 units for applications that involve composite manufacturing, structural health monitoring of bridges, and corrosion detection systems. Internal Blue Road Research projects involving these sensors include nondestructive evaluation of adhesive joints and chemical fiber optic sensors.

4. SUMMARY

Efforts to commercialize a multiaxis fiber grating sensor are ongoing and recent project effort are described. These sensors have widespread application to composite manufacturing, nondestructive evaluation and structural health monitoring.

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