Fiber Optic Sensing Monitors Strain and Reduces Costs

Originating Technology/NASA Contribution

In applications where stress on a structure may vary widely and have an unknown impact on integrity, a common engineering strategy has been overbuilding to ensure a sufficiently robust design. While this may be appropriate in applications where weight concerns are not paramount, space applications demand a bare minimum of mass, given astronomical per-pound launch costs. For decades, the preferred solution was the tactic of disassembly and investigation between flights. Knowing there must be a better way, Dr. Mark Froggatt, of Langley Research Center, explored alternate means of monitoring stresses and damage to the space shuttle.

While a tear-it-apart-and-have-a-look strategy was effective, it was also a costly and time consuming process that risked further stresses through the very act of disassembly and reassembly. An alternate way of monitoring the condition of parts under the enormous stresses of space flight was needed. Froggatt and his colleagues at Langley built an early-warning device to provide detailed information about even minuscule cracks and deformations by etching a group of tiny lines, or grating, on a fiber optic cable five-thousandths of an inch thick with ultraviolet light. By then gluing the fiber to the side of a part, such as a fuel tank, and shining a laser beam down its length, reflected light indicated which gratings were under stress. Inferring this data from measurements in light rather than in bonded gauges saved additional weight. Various shuttle components now employ the ultrasonic dynamic vector stress sensor (UDVSS), allowing stress detection by measuring light beamed from a built-in mini-laser.

By measuring changes in dynamic directional stress occurring in a material or structure, and including phase-locked loop, synchronous amplifier, and contact probe, the UDVSS proved especially useful among manufacturers of aerospace and automotive structures for stress testing and design evaluation. Engineers could ensure safety in airplanes and spaceships with a narrower, not overbuilt, margin of safety. For this development, in 1997, Discover Magazine named Froggatt a winner in the "Eighth Annual Awards for Technological Innovation" from more than 4,000 entries.

Partnership

Froggatt continued his work in monitoring stresses of fiber optic components, accessories, and networks through optical monitoring at Luna Technologies, a division of Luna Innovations Incorporated, based in Blacksburg, Virginia. At Luna, he headed a team that developed the Optical Backscatter Reflectometer (OBR) with distributed sensing. The OBR is a fiber optic diagnostic tool that locates and troubleshoots splices, breaks, and connectors in fiber assemblies. In addition, it transforms standard telecom-grade fiber into a distributed strain and temperature sensor.

In 2002, Luna Innovations Incorporated entered into a licensing agreement with NASA for patent rights to products developed from Froggatt's earlier work on the UDVSS. Since that initial licensing, Luna has released the Optical Vector Analyzer (OVA), Distributed Sensing System (DSS), and the OBR platforms.

Product Outcome

Luna now has several lines of sensing and instrumentation products that are sold under the branded name of Luna Technologies. The Luna Technologies brand offers advances in optical test products helping the communications industry to increase productivity and improve component characterization while dramatically reducing the development process and production costs. Fiber optic sensing instruments includes the OVA group, a set of instruments for linear characterization of single-mode optical components, and two different techniques for distributed sensing: the DSS, which uses Fiber Bragg Gratings (FBG), and the OBR, which uses standard telecom-grade optical fiber.

First profiled in *Spinoff* 2002, the OVA is the first instrument on the market that is capable of full and complete all-parameter linear characterization of single-mode optical components. The OVA further evolved into a fast, accurate, and economical suite of tools for loss, dispersion, and polarization measurement of modern optical networking equipment, including FBG, arrayed waveguide gratings, free-space filters, tunable devices, amplifiers, couplers, and specialty fiber.

The DSS is a fiber optic sensing tool for taking distributed measurements of temperature and strain. The DSS uses swept-wavelength interferometry to simultaneously interrogate thousands of sensors integrated in a single fiber. These sensors consist of discrete FBG point sensors which can each reflect the same nominal wavelength. As such, the sensors can be fabricated on the draw tower, eliminating the need for individual grating fabrication. DSS applications include structural monitoring for naval, aerospace, and civil structures; temperature profile monitoring in extreme environments; pipeline shift and leak detection; and electrical power line sag and temperature monitoring.

The OBR offers unprecedented diagnostic capabilities and is a true high-resolution optical time domain reflectometer designed specifically for qualifying fiber components, modules, and cable assemblies for telecommunications, avionics/military-aerospace, and fiber-sensing applications. Through distributed sensing, the OBR can transform standard telecom-grade fiber into a high-spatial-resolution strain and temperature sensor. Using swept wavelength interferometry (SWI) to measure the Rayleigh backscatter as a function of length in optical fiber with high-spatial resolution, the OBR measures shifts and scales them to give a distributed temperature or strain measurement. The SWI approach enables robust and practical distributed temperature and strain measurements in standard fiber with millimeter-scale spatial resolution over hundreds of meters of fiber

The Optical Vector Analyzer is the first completely integrated solution for measuring critical performance parameters of fiber optic components and modules.

with strain and temperature resolution as fine as 1 µstrain and 0.1 °C.

As with the other fiber optic monitoring tools, OBR provides isolation of faults and problems well before final testing, saving hours in rework and expenses in yield loss.

These abilities netted the OBR some prestigious awards:

- 2005 Lightwave "Attendees' Choice Award" in the Test Equipment category for the second consecutive year.
- 2005 Frost & Sullivan "Optical Product of the Year Award," as the industry's most sensitive frequency domain reflectometer.
- 2007 "R&D 100" award from the editors of R&D Magazine as one of the 100 most technologically significant new products introduced into the marketplace in the last year. Past "R&D 100" awards acknowledgements have included the automated teller machine (ATM), the fax machine, the NicoDerm antismoking patch, and high-definition television (HDTV).

"The 'R&D 100' award provides a mark of excellence known to industry, government, and academia as proof that a product is one of the most innovative of the year across a broad range of technologies," said Brian Soller, president of the Products Division at Luna. "This is the first year Luna has submitted an award nomination to the R&D 100, and we are honored to have our test and measurement instrument selected as part of this truly elite group."

Released in March 2007, the OBR 4400 is an upgraded version of the OBR instrument, with enhanced capabilities in a more compact design. Range has been increased to 2 kilometers, still with millimeters of resolution, and users can monitor the effects from component-level heating in optical amplifiers to strain and load redistribution in aircraft harnesses. Other applications include temperature monitoring inside telecommunications cabinets and enclosures, and a feature that allows users to identify the location in fiber assemblies simply by touching the fiber. With a small, easily transportable platform, the OBR 4400 provides the user with precision reflectometry and unprecedented optical-module inspection and diagnostic capabilities. Luna Technologies also recently introduced a tunable laser, a precision reflectometer, and an optical switch to round out their product offering. ❖

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