Appeal to the sensors

For years the aerospace industry has relied on foil strain gauges to test materials. But an emerging technology, fiber sensing, is offering advantages over more traditional methods

BY DAWN K. GIFFORD

While each foil gage requires at least two copper wires for a single point of sensing, a distributed fiber-optic sensor can provide thousands of sensing points with a single optical fiber and connection. Optical fiber sensors are immune to electromagnetic interference and they are efficient and cost effective to install. And because they are small and lightweight, they have little effect on the structure being tested.

With distributed sensing using optical backscatter reflectometry, introduced by Luna Technologies in 2004, strain can be measured at any point along the fiber with spatial resolution as fine as a few millimeters.

This makes it possible to measure the strain profile of structures at many locations rather than at a few points. This is beneficial for the aerospace industry, which is increasing the use of composite materials and their complex strain profiles. The use of composite materials is being pursued to achieve material and structural component-tailored design and to reduce the number of structural components, which leads to a valuable reduction in aircraft weight, and more efficient and environmentally friendly aircraft. The challenge in the application of composite materials resides in their complex nature at the material level, leading to the mentioned complex strain profiles. High-resolution distributed fiber sensing is ideal for measuring the non-uniform strain profiles in composite structures and identifying defects within the composite parts well before fatigue turns to catastrophe.

Despite these advantages, and though fiber sensing has been available in some form for more than 20 years, it has not yet been commonly adopted in aerospace. However, due to the advantages of and advances in the available technology, distributed fiber sensing is emerging as a desirable method for aerospace testing.

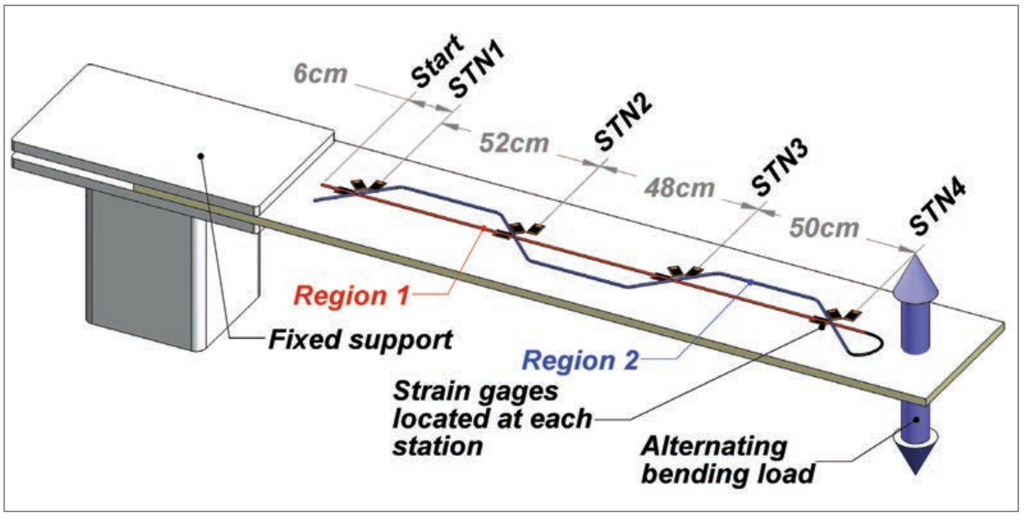
TESTING THE OPTIONS

One common concern with an emerging sensing technology is validating its performance against known techniques. The National Research Council Canada (NRC) recently performed independent comparative testing of Luna's distributed fiber sensing versus traditional foil gages on a test rig designed to simulate loading on a representation of a solid aircraft wing spar-web structure. NRC operates Structural Health Monitoring test facilities for load monitoring and damage detection sensor testing and validation. These testbeds present a range of structural complexity, from spar structures to the intricacies of the outer wing of a fighter jet.

The test, conducted earlier this year consisted of two aluminum beams clamped to a central pedestal, acting as the simulated wing root. The beams were loaded at the tips in a simple cantilever configuration. Though the pressure loading experienced by an aircraft wing would be better simulated with a distributed loading configuration, such a complicated setup was not required for this initial test.

An optical fiber to be used as a continuous sensor was bonded to one side of the beam, first running along the center line from root to tip and then returning in a pattern crossing over the center line at a 45° angle in four locations, running from tip to root. Foil strain gage rosettes were placed at the four points along the center of the beam on the underside opposite the fiber. Luna's optical backscatter reflectometer was used to measure the strain along the fiber sensor, while the MTS data acquisition component of the actuation equipment was used to acquire the strain data. The figure below illustrates the test configuration.

Data was collected with the fiber sensor and the foil gages with the beam fully deflected 4in up at the tip (maximum strain) and deflected 2in



LEFT: Test configuration showing fiber layout and strain gauge locations

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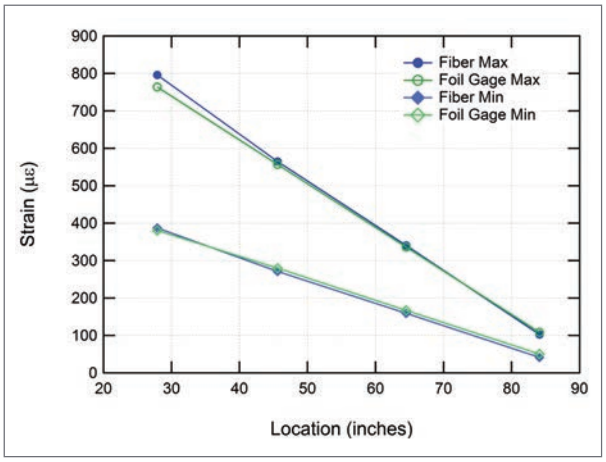
	Location (inches)	Fiber Max (με)	Foil Gage Max (με)	Difference (με)	% Difference
Station1	27.9	796.1	763.9	32.2	4.2
Station 2	45.6	564.7	556.9	7.8	1.4
Station 3	64.5	340.4	336.0	4.4	1.3
Station 4	84.1	102.6	108.5	-5.9	-5.5

	Location (inches)	Fiber Min (με)	Foil Gage Min (με)	Difference (με)	% Difference
Station1	27.9	387.3	380.3	7.0	1.8
Station 2	45.6	270.9	279.8	-8.9	-3.2
Station 3	64.5	159.2	166.9	-7.7	-4.6
Station 4	84.1	41.4	50.4	-9.0	-17.9



ABOVE: Comparison of foil gauge results with results from Luna fiber sensor at four locations along the test article. The max strains were taken with the beam deflected upward 4in at its tip, while the minimum strains were recorded when the beam was deflected downward by 2in

down at the tip (minimum strain) and compared at four locations in the fiber corresponding to the placement of the foil gages.

The figure above shows the plot of the maximum and minimum bending strains measured with both sensor types at each of the four stations along the span of the beam. The displayed strains are absolute values as the foil gage and fiber sensor were on opposite sides of the beam and therefore experienced strains with opposite signs.

The results showed good correlation between the two sensor types, with strain measurements differing typically by less than 10 microstrain. The highest difference of 32 microstrain occurred in the maximum loading condition at station 1 near the root of the beam. The percent difference was lower than 6% in all cases except for the minimum strain at station 4. The percent difference in this data point is high only because the overall strain value at the beam tip was low. Tables 1 and 2 (above) show the comparative results.

FATIGUE LIFE COMPARISON

Composite structures used in aerospace are often tested at strain levels higher than a few thousand microstrain, a point where metal foil gages are known to drift and eventually fail by fatigue[10,11] (of electrical circuitry, bonding, connectors, etc.). Optical fiber, however, is made of fused silica, which has a high fatigue life.

Separate from the Canadian research, Luna recently performed tests demonstrating the fatigue life of fiber sensors versus foil gages for high-strain fatigue life testing. A fiber sensor was bonded along the length of a fiberglass coupon 1/16in thick and ¾in wide. A foil gage was bonded immediately beside the fiber at the root of the coupon when placed in a simple cantilever configuration.

Vishay M-Bond 200 adhesive was used to bond both sensor types to the coupon. After placement in the test configuration, the cantilevered length of the coupon was 3.7in. The tip of the coupon was displaced cyclically by 0.65in to produce strains at the root of ±4,000με. Measurements were recorded with both types of sensors at the maximum, minimum, and zero load conditions after every 50 cycles. As expected, the foil gage deviated from the expected strain value with increasing number of cycles.

The fiber sensor, however, continued to make accurate strain readings throughout the fatigue testing, deviating by less than 2%. These results are illustrated in Figure 4. The foil gage used in this testing was a Vishay EA series gage in a quarter-bridge configuration. The optical fiber sensor was a commercially available polyimide-coated, low-bend loss fiber.

In subsequent tests, similar fiberglass coupons were loaded in a four-point bend configuration and cycled to ±4,250με. While foil gages bonded to the coupons typically failed after a few hundred cycles under this high-strain fatigue cycling, the fiber sensor continued to make accurate measurements over several thousand cycles. In the maximum tested case, the fiber sensor was unaffected after 28,000 cycles.

These results demonstrate the advantage of optical fiber sensors over foil gages for high-load fatigue testing, which is commonly needed for composite aerospace structural and material testing.

NRC said in its report, issued in March 2012, that: "It is evident that the use of Luna's fiber optic system compares very well with the strain gages applied by NRC to SHM Platform 1A for static loading conditions. The Luna fiber optic system has several advantages over strain gages, such as their immunity to electromagnetic interference. The values obtained from Luna's fiber optic system are accurate and repeatable as shown in this report. This technology shows promising results for static and quasi-static loading conditions, making it a promising technology for full-scale tests of aerospace structures in a laboratory environment."

As part of future work, Luna will apply its sensing system on additional testing platforms to evaluate capabilities on a more complex structure, as well as in the outer wing of a fighter jet testbed.

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