Engineering Note

EN-FY1316

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Distributed Fiber Optic Sensing: Measuring Strain Along Leaf Spring

Contents

Introduction

Leaf springs have many applications in the transportation industry ranging from use in railway cars to vans and tractor-trailers. These components are widely used in commercial vehicles for their cost, simplicity, and their ability to spread weight over a larger area than a helical spring. While foil gages adhered to the spring will be able to provide strain information at various discrete points, utilizing fiber optic sensing allows the user to measure the strain profile across the entire length of the leaf spring with very high spatial resolution. Due to the fact that the strain profile along even a simple leaf spring is not uniform, distributed strain measurements provide a way to better characterize the effect of load on the spring. Fiber sensors are also able to handle the cyclic loading conditions present in suspension systems where foil gages often cannot.[1]

Test Setup

Low bend loss, polyimide coated fiber was bonded along the concave side of a 16 inch leaf spring in two passes as illustrated by the blue line in Figure 1. In addition to the fiber, three foil gages were bonded in the space between the fiber passes. To ensure optimal strain transfer to the fiber and foil gages, the spring was sanded to the metal along the path of the fiber and the locations of the foil gages.

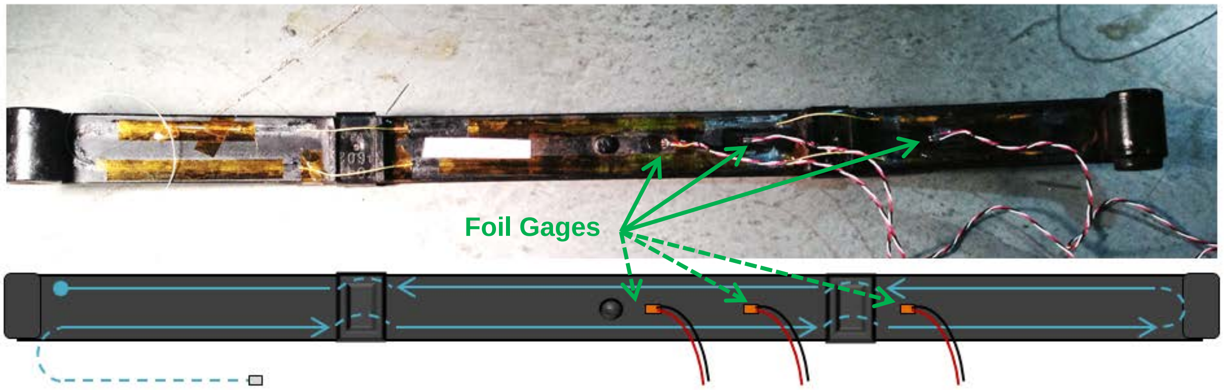

Figure 1: Blue lines represent path of the sensing fiber, dashed lines denote regions that are not bonded. The locations of the three foil gages are also shown in orange.

The spring was flipped over to its upright position and placed on a concrete floor where both the fiber and foil gages were zeroed. The spring was loaded in 45lb increments up to 180lbs with the load being placed on the center of the spring as can be seen in Figure 2.

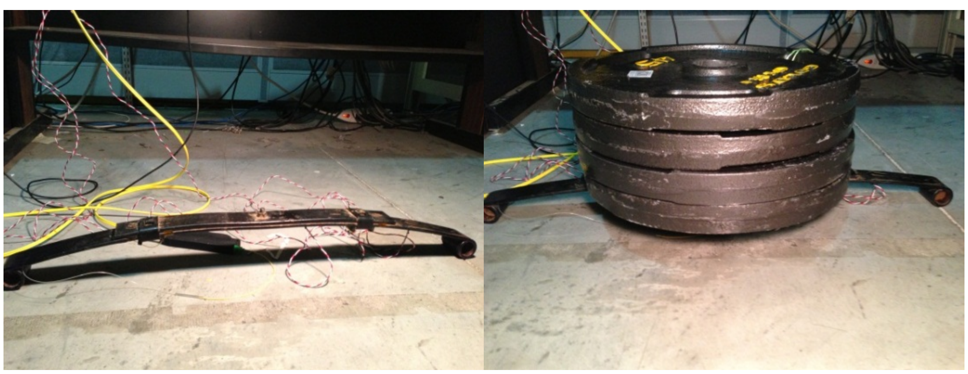

Figure 2: Experimental setup. Leaf spring was placed on a concrete floor and loaded with four 45lb weights one by one.

The fiber strain data was acquired at 100 Hz using an ODiSI-B with a gage length and sensor spacing of 5mm. A multi-gage reader was used to record data from all foil gages simultaneously, at 30 Hz. Both systems were set to acquire data during the duration of the test, including while the weights were being added and removed from the leaf spring.

Results

1. Single-Point Strain Measurements

A plot of the data over the duration of the test can provide useful information regarding how the test was performed and when the loads were applied. As can be seen in Figure 3, the fiber data correlate with the foil gage measurements at the co-located points throughout the test. Just after twenty seconds into the test, the first weight was added onto the leaf spring, resulting in a step in the strain measurement which stabilizes. Subsequent load additions result in similar steps in the strain data. At 90s, some adjusting was carried out to reposition and stabilize the final 45lb. This is faithfully captured by the data in the agitation and dip in measured strain at around this time.

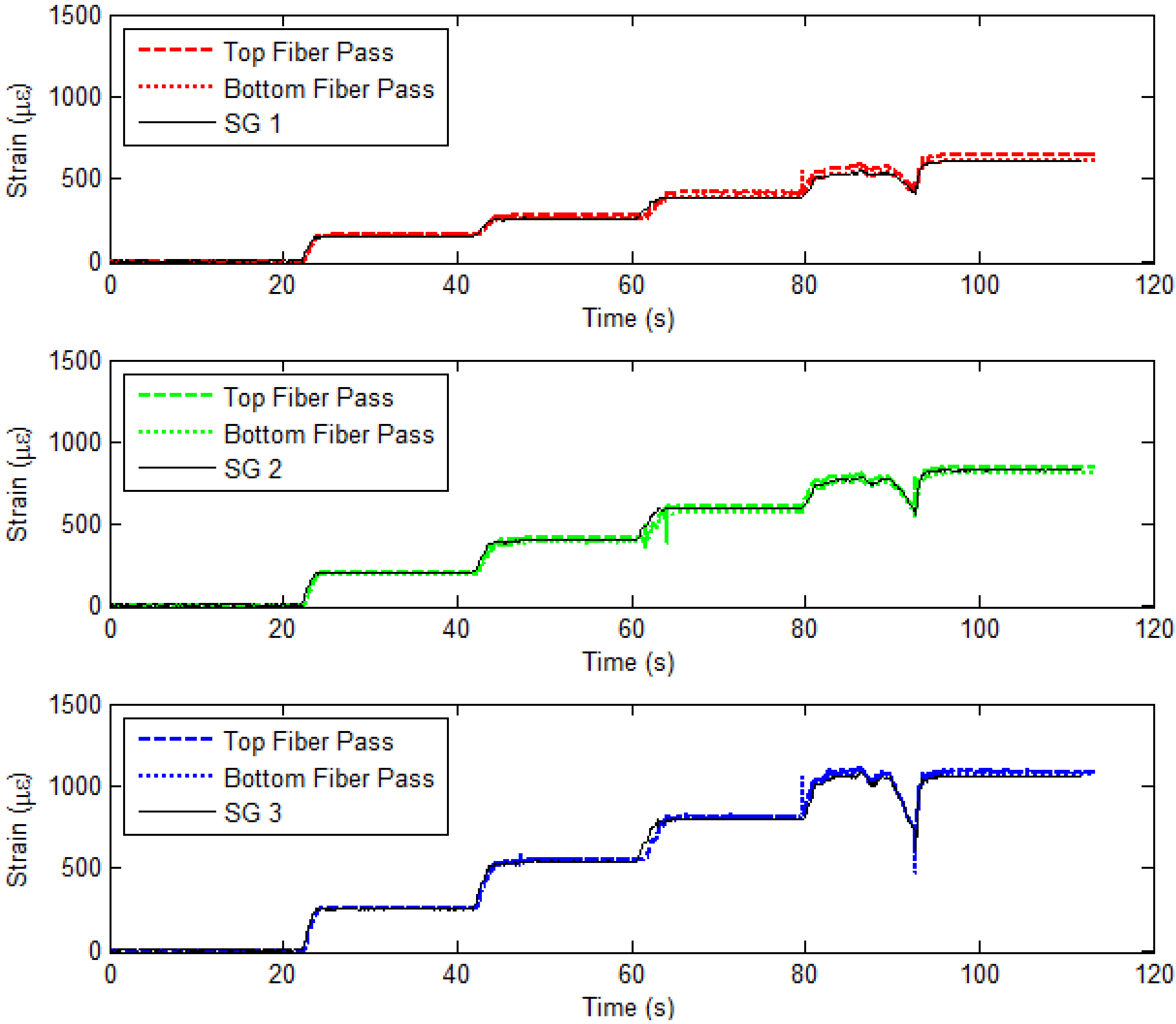

Figure 3: Single point fiber data compared to corresponding co-located foil strain gages (SG) in time. Outlier peaks are due to the physical process of adding the weights to the spring.

2. Distributed Strain Measurement

Fiber optic sensing results in high resolution distributed strain measurements along the length of the leaf spring. A plot of strain over the length of the fiber at the 135lb load case is shown below in Figure 4. The strain does not change significantly across the width of the spring, thus the symmetry of the fiber routing (down and back along the concave surface of the spring) results in a strain plot symmetrical about the 0.9m mark. The nonlinearity of the strain profiles along the sections of the leaf spring, labeled A through F below, is visible due to the small sensor spacing and gage lengths used (5mm). The bolt in the middle of sections B and E can be clearly identified as a region of reinforcement as evidenced by the dip in strain at those locations along the fiber. A heat map of the strain measured along each bonded section of the fiber (Figure 5) provides an alternative representation of the measured strain. Figure 6 shows a strain colormap of a single fiber pass along the spring as weights were added from 0 to 180lbs.

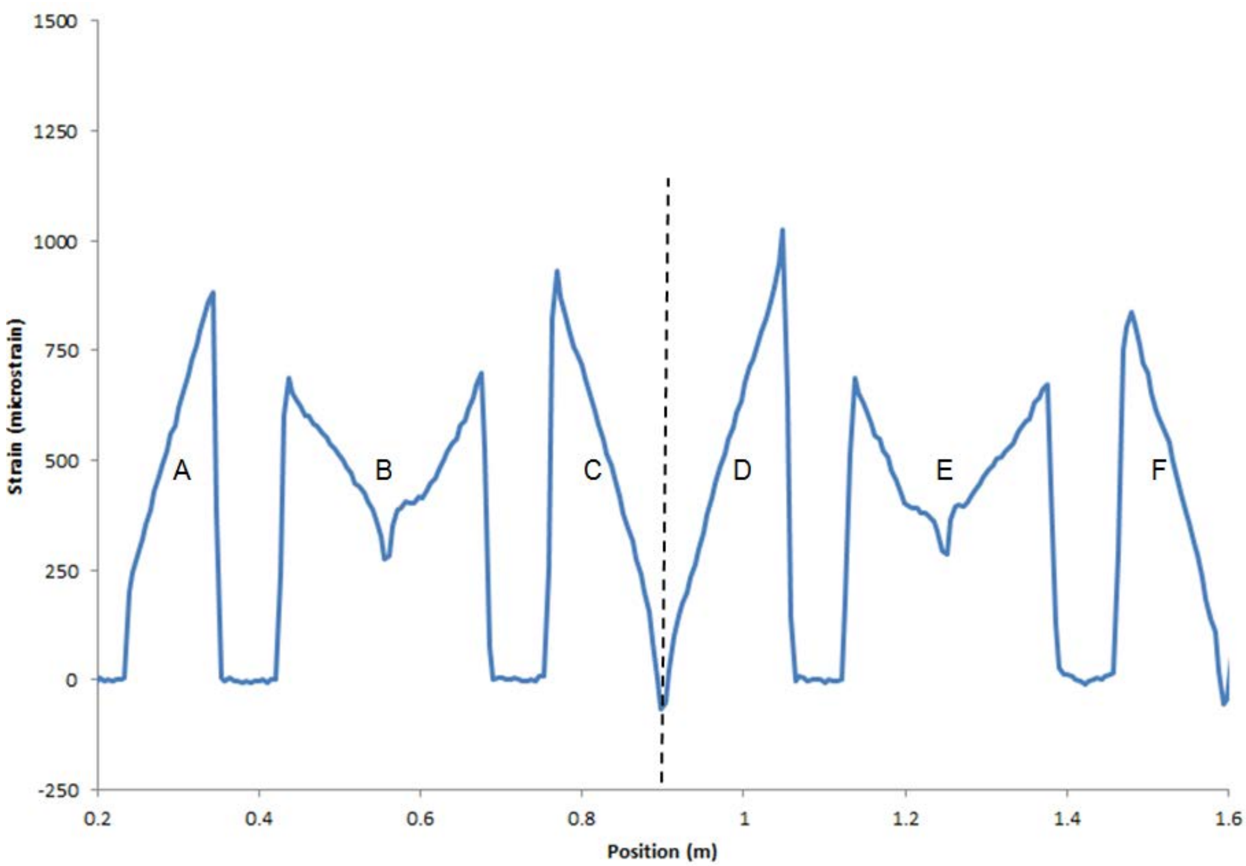

Figure 4: Strain profile along the length of the fiber at one time instance during 135lb load. The vertical dashed line shows where the fiber turns around and passes back along the length of the spring. Sections of the profile are labeled A – F, and correspond to the sections in Figure 5 below.

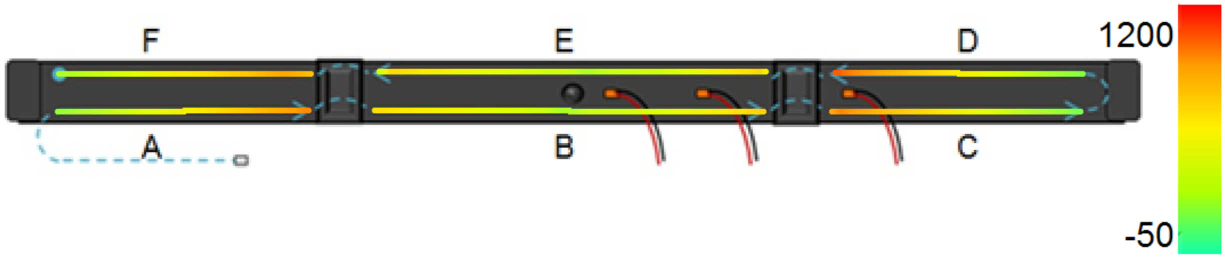

Figure 5: Map of strain along each section of the leaf spring during 135lb load case.

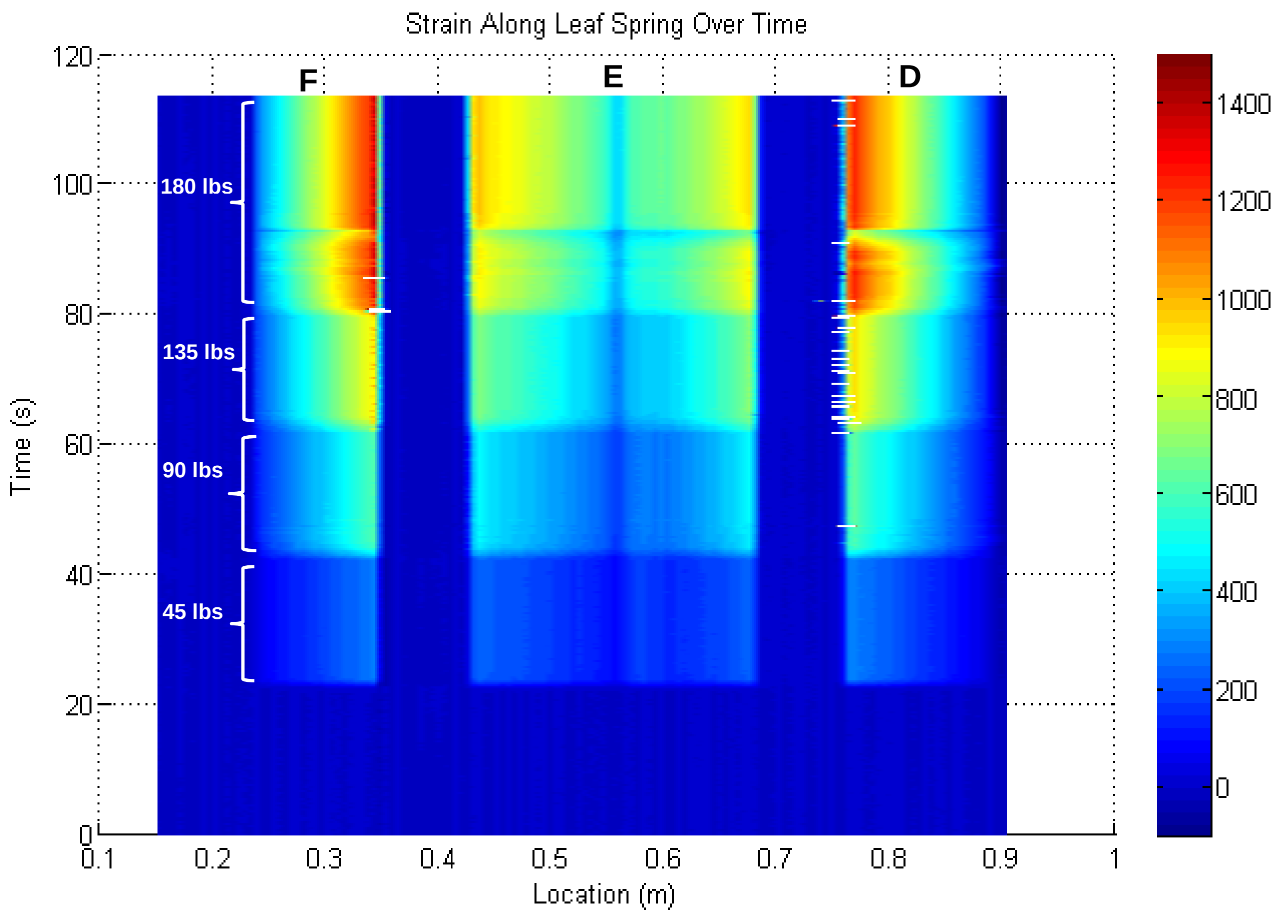

Figure 6: Strain along a single fiber pass of the leaf spring as load is increased from 0-180 lbs. Locations labeled 'F', 'E', and 'D' correspond to the same labeled locations along the leaf spring from Figure 5 above.

3. Comparing Fiber to Foil Gages

Figure 7 shows distributed strain at all load levels along with correlating foil gage measurements at each foil gage location. This data overlay further demonstrates the deficiencies of single point sensing. While distributed fiber optic sensing allows the user to obtain a comprehensive strain map of the leaf spring during the test, individual foil gages only provide data at isolated points along the test article.

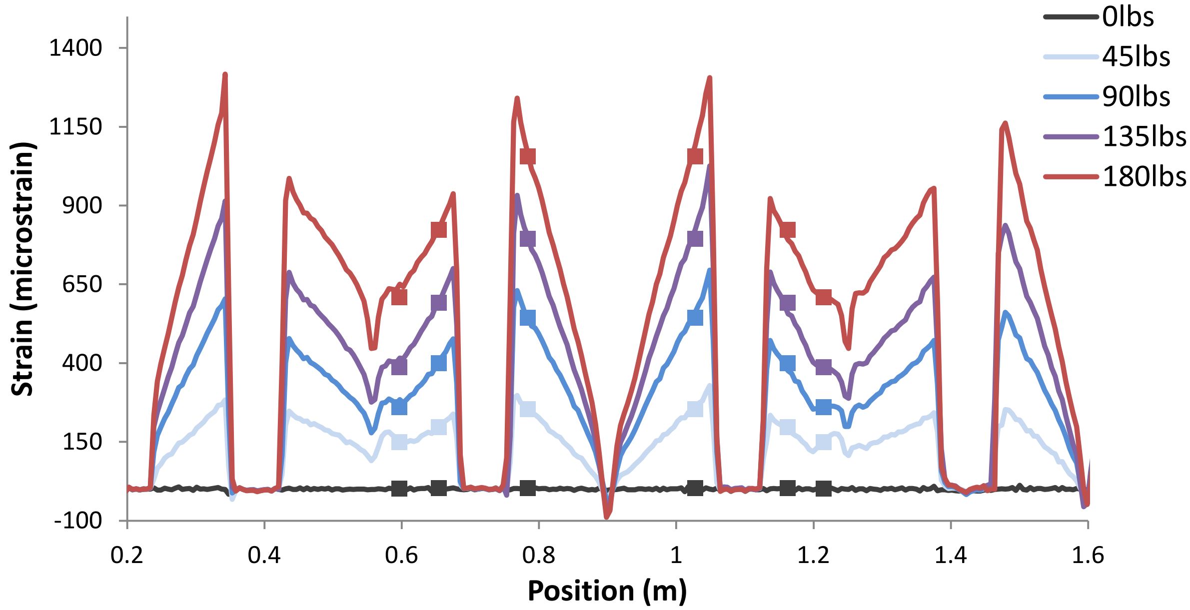

Figure 7: Strain along length of fiber for all load states with co-located strain gage measurements shown by boxes of the same color.

Summary

This Engineering Note demonstrates the ability of fiber optic sensors to measure strain profiles along the length of a leaf spring. In this test, the use of the ODiSI-B allows for locating and describing strain events in space and time. The strain profiles gathered using the ODiSI-B show that the strain gradients found on the spring are nonlinear and do not vary significantly across its width. While the fiber sensor and strain gage do match at the six collocated points, the fiber sensor provides a more complete picture of events over the length of the spring. The high acquisition rate and high spatial resolution of the ODiSI-B make it ideal for dynamic applications where strain is changing in both time and space.

1. Abdul Rahim, N. A., Thoreson, M. A., Gorney, T., Garg, N., Gifford, D. K., Froggatt, M. E., & Sang, A. K. (2012, November). Superior Fatigue Characteristics of Fiber Optic Strain Sensors. In *2012 Aircraft Structural Integrity Program Conference*.

Product Support Contact Information

Headquarters:	3157 State Street
	Blacksburg, VA 24060
Main Phone:	1.540.961.5190
Toll-Free Support:	1.866.586.2682
Fax:	1.540.961.5191
Email:	solutions@lunainc.com
Website:	www.lunainc.com

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