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LETTERS TO THE EDITOR

HEALTH MONITORING OF STEEL CABLES BY INTERROGATION OF OPTICAL FIBER GRATING SENSORS

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1. INTRODUCTION

The importance of real-time detection and localization of structural damage in steel cables can hardly be overstated, especially in those applications where a high degree of efficiency and reliability is required. Recent surveys reviewing the state of the art of non-destructive testing of mechanical cables show that the current methods are either visual or based on the use of X-rays, induced wave propagation, electromagnetic fields, and acoustic emission [1–3]. As an alternative to these traditional methods, the use of optical fiber sensors in the detection of breakage of individual wires in a rope, has been recently proposed [4–6]. The advantages of fiber optics sensors are well known, and include their small size, environmental ruggedness, immunity to electromagnetic interference, and high sensitivity [7, 8].

Although the fiber optic systems described in references [4–6] exhibited a high potential for the development of workable sensors to monitor the structural health of both metal and synthetic cables, the sensing principle used in these experiments did not show multiplexing capabilities. These capabilities are highly desirable in the development of embedded sensors for smart structures. In these applications where multiplexing is sought, fiber Bragg gratings have become one of the most favored solutions, since they are easily multiplexed by connecting them in series in a single span of fiber [9]. A fiber Bragg sensor is based upon the inscription of a periodic variation of the index of refraction in the core of a single-mode optical fiber. When a relatively broadband optical source is coupled into the fiber, a narrowband portion of the spectrum is reflected by the grating at a characteristic wavelength, called the Bragg wavelength, which depends upon the period of the grating. Under the effect of an external agent such as strain or temperature, the period of the index modulation will change, thus shifting the wavelength of the reflected peak. This shift can be used to measure the axial strain or temperature change and, obviously, to detect the dynamic behavior of a traction cable when breakage of one or more wires takes place.

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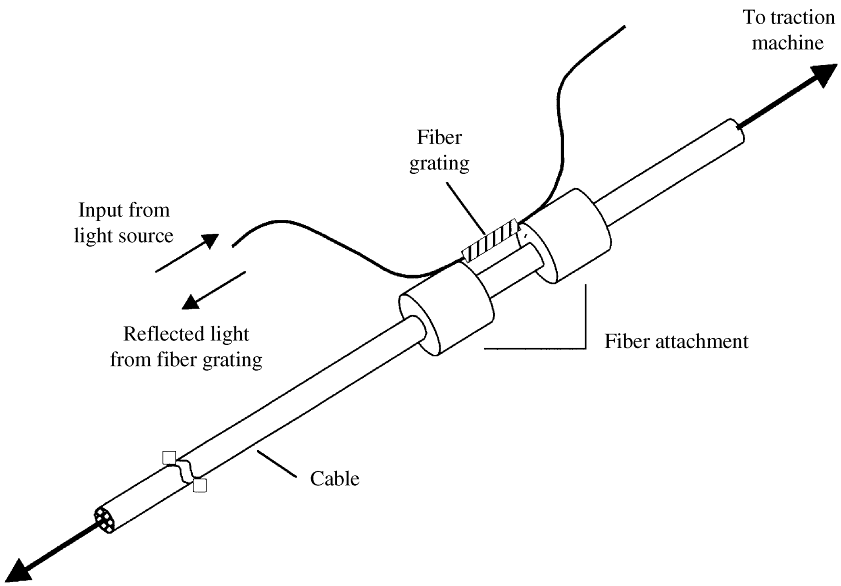

Figure 1. Experimental set-up.

This letter describes an experimental set-up where fiber grating sensors are used to detect the breakage of single wires in steel cables. It is shown that these sensors are promising candidates toward the development of practical sensing systems for monitoring of wire ropes.

2. EXPERIMENTAL SET-UP

The set-up is schematically described in Figure 1. In this set-up, a 40-cm long piece of cable is stretched by means of a hydraulic system. The steel cable used for the experiments consisted of six strands of seven wires each, resulting in a total outer diameter of 4·5 mm. Clipping outer wires while maintaining the steel cable under tension produced the individual breakages used to test the optical set-up. The sensitive portion of the fiber was fastened to two small aluminium cylinders attached to the cable.

The system used to interrogate the fiber grating sensor is shown in Figure 2. Light from a laser diode centered at 1·3 μm (Type: Mitsubishi 725B8F) was focused into a 2×2, 50/50 split ratio fiber coupler (Type: Thorlabs 10202A-50). One output of the coupler was connected to a Bragg grating (Type: Innovative fibers FBG-1300) centered at 1·30 μm with a reflectivity of 80% at the center wavelength and a bandwidth of 0·2 nm. The other output was covered with index matching grease to eliminate spurious reflections from the fiber end. The reflected light from the Bragg grating was monitored using a 75-cm Czerny–Turner monochromator, which was used to analyze a narrow portion of the reflected spectrum. The monochromator was provided with a high-speed InGaAs detector (Type: Thorlabs DET410) whose output signal was acquired by a 100 MHz, 1 Gs/s digital oscilloscope (Type: Tektronix TDS 220).

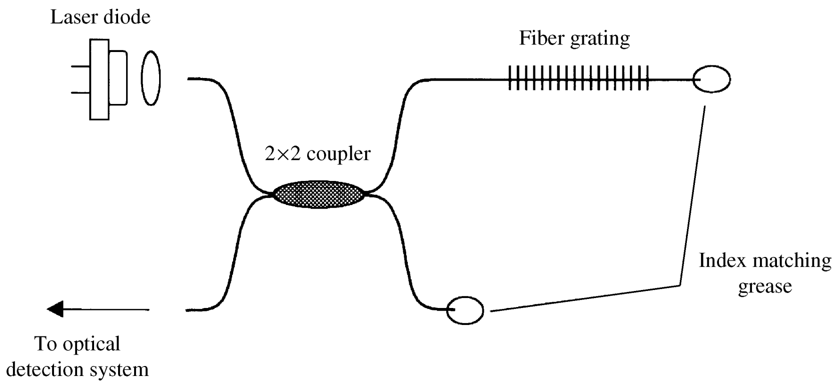

Figure 2. Details of the optical detection system.

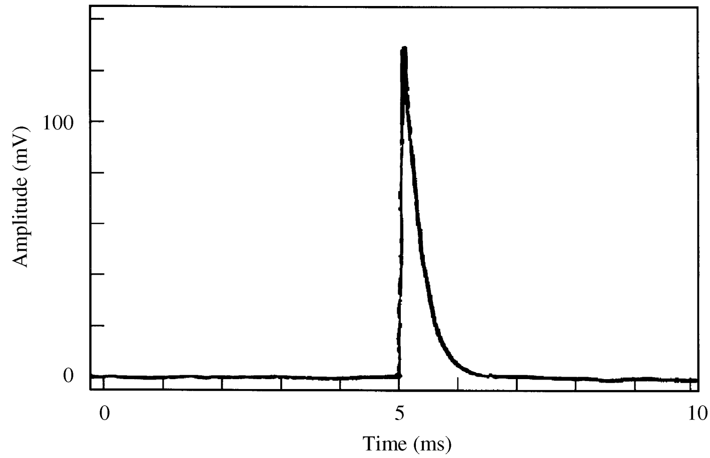

Figure 3. Typical breakage signal recorded by the digital oscilloscope.

To operate the detection system, the cable with the mounted sensor was loaded and the monochromator was tuned to select the peak of the reflected spectrum. Additional stretching of the portion of the cable containing the sensor, such as that produced by travelling disturbances, was expected to shift the center wavelength of the fiber grating, thus producing a change in the output signal from the detector.

3. RESULTS AND CONCLUSIONS

A series of 20 breakages showed that the signals from the detection system were essentially noise-free and highly reproducible. Figure 3 shows a typical rupture signal, induced by the dynamic response of the cable, as acquired by the digital oscilloscope. At time scales comparable to the pulse width, the recorded pulse exhibits a sharp risetime that makes it suitable for automatic electronic detection. In summary, the method hereby outlined shows potential as a promising alternative to traditional on-line methods of non-destructive evaluation in wire ropes.

Future work on fiber grating sensors for monitoring structural condition in cables should include the testing of serial systems, which would allow for precise localization of partial breakages. Besides, a practical sensing network needs transducers that attach easily to the cable, and cost-effective instrumentation systems capable of interrogating multiple gratings. An added advantage in the use of fiber grating sensors is that they can convey data about environmental conditions, information that combined with suitable electronic processing may prove to be useful in the development of smart structures involving metallic cables.

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REFERENCES

1. P. A. A. LAURA 1993 *American Society of Mechanical Engineers Applied Mechanics Reviews* **46**, 133–138. Nondestructive testing and structural condition monitoring of mechanical cables.
2. P. A. A. LAURA 1993 *American Society of Mechanical Engineers Applied Mechanics Reviews* (*Mechanics Pan-America* 1993) **46**, S312–S315. Evaluation of the structural health of mechanical cables.
3. P. A. A. LAURA 1995 *Ocean Engineering* **22**, 551–562. Evaluating the structural condition of synthetic and metallic cables.
4. O. D. CORTÁZAR, H. A. LARRONDO, P. A. A. LAURA and D. R. AVALOS 1996 *Ocean Engineering* **23**, 193–199. A low-cost fiber-optic system for monitoring the state of structural health of a mechanical cable.
5. O. D. CORTÁZAR, H. A. LARRONDO, D. R. AVALOS and P. A. A. LAURA 1997 *Journal of Sound and Vibration* **203**, 536–541. Fiber-optic technology and structural condition monitoring of mechanical cables.
6. O. D. CORTÁZAR, F. G. TOMASEL and P. A. A. LAURA 1998 *Journal of Sound and Vibration* **214**, 576–579. Monitoring the structural health of kevlar cables by means of fiber-optic technology.
7. E. UDD 1995 *Review of Scientific Instruments* **66**, 4015–4030. An overview of fiber-optic sensors.
8. B. H. HOUSTON and J. A. BUCARO 1997 *Journal of the Acoustical Society of America* **102**, 3125. Fiberoptic sensors for structural–acoustic applications.
9. A. D. KERSEY, M. A. DAVIS, H. J. PATRICK, M. LEBLANC, K. P. KOO, C. G. ASKINS, M. A. PUTNAM and E. J. FRIEBELE 1997 *Journal of Lightwave Technology* **15**, 1442–1463. Fiber grating sensors.