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MONITORING THE STRUCTURAL HEALTH OF KEVLAR CABLES BY MEANS OF FIBER-OPTIC TECHNOLOGY

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1. INTRODUCTION

Non-destructive inspection of wire ropes in service is of critical importance in multiple applications where a high degree of efficiency and reliability is required. Recent surveys summarizing the present status of non-destructive testing of mechanical cables show that, apart from thorough visual inspection and measurement of their external diameter, the methods available are based on the use of X-rays, induced wave propagation, magnetostrictive sensors, electromagnetic field, and acoustic emission [1–3].

Alternatively, it has been recently shown that optical fiber sensors can be used for detecting the breakage of individual wires in a rope [4, 5]. Fiber sensors have a series of unique advantages that make them extremely useful for non-destructive evaluation of the integrity of structures and composite materials. These advantages include small size, capacity to withstand high operating temperatures and pressures, immunity to electromagnetic interference, and intrinsically passive all dielectric configurations. Many of them show high potential for multiplexing and sensing of multiple parameters, as well as high ability to be embedded and dynamic ranges spanning several decades. The literature on the area of fiber sensors is very extensive, see references [6]–[8] for an overview of the subject.

The present communication shows the feasibility of using a fiber optic system to detect the breakage of individual strands in synthetic, Kevlar cables, where traditional electromagnetic techniques are not applicable. It is important to point out that Kevlar cables have commonly been used in ocean engineering applications since the late 60's. On the other hand, Kevlar-made structural elements are of common use in aerospace applications.

2. EXPERIMENTAL SETUP

The experimental setup used for the experiments discussed herein is schematically shown in Figure 1. The fiber optic system, already described in previous communications [4, 5], is designed to use the stress-dependent birefringence of the optical fiber as the main modulation effect. It consists of a 5 mW GaAs laser diode used as a light source, a single mode communications fiber (Type: SIECOR SMF 1528), and a photodiode detector. Two polaroid sheets are used at the input and output ends of the fiber as polarizer and analyzer, respectively. The fiber has a core diameter of 8 μm and an overall diameter of about

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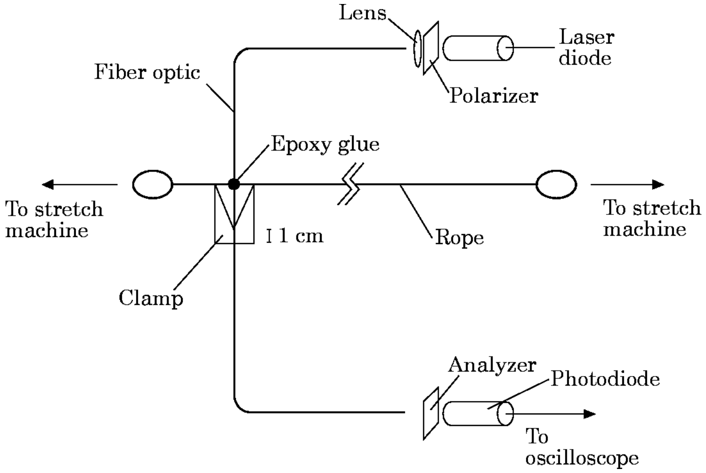

Figure 1. Experimental setup.

245 μm, including the cladding and a coating of acrylate resins. The fiber is glued to the cable with an epoxy resin and held by a fiber clamp designed to detect transverse perturbations. The output signal from the photodiode is acquired by a 100 MHz, 500 Ms/s digital oscilloscope (Type: Tektronix TDS 320).

A 40 cm long piece of rope is stretched by means of a hydraulic system. The synthetic rope used for the experiments consisted of six strands of Kevlar with 35 twists per meter. Each strand contained about 12 000 Kevlar filaments 13.5 μm in diameter. To simulate the breaking of a single strand, the rope was first stretched and then one of the strands was ablated with a 25-Watt CO2 laser (Type: Synrad E48-2-28) (Figure 2). Ablation of a single strand was achieved by wrapping all but one of the strands with aluminum foil. This method of producing failure resulted in highly reproducible signals.

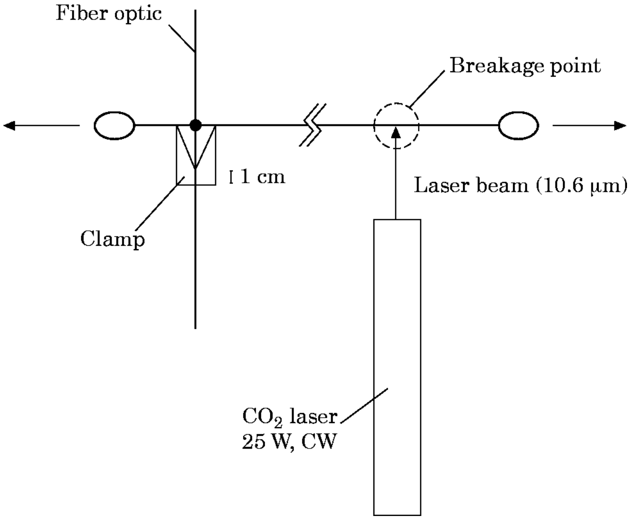

Figure 2. Detail of the ablation system.

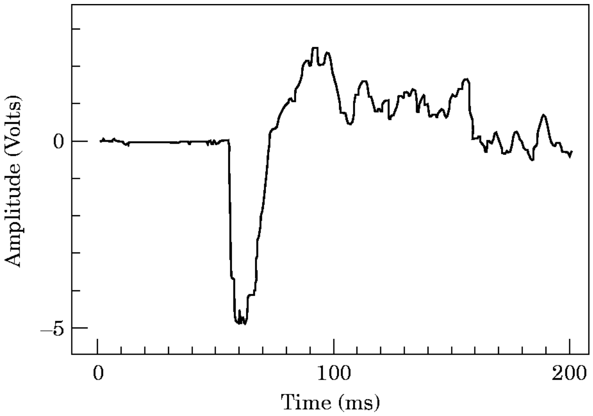

Figure 3. Typical rupture signal of the Kevlar cable displayed by the digital scope.

3. RESULTS AND CONCLUSIONS

Figure 3 shows a typical rupture signal as displayed by the digital scope. The signals from the photodiode exhibit sharp risetimes and amplitudes of several volts, making them suitable for automatic electronic detection. The characteristics of the output pulse resemble those of previous experiments conducted in steel cables (Figure 4) [4]. In summary, the methodology hereby demonstrated shows high potential for the development of workable optical fiber sensors to monitor the structural health of both metal and synthetic cables.

Further work on this subject should include, on the transducer side, the development of fiber sensors that could be easily attached to the cable, and designed to discern the different modes propagating along the cable. The optimal sensor should also exhibit high embedibility and multiplexing capability. Additional research on the propagation of pulses along mechanical cables will be needed to characterize the broadening and dissipation of the breakage signals. This information will help in the design of optical sensing networks. Besides the structural condition of the cables, these networks could also convey data about environmental conditions, information that combined with suitable electronic processing can lead to the development of smart cables.

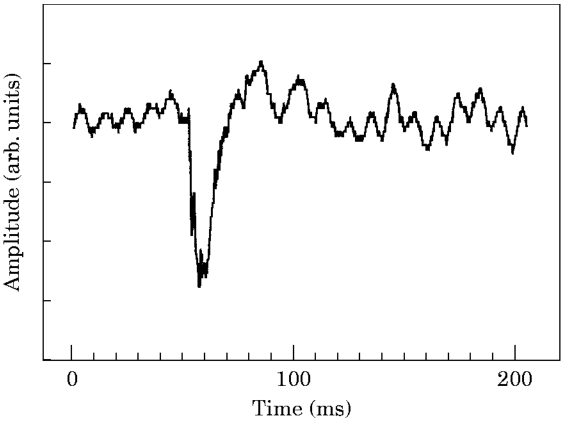

Figure 4. Typical signal in the case of wire rupture when conducting experiments on a wire rope [4]. Note: a photomultiplier was used as a photodetector.

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