Detection of micrometer crack by Brillouin-scattering-based distributed strain and temperature sensor

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ABSTRACT

A Brillouin-scattering-based distributed strain and temperature sensor (DSTS) has been employed to detect cracks on ceramic by measuring the strain distributions along the surface of the ceramic for the first time. The existence of cracks and their locations are identified by measuring the strain distribution on a sensing fiber bonded on the ceramic surface. Due to innovated design and signal processing, the distributed Brillouin sensor developed for this study achieves a uniquely high resolution and accuracy. Experimental study on ceramic tile specimens demonstrated the efficacy of the distributed Brillouin fiber optic sensor in detecting and locating fine cracks.

Keywords: distributed strain, distributed temperature, optical fiber sensors, Brillouin scattering, crack detection, power line monitoring, oil pipeline monitoring, bridge monitoring, dam monitoring, distributed strain and temperature sensor

1. INTRODUCTION

Detection of cracks in materials and structures poses a major technical challenge: only a specialized tool can find the target, and a high resolution is required to take its measurement. There are a number of nondestructive evaluation (NDE) methods that can be used for detecting cracks, including the infrared thermography, ground penetrating radar, digital X-ray, and ultrasonic waves [1-3]. Fiber optic based sensing for structural health monitoring has received a lot of attention over the last two decades and many different sensing techniques have been developed to monitor specific parameters. Since the crack locations in a structure are not known *a-priori*, conventional "point" sensors are not effective in crack sensing. A truly distributed sensor system is desired for detection of cracks. Brillouin-scattering-based distributed strain and temperature sensors (DSTS) provide an excellent opportunity for structural health monitoring of civil structures by allowing measurements to be taken along the entire length of the fiber, rather than at discrete points, by using fiber itself as the sensing medium.

2. HIGH-RESOLUTION AND HIGH-ACCURACY DSTS

To take its measurement for crack detection, OZ Optics Ltd offers special edition of Brillouin-scattering-based DSTS with 0.1m spatial resolution, in which a combination of continuous wave (cw) and pulse source as the probe (Stokes) beam interacts with cw laser as the pump beam for the probe-pump Brillouin sensor system [4]. The Brillouin interaction of Stokes and pump in the fiber includes both DC-pump and pulse-pump interactions. The coherent portion inside the pulse-length of these two interactions due to the same phase has a very high Brillouin amplification. It provides localized information of strain and/or temperature and enhances measurement accuracy, which enables the Brillouin-scattering-based DSTS to detect micrometer cracks.

Figure 1 displays a set-up for a simulated crack detection using the high-resolution and high-accuracy DSTS based on the unique coherent probe-pump interaction technology. The optical fiber was mounted on the surface of a PVC plate by a special glue tape. There is a gap in the PVC plate, which is used for the simulation of producing crack. The sensing fiber passed through the gap four times (Fig. 1a). After increasing the gap by 40μm where the farthest piece of sensing fiber located, as shown in Fig. 1b, the strain distribution was measured, as illustrated in Fig. 2, in which the four strain peaks corresponding to four pieces of sensing fiber passed through the gap.

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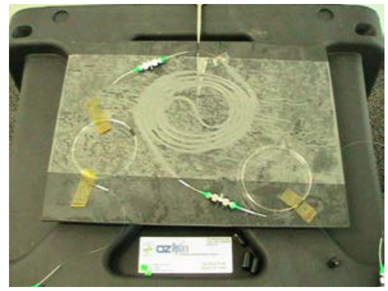
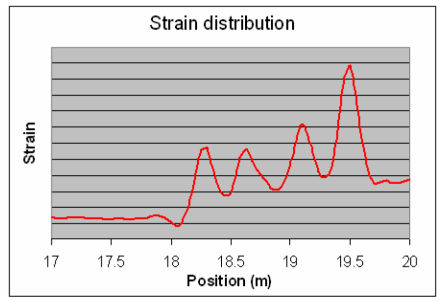
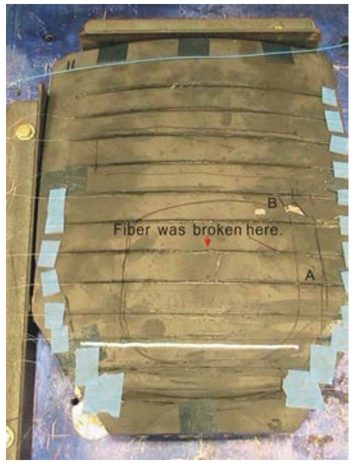
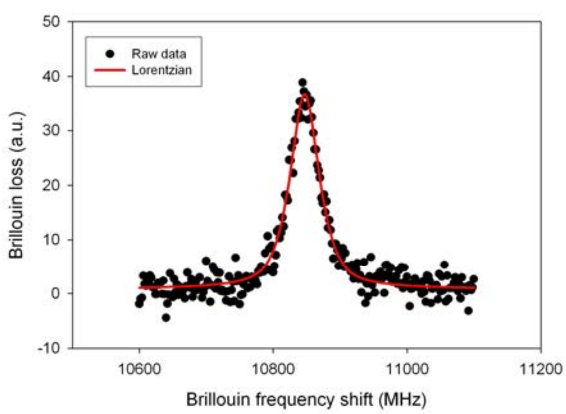
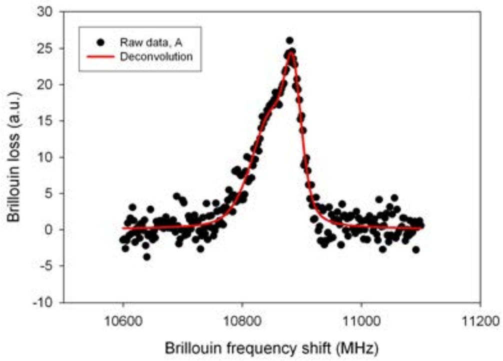
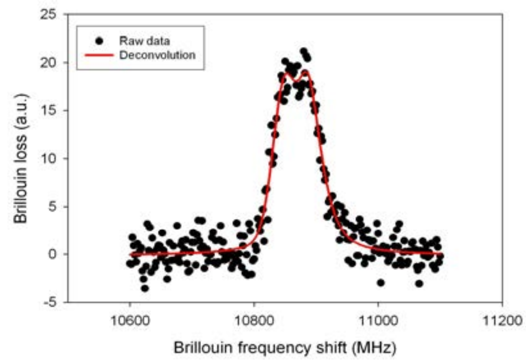


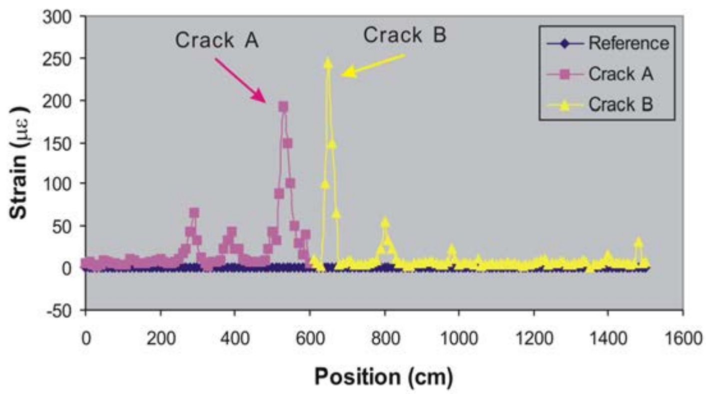

Strain distribution
Strain
17
17.5
18
18.5
19
19.5
20
Position (m)


B
Fiber was broken here.
A


Raw data
Lorentzian
Brillouin loss (a.u.)
Brillouin frequency shift (MHz)
50
40
30
20
10
0
-10
10600
10800
11000
11200


Raw data, A
Deconvolution
Brillouin loss (a.u.)
Brillouin frequency shift (MHz)
30
25
20
15
10
5
0
-5
-10
10600
10800
11000
11200


Raw data
Deconvolution
Brillouin loss (a.u.)
Brillouin frequency shift (MHz)
25
20
15
10
5
0
-5
10600
10800
11000
11200


Crack A
Crack B
Reference
Crack A
Crack B
Strain (με)
Position (cm)
300
250
200
150
100
50
0
-50
0
200
400
600
800
1000
1200
1400
1600