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ABSTRACT

A novel scheme of quasi-distributed vibration disturbances detection system based on incomplete Polarization optical time domain reflectometry was proposed. The system was enhanced by employing Fresnel-reflection caused by FC/PC connector, which can improve the signal's SNR significantly, while the temporal depolarization effect can be almost completely suppressed. Without performing any data averaging, the intrusion event can be detected and located precisely/instantaneously with good stability. Also the frequency components of vibration events applying on sensing fiber can be obtained with large dynamic range. It shows a very good potential in intrusion detection, vibration frequency measuring, etc.

Keywords: Fiber optics sensors, Polarization optical time domain reflectometer, Fresnel-reflection

1. INTRODUCTION

Polarization optical time domain reflectometry (POTDR) system is widely used in PMD measurement and intrusion detection system[1,2]. Generally, the P-OTDR can be divided into two categories, the complete P-OTDR and the incomplete P-OTDR. In the scheme of complete P-OTDR, light in different polarization state is transmitted into the sensing fiber, and the backscattered light is collected. By taking the Stokes parameters of the input and output light into a matrix equation, the round-trip Mueller matrix along the sensing fiber can be obtained[3]. Since this scheme can get the local polarization parameter of the fiber, it can achieve distributed measurement and distinguish multiple events along the fiber. But the structure of the system is complicated, costly and usually has a low signal-to-noise ratio (SNR). In comparison, the incomplete P-OTDR system only measures one of the Stokes parameters of the backscattered light[1]. It is simpler in structure, more cost-effective, easier to be used in practice, and has a higher SNR level. In a general way, people still detect backward Rayleigh scattering (BRS) light as the sensing signal in the incomplete P-OTDR system. As the intrinsic Rayleigh scattering (RS) coefficient of the optical fiber is low and the exact intensity of BRS is random, the system has a low SNR and is instable. In intrusion detecting system it may cause false alarm. Furthermore, as a result of imperfect manufacturing and the influence of external environmental factors, the birefringence of the fiber is randomly distributed. When a light pulse covering a certain length of optical fiber propagates, BRS light arrived at the photodetector from different position has different polarization states, so the intensity will superimpose on the photodetector. It's a sort of depolarization effect which can reduce the system dynamic range. In addition, the light source of the P-OTDR system based on RS light has special request. The laser linewidth should be narrow enough to prevent the depolarization in wavelength that is induced by different polarization transformations of various frequency components in the light source; while the interference of backscattered components from different parts of the fiber due to the coherent light source should be avoided. Therefore, the laser linewidth of P-OTDR which requires GHz bandwidth usually falls between that of conventional OTDR and Coherent-OTDR[4].

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In this paper, we embed FC/PC connectors along the sensing fiber link to produce Fresnel-reflection to enhance the incomplete-POTDR system. First of all, the introduction of Fresnel-reflection point can improve the system's SNR. Once formed, the reflection coefficient of Fresnel-reflection point could keep constant, which makes the system more stable. What is important is that by employing Fresnel-reflection point, the depolarization caused by the above mentioned factors can be almost completely suppressed. Moreover, as the signal we used in the system is from Fresnel-reflection point, there is no special requirement for the laser linewidth. Even the SLED light source with dozens of nm bandwidth can be used in our system. In our current scheme, 31 optical fiber patch cords of 50m length each connected by 31 FC/PC connectors are employed as the sensing fiber link. The average loss of adjacent FC/PC connectors is about 0.2dB. We employ an attenuator after the 31^{st} FC/PC connector to introduce 21.6 dB loss. After the attenuator a fiber mirror is used to reflect the left optical power. Signal's visibility of the fiber mirror is just like the ones before the attenuator. That means we can employ more than one hundred FC/PC connectors in the system. Location accuracy of the system depends on the distance between adjacent FC/PC connectors.

2. EXPERIMENTAL CONFIGURATION

The experimental setup constructed is shown in Fig. 1. Here, a pulsed laser with 0.15nm spectral linewidth had been chosen as the light source. The peak power of the optical pulse was 10 mw. An electrical signal with a pulse-width of 200 ns and a repetition period of 700 μs generated by the waveform generator was directly modulated on the light source. 31 optical fiber patch cords of 50m length each are connected by 31 FC/PC connectors. The average loss of adjacent FC/PC connector is about 0.2dB. We employ an attenuator after the 31^{st} FC/PC connector to introduce 21.6 dB loss. After the attenuator a fiber mirror is used to reflect the left optical power. Signal's visibility of the fiber mirror is just like before the attenuator. That means we can employ more than one hundred FC/PC connectors in the system. Although the distance between adjacent FC/PC connectors determines the lower bound the location accuracy, it can be further improved by optimizing the fiber cable topology according to the real application. The longer sensing length is, the longer time it takes optical pulse to travel in the fiber, which leads to the decrease of the maximum detectable frequency. Therefore, there is always a tradeoff among the sensing length, spatial resolution and detectable vibration frequency range. Thus, all the parameters should be carefully chosen according to the specific application.

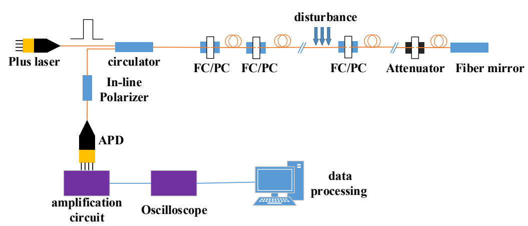

Fig. 1. Setup of Fresnel-reflection-enhanced Incomplete-POTDR system

3. EXPERIMENT RESULTS

3.1 Intrusion detection

We constructed the experimental system as Fig.1. In order to observe signal intensity of each Fresnel reflection-points, the in-line polarizer was removed at first. The OTDR trace was shown in Fig 2 (left). There were four marked boxes in Fig2 (left). The first one was the typical Fresnel-reflection signal while the second one was Rayleigh scattering signal. It is obvious that the difference between the two signals is about 5dB or even higher. The third one was the reflection-points shown in Fig2 (right) while the fourth was the signal generated by attenuation. The fifth one was the signal reflecting from fiber mirror. Then we installed the in-line polarizer before the APD to construct an in-complete POTDR system. After that, the intrusion behavior was simulated by shaking the fiber between 7^{th} and 8^{th} FC/PC connectors. We continuously stored 200 traces while the intrusion behavior lasted. In order to observe clearly, we draw all the 200 traces between 6^{th} and 15^{th} FC/PC connectors in one diagram (Fig 2 right). The abscissa represents the length of the fiber link and ordinate represents time, while the intensity of the signal is denoted by different colors. As the figure shows, the intensity of signal from the Fresnel-reflection points after disturbance changes with time obviously due to the polarization states of the light reflected from those Fresnel-reflection points are disturbed by the intrusion, yet the polarization states of the light reflected from those Fresnel-reflection points before the disturbance region keeps unchanged. This feature can be easily identified without any average processing. Moreover, by employing Fresnel-reflection point the temporal depolarization can be almost completely suppressed. The DOP of the light reflect from FC/PC connector was measured and the result was about 95%. As the DOP of RS light may reduce to about 20% and the DOP of the signal light in incomplete-POTDR system directly affect the system's dynamic range, the scheme we proposed can increase system's dynamic range by about 75%[2]. It has potential application in intrusion detectors with instantaneous data processing and excellent performance.

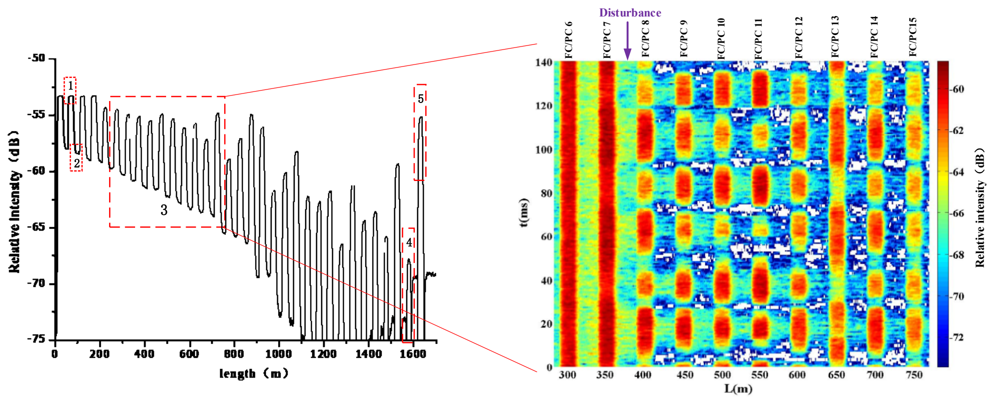

Fig 2. (left) the reflection points in the whole fiber link; (right) reflect signal changes when intrusion exist

3.2 Vibration frequency measuring

The piezo-transducer (PZT) based fiber stretcher (OptiPhase PZ3) was used to produce continuous vibration by applying periodic electric signal after high voltage electrical amplifier. It is constructed by a 15m long single mode fiber (SMF) wound on a piezo- transducer plate. The fiber stretch coefficient is 1.33um/V, and it is able to stand 800V peak to peak input. The stretch of the fiber in the PZT causes the change of birefringence, and birefringence modulation was detected by spectral-domain analysis with detected POTDR traces. At first, we should make sure the modulated fiber birefringence is a linear transfer of the input electrical signal to the PZT. Continuous light was first used in this experiment and the setup was shown in Fig3 (left). The light went though the PZT, fiber, polarizer, and then was collected by an oscilloscope. A single frequency sinusoidal electrical signal at 50 Hz was applied as the driving source. The collected signal and the FFT spectrum of the signal was shown in fig3 (right). The generated peak frequency of the FFT figure is exactly the one used to drive the PZT, which means the frequency of the birefringence modulation corresponds exactly to the frequency of the stretch of the fiber.

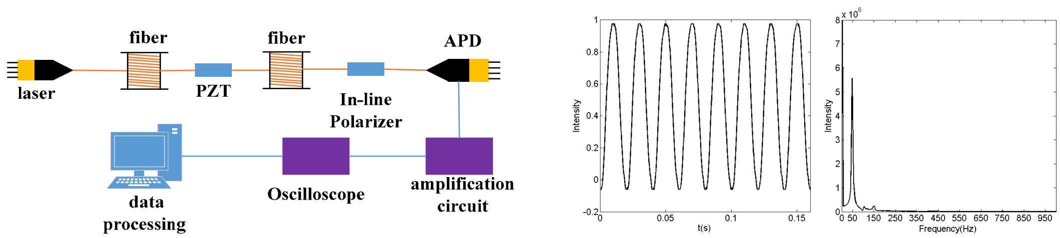

Fig 3. (left) setup of forward test; (right) time-domain signal and the FFT of the signal

In order to recover the frequency component of reflected optical pulse with vibration signal, the detected signal collected by oscilloscope were processed in the following way as illustrated in Fig. 4. Firstly, 10M sampling points of incomplete P-OTDR curve was stored by the oscilloscope. Once the storage finished, all of the sampling points would be processed offline to perform the spectral-domain analysis. Then, the trace was cut into many pieces and rearranged according to the cycle of optical pulse as in step ii. So the change of signals at a certain position would be observed easily. Also we could extract signals from the area we have interests and plot the intensities verse time as shown in step iii. So if the fiber between FC/PC1 and FC/PC2 was modulated by a PZT fiber stretcher, the temporal trace after (include) FC/PC2 peak would not be constant but variable, indicating one disturbing point. As shown in step iv, the FFT spectrum could be achieved for every reflected pulse. By varying the frequency of input electrical driving signal, different frequency range of vibration signals are tested as shown in Fig 5. We can see that, FFT spectrum of any reflected pulse before the disturbing point doesn't have any obvious peak while FFT spectrum of reflected pulse after disturbing point has an obvious frequency peak exactly at the frequency we applied on the fiber stretcher. The typical FFT spectra of the above cases were plotted in Fig 5. So, we can easily locate the position and obtain the frequency spectrum of vibration.

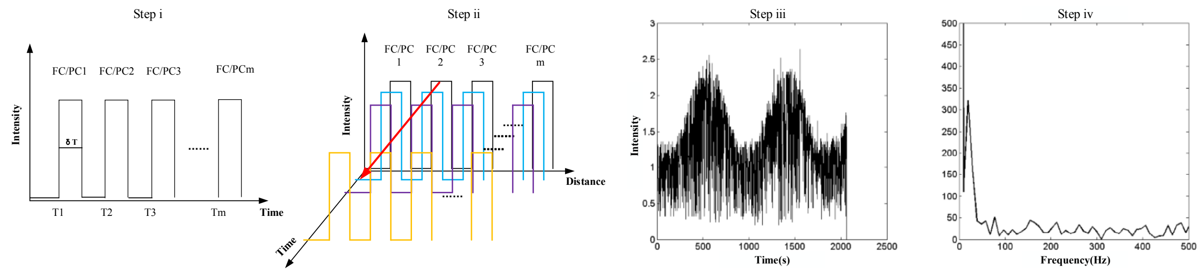

Fig 4. Schematic diagram for data processing

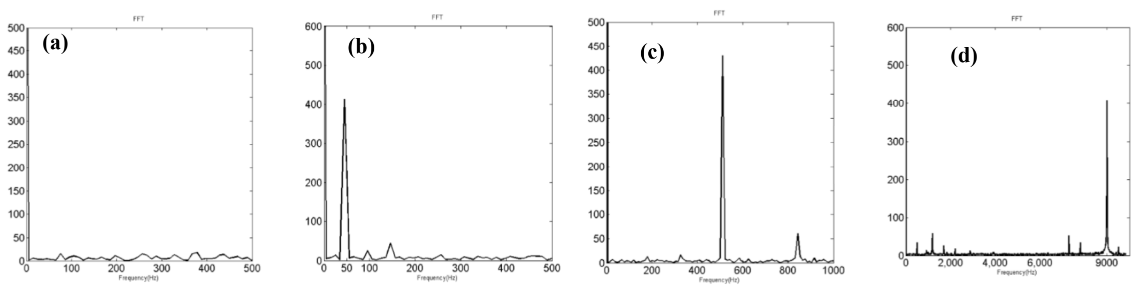

Fig 5. Piezo fiber stretcher driven by sinusoidal wave, FFT spectrum of time trace signal at

(a) location before PZT; (b) location after PZT with 50Hz 220Vpp driven signal; (c) location after PZT with 500Hz 165Vpp driven signal; (d) location after PZT with 9000Hz 165Vpp driven signal

4. CONCLUSION

In summary, we proposed a novel scheme of quasi-distributed vibration disturbances detection system based on the polarization optical time domain reflectometry. Fresnel-reflection caused by FC/PC connector was used to enhance the SNR and the stability of incomplete-POTDR system. As the signal we detected is the light reflected from FC/PC connectors, there is no temporal depolarization induced performance degradation. Owing to the above advantages, the scheme we proposed has been demonstrated to locate intrusion event instantaneously and get vibration frequency without any data averaging. Although the distance between adjacent FC/PC connectors determines the lower bound the location accuracy, it can be further improved by optimizing the fiber cable topology according to the real application. It has a very good potential in intrusion detection, vibration frequency measuring, etc. Furthermore, by accurately regulating the distance between fiber end faces in connectors, the reflectivity and transmitivity can be controlled and optimized. Therefore the sensing fiber link can be easily extended with more connectors without sacrificing the system dynamic range.

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