Distributed Optical Fiber Micro-vibration Sensing for Broken Fabric Bag Inspection in a Baghouse Filtration System

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Distributed Optical Fiber Micro-vibration Sensing for Broken Fabric Bag Inspection in a Baghouse Filtration System

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Abstract. A method based on phase sensitive optical time domain reflectometer (φ-OTDR) distributed optical fiber micro-vibration sensor, is proposed to detect and locate the broken fabric bags in a baghouse filtration system. The mechanism is by detecting the laser intensity change in a standard optical fiber cable hang in the filter bag, and which is the result of the dynamic airflow's perturbation in the baghouse. While the location of broken bags is realized by optical time domain reflector method. Field trial in Hefei cement industry platform is conducted and test results show that the minimum detectable hole size is 1cm^2. The method provides an alternative way for environmental dust emission monitoring and pre-warning in cement industry. Other application niches such as power plant, coalmine industry could also benefit from this new monitoring technology.

1. Introduction

The protection of environment is one of the most important objectives established by national and international organizations [1], and fabric filter baghouses, which may be one of the most important technologies, have been utilized for more than a century to control particulate emissions [2].

Because of its more and more powerful usage in environment protection, the leak detection of fabric filter baghouses has been more urgent and valuable than before. The methods of leak detection for baghouse filter mainly include direct visual inspection and indirect detection. Hayes J and Cabot C [3] used a label gas material to trace the leakage. Gernot P [4] developed a bag filter detection system based on light turbidity. Y T He, X D Wei and Q W Hu reported a technology of filter bag leakage based on capacitive sensing [5], and J Zhang analyzed the application of fluorescent powder detection technology in bag filter (in Chinese) [6].

In this paper, a method based on distributed optical micro-vibration sensor is proposed to monitor the health condition of the filter bags by detection of the dynamic vibration signals applied on the optic fiber cable placed inside the baghouse filtration system. The method provides a new route for smart positioning of the broken bags because of its unique advantages, such as electromagnetic interference resistant, capable of real-time and long distance monitoring.

2. Sensing Principle

The principle of a typical φ-OTDR distributed optical fiber micro-vibration sensor (DMVS) is shown in figure 1.

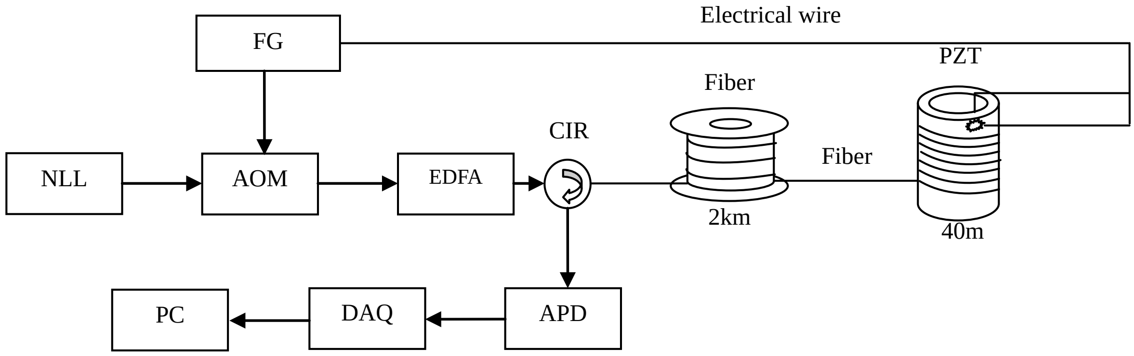

Figure 1. Laboratory set-up of a φ-OTDR distributed optical fiber micro-vibration sensing structure.

A continuous narrow linewidth fiber laser with a center wavelength set at 1550.12 nm is converted into pulsed light through an Acousto-Optic Modulator (AOM), and then amplified by Erbium-doped Fiber Amplifier (EDFA). Ultra narrow linewidth and low frequency drift can effectively improve the signal-to-noise ratio and location accuracy. The amplified pulsed laser is coupled into a 2km single mode optical fiber via an optical circulator and the Rayleigh backscattering signals are converted to electronic signal by an Avalanched Photodiode. A digital function generator with a 30 kHz repetition rate triggers a Data Acquisition card (DAQ) with a sampling rate of 100M to acquire the Rayleigh backscattering signal from the laser pulse. In order to accurately locate the micro-vibration, the spatial resolution of sensor is designed to be ±5m.

The experiment to test the frequency response of DMVS was carried out under 1kHz triggering rate when the PZT tube's driving frequency is set at 10Hz, 50Hz, and 100Hz respectively. The result is shown in figure 2

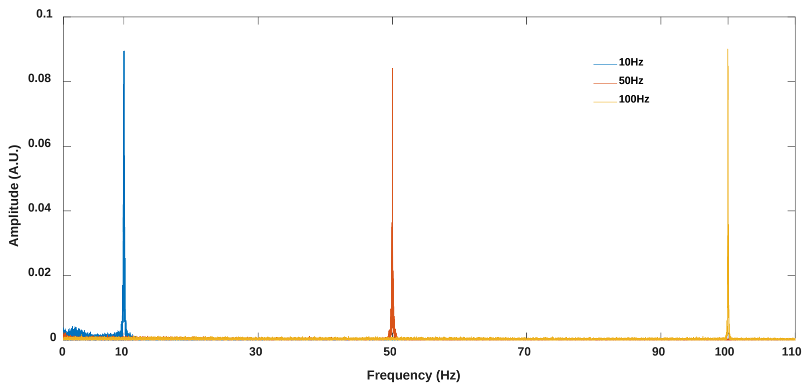

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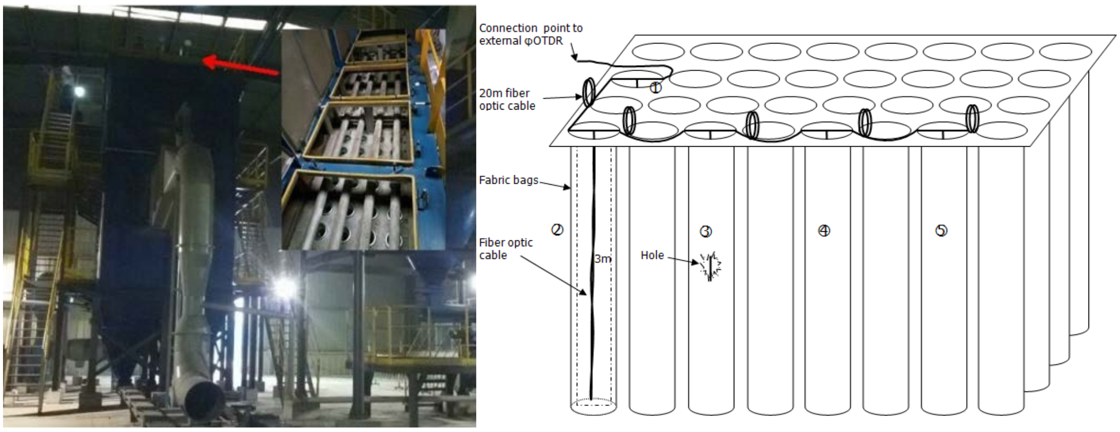
Figure 2. FFT spectrum with perturbation frequencies set at 10Hz, 50Hz, and 100Hz respectively under 1 kHz triggering rate.

3. Field Setup and Experiment

In this section, field test was carried out in a pulsejet baghouse filter system at Hefei Zhongya Environmental and Protection Co.Ltd., Anhui, China. The optical fiber cable with a total length of 1.2km was folded twice every 20m to produce a 3m optical fiber segment and tied up in place. Then the cable was placed into each fabric bag with a length of 4m as shown in figure 3(b). The 3m optical fiber cable segment hangs freely in the fabric bags and was labeled from 1 to 5 as shown in figure 3(b). There is a 20m optical fiber between each bag. It is noted that the spatial resolution of the DMVS is ±5m for our field trial, therefore, 20m will be long enough to distinguish micro-vibration signals from two adjacent bags. The cable is then connected to the DMVS with fusion splicing process to reduce reflection at optical fiber connection points. To simulate the broken bag in the baghouse filtration system, holes with a size of 1×1, 2×1, 3×1 cm^2 are manually created respectively. If there is a hole filter bag was broken, the dust air will flow inside through the leak point, and this airflow will apply a perturbation onto the sensing fiber. The small perturbation will change the optical phase difference at the leak point. Therefore, by using the demodulation algorithm, the broken bags can be detected.



(a) (b)

Figure 3. (a) Fabric baghouse filter experimental platform at Hefei Zhongya Environment&Protection Co. Ltd; (b)Schematic diagram of distributed optical fiber micro-vibration sensor deployment structure at cement plant platform.

4. Result and Discussion

The temporal stability correlation factor *sta_cor* and temporal difference correlation factor *dif_cor* is defined as follow equations (1) and (2), to describe the stability of the vibration signal in a fixed filter bag, and the difference of vibration signal between normal filter bag and broken filter bag in different time slice, respectively.

$$sta\_cor(i) = \frac{1}{n-1}\left(\sum_{j=1}^{n} corrcoef\,(f\_sig(i), f\_sig(j)) - 1\right) \tag{1}$$

$$dif\_cor(i) = \frac{1}{n}\sum_{j=1}^{n} corrcoef\,(f\_ns(i), f\_ds(j)) \tag{2}$$

Where i is the serial number of the time slices, n is the total number of the time slices, $f\_sig(i)$ is the frequency of the vibration signal in i^{th} time slice, $f\_ns(i)$ is the frequency of the normal bags' vibration signal in i^{th} time slice, $f\_ds(i)$ is the frequency of the damage bags' vibration signal in i^{th} time slice and $corrcoef$ is the correlation coefficients function.

Regarding real-time monitoring, 51200 ms is chosen as the length of time slice for its temporal stability, which has been experimentally proved, and for the convenience of data processing, 3rd filter bags is selected to be the presentation of other 4 filter bags.

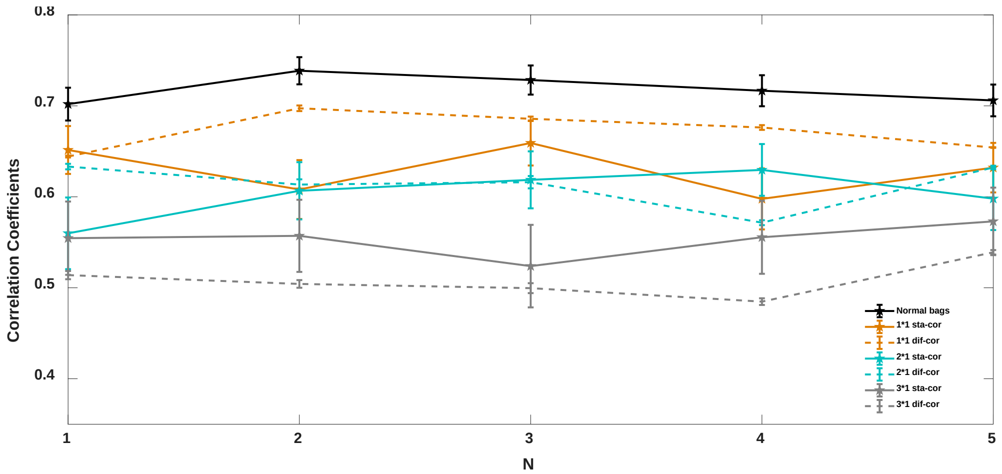


Figure 4. The error bar of temporal stability correlation factors and temporal difference correlation factors of 3rd filter bag under 4 situations mentioned below.

In figure 4, the temporal stability correlation factors and temporal difference correlation factors of 3rd filter bag under 4 situations: normal, broken with $1\times1cm^2$ hole, $2\times1cm^2$ hole $3\times1cm^2$ hole respectively, is plotted. The temporal stability correlation factors between the normal bag and broken filter bags demonstrate that the signal's stability of the former is stronger in general. Comparing the temporal difference correlation factors, the broken filter bags are smaller than the normal bag overall, while the variances are almost the same, which means the differences between of normal bag and the broken bags can be easily identified.

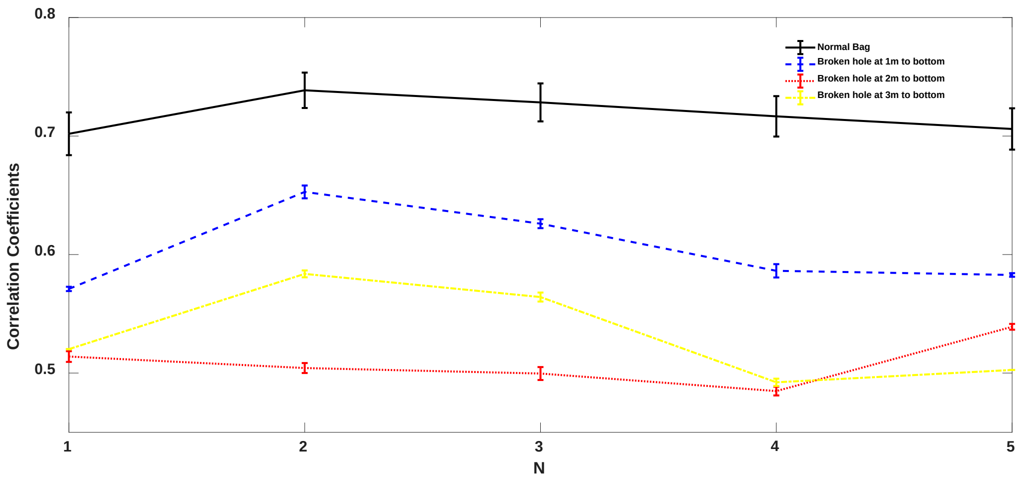


Figure 5. The error bar of temporal difference correlation factors of the 3rd filter bag under 4 situations.

The results of the temporal difference correlation factors of the 3rd filter bag under 4 different situations are shown in figure 5: normal filter bag, broken filter bag with 1×3 cm^2 hole at 1 meter, 2 meters, 3 meters to the bottom of the filter bag respectively. The difference between the normal filter bag and the broken one is obvious; furthermore, the location of the hole has complex effects on the signal, which may be caused by the irregular distribution of the airflow inside the filter bag due to the leak.

5. Conclusion and Future Work

In this paper, we propose a method to monitor the states of fabric bags in a baghouse filtration system. The method uses a distributed micro-vibration sensor to detect airflow perturbation signals through the

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hole on the broken bags. Cross correlation algorithm is employed to identify the characteristics of the broken bags. On-site measurements at Hefei Environmental and Protection Co. Ltd experiment test platform is carried out for long term monitoring and results are found that broken bags with hole diameter as small as 1cm can be identified with correlation algorithm. The technique has provided a new way for dust emission control in cement industry as well as other industry environment.

6. Acknowledgement
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7. References
[1] M Pham, C Clark and J McKenna, The evolution and impact of testing baghouse filter performance, *Journal of the Air & Waste Management Association*, 62:8, pages 916-923, DOI: 10.1080/10962247.2012.687360
[2] A Lay-Ekuakille,S Ikezawa, M Mugnain, iR Morello and C De Capua, Detection of specific macro and micropollutants in air monitoring: Review of methods and techniques, *Measurement*, vol 98, pages 49-59, 2017.
[3] Hayes J R, Cabot C, Bag filter leak detection [P]. US. 1976.
[4] M A E Plinke, G Pranghoferg and U Virnich, Remote leak detection sensing method and device [P]. US. 1996.
[5] Y T He, X D Wei and Q W Hu, Technology of bag -house filter leakage detection by capacitive sensor, *Industrial Safety and Environmental Protection*, vol 39, No.1, pages 44-46, January 2013.
[6] J Zhang, Application of Fluorescent Powder Leak Detection Technology in Bag Filter, *Journal of electric power,* vol 28, No.3, June 2013.