OPTICS11

APPLICATION NOTE

ALL-OPTICAL FIBER SENSORS FOR ACOUSTIC EMISSION MONITORING

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All-optical fiber sensors for acoustic emission monitoring

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Abstract – In this study optical AE sensors developed by Optics11 are compared with traditional electrical AE sensors. It is demonstrated that the novel optical AE sensors demonstrate performance close to market leading electrical sensors. The sensitivity of the optical sensors along with intrinsic advantages of the measuring platform represents a powerful tool, which aims to fill the gap in the industry where electrical sensors are not successful.

Index terms: Acoustic Emission (AE), Optical AE sensor, Sensitivity, Performance.

INTRODUCTION

Optical fiber sensors for structural health monitoring and condition monitoring have proven to be of value in many industrial applications. This is mainly due to their intrinsic benefits such as ability to provide reliable data in strong EMI fields, extreme temperatures and remote operation without requirement of additional electronic equipment at the sensing location. However, for Acoustic Emission (AE) monitoring, which is one of the Non-Destructive Testing (NDT) methods, optical fiber interrogation techniques have so far not been able to reach both sensitivity and bandwidth required for this application. AE monitoring is a crucial technology due to its numerous advantages over other techniques such as real time diagnosis of the system and monitoring of dynamic processes over large areas. Optics11 has developed the *OptimAE Acoustic Emission System,* an optical measuring platform that offers both extremely high sensitivity (fε level) as well as high measurement bandwidth (up to 500 kHz). The system features dedicated all-optical fiber acoustic emission sensors, optimized for structural health monitoring and condition monitoring applications. In this study, these sensors are compared with market leading electrical AE sensors which presently dominate the market.

BACKGROUND OF AE TECHNOLOGY

Acoustic emission sensors, be it optical or electrical, detect events resulting from rapid release of energy within material in a structure. This release of elastic energy can be due to stress, loading, growing of internal cracks or other discontinuities. The stress waves are usually of higher frequencies, in 100 kHz range. Presently, AE monitoring in structures is dominated by ultrasonic transducers which can detect acoustics of the order of 20 kHz to 1 MHz. Accuracy of measurements form such sensors depend on the number of sensors and the signal interrogation system. An illustration of a typical acoustic emission monitoring process is shown in Figure 1.

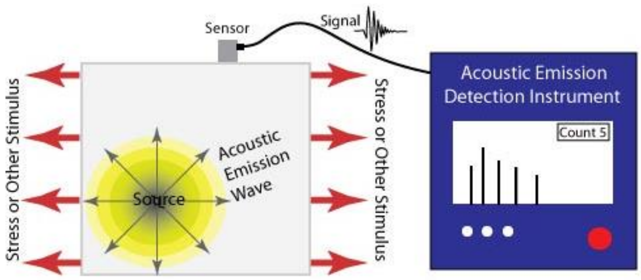

Figure 1: Schematic of a typical acoustic emission monitoring technique (Department of Mechanical engineering, Vrije Universiteit Brussel).

Advantages offered by AE monitoring compared to other NDT techniques are listed below (Baillie, 1999).

1. The technique can detect propagation of minute cracks.
2. AE monitoring provides the advantage of real time diagnosis of the system i.e. while the structure is still in service.
3. While monitoring, no external energy is released into the structure.
4. Knowledge of location of sensor is not important, since AE examination is non-directional.
5. Size of the structure does not pose a limitation.
6. Dynamic processes associated with damage initiation and material degradation can be monitored.

The sensors which can detect these acoustic signals can define the nature of the source event depending on the amplitude, frequency and speed of the wave. However, the electrical sensors sometimes may not able to provide accurate input signals to the interrogation system due to electromagnetic interference leading to system malfunctions. There is also an increased risk of using electrical sensors in challenging applications such as high temperatures, high-radiation, corrosive or high humidity environments.

SOLUTION

Acoustic emission monitoring using optical sensors provide solutions to the problems faced by electrical sensors in variety of environments. The acoustic signal obtained from the optical sensor is true representation of the original wave without any influence of the cabling and electronic processing that may potentially introduce distortions. Various technologies have been evaluated by the industry and researchers over last years. These mainly include Fiber Bragg Grating (FBG) based sensors which are presently used for local strain, temperature and force measurements, and interferometric fiber optic sensors. Some of these technologies come up with certain restrictions such as lower bandwidth (only 10s of kHz), high system complexity or low sensitivity, effectively hindering measurement of weaker signals (Tongzhi Zhang, 2016).

Optics11 has developed all-optical acoustic emission sensors, based on the unique ZonaSens optical fiber interrogation technology. The combination of sensors and interrogation system allows one for measuring multiple sensors with each sensor having high sensitivity (fε level), high measurement bandwidth (up to 500 kHz, hence acquisition speed of 1 MHz) and high dynamic range.

The light weight AE sensors from Optics11 compete with the conventional electrical sensors in size and shape and require no local power source. The output cable can be from meters to kilometers in length without requirement of any additional equipment while maintaining the high sensitivity and no signal loss. Next to this, presence of (strong) EMI fields have no influence on the working of these sensors. The resonance frequency of these sensors can be tuned according to the application area anywhere between 100 kHz and 300 kHz. The sensor shown in Figure 2 has a resonance at 200 kHz.

Figure 2: Optical AE sensors 6300 series. The working principle is based on ZonaSens technology.

A performance comparison with a conventional electrical sensor can provide insight into the minimum signal field which can be resolved by this optical sensor. Furthermore, signal to noise ratio (SNR) can also be compared for a certain excitation signal. The description of the experiment and the results are covered in the following sub-sections.

Purpose

The experiment is performed to obtain global understanding of the performance of optical sensor developed by Optics11 by comparing it to a conventional electrical sensor.

Materials

To perform this experiment, the following was used.

1. Optics11 AE Sensor with resonance at 200 kHz and a suitable magnetic clamp.
2. An electrical sensor with resonance at 180 kHz with a suitable magnetic clamp.
3. Steel plate with dimensions 1000 mm x 500 mm x 5 mm.
4. Ultrasonic excitation source – Piezoelectric bender
5. Silver conductive epoxy
6. Signal Generator
7. Data acquisition unit
8. BNC cables and connectors
9. OptimAE optical measuring system
10. Signal post processing software – LabVIEW
11. Computer
12. External preamplifier for electrical AE sensor
13. Signal / DC voltage decoupling module for electrical sensor.

Methods

During the experiment, *sinusoidal* bursts were chosen as the appropriate excitation signal. The length of the burst was defined by taking the dimensions of the plate into consideration. It is required in order to avoid an interference between individual bursts. The product of the plate thickness and the excitation frequency provided an indication of presence of lamb waves (mainly A0 and S0 modes). The signal content which is used to compare response from the sensors pertains only to the first wave which arrive at the sensors. This is to rule out any effect on signal amplitude due to reflections from the plate boundaries. Figure 3 provides visual representation of the setup utilized during the experiment.

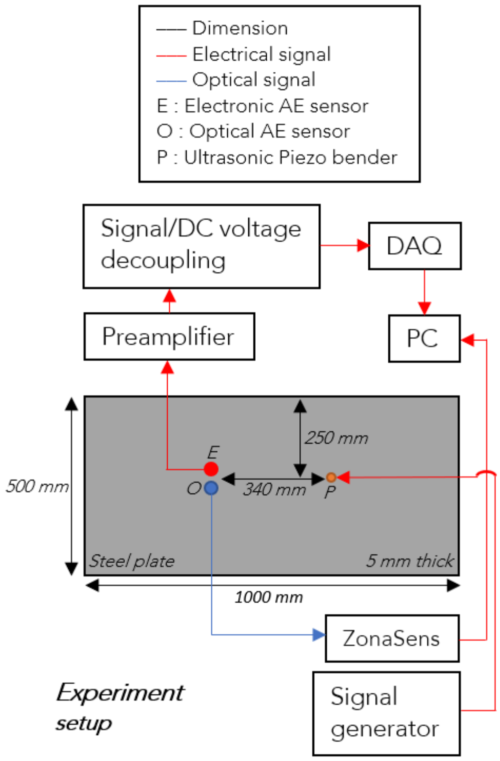

Figure 3 (Above) The steel plate test setup used in the laboratory. (Below) The connection diagram showcasing the role and placement of components used during the experiment.

Data

The input signal characteristics are given in Table 1.

Characteristic	Description
Signal type	Sinusoidal bursts
Cycles	4
Frequency	180 kHz
Excitation voltage	20 Vpp

Table 1: Input signal characteristics for the excitation source.

The characteristics of the electrical sensor and the optical sensor are given in Table 2. Figure 4 showcases the response of the electrical sensor and the optical sensor to the input excitation.

Characteristic	Electrical Sensor	Optical Sensor
Gain of the external preamplifier	40 dB	None
Noise floor [Chosen bandwidth: 95 kHz to 300 kHz]	-108 .92 (dB re [V/√Hz])	150 fε/√Hz

Table 2: Characteristics of the electrical and optical AE sensors.

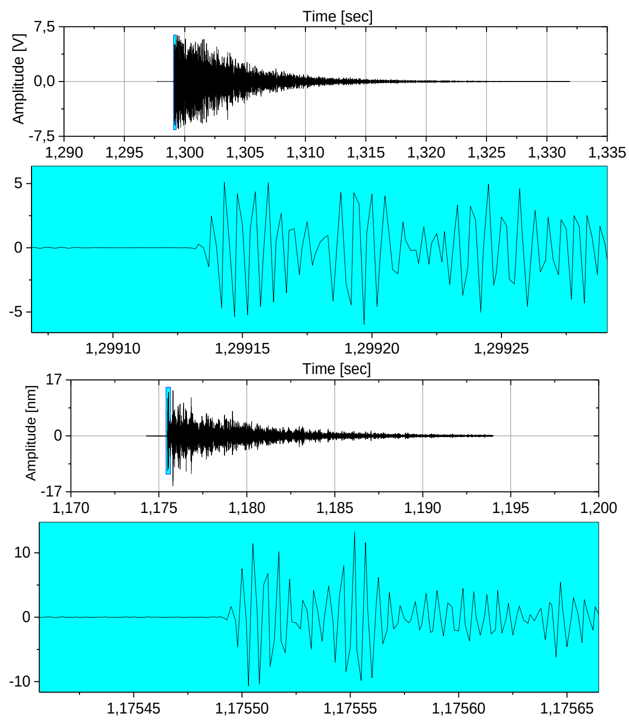

Figure 4: (First pair) AE burst recorded by the electrical sensor. (Second pair) AE burst recorded by the optical sensor. Magnified views of the very first section of the bursts are shown in colored graphs (marked in blue box).

In addition to the output characteristics obtained for the optical sensor described in Table 2, the signal field which can be resolved by the optical sensor has been calculated as -37 (dB re [μbar/√Hz]).

Results

SNR comparison between sensor types provide an insight into the performance of the optical sensor. Performance comparison between the optical sensor and the electrical sensor is given in Table 3.

Characteristic	Electrical Sensor	Optical Sensor
SNR at 20 Vpp excitation	66.2 dB	47.4 dB
Equivalent sensitivity level	-40 (dB re [V/µbar])	-59 (dB re [V/µbar])

Table 3: Performance comparison between the electrical and optical AE sensors.

The equivalent sensitivity level described for the optical sensor in Table 3 pertains only to the excitation conditions mentioned in Table 1. The optical sensor has 19 dB lower SNR than the electrical sensor. The performance of the optical sensor can be scaled up by using longer optical fiber inside the sensor by 4 to 6 dB. By utilizing the calibrated V/µbar sensitivity of the electrical sensor, the minimum optical signal field in dB re [µbar/$\sqrt{Hz}$] has been obtained. It represents the minimum detectable signal level that the optical sensor is able to pick-up. The V/µbar reference is however an ill-defined term for electronic AE sensors and requires more explanation. Hence SNR for a certain excitation provides a more reliable sensitivity comparison (Ono, 2016). Furthermore, examination of burst signatures from both sensors showcases similarity.

CONCLUSION

The optical AE sensors powered by Optics11 developed ZonaSens technology showcase performance very close to that achieved by the electrical sensors in the similar frequency domain. Currently this is the only optical acoustic emission technology on the market with this performance. This mainly can be attributed to the very low noise floor of the measuring system, with the optical sensor tailored to obtain the minimum level. The functional and operating benefits provided by the optical measuring platform out performs its electrical counterpart. Moreover, comparable sensitivity level in respect to traditional sensors clearly shows the potential of the OptimAE system and lays the ground for successful applications for all-optical AE sensors.

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