A New Strategy For Eliminating Noise From Acoustic Signals

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Abstract

This paper introduces a new strategy for extracting Rayleigh waves from a noisy environment using a differential optical interferometer (DOI). The DOI consists of a bidirectional coupler; one arm, positioned over a test specimen, senses an acoustic signal immersed in noise while the other arm, positioned over an acoustic isolator, senses the noise alone. Analytical arguments show that when the coupler is designed properly, the phase shifts between the signals returning to a photodetector produce an intensity modulation which is directly proportional to the pure acoustic signal.

Introduction

Acoustic emission (AE) takes place whenever energy is redistributed in a material due to deformation, corrosion, transformation or fracture. Even though the measurement and analysis of this emission is a well accepted means for nondestructive evaluation, it is very difficult to obtain satisfactory results when operating in noisy environments typically encountered under field conditions. Simply put, the ability to identify or eliminate dominant noise generators is *the* most outstanding problem facing the AE community today. Solutions are currently restricted to increasing the signal-to-noise ratio and/or filtering the acoustic signal from the noise. However, increasing the signal-to-noise ratio generally requires carefully controlling the operating environment, whereas filtering necessitates that the signal is at a frequency different from that of the noise.

This paper introduces a new strategy for extracting acoustic signals from a noisy environment using a differential optical interferometer (DOI). Results show that this noncontacting, fiber optic transducer can be configured to detect R-waves in the presence of noise even when the noise is at a level substantially greater than that of the acoustic signal.

The Differential Optical Interferometer (DOI)

As shown in Fig. 1, the DOI consists of a bidirectional coupler preferably constructed using polarization preserving single mode optical fibers. Laser light, launched into the input arm, is divided equally by the coupler into the two output arms labeled as #1 and #2. Arm #1 is positioned normal to the test surface while arm #2 is positioned normal to an acoustic isolator designed to eliminate the desired acoustic signal. In this configuration, arm #1 detects both the noise and the acoustic signal from the surface while arm #2 picks up only the noise from the isolator. By employing GRIN lenses on the fiber tips and reflective foil stickers on both test surfaces, most of the impingent light is reflected back into the fibers. However, a small portion of the light is internally reflected by the glass/air interface at the fiber tips. These back reflections interfere with the light coming from the surface and the acoustic isolator.

When the fiber arms are cut so that the difference in path length produces a relative phase change of π and the coupler divides the input light equally between the output legs, the output from the DOI is given by,

$$I = \frac{1}{2} [I_3 + I_4] + \sqrt{I_3 I_4} \cos (\phi_3 - \phi_4) \ . \qquad (1)$$

Equation 1 shows that the output from the DOI provides a direct measurement of the pure acoustic signal.

Performance

By using GRIN lenses and by applying reflective stickers onto the illuminated surfaces, 92% of the laser power is utilized and modulation occurs over 100 percent of the output intensity. The DOI will be self-compensated against temperature when both arms are approximately the same length and operate under the same environmental conditions. In addition, the two air gaps between the fiber tips and the test surfaces must be equal and have the same index of refraction.

A schematic representation of the apparatus is illustrated in Fig. 2. Each fiber tip is housed in a 3.3 mm diameter sleeve which allows it to be positioned relative to a 1.8 mm diameter, quarter pitch GRIN lens. The holders were mounted in micro-positioners to facilitate the adjustment of the optrodes relative to the test surfaces.

It was found that a convergent illumination was required to ensure that the size of the illuminated spot was small compared to the acoustic wavelength of the R-wave. Calculations showed that for R-wave generated at a frequency of 2.25 MHZ, the spot size had to be less than 1.3 mm. A typical stand-off distance measured from the optrode to the surface was 2 mm.

The center-to-center distance between the optrodes was found to place a restriction on the frequency range over which noise could be eliminated. In general, the spacing between the optrodes must be relatively small with respect to the wavelength of the noise so that the noise is the same in both sensing locations. Assuming that the noise is characterized by a cosine wave of length, λ, and that it is desired to eliminate 90 percent of the noise, the optrodes must be positioned at a center-to-center distance of approximately 0.03λ. Since the smallest center-to-center distance which can be achieved with the present optrode design is 5 mm, the upper threshold on noise removal is 37.7 kHz. However, higher frequency noise (on the order of MHZ) may be removed provided that the testing geometry is carefully chosen.

System Evaluation and Proof of Principle

The analysis was verified by using the DOI to track the surface displacement of a piezoelectric transducer. When the device was positioned asymmetrically, a signal corresponding to the transducer's output was detected. When it was positioned symmetrically, the signal reduced to the level of the dark noise.

Extraction Of An R-Wave From Random Noise

Figure 3 shows a test setup in which a DOI was used to acquire an R-wave in the presence of random noise. Arm #1 was positioned directly over a reflective foil sticker placed on the surface of a 406 mm long x 25.4 mm wide x 2.54 mm thick aluminum specimen while arm #2 was positioned over a second sticker on an acoustic isolator mounted on the test surface. Random noise was generated by placing an electric motor equipped with a rotating eccentric cam on the same table that supported the specimen. The resulting longitudinal waves were transferred to the specimen through the support posts.

The arms of the DOI were spaced 14 mm apart and were intentionally located at the same distances from the posts and positioned symmetrically over the width of the specimen so that the acoustic waves created by the motor arrived to both arms at the same time. Only in this configuration could the noise be completely removed independent of frequency. Otherwise, for the 14 mm spacing, the upper bound for 90 percent noise removal would have been only 13.5 kHz.

The 0.5 MHZ piezoelectric transducer, used to illustrate proof-of-principle and labeled as #2, was attached to the lower surface of the test specimen to verify that the noise created by the motor was actually transmitted to the specimen. An R-wave was generated on the upper surface of the specimen using a 2.25 MHZ R-wave transducer labeled as #1. This transducer was positioned along the center line of the specimen at a distance of 24.5 mm from both arms of the DOI. It should be noted that the R-wave speed in the aluminum specimen was 2.89 mm/µsec.

The upper trace in Fig. 4 shows the response of the 0.5 MHZ transducer while the lower trace shows the output from the DOI. A distinct R-wave appears at the expected arrival time of 18.5 µsec which includes the 10 µsec delay in the transducer and 8.5 µsec for the time of flight. When arm #2 was removed, an R-wave of approximately the same amplitude could be observed but the baseline moved so erratically that it was impossible to capture the wave in real time without substantially reducing the vertical gain of the oscilloscope.

It should be noted that the signal in the upper trace of Fig. 4 is displayed without amplification while the signal from the DOI is amplified 1000 times. It is apparent from the upper trace that substantial noise is present in the frequency range extending from 0.4 to 0.6 MHZ and even though this noise is 100 times greater than the R-wave signal, it is not apparent in the lower trace.

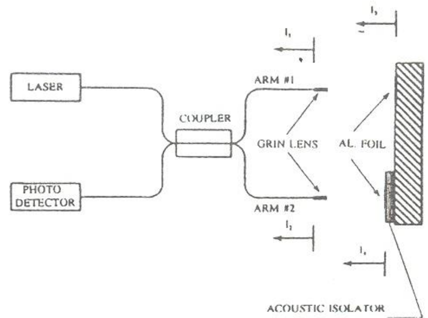

Figure 1. Schematic of the differential optical interferometer.

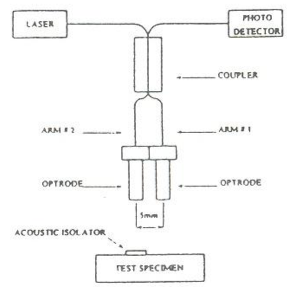

Figure 2. A schematic representation of the apparatus.

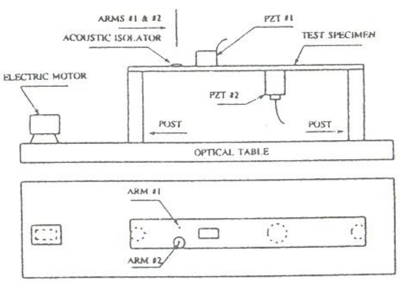

Figure 3. The experimental setup used to acquire an R-wave in the presence of random noise.

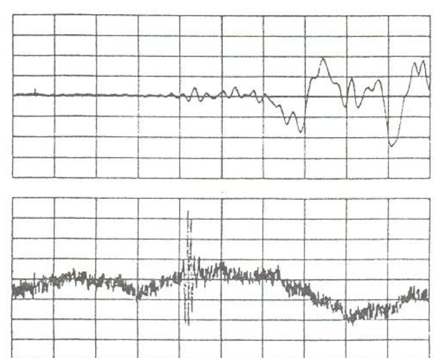

Figure 4. Results obtained from the setup shown in Fig. 3. The upper trace shows the noise detected by a 0.5 MHZ transducer while the lower trace shows the R-wave detected by the DOI. The vertical gains on the upper and lower traces are 5 mV/div and 50 mV/div, respectively; the horizontal gain on each trace is 5 µsec/div.