TRANSIENT RESPONSE OF FABRY-PEROT FILTER-BASED DYNAMIC INTERROGATOR

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ABSTRACT
We have developed a high frequency dynamic interrogator capable of sensing vibrations with amplitudes less than 1 microstrain. The dynamic interrogator uses fiber Bragg grating based Fabry Perot filters for high sensitivity sensing. In this paper we demonstrate the capability of our interrogator to capture the transient response of acoustic emissions from a ball drop test. The results of the ball drop tests along with adaptive signal processing techniques applied to improve the Signal to Noise ratio are reported here.

Keywords: Transient response, Fiber Bragg Gratings, Adaptive Line Enhancement

INTRODUCTION
Acoustic emissions from mechanical structures can be used to monitor their structural health. Conventional methods of sensing these emissions use piezo-electric transducers (PZTs). PZTs are prone to electromagnetic interference (EMI), require heavy cabling, and provide narrowband response owing to their inherent resonances. Fiber Bragg gratings (FBGs) are aptly suited for sensing such high frequency acoustic emissions since they do not suffer from the above. Apart from having a flat response for a range of frequencies from few kHz to 1 MHz, FBGs are amenable to array sensing [1, 2].

We had previously demonstrated the use of Fabry-Perot filter based on fiber Bragg gratings (FP filter) for dynamic interrogation of acoustic emissions in the range of 10 kHz to 1 MHz with a sensitivity of less than 1 microstrain [3]. Such sensitivity was achieved using FP-FBG as not only the interrogator element but also the sensor element, and was testing using a continuous wave source of acoustic emissions on an Aluminum plate. In the present work, we extend the testing to the detection of transient acoustic emissions.

The change in the intensity of the light due to the vibrations experienced by the sensor FP filter is interrogated by a matched FP filter and detected by the Avalanche Power Diode-Trans impedance Amplifier (APD-TIA). The acoustic emissions are captured and subsequently processed to get the time as well as frequency domain data. The signal processing consists of over sampling 16 bit ADC and Sharc DSP for online monitoring of the acoustic emissions. The entire optics and electronics is integrated in to a compact box for ease of handling. The vibration sensor was carried to IGCAR, Kalpakkam for testing the transient performance.

The transient performance of the system has been demonstrated through ball drop tests using steel balls of different diameters in a range of 2-12.5 mm. The sensor was pasted on to the plate using epoxy and the impact waves were generated in the plate by hitting the plate with the spring loaded balls. The data was logged to a PC and subsequently plotted to analyze the frequency content of the ball impact. The frequency content of the impact wave decreased with increase in the ball diameter and could be quantitatively correlated with the diameter of the ball. The present study demonstrates the applicability of the developed Fabry-Perot filter based acoustic emission sensor as a broad-band detector of in-plane transient vibration.

EXPERIMENTAL SETUP

Use of FP filter for Acoustic emission sensing
The experimental setup to examine the performance of the Fabry-Perot filter based vibration sensor is shown in Figure 1. A broadband EELED source is used to illuminate the FP sensor glued to the aluminum plate. The reflected signal from the sensor FP element is interrogated by a matched FP element. Even though the Fabry Perot filters are matched, the resonant peaks within the spectrum may not match with each other.
Hence interrogator FP is pasted on a PZT element and tuned to the appropriate center wavelength. The transmitted light, which consists of amplitude modulation corresponding to wavelength modulation of sensor FP element is detected by an Optical receiver and subsequently analyzed.

The optical receiver module is shown in the figure is shown in Fig. 2. It consists of a fiber-pigtailed APD-TIA (APD-12, oemarket.com) with a high pass cutoff frequency of 10 kHz as the light detector. The corresponding signal is passed through a low pass anti-aliasing filter with a cutoff frequency of 1 MHz. A 16-bit Sigma-Delta over-sampling ADC (Texas instruments, ADS1602) is used to digitize the signal such that a frequency resolution of <1 kHz is obtained. The ADC samples at 40 MSa/s and subsequently down-samples to 2.5 MSa/s to reduce the background noise level. The output of the ADC is fed into the data processing module through a serial link as shown in Fig. 8. The heart of this module is the Actel ProASIC 3 (A3P1000) FPGA, which provides clock signals to the ADC and synchronizes the data transfer to other on-board processors. An Analog Devices Sharc processor (ADSP-21363) is used for real time digital processing of the acquired data. A microcontroller (Cypress semiconductor, EZ USB FX2) is used to connect the system to a personal computer through USB 2.0 for displaying/logging the data.

**Transient response with ball drop test**

In order to capture the transient response of our dynamic interrogator we performed ball drop experiments with steel balls of different sizes. The test bed consists of an aluminum plate of dimensions 300 mm X 150 mm X 2mm as shown in the figure Fig. 1. A sensor FP filter is pasted to the plate using a room temperature curing epoxy. Steel balls of different diameters are taken and are used for drop ball tests. The time domain data from the dynamic interrogator is logged on to a PC and subsequently Adaptive Line Enhancement (ALE) with an order of 300 is applied to the signals. Fig. 3 shows the plot of the transient response of the sensor along with the frequency domain response. It also shows the time domain signal after
Fig. 3: Time domain plot of the ball drop tests for different sizes of ball with diameter (top to bottom) 2mm, 5mm, 6.5 mm and 9 mm.
ALE is applied on the signal. It is evident from the Fig. 3 the ALE enhances the SNR of the noisy signal so that we get a better performance in the time domain.

Another key fact to notice from Fig. 3 is that the frequencies which are excited in the plate due to the different ball sizes are following a pattern. The frequencies excited are decreasing with the increasing in the ball size. This behavior is seen because the time of contact of the ball with the plate due to a drop increases with the increase in ball size. Hence smaller the size of the ball, lesser is the time of contact of the ball on plate and higher are the frequencies that are excited in the plate. As can be inferred from the Fig. 3 the behavior is seen to be consistent with the expected performance.

The signal which is logged on to the personal computer from our dynamic interrogator is noisy as seen from the Fig. 3. In order to increase the SNR to get a better time domain signal we use an adaptive filtering technique called Adaptive Line Enhancement (ALE). ALE is capable of increasing the SNR effectively from noisy signal without altering the frequency content of the original signal as can be seen in the Fig. 3. ALE works on the fact that the noise is uncorrelated whereas the signal is correlated. However, the improvement is achieved at the expense of increased computation cost and processing delay. For our case, the Sharc processor is capable of executing instructions at 250 MIPS, which results in a processing time of 30 ms. Further attempts are made to improve the performance of the interrogator using appropriate parameters for ALE. Choosing the right delay and filter order is crucial for getting a better performance from the ALE.

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REFERENCES