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INTELLIGENT TRANSDUCERS – FOR GENERATION OF BAT ECHOLOCATION SIGNALS

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1 INTRODUCTION

Echolocation calls can be categorised as either frequency modulated (FM) or constant frequency (CF). Some bats, such as the Pteronotus Parnelli (mustached bat) emit a compound signal consisting of both FM and CF components. The bat is of particular interest to scientists and engineers as their resolution capabilities far exceeds the most technologically advanced manmade systems [1,2]. One possible reason why the bat is able to effortlessly achieve such resolution capabilities is their ability to retain information on the emitted call.

The focus of the current research is to develop a transducer capable of non-invasive direct measurement of the amplitude and phase of the radiated ultrasonic field; conferring significant advantages for many practical ultrasound systems. Potentially, it would be possible to counteract rapid changes to the impulse response of the transducer via feedback to the drive electronics. The ability to perform in situ calibration is of obvious benefit as it negates the need for costly and often disruptive maintenance procedures. Such a monitoring system would have the ability to accurately control and optimise the transducer output, which would ultimately improve the performance of existing signal and image processing algorithms. If the monitoring system could be implemented in an array, it would allow for correction of non-uniformity across the array surface with resultant improvements in signal processing and beamforming.

An embedded piezoelectric device, such as a Polyvinylidene Fluoride (PVDF) layer provides one possible monitoring solution for such a transducer. However, PVDF devices are prone to electromagnetic interference from the transducer excitation signal and are relatively invasive to the ultrasonic field. An alternative is an optical fibre sensor which has several advantages over the piezoelectric device. Optical fibre sensors are small in size and therefore relatively non-invasive, lightweight, have a broadband response, and perhaps most importantly are immune to electromagnetic interference. This work will present proof of concept results on two different optical sensing systems for monitoring the ultrasonic output of a piezocomposite sonar transducer. The first proposed system uses the intrinsic sensitivity of a singlemode optical fibre to an external dynamic strain field to modulate the polarisation of light propagating in the fibre [3]. This polarimetric approach can utilise a relatively simple detection system, but has the drawback of integrating the response along the entire length of fibre exposed to the incident sound field. An alternative approach lies in the use of fibre Bragg gratings (FBGs) formed directly in the optical fibre through periodic modulation of the refractive index profile [4]. The dynamic strain field to be measured now modulates the optical wavelength response of the FBG. Although the detection systems are more complex than for the polarimetric sensor, the FBG has the advantages of pseudo-point measurement and excellent capability for multiplexing, thus making it an excellent candidate for array monitoring applications.

2 POLARIMETRIC SENSOR

An optical fibre sensor bonded along the surface of the transducer provides a means of measuring the amplitude and phase of the emitted acoustic wave. The optical fibre positioned on the transducer front face is radially compressed by the radiated ultrasonic wave to the extent that the polarisation of the light travelling through the fibre is altered. A suitable detection system enables the change in polarisation state to be monitored, which can be directly related to the emitted acoustic wave at the transducer surface. The detection system for a polarimetric sensor is relatively simple and includes the use of a polarisation controller, polarisation analyzer, photodiode and amplifier circuit, as illustrated in Figure 1.

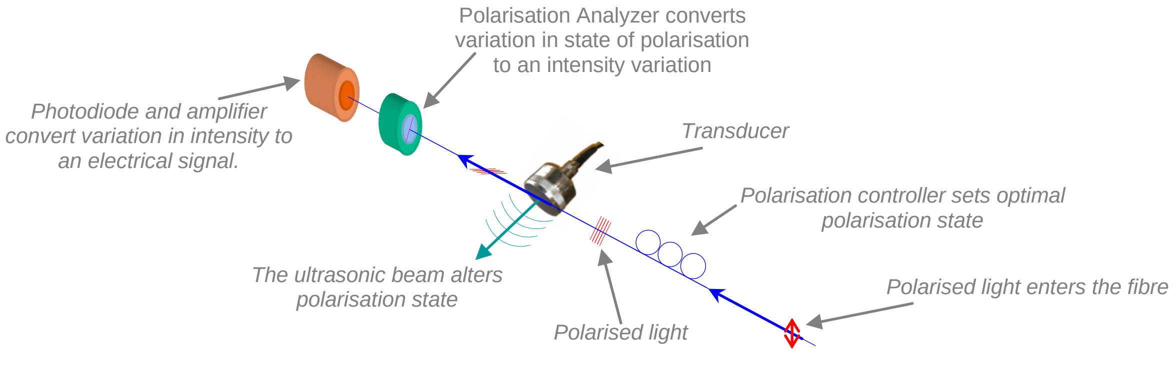

Figure 1: Polarimetric Detection System

2.1 RESULTS

To demonstrate the response of the polarimetric system a fibre was bonded along the full length of a 250 kHz piezocomposite immersion transducer. The transducer was placed in a water tank and a narrowband excitation signal was applied to the transducer. Specifically, the transducer was driven with a 15 cycle toneburst at 250 kHz with an amplitude of 80 V peak-to-peak, as shown in Figure 2. To evaluate the validity of the optical sensor the output of the transducer was simulated using Piezocad, a software package developed by Sonic Concepts [5]. The response of the sensor was captured by the detection system and the comparison between this signal and the simulated transducer output is shown in Figure 3. It can be observed that a good correlation between the theoretical transducer output and the signal detected by the polarimetric sensor exists.

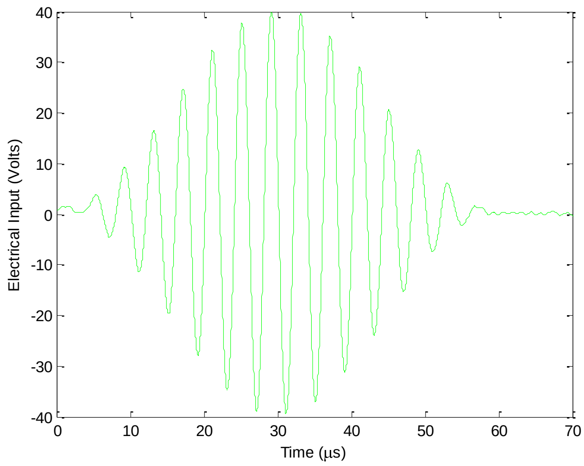

Figure 2: Transducer Excitation Signal

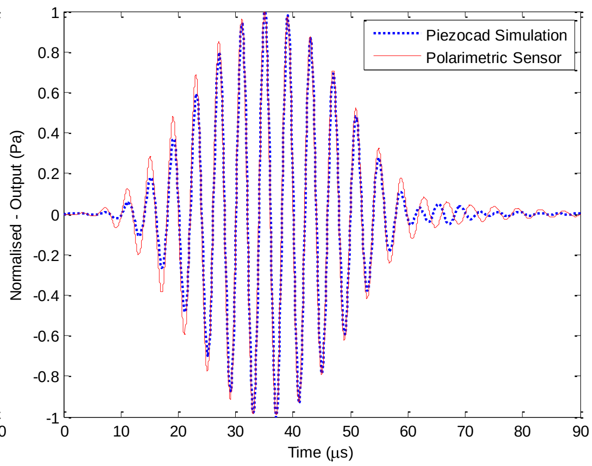

Figure 3: Comparison of Polarimetric Signal and Theoretical Transducer Output

3 FIBRE BRAGG GRATING

A FBG is an optical fibre with a periodic perturbation of the refractive index along the length of the fibre core. The perturbation, or grating, extends over a finite length of the fibre core and is typically of the order of 1 to 20 mm in length. An illustration of a uniform FBG is shown in Figure 4. The regions of varying refractive index are created by exposing the photosensitive fibre core to the interference pattern of an intense ultraviolet interferometer. Alternatively, a phase masking technique may be employed whereby a mask of suitable structure is placed between a light source and the fibre core to create the permanent change in the refractive index.

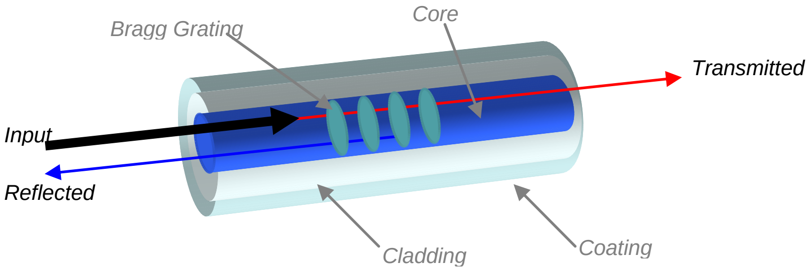

Figure 4: Illustration of a Fibre Bragg Grating

The FBG is a filter, reflecting a designated portion of the incident electromagnetic spectrum [4]. The wavelength λ_B of the reflected electromagnetic signal is governed by Bragg's Law and is related to the grating's period Λ and mean effective refractive index n_{eff}, as shown in Equation (1).

$$\lambda_B = 2n_{eff}\Lambda \qquad (1)$$

It is evident from Equation (1) that the Bragg wavelength is a function of the fibre and grating characteristics, specifically the pitch and perturbation profile. It follows that any physical change in the grating period or refractive index will result in a change in the Bragg wavelength. In terms of accuracy a FBG holds an advantage in that the signal is encoded directly into wavelength and is not subject to intensity fluctuations like many other optical fibre sensors. Measuring a wavelength shift and not a change in polarisation state provides a direct measurement of the state of the grating and is repeatable over the lifetime of the sensor despite potential uniform transmission losses in the optical system.

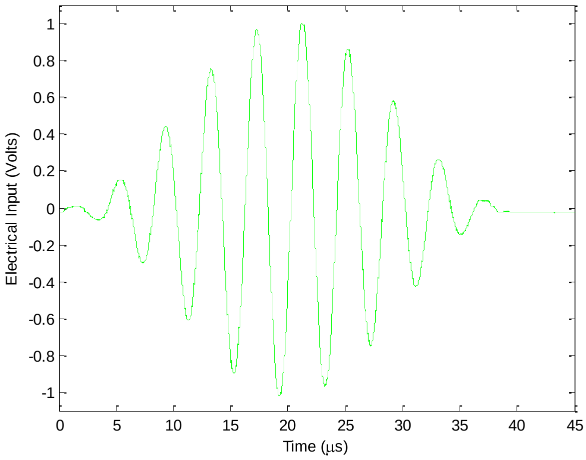

Figure 5: Transducer Excitation Signal

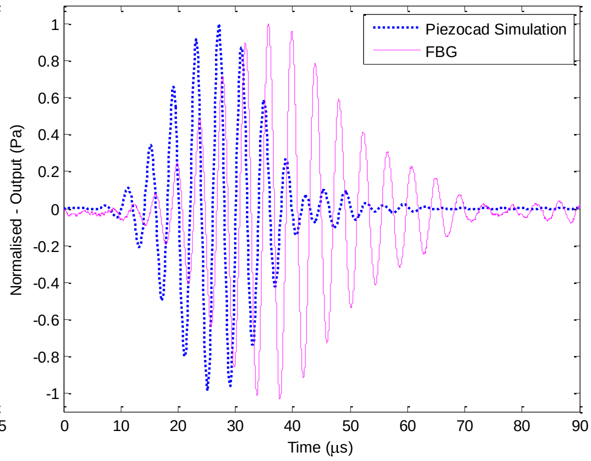

Figure 6: Comparison of FBG Signal and Theoretical Transducer Output

3.1 RESULTS

A 1 mm uniform FBG was bonded to the front face of a 250 kHz piezocomposite immersion transducer. The bonding extended slightly beyond the 1 mm grating region to ensure the grating was firmly attached to the transducer surface. The signal used to drive the transducer was a 10 cycle toneburst at 250 kHz, with amplitude of 80 V peak-to-peak, which is shown in Figure 5. The response of the FBG sensor is shown along with the theoretical response of the transducer as simulated by Piezocad in Figure 6.

Generally, poor correlation between the simulated transducer response and the FBG sensor was observed. In particular, note the unexplained delayed response and extended ringing in the FBG response in Figure 6. The discrepancy between the FBG sensor and simulated transducer output results from the FBG being primarily sensitive along the main fibre axis, but the force from the transducer acts in a radial direction. It is critical that any axial motion along the fibre from unwanted transducer modes is eliminated. Only then can the response of the FBG be related to the radial force through the Poisson effect. Embedding the FBG in a suitable material that adequately attenuates modes of vibration along the fibre axis should improve the FBG response.

4 FUTURE WORK

In regard to the polarimetric sensor the initial experimental work has focussed on narrowband excitation of the transducer. Experimental evaluation of the polarimetric sensor's ability to measure wideband signals will be conducted. In addition, finite element modelling will be undertaken to advance understanding of the physical interaction of the optical fibre and ultrasonic field. A suitable test of the polarimetric sensor's ability to optimise and control the transducer output via feedback to drive electronics will be conducted. Such a test will involve the generation of bioacoustic signals, in particular those containing multiple harmonics. The sensor technology will be extended to sonar array applications, where the work will focus on embedding the sensors in a suitable material.

5 CONCLUSION

Outlined herein is the introduction of two optical sensors for the measurement of the amplitude and phase of the radiated ultrasonic field at the front face of a transducer. A polarimetric sensor was demonstrated as a good ultrasonic field sensor for narrowband excitation. Disappointingly the FBG sensor did not provide as good sensing capabilities and further work is required tounderstand the observed response. Key areas of future work have been outlined to fully evaluate the proposed optical sensors as adequate monitors of the radiated ultrasonic field.

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