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Damage detection in piezoelectric crystal using surface acoustic wave sensors

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1. Introduction

Lithium niobate ($LiNbO_3$) has generated considerable interest as potential materials for acoustic device applications due to their high piezoelectric properties [1]. $LiNbO_3$ single crystal, became widely used in applications such as acoustic wave transducers, high speed communication systems (mobile phones, GPS,TV), acoustic delay lines, acoustic filters, optical amplitude modulators, second harmonic generators, beam detectors, phase conjugators, dielectric waveguides, memory elements and holographic data processing devices [2-5].

$LiNbO_3$ based acoustic wave sensors are used for generation and detection of bulk waves, guided waves, and surface acoustic waves (SAW) for application in material characterization, non-destructive testing and structural health monitoring (SHM). The generation and detection of SAW in piezoelectric crystals with the aid of digital (DT) or inter-digital transducers (IDT) has found widespread technological applications since the 1960s for signal processing and filtering applications [6].

The capability of SAW is to travel over long distances with low attenuation and their non-dispersive behavior makes them ideal choice for structural health monitoring (SHM) applications. A wide range of investigations have demonstrated the utility of SAW for nondestructive evaluation of detection of crack, fracture and delamination [7-9]

Degradation in the performance of the wind turbines, gas turbine, and nuclear power plants, are associated with structural changes induces by vibration, erosion/corrosion and excessive thermal stresses. There is a need to develop online conditional monitoring sensors systems for detection of damages in the nuclear power plants, wind turbine or gas turbine, supply lines during operation. Due to high cost and risk involved in operation and maintenance of the nuclear power plants, the developed ultrasonic sensors has to be sensitive to minuet abnormality in the performance of nuclear plant. We proposed to develop a SAW sensor, which will be rigidly attached to the structure. The damages induced due to corrosions, temperature variations and mechanical stress onto the SAW sensors reflect the current state or "health" of the structure. We will operate under the assumption that any changes in sensors outputs are directly related to the health of the structure. Therefore, accurate measurement of sensor response will help us in quantifying the current health of base structures.

The acoustical characterization of $LiNbO_3$ has been reported earlier [10-13]. Here, we explored the SAW sensors for damage detection in piezoelectric material.

2. Experiments and Results

The surface acoustic waves were excited using the IDT which was fabricated as a SAW sensor on Y cut $LiNbO_3$ crystal. **Fig. 1**, shows the experimental set-up for the defect detection with IDT.

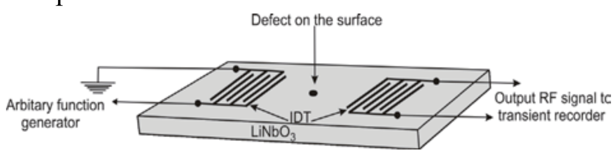

Fig. 1. Schematic representation of IDT experiments

An IDT consists of two overlapping comb-shaped gold electrodes which are placed on the piezoelectric ($LiNbO_3$) substrate. The inter-spacing distance between two electrodes and width of the electrode were kept constant. The size of single electrode was 70 µm in width and 4000 µm in length. The resonating frequency of the IDT sensor was 12.5 MHz. The distance between transmitting and receiving IDT sensor was 2.5 mm. All the

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experiments are conducted at the crystal orientation of zero degree.

Initially, SAW were generated and detected on the $LiNbO_3$ sample. The transient signal was amplified and recorded by an oscilloscope. Later on, a calibrated defect was created on the surface of the IDT using a high speed diamond drill of radius 300 µm and 0.2µm deep. The surface acoustic and skimming transverse waves were excited and detected using the IDT.

Based, on the broadband frequency spectrum of the IDT, we excited the sensors using a burst signal for a selected frequency at 12.5 MHz. The received transient signal of the SAW for the reference sensor is displayed in **Fig. 2a**. Similarly, the transient signal for the damage sensor is shown in **Fig. 2b** (normalized with respect to Fig. 2a). There is a dramatic change in the normalized amplitude of the signal from 1.5 to 0.4 corresponding to reference state and damage state, respectively. The changes in time of flight (TOF) of the SAW due to perturbation in surface material property were determined using cross correlation technique. It is quite difficult to observe small differences in TOF from the conventional method due to difficulty in identifying the first arrival of the signal. A. Shelke *et. al* (2011) have shown that such small differences in TOF (>10 ns) can be obtained using cross correlation where the sampling rate of the signal is significantly high [14].

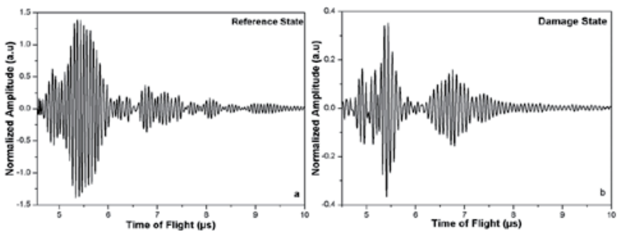

Fig. 2. Transient signal of the guided wave (a) in reference and (b) damaged sensors excited using burst signal

Fig. 2 shows the time domain spectrum of the response signal from reference and damaged sensor. From Fig. 2, it is evident that undamaged sample signal (2a) showed different trailing than Fig. 2b (damage state). On the other hand, for the damaged sample as shown in Fig. (2b), the amplitude of the time domain signal is reduced dramatically. The perturbation visible in the damage response spectra is associated with the surface abrasion on the sensors. Also, we observed that there is a frequency shift (towards right) of the entire spectrum which could be related to the surface aberrations. Based on the experimental results, it is evident that there exist a surface defect which is manifested through a difference in TOF and a shift in the frequency spectrum acquired through IDT.

3. Conclusion

In this study, the magnitude of a surface damage was quantified using surface acoustic wave's sensors in piezoelectric materials. The incubation of damage at the micro-scale acts as a precursor to the macro-scale effect, which is an indicator for prognosis of the damage. The changes in time of flight and frequency content of the guided waves and bulk waves were determined for the detection and quantification of the damage. The method we proposed here may find a new avenue in the field of SHM.

Acknowledgement

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