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TUNABLE INTERDIGITAL TRANSDUCER FOR LAMB WAVES

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ABSTRACT

In this paper a novel concept of a tunable transducer for exciting and sensing Lamb waves is presented. The proposed transducer is an extension of the Interdigital Transducer (IDT), which main advantage is mode selectivity. In the proposed transducer, further referred to as the Tunable IDT (T-IDT), comb electrodes with fixed pitch are replaced by a series of densely distributed discrete electrodes. They can be easily interconnected in different configurations to match required wavelength, which makes possible matching to different wavelengths without a need of physical changes of the electrodes layout. In order to verify the properties of the T-IDT, numerical simulations and experimental tests were performed and their results compared to the ones obtained with a traditional IDT. Both the numerical and experimental results show that the T-IDT generates beam patterns similar to those generated by the conventional IDT. The preliminary results presented in the paper prove that the proposed T-IDT can be easily tuned to various wave modes and show the performance similar to the one observed for the conventional IDT.

KEYWORDS : *SHM, Lamb Waves, Transducer, Ultrasound*

1. INTRODUCTION

Recently, a considerable interest for application of Lamb waves (LWs) to monitoring planar structures has been observed. LWs that are confined and guided by the structure boundaries can propagate over long distances and have an ability of interacting with different types of material discontinuities. Dedicated transducers may be used for this interaction's detection to determine the structure's condition. The physical nature of the LWs is complicated but despite this fact they are widely used in SHM systems, mainly because of their ability to propagate over long distances with little attenuation and selective sensitivity for different structural defects [1].

LWs can be excited in planar structures using different types of transducers, e.g. ultrasonic angle beam transducers [2], electromagnetic acoustic transducers (EMATs) [3], laser ultrasound systems (LUS) [4, 5], or other piezoelectric transducers made of lead zirconate titanate (PZT), Active Fiber Composite (AFC) or Macro Fiber Composite (MFC). Most of them are designed to excite a multi-modal, wide-band ultrasonic wave that propagates in all directions. Only few types of transducers may be designed to excite a narrowband, single mode wave that may propagate in desired direction.

In this paper a novel concept of a tunable transducer for exciting and sensing Lamb waves is presented. The proposed transducer is an extension of the Interdigital Transducer (IDT) with comb electrodes. The main advantage of the IDTs is their mode selectivity, which means that their performance can be optimized for assumed wavelength of a chosen wave mode [6]. Tuning an IDT to a particular wavelength is performed by matching the pitch of its comb electrodes to this wavelength [7]. In the proposed transducer, further referred to as the Tunable IDT (T-IDT), comb electrodes with fixed pitch are replaced by a series of densely distributed discrete electrodes, which can be interconnected in various configurations [8]. This makes possible matching to different wavelengths without a need of physical changes of the electrodes layout.

This paper is organized as follows. Section 2 contains a short presentation of the IDT and T-IDT transducers with focus on their advantages and disadvantages. The results of the numerical simulations are reported in Section 3 and they are compared with the experimental results in Section 4. Finally, Sections 5 and 6 present the authors' conclusions and future research plans considering T-IDT.

2. TRANSDUCER DESIGN

One of the transducers that may be optimized for a particular wave mode and length is Interdigital transducer. The most significant feature of IDTs is the electrode pattern that has a comb/finger-like shape (figure 1a). By adjusting finger spacing in the comb electrodes, accordingly to the specific wavelength in the inspected plate, the transducer will become a mode selective filter. A typical IDT, shown in figure 1, consists of three layers, the bottom and top electrodes are separated by the piezoelectric layer.

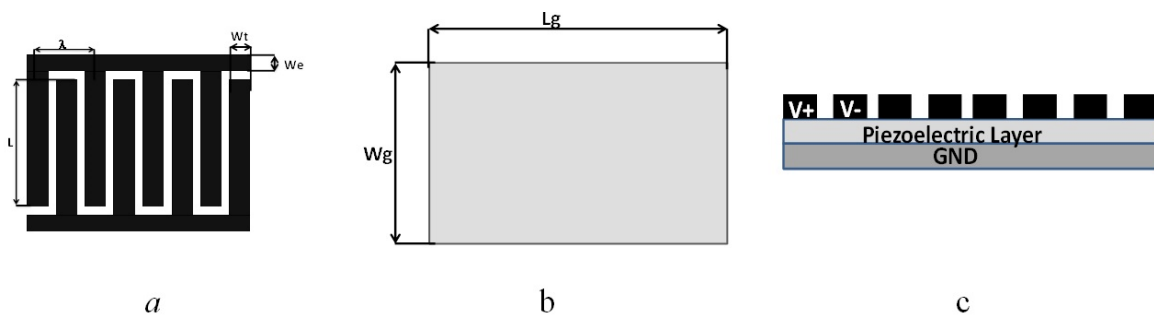


Figure 1 : Structure of the single sided IDT transducer: (a) top electrode, (b) bottom electrode, (c) cross-section.

This design allows for generation bi-directional waves [9, 10], in the direction perpendicular to the finger electrodes. The wave divergence (the main lobe width) depends on the number of fingers and their length. The main drawback of the IDT is that the tuning to a particular wavelength is performed by matching the pitch of its comb electrodes to this wavelength [6], what cannot be changed on the fly but requires a new electrode pattern.

Motivated by the specific needs of SHM applications, this paper is focused on flat transducers that are capable of generating directional waves, can be easily integrated with monitored structures and adjusted for desired wavelength without a need of introducing changes in its structure.

In the transducer proposed in the paper top comb electrodes with fixed pitch, present in a traditional IDT (figure 1a), are replaced by a series of densely distributed discrete electrodes that can be interconnected in a number of different configurations (figure 2) [8].

Each of electrodes can be easily attached with any other in order to have the spacing between the centers of the connected together electrodes matched with required wavelength (figure 2a). This distance can be adjusted by reconnection of the discrete electrodes (figure 2b), which makes possible matching to different wavelengths without a need of physical changes of the electrodes layout.

The properties of the T-IDT were verified by a series of numerical and experimental tests. In order to compare the results with previously performed experiments the proposed transducer was set in configuration to excite the A0 mode in a 4mm-thick aluminum plate at the frequency where the dispersion is low [6]. In the presented case the A0 mode has the lowest dispersion at frequency 329 kHz, what corresponds to the wavelength of 7.5mm.

The IDT and T-IDT investigated during tests have very similar dimensions and the design process was presented in the authors' previous publications [6, 11, 12]. The layout and the overall dimensions of the transducers are shown in figures 3a-b.

The T-IDT used in tests has the discrete electrodes 0.1mm wide, and the distance between electrodes is 0.4mm. This distribution allows for tuning the electrode spacing with accuracy of 1mm, in

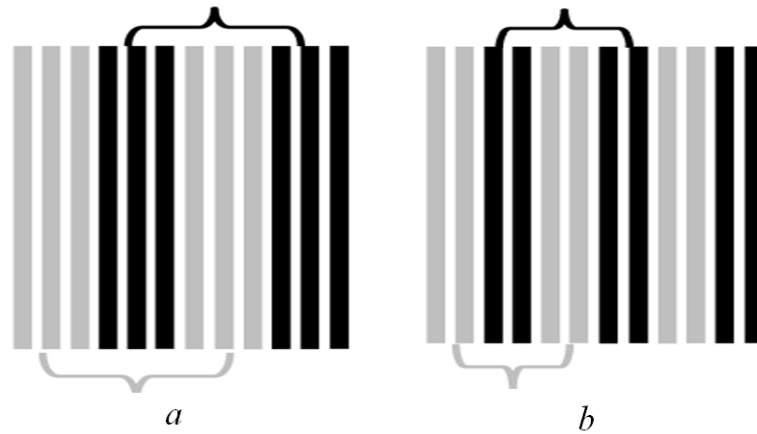


Figure 2 : Top electrode layout in Tunable Interdigital Transducer. (a) Configuration 1; (b) Configuration 2.

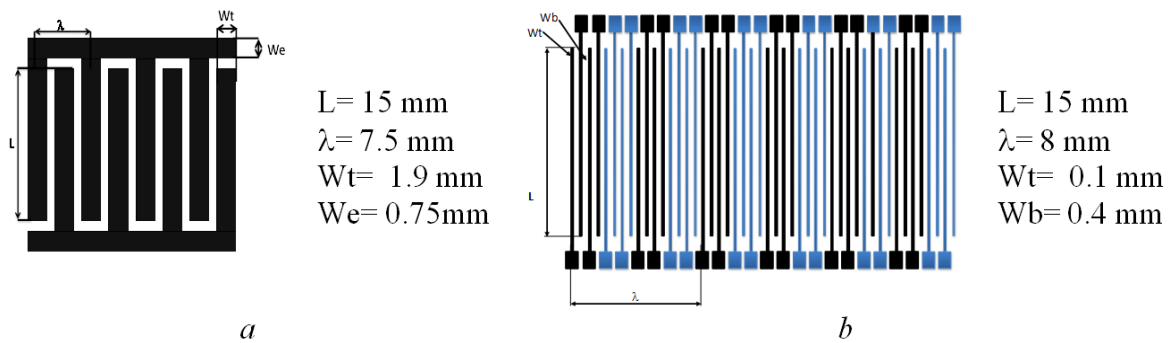


Figure 3 : Top electrodes layout and dimensions. (a) IDT; (b) T-IDT.

presented case the closest electrode configuration to the desired one is at 8mm and this layout was used during numerical and experimental tests.

3. NUMERICAL SIMULATIONS

In order to identify the properties of the designed transducers and compare it with the IDT, a set of numerical simulations were performed. Numerical models of the transducers and aluminum plate were created in ANSYS Multiphysics software. Each of the transducers was placed centrally on a 4mm-thick aluminum plate with dimensions 500 x 500 mm. The model of the structure was built using 20-node brick finite elements. Fully coupled transient analysis was performed to simulate piezoelectric effect. The transducers were excited with electrical signals (five-cycle tone burst modulated with Hanning window, amplitude 100Vp-p) and the plate response was measured at radius of 150mm from the centre of transducer. For the tests four excitation frequencies were chosen: 330kHz, which is the nominal frequency for designed IDT (minimum dispersion for the A0 mode in 4mm-thick aluminum plate); 300kHz the nominal frequency for the A0 mode with the wavelength 8mm; 425kHz - the frequency for which the S0 mode's wavelength is equal 7.5mm (finger separation); 100kHz - low frequency excitation to verify the behavior of the tested transducers at low frequencies.

3.1 Simulation results

The results obtained from the numerical simulations performed for both transducers are presented in figures 4a-d where beampatterns for different excitation frequencies are shown

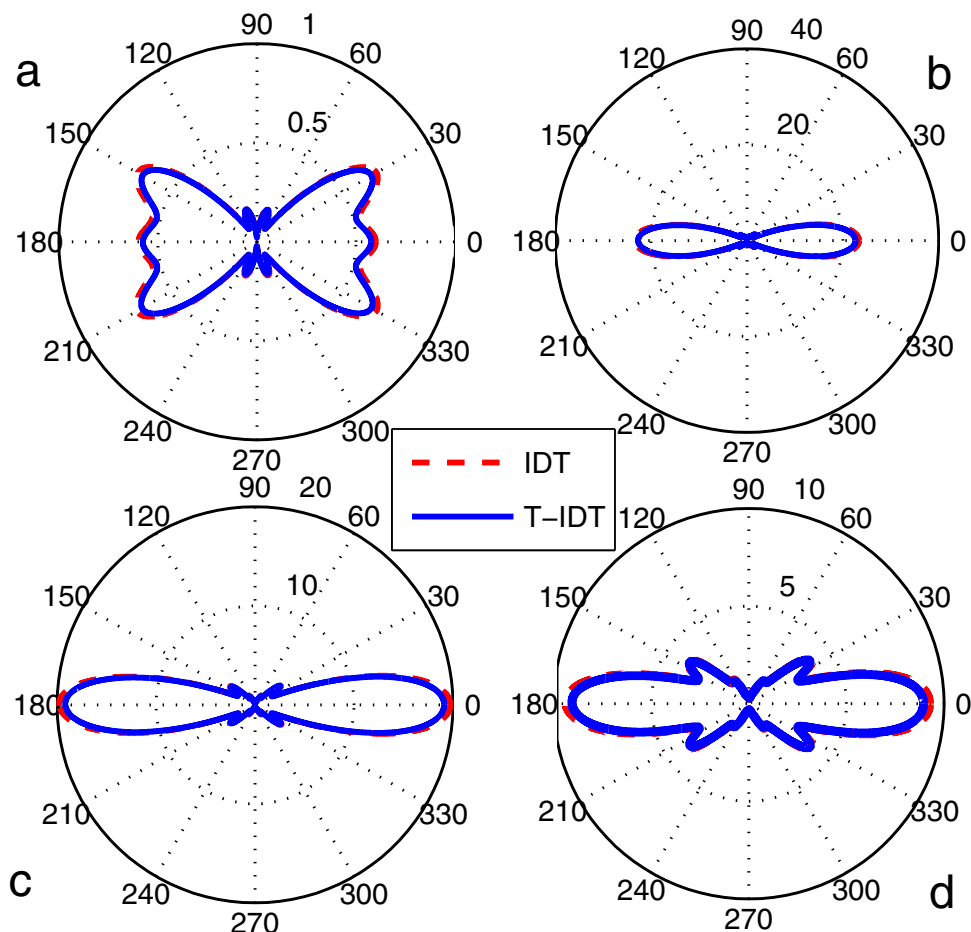


Figure 4 : Simulated and experimental beampatterns of the IDT(dashed) and T-IDT (solid) for different frequencies: (a) 100 kHz, (b) 300 kHz, (c) 330 kHz and (d) 425 kHz. The scale in $\mu\text{m/s}$.

It can be seen that the GWs generated by both transducers are very similar. The shapes and amplitudes of the generated waves in all of the directions are almost the same, except a small amplitude reduction of the wave generated by the T-IDT.

Also snapshots of the signal obtained during simulation in the direction perpendicular and parallel to the electrodes are very similar for both transducers (figures 5a-b). Also in this case the only observable difference is amplitude reduction in the signal generated by T-IDT.

4. EXPERIMENTAL TESTS

In order to validate the results obtained during numerical simulations, the prototypes of the transducers were manufactured and the experimental test rig was developed.

4.1 Prototype

The prototype of the Tunable Interdigital Transducer was manufactured using a rapid prototyping method for creating the electrode pattern on the piezoelectric patch (figure 6). Both top and bottom

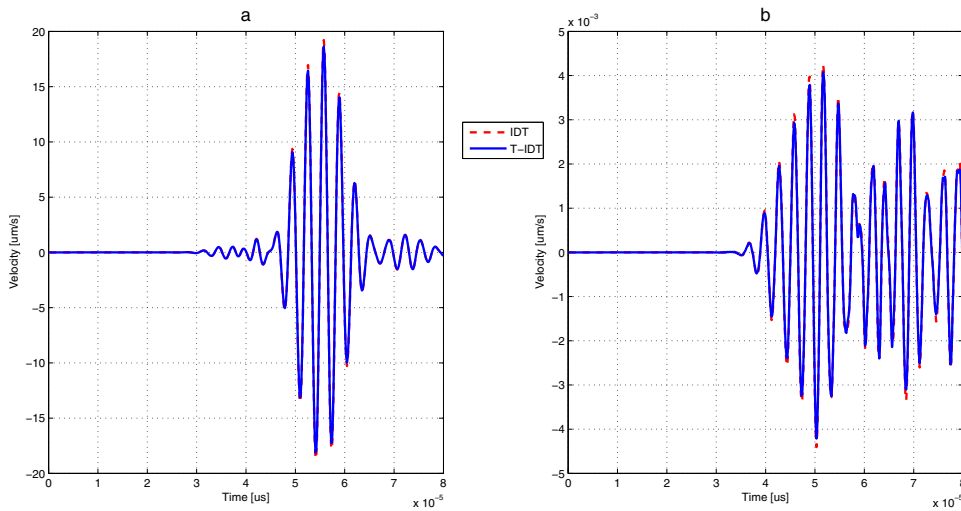
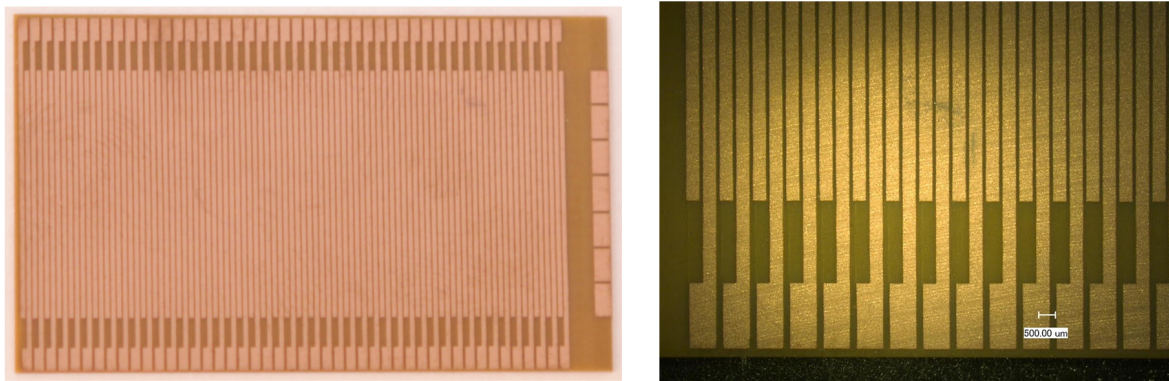


Figure 5 : Snapshot of the signal obtained for the IDT(dashed) and T-IDT(solid) at the excitation frequency 330kHz in (a) perpendicular, and (b) parallel direction.

electrodes were sculpted with use of a laser ablation micromachining technique. Ablation is the phenomenon in which a small amount of material is evaporated from the surface of the object as a result of being subjected of laser radiation. The used laser had a spot resolution of 30m, minimum pulse length equal 12ps, and 16MW of the peak power. The use of picosecond laser allowed for removal of the surface electrode without overheating the transducer. This is particularly important in the case of piezoelectric ceramics, for which too high temperature can lead to loss of polarity, resulting in the damage of the transducer. The energy of the laser pulse was set to remove a layer of material 10 μm thick. The chosen machining depth was sufficient to fully delete the nickel-cooper electrode in the selected areas without overmuch reduction of the transducer strength.



a

b

Figure 6 : Prototype of T-IDT: (a) overall view; (b) soldering pads.

4.2 Experimental setup

The both investigated transducers were mounted on the 1000x1000x4mm aluminum plate. The measurements of the out-of-plane vibrations were performed using the Polytec PSV-400 scanning laser vibrometer located in front of the tested plate. To improve the reflective properties of the surface, the measured area was covered with the retroreflecting material dedicated for laser vibrometry tests. Sampling frequency of the vibrometer was set at 5.12MHz, and the sensitivity at 20mm/s/V. To suppress the influence of the noise, the measurements were repeated 100 times in each point. The excitation signals used in the experiment consisted of five-cycle tone sine burst modulated with Hanning window. The burst frequencies used in the experiments were the same as in the FEM simulations: 100kHz, 300kHz, 330kHz and 425kHz.

Transducers beampatterns were calculated for each of the excitation frequencies based on the vibrometer measurements. For each of the measured points the Hilbert transform was used to determine envelopes of the snapshots of the out-of-plane velocity. Next, the maximal value of each envelope was found and used for the beampattern calculation. The beampatterns obtained from the vibrometer data for frequency 300kHz are presented and compared in figure 7.

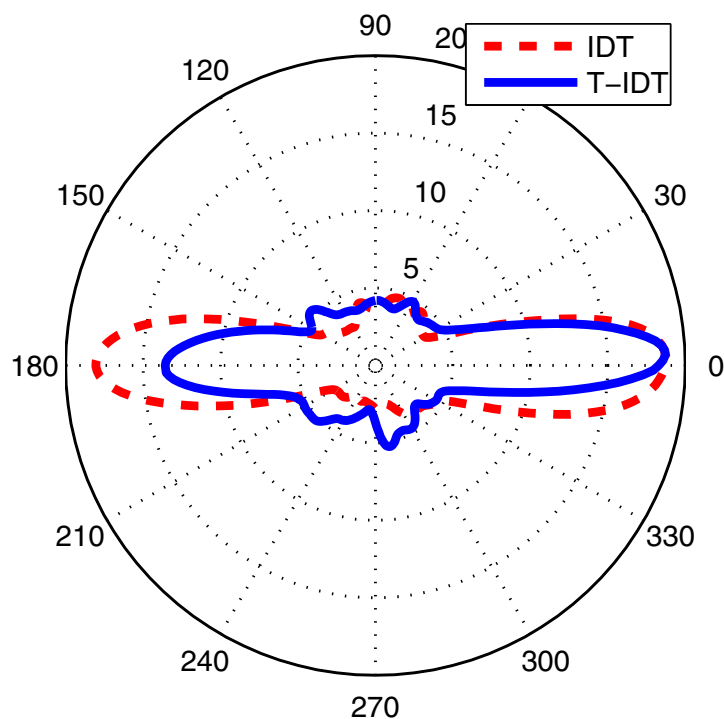


Figure 7 : Experimental beampatterns of the IDT and T-IDT for frequency 300kHz

The experimental results confirm the numerical results in terms of the beampatterns shape, however, contrary to the numerical results there is observable asymmetry in the beampatterns, as it is presented in figure 7.

5. DISCUSSION

Numerical and experimental results presented in the paper show that the proposed T-IDTs have very similar performance to that of the traditional IDTs. The T-IDT is able to generate a directional, narrow-band wave, which can be easily tuned to the desired frequency. The only difference between the beampatterns of both transducer types pronounced in the tests is slightly smaller amplitude of the wave generated by the T-IDT. This, however, had been expected because of the reduced electrode area. Another difference observed during the experimental tests was a small asymmetry in the beampatterns that was most probably caused by the soldering pads located at the transducer side; this will be eliminated in the future design of the transducer.

6. CONCLUSIONS AND FUTURE WORK

The preliminary results presented in the paper proved that the proposed T-IDTs can be easily tuned to different wave modes and they show similar performance to that observed for the conventional IDTs. This type of transducer may be used in the applications where narrowband directional signal is required and its frequency or wavelength are not known a priori or need to be tuned during tests. In the future tests more detailed analysis will be performed including analysis of the frequency-amplitude characteristics as well as the effect of electrode layout variation on the generated amplitude.

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