CHOOSING AN APPROPRIATE SENSOR FOR THE DESIGNED SHM SYSTEM BASED ON LAMB WAVES PROPAGATION.

JANUSZ OCHONSKI

Department of Robotics and Mechatronics AGH - University of Science and Technology Al. Mickiewicza 30, 30-059 Kraków janusz.ochonski@agh.edu.pl

LUKASZ AMBROZINSKI

Department of Robotics and Mechatronics AGH - University of Science and Technology Al. Mickiewicza 30, 30-059 Kraków lukasz.ambrozinski@agh.edu.pl

ANDRZEJ KLEPKA

Department of Robotics and Mechatronics AGH - University of Science and Technology Al. Mickiewicza 30, 30-059 Kraków andrzej.klepka@agh.edu.pl

TADEUSZ UHL

Department of Robotics and Mechatronics AGH - University of Science and Technology Al. Mickiewicza 30, 30-059 Kraków tuhl@agh.edu.pl

TADEUSZ STĘPIŃSKI.

Signals and Systems Uppsala University P O Box 534 SE – 751 21 Uppsala Sweden

The guided waves – based damage detection and localization methods are increasingly used as tools for structural health monitoring and non-destructive damage detection. Propagating waves are very sensitive to both structure damages and boundaries, however Lamb waves propagation is a rater complex phenomenon and many factors like sensors/actuators location, electronic system design, sensor shape, frequency range of excitation and more, should be taken into account. In this paper sensor study on the transducer used for Lamb waves generation and acquisition has been presented. A measured signal includes not only a structure response, but also it depends on a transducer characteristics, coupling agent and more. Actuator/sensor selection based only on specification sheet can be insufficient, so time and frequency analysis have been applied to signals acquired when an examined transducer was attached to a plate. Ceramic multilayer rings and plates have been tested to be used in

phased array technique. Robustness of the array consisting of chosen transducers has been verified with the scanning vibrometer and showed a good agreement with the theory.

1. Introduction

A variety of means can be used as Lamb waves actuators and sensors such as ultrasonic probes, lasers, piezoelectric element, interdigital transducers, optical fibers. Brief description of transducers can be found in [2]. A selection of the transducer used in a system depends on many factors like a size and a shape of a monitored element, its material properties and signal processing applied to a damage detection algorithm. In this paper a SHM system based on piezoelectric transducers used to the damage detection method based on the phased array technique was presented. Giurgiutiu in [1] showed that piezoelectric active wafers can be used in this method with good results.

Lamb waves are dispersive and multimode – many modes can exist at one frequency. It means, that Lamb waves excited by PZT contains multiple modes. However when excitation frequency is limited below so called cut-off frequency only two: A_0 and S_0 modes exist. Moreover it is possible to enhance one mode and reduce the other by mode tuning technique based on a transducer size and an excitation frequency selection [3].

Phased array technique is very often used as a non-destructive damage detection method based on ultrasound waves. Main idea of that method is to steer of wavefront shape, generated by a matrix of piezoelectric transducers [5,6]. The selection of transducer size, and the excitation frequency is essential for the phased array technique. Time delays calculation for each transducer is based on the phase velocity and transducers spacing so exact material properties of examined structure are necessary to calculate the phase and the group velocity. The excited wavelength should be at least twice as long as transmitters spacing, in another case the side lobes and additional false ghost damages could be disclosed. The size of a PZT determinates the lowest wavelength and the highest excitation frequency.

2. Hardware

In all experiments Phased Array Non Destructive Testing System (PAS-8000) was used. The system enable sinusoidal signal generation with frequencies between 40 – 500kHz. Additionally many types of windows can be applied (square, triangle or Hanning). 8 channels wave used for signal sending with simultaneous phase shifting generation between generated signals. Data acquisition was performed by PAQ-16000D at 2.5 MHz sampling frequency.

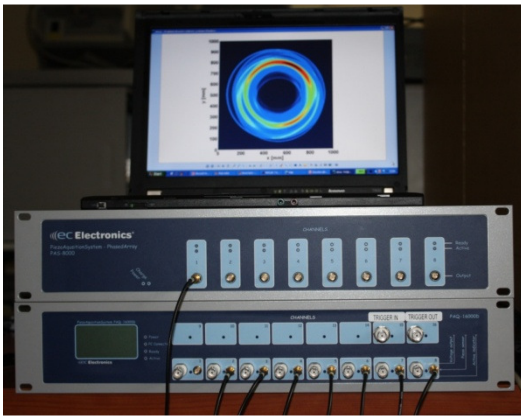
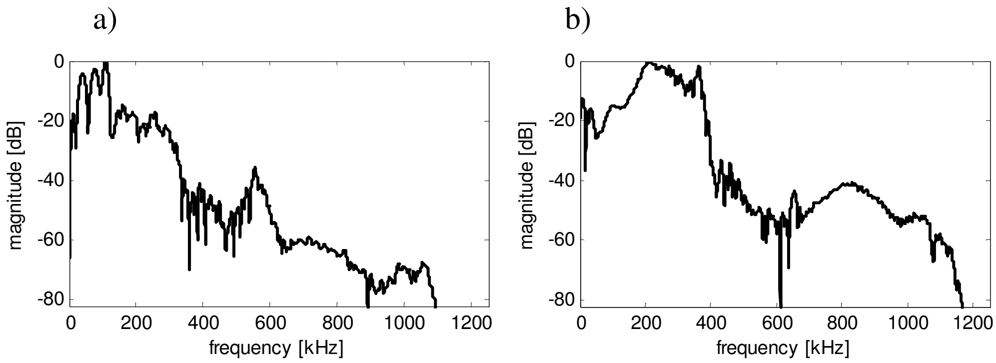


Fig. 1. PAS-8000 and PAQ-16000 used in experiments.

3. Sensor study

3.1. Time and frequency domain tests.

As mentioned above many factors affect the wave propagation so transducers attached to an aluminum plate were tested rather than unbounded ones. 3 types of multilayer Noliac PZTs transducers were examined: a ring actuator CMAR03 of the diameter 12 mm and two plate actuators: CMAP07 and CMAP12 of the size 5x5x2 and 2x2x2 respectively. All transducers were made of material NCE57 with frequency constant 1950 m/s, so resonance frequencies corresponding to the largest transducer dimension was calculated as 166 kHz, 390 kHz and 975 kHz for CMAR03, CMAP07 and CMAP12 respectively.
Examined transducers were placed on the 2 mm thick plate in a pitch-catch setup. Wax was used as a coupling agent. The actuator-sensor distance was 150 mm. In the first step transducers were excited with a broadband square pulse. Frequency responses presented in the Fig. 2. reveal resonance frequencies calculated above.



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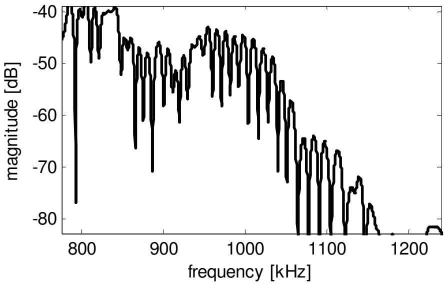

Fig. 2. Frequency responses of transducers excited with a broadband square signal a) CMAR 03 b) CMAP07 c) CMAP12.

In the second step transducers were excited with a tone-burst signal – 4 cycles of sinusoid with the centre frequency 100 kHz, modulated with Hanning window. Comparisons of the excitation pulse to the time responses, presented in the Fig. 3, reveals that the best representation of the excited signal can be found in the signal acquired with the CMAP 12. The CMAP 7 response distinctly contain high frequency components, for the CMAR03 it was impossible to isolate the excited pulse.

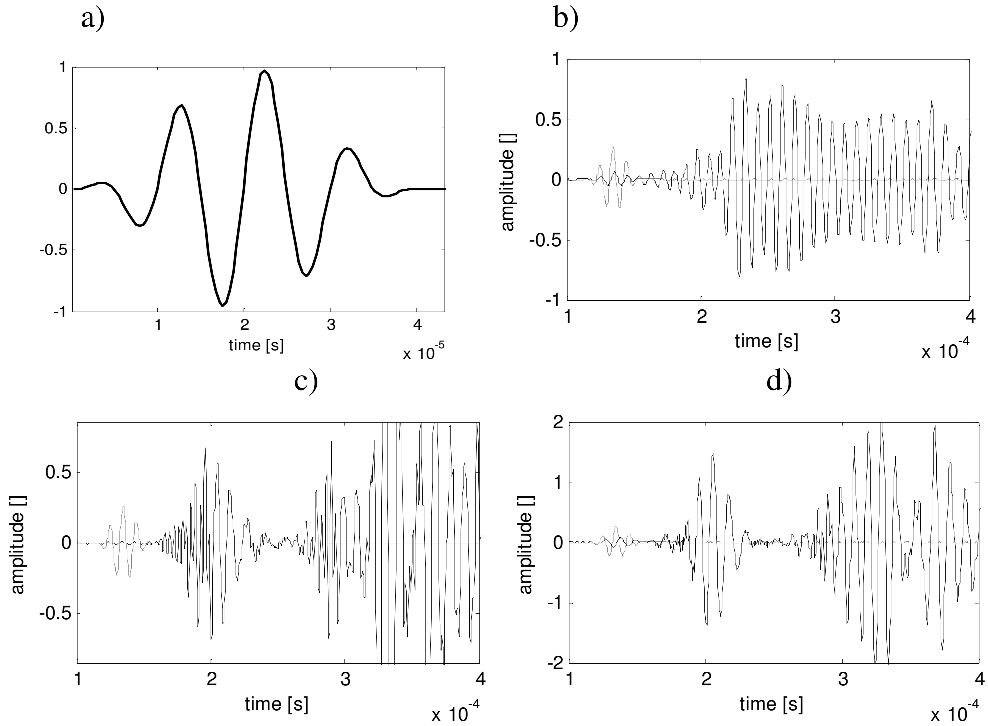

Fig. 3. Time responses acquired at 100 kHz narrowband pulse excitation a) excitation signal b) CMAR 03 c) CMAP07d) CMAP12.

3.2. Dispersion curves validation.

In the phased array technique time delays calculation based on the phased velocity of excited mode. To validate the analytically calculated curves by comparing them with the experimental ones and to assess the sensitivity of the transducer to the particular Lamb mode, the 2D Fourier transform method for the measurement of propagating multimode signals was used [4]. In Fig. 4a. can be seen that the S_0 mode is hardly recognizable for signals acquired by CMAP07 at lower wavenumber-frequency range. In the response from CMAP12 A_0 mode is even more dominant for whole frequency range.

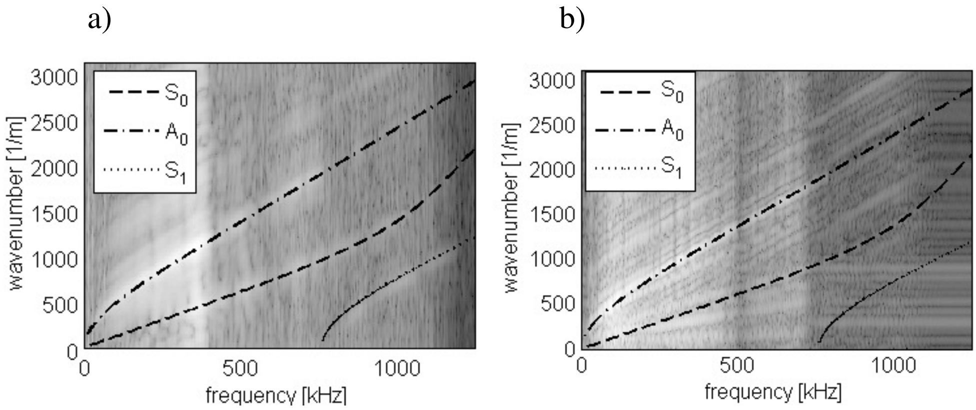

Fig. 4. Theoretical and measured wavenumber vs. frequency plot obtained for signals acquired by a) CMAP07, b) CMAP12.

When a mode with different wavenumber is generated with a PZT element an additional beam is formed in the unintentional direction. Generated signal contains multiple frequency components with significant amplitude. It may affect more unwanted beams. The least of the tested transducers (CMAP12) allows for narrowband excitation without high frequency components, moreover in the tested plate it generated enhanced A_0 with reduced S_0 mode.

4. Experimental results for phased array.

Eight CMAP12 plate actuators of the size 2x2x2 mm were used to built an linear array. The distance between PZTs centers was equal to 5 mm. The array was set in the centre of an aluminum plate with size 1000x1000x2 mm. As a coupling agent a wax was used. Disadvantages of this coupling method is irregular wax layer for all transducers. In the end the amplitudes of the signal sending to the plate can be different for particular elements. Before the experiment a calibration procedure was performed. Each actuator one by one generated signals captured by one PZT element. Output amplitude gains for all channels were adjusted so the linear aperture [7-9] was achieved. Time delays calculation was based on theoretical dispersion curves presented in Fig. 4.

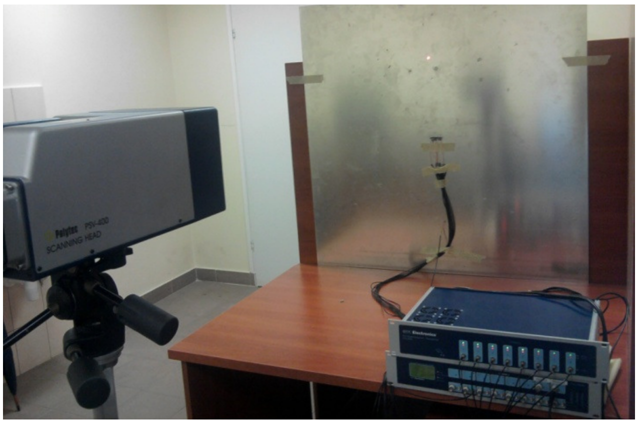

Fig. 5. Experimental setup for phased array testing.

During experiment assumed excitation frequency equal to 100kHz. It is correspond wavelength equal 13.57mm. This parameters provided “half wavelength” condition fulfill (half of the wavelength should be grater then transducer spacing). The steering direction was 120 degrees. To validate the performance of steering the wavefront a scanning laser vibrometer POLYTEC PSV 400 was used. Examined points were distributed in a circle shape so distances between point and source of the wave were equal.

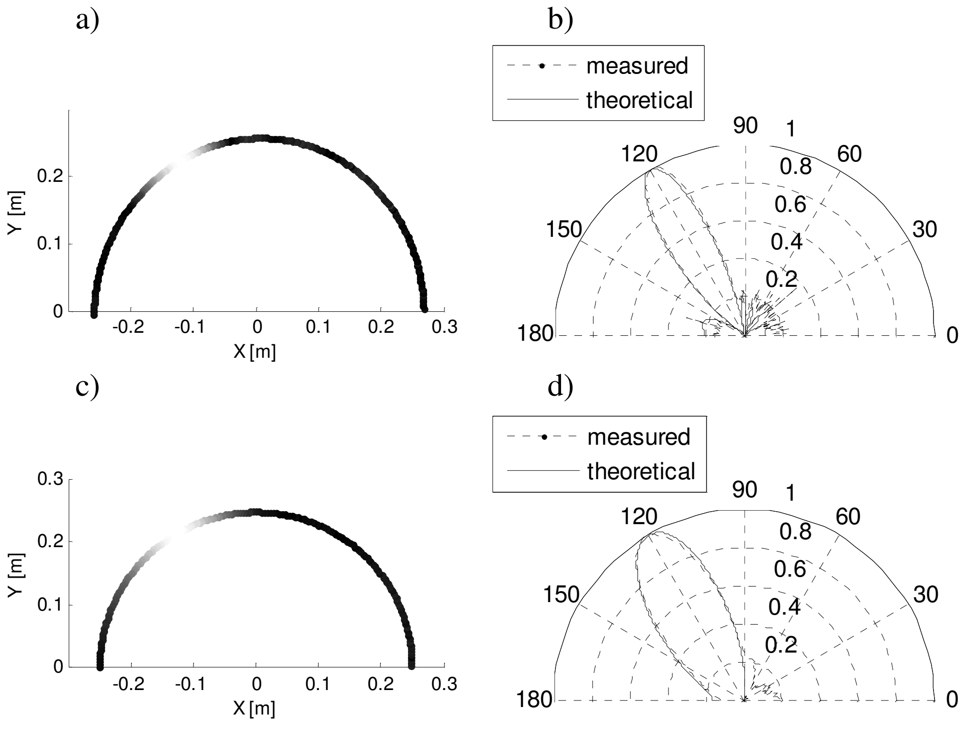

Fig. 6. Measurement points and amplitude values- a) linear apodization c) linear apodization. Theoretical and experimental normalized results of wave amplitudes in measured direction. - b) linear apodization d) linear apodization.

The results of the experiment can be seen above. Intense of the color of each point in Fig. 6a) represents an amplitude value. The highest vibration amplitude was appeared in the desired direction. Fig. 6b presents calculated beam pattern in polar plot. It represents the normalized maximum amplitude in all directions for a specified array configuration. A theoretical beam pattern was added to Fig 6b. It showed good agreement with a measured signal and theoretical calculation. A slight difference of steering angle is caused by a small error in the theoretical disperse curves estimation. The array used in experiments was linear so an additional, symmetric beam is expected at direction 240 degrees.
Similar experiment with Hamming apodization for actuators was performed. Good agreement of measured beam pattern with theoretical one can be observed (Fig 6. d). The main beam obtained for Hamming apodization is wider than the obtained for the linear apodization, but as expected side lobes has been reduced.

5. Conclusions

The dimension of a transducer is essential for a designed array - it affects the spacing distance between elements and determinates the minimum wavelength that can be used for a specified array. Resonance frequencies arising from the geometry can be predicted, however experimental results revealed that transducer excited at frequency considerably lower than the resonance one can produce additional components. This surplus components, shifted in accordance with delays calculated for desired wavelength, may produce beams at unwanted angles. Generated with tested array beams showed good agreement with theoretical. In the next step a receiving array will be added to the damage detection system.

6. Aknowledgments,

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