Analysis of Acoustic Wave Generation by Low Frequency Air-coupled Transducers

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ABSTRACT

In this paper phenomenon of acoustic waves generation in the air by low-frequency air-coupled transducers (ACT) is investigated. Numerical modelling of acoustic waves propagation in the air was investigated in the COMSOL Multiphysics software. The propagation of acoustic waves generated by a single ACT was modelled, to consider its angular pressure characteristics. Furthermore, the process of acoustic waves generation by multiple ACTs was investigated. Numerical results were validated by experimental measurements based on the scanning laser Doppler vibrometry using the acousto-optic phenomenon. The results of this research are focused on the elastic wave generation in the structures by ACT and are targeted towards non-destructive testing.

INTRODUCTION

The non-contact measurement systems have gained attention in the field of non-destructive testing (NDT). This is caused by a lot of advantages related to the non-contact measurement approach. First of all, the surface of the structure is not modified by bond lines and attached transducers. Such modifications are not allowed for e.g. the final product. The second important aspect is an easy application in manufacturing lines. The sensor bond process is related to surface preparation and modification which is time-consuming. The third aspect is the possibility of measurements in the structures working at high temperatures by using for example laser-based equipment for sensing. It should be also mentioned that commonly used for contact elastic wave excitation piezoelectric transducers' operational temperature is limited to its Curie temperature.

One of the non-contact elastic wave generation methods is based on air-coupled transducers (ACT) [1]. The ACT generates acoustic waves that are converted to elastic waves at the interface air/structure.

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Based on the changes in elastic wave propagation in the structure, damage detection is possible. The process of non-contact wave sensing is very often based on the scanning laser Doppler vibrometry (SLDV) [2]. In the case of ACT for elastic wave generation, high frequencies (hundreds of kHz [1],[3]) as well as low frequencies (tens of kHz [4], [5]) are utilized in the literature. Low frequencies are more suitable for composite materials inspection due to their high attenuation of elastic waves [3]. Fan et. al. [6] investigated acoustic-wave focusing transducers. This was achieved by masking an aperture made from cardboard and felt, placed at the focal point of the transducer. The authors of [7] investigated the spherical focusing technique of a ferroelectric transducer.

On the other hand, SLDV allows for full wavefield measurements. It means that elastic wave signals are gathered in a dense mesh of points covering the whole inspected area of the structure. Elastic wave generation is very often performed in one fixed point while the measurements are performed by SLDV in the scanning mode [2].

The authors of this paper investigated earlier problems of elastic wave generation in composite GFRP panel using ACT TR4016T with a diameter of 16 mm [8]. In the current paper, results of the investigation of acoustic wave generation in the air by this transducer as well as a transducer with a smaller diameter – 10 mm (TR4010T) are presented. Research is related to resonant ACT with a frequency of 40 kHz. Because ACT-based elastic wave generation in structures is based on the phenomenon of acoustic wave excitation in the air, we comprehensively investigated the latter. The problem of acoustic wave generation by multiple sources is also considered. The results of this research may be useful for the potential application of ACTs in non-destructive testing (NDT).

MEASUREMENT SET-UP

The measurement set-up consisted of an arbitrary waveform generator, multi-channel piezoelectric signal amplifier, SLDV, and ACTs. Resonant transducers (40 kHz) TR4010T (diameter 10 mm) and TR4016T (diameter 16 mm) were utilized for the experiment. To visualize the ACT-based generated acoustic wave in the air, the acousto-optic effect was utilized. Measurements were conducted with SLDV oriented perpendicularly to the ACTs acoustic wave generation direction. The laser beam was reflected from the panel covered with the retro-reflective tape placed behind the transducer (Figure 1).

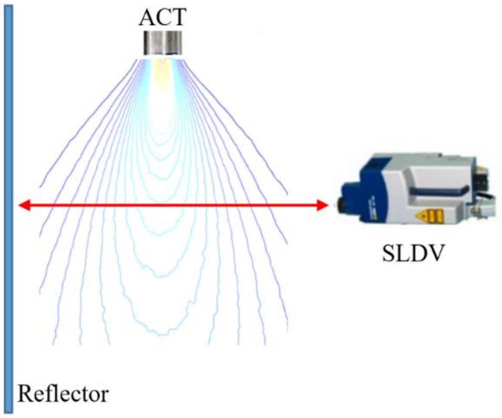

Figure 1. SLDV-based acoustic wave measurement principle.

Propagating acoustic waves cause a local change in the air density which causes local changes in the air refractive index. Since the SLDV measures changes in the optical path of the laser beam, changes in the air refractive index along the measuring beam can be registered. In the case of SLDV, the air density changes are seen as apparent vibration of the reflector.

ACOUSTIC WAVE GENERATION BY ACT

In the first step, the acoustic wave propagation through the air by SLDV was measured based on the acousto-optic effect. The ACT was excited by a signal in the form of 10 cycles of sine with a carrier frequency of 40 kHz modulated by the Hann window. Such signals are utilized in guided elastic wave-based NDT. The SLVD was used for measurements on the regular grid of 127 x 127 points. Experimental results were compared with numerical results obtained from COMSOL software.

In Figure 2, the results of acoustic wavefields in the air are presented. The numerical and experimental results were compared in the cases of ACTs with 16 mm and 10 mm diameters. It could be noticed that the latter generates acoustic waves with large amplitudes for wide angles. This means that the acoustic beam is wider for ACT with a smaller diameter than for the one with a larger diameter. The same effect could be observed in the case of numerical results. Moreover, it could be noticed that in the numerical simulations elastic wave generation is terminated just after the end of 10 cycles excitation. In the experimental results, ACT still generates acoustic waves.

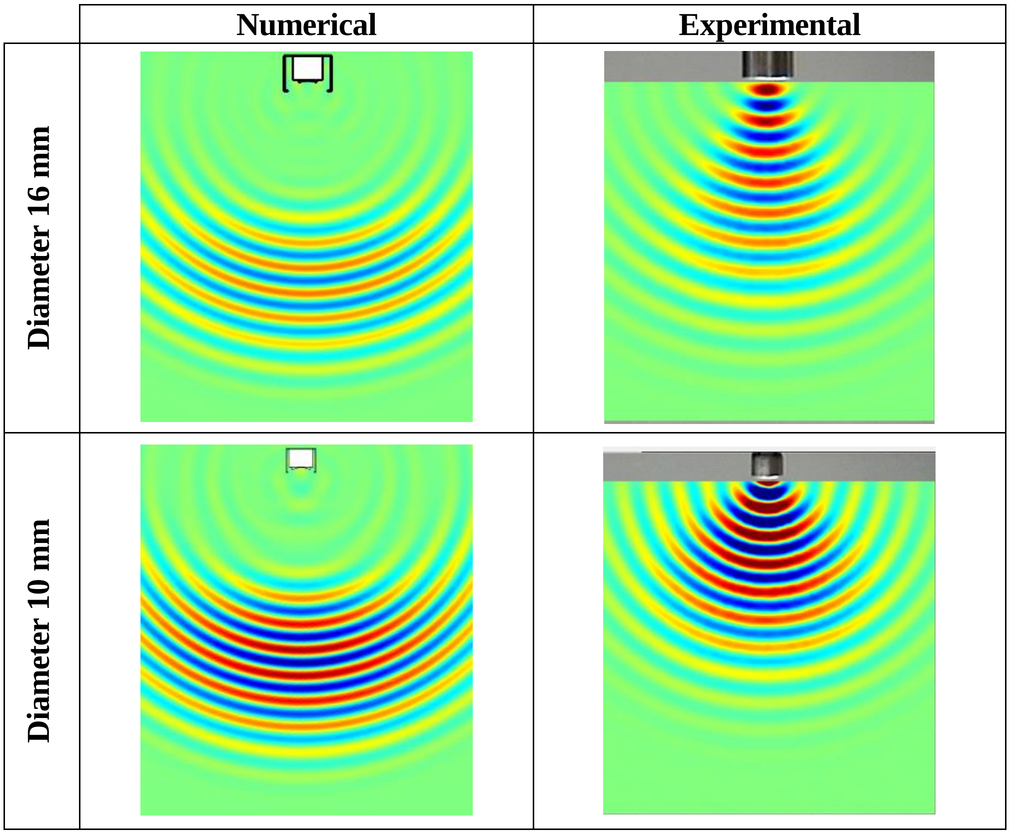

Figure 2. Acoustic wavefields generated by ACTs with different diameters.

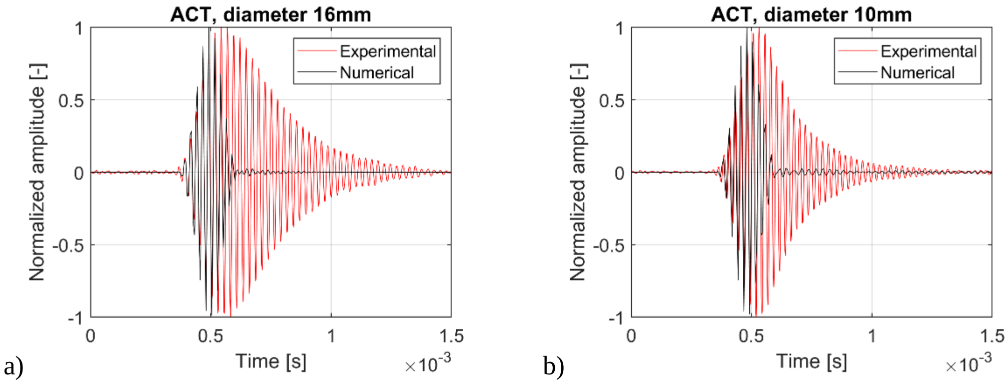

Figure 3. Time signals for ACT with diameter: a) 16 mm, b) 10 mm.

This effect could be observed in Figure 3 where time signals gathered at one point (13 cm in front of ACT) for numerical and experimental results are compared. It could be noticed that for both types of ACT, the signals from numerical simulations are shorter in time than for experimental results. In the case of experimental results, the acoustic wave is still generated and its amplitude decrease with time. In the case of ACT with larger diameter, the process of acoustic wave generation is longer. This could be caused by the vibration of the membrane of ACT. In Figure 4, RMS maps calculated for acoustic wavefield from numerical simulation and SLDV measurements are compared. In the case of experimental results, larger amplitudes of acoustic waves are generated for narrower angles in the case of ACT with a diameter of 16 mm than for a diameter of 10 mm.

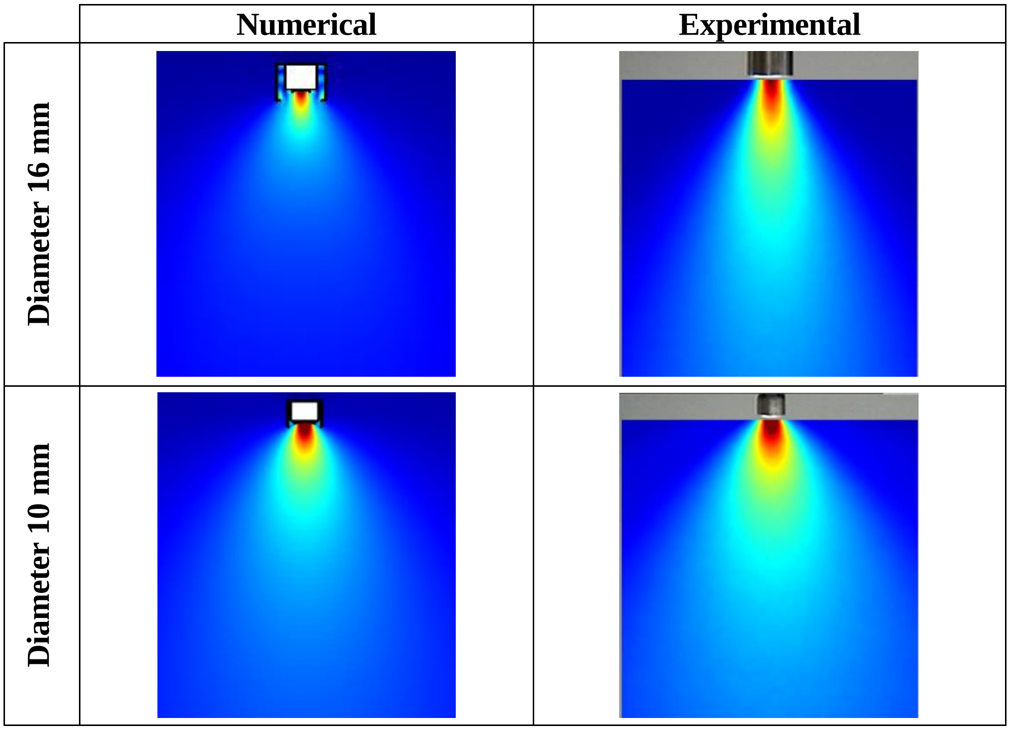

Figure 4. RMS of acoustic pressure generated by ACT with different diameters.

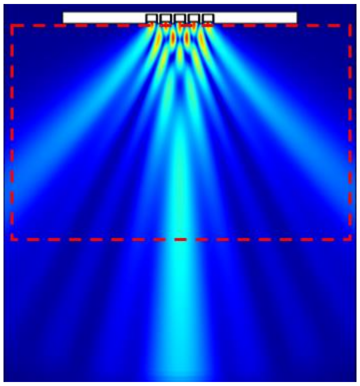

Figure 5. Linear array with 5 ACTs.

Presented in Figure 4 RMS maps illustrate the angular characteristic of acoustic wave generation by both types of ACTs. Numerical results agree with experimental ones. The ACT with a diameter of 16 mm has a narrower angular characteristic than one with a 10 mm diameter.

Further studies were related to array with multiple acoustic wave sources. For this purpose, only the ACTs with smaller diameter were utilized. This research aims to achieve the generation of acoustic waves with higher amplitudes.

ACOUSTIC WAVE GENERATION BY MULTIPLE ACTs

To study the phenomenon of acoustic wave generation by multiple ACTs, a linear array of transducers was investigated. In Figure 5 the linear array with 5 ACTs and acoustic wavefield generated by transducers were presented. The wavefield area that is analyzed further is marked with a red dashed line. It should be emphasized that ACTs were mounted on a flat surface. ACTs with a diameter of 10 mm were utilized in the array. The total length of the array was equal to 60 mm and ACTs spacing was equal to 12.5 mm.

In Figure 6, selected time frames of acoustic wave propagation in the air for the case of excitation performed by one ACT, three ACTs, and five ACTs were presented. It needs to be emphasized that in the case of multiple ACTs, they were excited simultaneously. Figure 6 contains both numerical and experimental results. It could be noticed that the amplitude of acoustic waves increases with the number of transducers. Moreover, the wavefields are not symmetrical in the experimental case in contrast to numerical results.

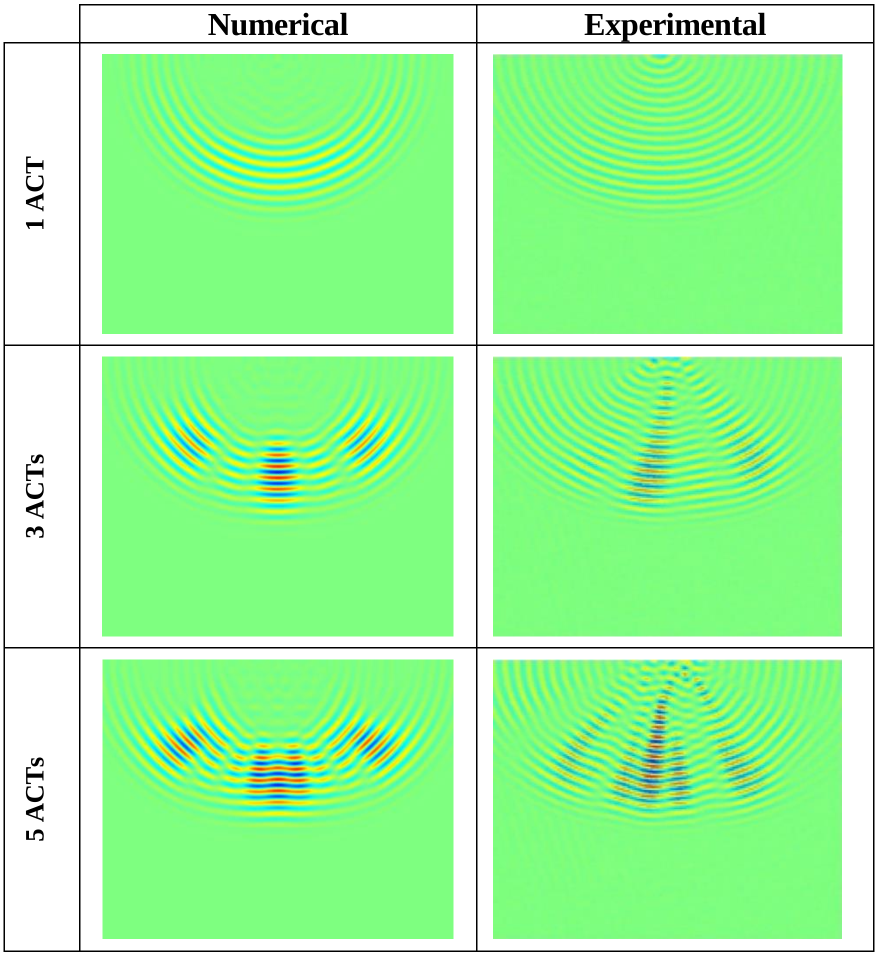

Figure 6. Selected time frames of acoustic wave propagation for array with different number of transducers; ACT with diameter 10 mm.

In Figure 7, RMS maps of acoustic wavefield for various number of ACTs generating waves in the linear array are presented. This figure contains the comparison of numerical results obtained from COMSOL simulation with experimental results obtained by SLDV measurements.

In the case of one ACT, it could be seen that numerical and experimental results are very similar. They slightly differ from the ones presented in Figure 4 since there was a lack of flat surface behind ACT as in the case of results from Figure 7. In the case of 3 ACTs, there are some differences in the wave patterns (Figure 7). The main lobe is vertical in the numerical results while it is inclined in the case of experimental results. A similar situation could be observed for 5 ACTs. There is a lack of symmetry in the case of experimental results.

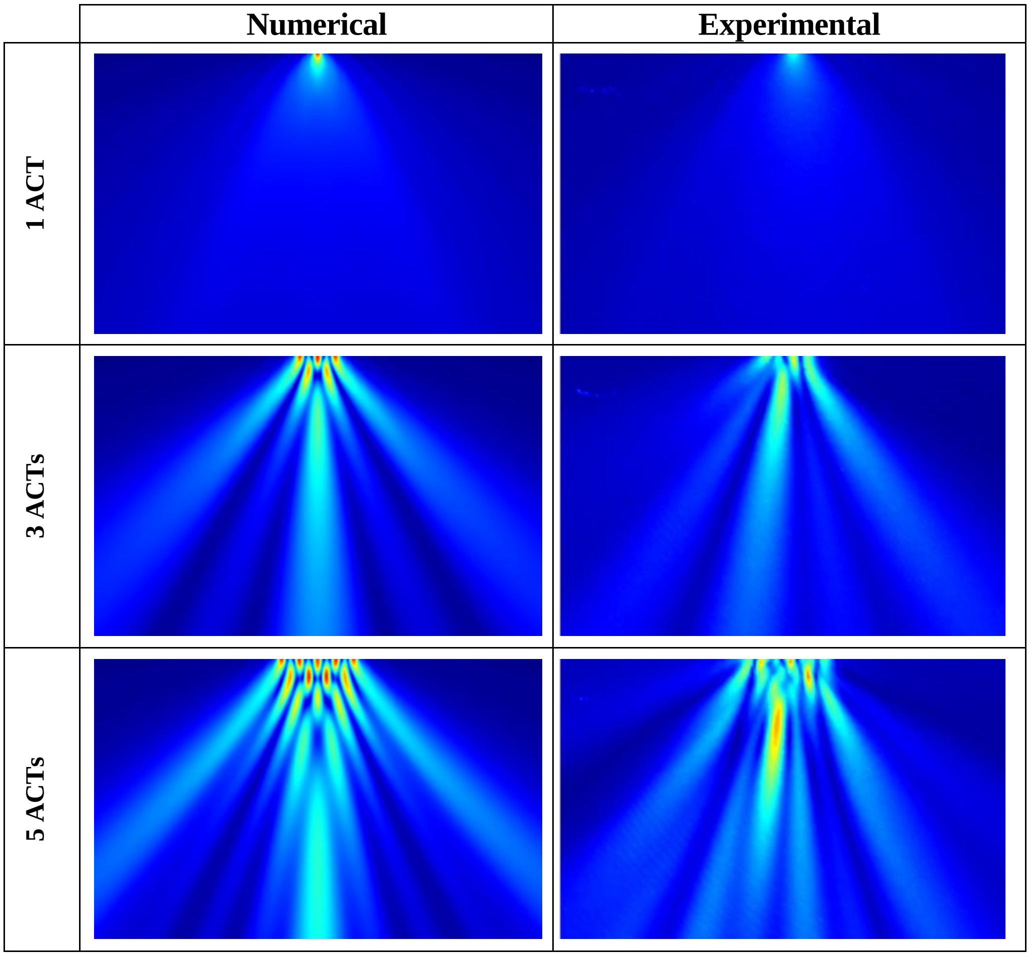

Figure 7. RMS of acoustic pressure generated by a linear array with different numbers of transducers; ACT with diameter 10 mm.

The lack of symmetry in the case of experimental results could be related to not ideal angular characteristics of acoustic wave generation for each ACT and by not perfectly mounted ACT in the array (not perpendicular to the surface). This will be further studied.

However, it could be noticed that the amplitude of the RMS map increases with the number of ACTs both in the case of numerical and experimental results. This could be useful in the NDT field because larger amplitudes of acoustic waves allow to generate larger amplitudes of elastic waves in the structure.

CONCLUSIONS

In this paper interesting technique of measurement of the acoustic wavefield of ACT based on SLDV and the acousto-optic effect was presented.

Obtained results showed that ACT with a diameter of 16 mm generates a narrower acoustic beam than the one with a diameter of 10 mm. Due to the smaller size of the transducer, they were further investigated in the linear array. Numerical and experimental results for an array consisting of multiple ACTs indicated that the amplitude of generated acoustic waves increases with the number of ACTs. However, in the numerical results, a symmetric acoustic wave pattern was obtained but in the experimental results, there was a lack of symmetry. This could be caused by not symmetric angular characteristics of wave generation by ACTs or not perfectly mounted ACTs in the array. This problem will be further studied. Further research will be also related to the problem of focusing the acoustic waves generated by multiple ACTs.

ACKNOWLEDGEMENTS

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