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CHARACTERIZATION OF THE ACOUSTIC FIELD GENERATED BY THE SINGLE-AXIS ACOUSTIC LEVITATOR

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Abstract

The acoustic levitator utilizes two vertically-aligned, face to face, transducers that emit identical acoustic waves. A standing wave is generated between the two transducers that allows the levitation of liquid droplets at the nodes. These levitated droplets experience an instability. In order to aid in the process of solving this instability, the acoustic field created by one of the transducers was characterized in this experiment and simulated using numerical methods. This characterization and simulation helps to understand the intensity and shape of the acoustic field at different points throughout the region and how the acoustic wave diverges as it travels away from the transducer.

INTRODUCTION

X-ray characterization of the liquid sample usually needs to be held in a container. While x-ray passes through liquid sample, it also passes through the glass capillary. [1, 2] Thus, resulting spectra will have background information with the capillary material. In order to provide container less and contamination free environment, acoustic levitator is utilized for x-ray characterization of material.

When using the acoustic levitator in experiments, levitated particles experience an instability in the acoustic field. This instability can steer the levitating sample away from the X-ray beam. The acoustic field that is generated by the levitator is affected by various components, such as the driving voltage, the frequency and amplitude of the acoustic wave, and the distance between the two transducers that emit the acoustic waves. [3] This paper presents our efforts to understand the instability by characterization and finite element analysis of the acoustic field. We simulated the acoustic field generated by a single transducer using finite element analysis. The simulation results of a sound level profile were compared to the experimental results. The results are discussed in the following sections.

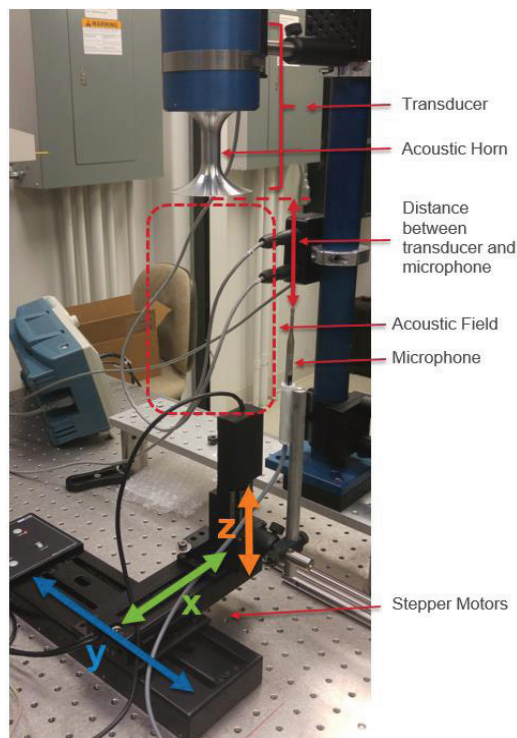
EXPERIMENTAL SET-UP

The characterization of the acoustic field was performed using a high precision microphone (B and K, 4138 - 1/8-inch pressure-field microphone, 6.5 Hz to 140 kHz, 168 dB, 200 V polarization). [4] The position of the microphone was controlled using three stepper motors in

Cartesian geometry. The goal was to manipulate the motors to have them move the microphone incrementally throughout a three-dimensional region.

The microphone received the acoustic signal transmitted by the transducer of the acoustic levitator. We placed microphone body away from the measuring point to avoid any interference. The microphone signal was sent to an oscilloscope that digitized the acoustic signal and passed it to a computer for processing. In order to complete accurate and detailed characterization of the acoustic field, a step size of 1 mm was used in the X-Y plane and a step size of 7.5 mm was used on the Z-axis. The wavelength of the acoustic wave is 15 mm; half of this wavelength, 7.5 mm, was chosen as the step size for the Z-axis so as to achieve characterization at key points throughout the acoustic field.

The motion of the motors, control of the microphone, data acquisition, and post processing was performed using LabVIEW. [5] Fig. 1, as seen below, depicts the experimental set-up of the motors along with the microphone and how they are positioned with respect to the transducer.



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Figure 1: The experimental set-up, involving the stepper motors, microphone, and single transducer.

The data analysis was done with MATLAB. Using MATLAB, the data recorded by LabVIEW was processed and plotted. The analysis of the data is being done using the X, Y, Z position data and the data for the amplitude of the acoustic field. Although this MATLAB code can also be used to analyse the relative phase of the acoustic field, the focus of this experiment was to analyze the amplitude of the acoustic field.

The numerical simulation was performed using COM-SOL® Multiphysics software version 5.2a. [6] The geometry of the air volume and transducer were modelled as shown in Fig. 2. 2D axisymmetric modeling was used to simplify the analysis. The pressure acoustic, solid mechanics, and electrostatic modules were used for this simulation. The numerical calculation was performed in the frequency domain with a frequency of 22.3 kHz. The acoustic field intensity is obtained at various planes located at 1.5, 3, 6 and 10.5 cm away from transducer surface.

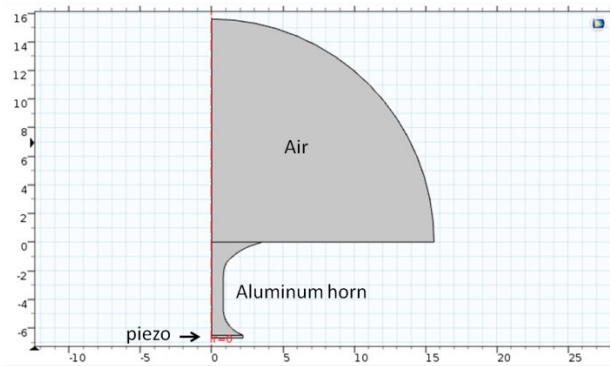


Figure 2: The geometry of one transducer in air.

RESULTS & DISCUSSION

Numerous experiments were required to achieve proper characterization of the acoustic field. A major factor that defined the quality of the characterization was the step size used in moving the X, Y and Z motors. The results of these measurements can be seen in Fig. 3.

The plots show how the peak intensity of the waveform in the center increases until the measurements are past the near-field region. Since the acoustic levitator utilizes a circular transducer, the wave-front looks like a peak with several pressure rings surrounding the peak. The pressure is always higher at the center of the acoustic wave. The pressure is 3200 Pa at 1.5cm from the transducer. In this acoustic field, the near-field region extend to about 3 cm and the maximum pressure reaches about 5000 Pa. After that point, it is clear that the peak intensity gradually starts to decrease. It can be inferred that as the distance between the transducer and waveform increases, the acoustic wave diverges, Fig. 5 & 6. Specifically, the size of the center wave and outer rings increases. The data representing the peak intensities at all the measured distances from the transducer were compiled and plotted in Fig. 5.

The numerical simulation results of the acoustic-pressure intensity profiles are compared with the experimental data and shown in Fig. 4. This comparison was completed at the same distances as the 2D profiles shown in Fig. 3.

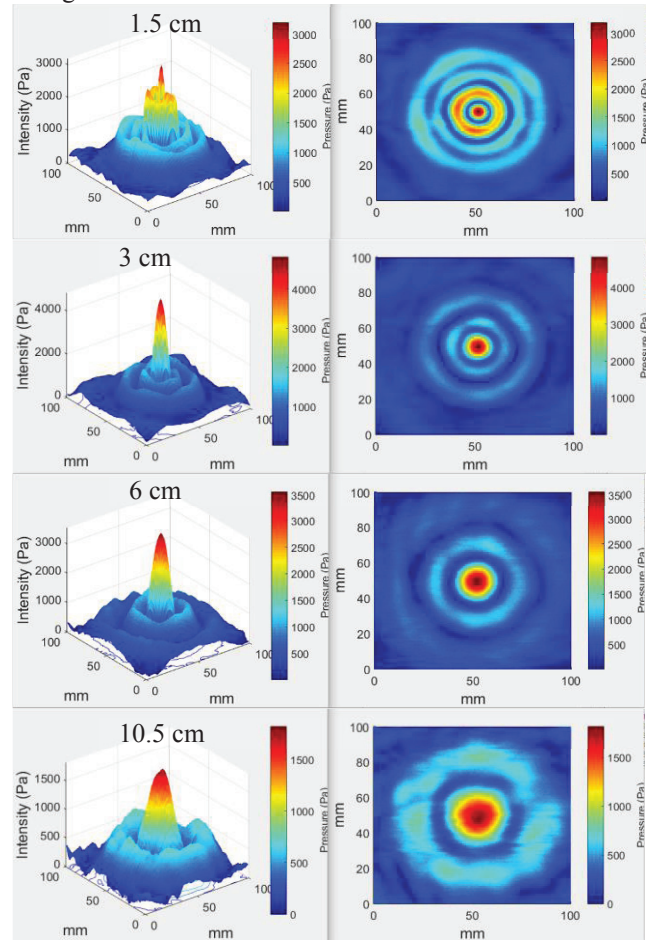


Figure 3: Intensity plots 1.5cm, 3cm, 6cm, and 10.5cm away from the transducer. Left column show pressure (Pa) as height with respect to x and y coordinates and right side column show intensity in 2D.

At all distances, the simulation results are in agreement with the experimental results both in pressure distribution and sound intensity. At 1.5 cm, the simulation results differ the most from the experimental data, but that can be attributed to the background noise or discrepancy in material properties. A small difference between the piezoelectric material properties and modelled material properties could also cause a slight deviation in results.

Fig. 5 & 6 shows the acoustic wave divergence obtained through FEA and experimental data. The diameter of the wave front has a bell shape distribution and it is obtained by measuring the full width half maximum of the distribution. This process was done along the X- and Y-axes, and the average value was used as the final diameter the bell shape distribution in the central region. The outer ring diameter was measured from peak-to-peak of the first ring around central peak. The average value was used as the final outer ring diameter. The plots of this data are shown in Fig. 5 & 6. The simulation of peak intensity

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and wave-front divergence are also plotted for comparison. The simulation results are in good agreement with the experimental test data on both peak pressure-intensity and acoustic wave divergence.

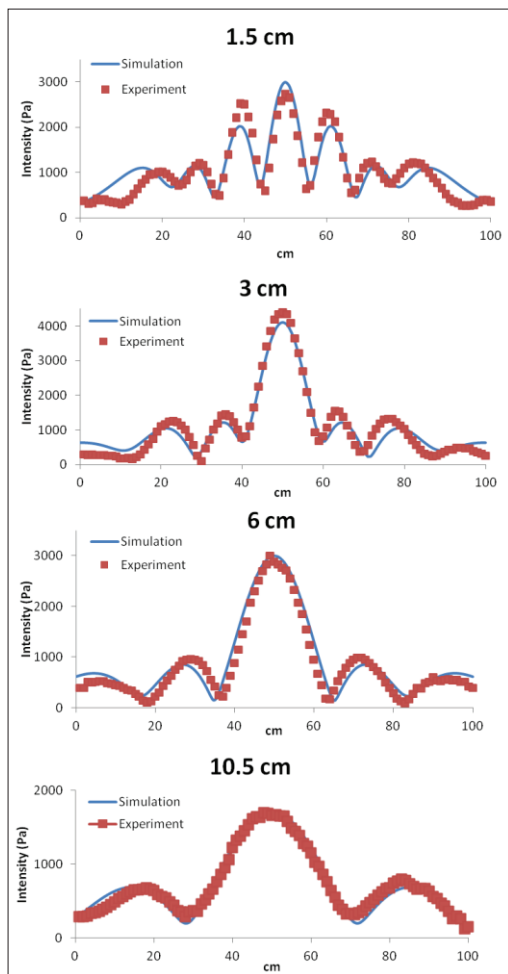


Figure 4: Comparison of acoustic sound profile between experiments and numerical simulation.

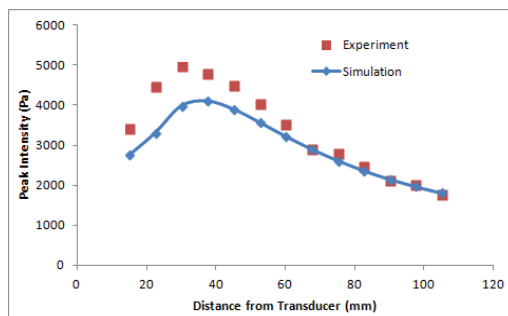


Figure 5: Comparison of experiment and simulation of peak intensities.

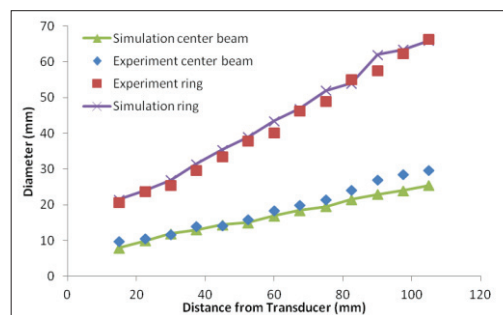


Figure 6: Comparison of experiment and simulation of beam and outer ring divergence.

CONCLUSION

The presented investigation was conducted on the acoustic field produced by a single transducer. The experimental characterization and numerical simulation of the acoustic field and acoustic wave divergence are in agreement with each other. Thus, the numerical simulation strategy was also validated. A closer look at the 2D pressure intensity graph (Fig. 3 right column) shows variations in intensity in second ring. This variation could be due to mix mode harmonics. This variation in pressure intensity could be a source of instability, however this can not be inferred from the single transducer analysis. To understand the instability in acoustic levitation, the entire acoustic field should be analysed using FEA, with some perturbation, in order to understand the variation in pressure intensity in annular area of the acoustic wave. Knowing the divergence of the acoustic wave is vital information when attempting to focus the wave for more stable levitation. Additionally, characterization of the outer rings in the acoustic field will aid in understanding where the instability in levitated particles is coming from. Overall, this experiment provides a greater understanding of how the acoustic levitator works, hence allowing for a more adept application of a more stable trapping in the acoustic field.

ACKNOWLEDGMENT

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