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Finite Element Simulation and Experimental Evaluation of an Ultrasonic Radiator

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ABSTRACT: In the current research, finite element simulation and experimental tests have been used to design, manufacture, and evaluate the performance of a high-power ultrasonic circular radiator called ultrasonic airborne. The two main goals in the design are to achieve a nominal resonance frequency of 20 kHz in the longitudinal mode shape of the transducer and booster assembly and the flexural mode shape of the circular radiator plate and to remove the disturbing modes from the frequency range of the main mode shape. After designing and manufacturing the sample based on the simulation results, experimental tests consisting of a modal impact test, impedance analysis, and amplitude measurement were performed. Simulation results, including the resonance frequency and position of the node and anti-node, were compared with the experimental results. The experimental test results of the resonance frequency compared with the simulation results, indicate the accuracy of the prediction of the results of the resonance frequency with the designed nominal value (error less than 0.5%). Also, the disturbing mode shapes were at an acceptable distance from the main flexural mode shape of the radiator. Reasonable agreement is achieved between experimental vibration amplitude measurement and finite element simulation predictions (position of the node and anti-node).

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1- Introduction

High-power ultrasonic technology is used in various processes such as machining, material forming, nano-powder production, degassing of liquids, etc [1, 2]. Applying high-power ultrasonic vibrations to the gaseous environment and multiphase media also has unique effects. Such as the application of high-power ultrasound technology in food drying, degassing and defoaming in the food industry, separation of small particles in the air, atomizing liquids, etc. In all of them, the acoustic field created by an ultrasonic circular or rectangular radiator called ultrasonic airborne causes effects in air or multiphase environments [3]. Figure 1 shows the industrial applications of ultrasonic radiator technology, including (a) food dryer (alone or hybrid with other technologies), (b) foaming and defoaming of liquids and beverages in the production line, (c) separation of fine particles in the air and (d) atomization of liquids in micro and nanoscale [3, 4].

Improving the design and achieving optimal performance has always been one of the important goals in the design and manufacturing of high-power ultrasonic systems used in scientific research and industrial applications. Numerical methods such as finite element simulation are useful for achieving this goal [5]. In this research, with the aim of designing and manufacturing a vibrating radiator at the resonant frequency of 20 kHz, first, by selecting some input parameters, CAD design of the ultrasonic airborne radiator including transducer, booster, and horn has been done. Then, to achieve the design goals, the important dimensions of the

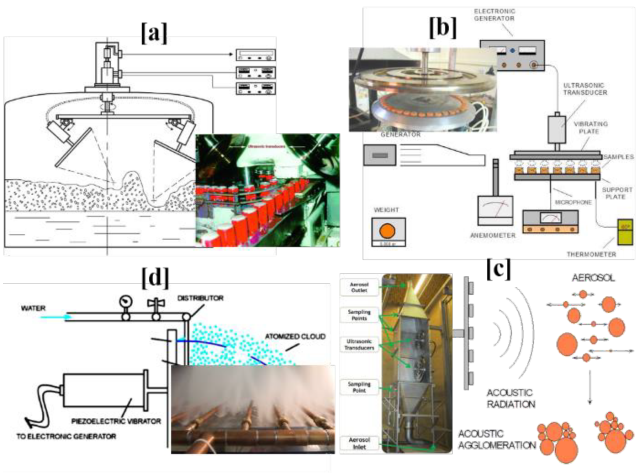

Fig. 1. Applications of ultrasonic radiators: (a) Food drying, (b) Defoaming in the beverage industry, (c) Separation of fine particles in the air, and (d) Atomization of liquids [2, 3]

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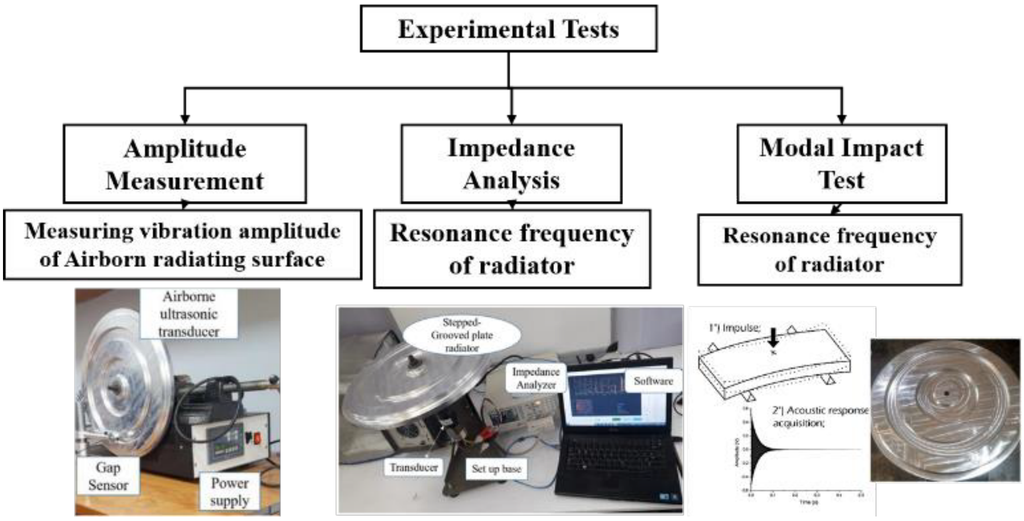

Fig. 2. Experimental tests to evaluate the performance of the ultrasonic airborne

radiator plate were changed so that the resonant frequency of 20 kHz for the radiator is obtained and the un-wanted mode shapes that can be excited are at a good distance from the mode shape of the main mode shape of the radiator. After changing the dimensions and improving the design, the radiator plate was made and independently evaluated by modal impact test and impedance analysis. After achieving the design resonance frequency, the radiator plate was assembled for the transducer and booster. The resonance frequency of ultrasonic airborne was determined with an impedance test and finally, the vibration amplitude of different areas on the radiator surface was determined by the gap sensor.

2- Methodology

To validate the simulation results and evaluate the performance of the ultrasonic airborne (including transducer, booster, and radiator plate), three experimental tests (1) Modal impact test, (2) Impedance Analysis, and (3) gap sensor test were performed (Figure 7). Modal impact tests and impedance analysis were performed to determine the frequency characteristics of the radiator plate (alone) and the assembled ultrasonic airborne. Finally, a gap sensor test was performed to measure the amplitude of different positions on the vibrating surface of the radiator.

3- Results and Discussion

After the simulations were carried out, the desired mode shape was obtained at the frequency of 20108 Hz. Figure 5-a shows the result of the modal analysis simulation of the main mode shape at the resonant frequency of 20108 Hz and with 5 circular vibration nodes. Figure 5-b shows the adjacent un-wanted mode shape at the frequency of 19178 Hz. In the figure of vibration mode, the Min and Max signs represent the positions with minimum (vibrating node) and maximum (vibrating anti-node) vibration amplitude on the radiator plate, respectively. It can be seen that the unwanted mode shape is located at a distance of about 1 kHz from the main mode shape.

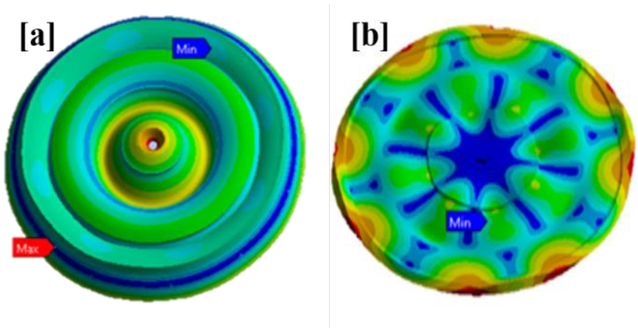

Fig. 3. (a) Main mode shape (frequency 20108 Hz) and (b) Adjacent un-wanted mode shape (19178 Hz)

The main resonance frequencies in the range of 10 to 25 kHz for the shape of the bending modes of the ultrasonic radiator assembly were obtained as 11820, 14680, 19860, 24660, and 25060 Hz, respectively. As can be seen, in the range of 10 to 25 kHz, the shape of the longitudinal mode of the transducer and booster and the flexural mode shape of the radiator (for flexural vibration mode shapes with NC = 3-7) has appeared in the diagram. The exact value of the resonance frequency with five circle nodes (=5NC) is equal to 19863 Hz. The resonance frequency in the finite element simulation was 19967 Hz, and this 104 Hz difference represents less than 0.5% error in the simulation.

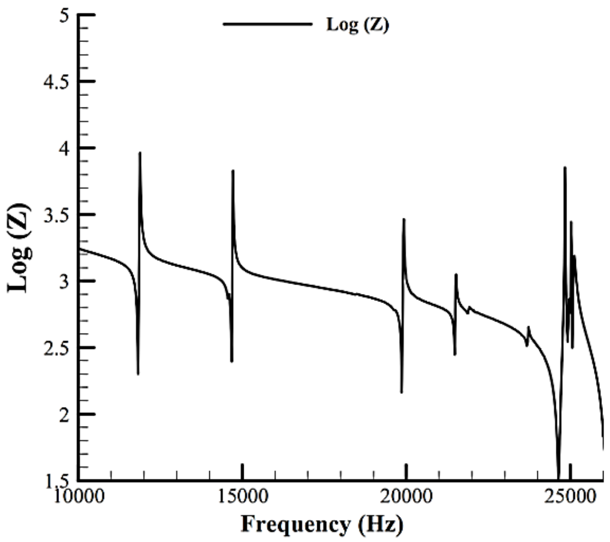

Fig. 4. Impedance-frequency measurement in the frequency range of 10 to 25 kHz by the impedance analysis test

4- Conclusion

In this research, the design and manufacturing of a high-power ultrasonic radiator called ultrasonic airborne based on the results of finite element simulation and modal analysis has been done. The main goal of the design was to achieve the desired nominal resonance frequency (20 kHz) and at the same time to remove the unwanted mode shapes from the main flexural mode shape. After manufacturing the circular radiator plate, it was assembled on the transducer and booster. In order to evaluate the performance and accuracy of finite element simulation results, experimental tests including modal impact test, impedance analysis, and vibration amplitude measurement test were performed on the ultrasonic airborne assembly. The results of the modal test and the impedance test show that the results of the resonance frequency of the ultrasonic airborne assembly are in agreement with the nominal frequency of 20 kHz. Also, the results of the vibration amplitude measurement test, indicate the location of the nodal points and the vibrating anti-node on the desired points in the CAD design of the radiator.

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