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Considerations and guides of the wattmeter method for measuring output acoustical power of Langevin-type transducer systems – II: experiment

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Abstract

Experiments have been carried out on a clamped transducer system with electrical resistance loads and a transducer–horn system with water loads. The results show that the distributions of the vibration velocity amplitude of a Langevin-type vibration system change with loads and the wattmeter method implies certain theoretical errors. However, under light load conditions ($<\rho VS$) the error is small and the ratios of the amplitudes of two anti-nodes are almost equal under the condition of loads and without loads. The results also gave out the characteristics of power ultrasonic transducer systems, including frequency, load and power dependent characteristics of electric input impedance and electric–acoustic efficiencies. The results agree well with general linear acoustic theories. They may serve as guidelines on the wattmeter method even for applications of high-power ultrasonics, especially in sonochemistry. © 1997 Elsevier Science B.V.

Keywords: Acoustic power measurement; Power ultrasonics; Ultrasonic liquid processing; Ultrasonic transducer

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1. Introduction

The characteristics of high-power ultrasonic transducer systems are very important in experimental research and in the industrial application of power ultrasonics. In particular, the growth of sonochemistry and ultrasonic materials processing has emphasized the importance of acoustic parameters. Because of manufacturing effects and the limits of measuring methods, some theories cannot guide practical applications. In recent years, many measurement methods have been proposed by researchers in sonochemistry. Due to the characteristics of the ultrasonic sources being overlooked, it is difficult to repeat these experimental results. The wattmeter method has not been taken seriously by sonochemistry researchers as being a valid method for measuring output acoustical power. Banno [1] gave the theoretical results of acoustic load matching at a certain conditions and proved by the wattmeter method [2]. Some characteristics of Langevin-type transducer systems had also been measured through the wattmeter method by Mori [3] and Lin [4]. Part I of this paper gave the theoretical results and proposed some considerations and guidelines for the wattmeter method and applications of power ultrasonic transducer systems. Whether these guidelines are appropriate, is confirmed from experimental points in this paper (Part II).

2. Experimental set-up

A diagram of the experimental equipment is shown in Fig. 1 with: (1) the power generator, EGR-800 (Eni Power Systems Inc.); (2) an EGR-800 accompanied power meter, EMB2k250; (3) an M1/SC3 wattmeter (Wave Energy Systems, Inc.), measuring the current, the input electric power of vibration system and including matching circuit losses; (4) an EGR-800 accompanied matchbox, model EVB-1; (5) a turntable matching capacitor; (6) a vibration system (a clamped transducer system or a transducer–horn system; (7) a measuring amplifier, B- and K-type 2636; (8) a VHF transistor minivolt meter, HFJ-8; (9) a digital multimeter, Weston series 6400; and (10) a small piezoelectric disc.

The vibration amplitudes of front and back surface of the transducer were measured by the piezoelectric disc. They are relative amplitudes, presented by values

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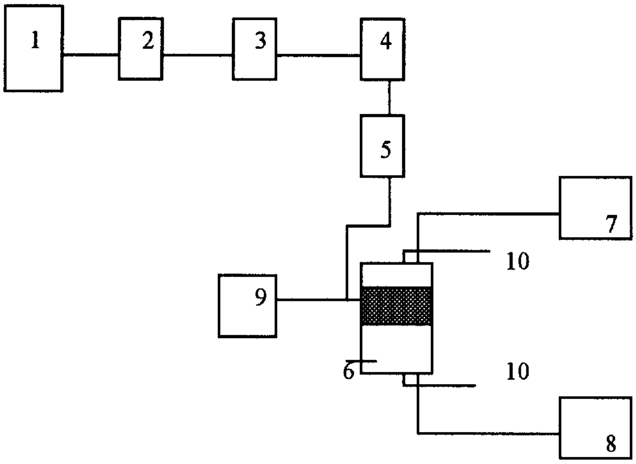

Fig. 1. Diagram of the experimental equipment.

of the output voltage of piezoelectric discs. The experiment was carried under nonsaturation conditions, i.e. the values of output voltage always increase with driven input electric power. The relative values were suitable enough for this experiment. The dielectric and inductance coil (in matchbox) losses were also measured, but compared with the errors of the experiment itself were small enough to be neglected in data processing. The vibration system (6) included two kinds of systems. One was a clamped transducer system consisting of two connected transducers having almost the same properties. The transducer is shown in Fig. 2, one transducer being driven by a power generator, the other connected to electric resistance as a dummy acoustic loads. The other system was the transducer–horn system with a transducer as above. There were two types of stainless-steel horns with a surface area ratio of 4:25 (tapered horn) and 1:1 (straight horn); the radiation surface diameters were 20 and 50 mm, respectively.

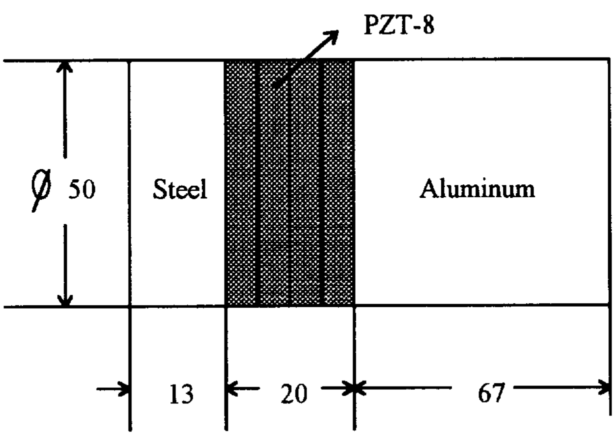

Fig. 2. Diagram of the transducer used in the experiment.

3. Results and discussions

3.1. Vibration velocity amplitude ratios and measuring errors

The relationships of the vibration velocity amplitudes of the back surface and the front surface of the driven transducer in the clamped transducer system are shown in Fig. 3. If the amplitude of the front surface remains unchanged, when the loads are less than 200 Ω, the amplitudes of the back surface are almost the same between the 'load' and 'no-load' conditions. The greater the loads become, the more different the amplitudes of the back surface under these conditions. Fig. 4 indicates the relationships of the amplitudes of the front and the back surface of the transducer in transducer–horn systems 4:25 and 1:1 respectively (see above). 'Air' in the frame represents the no-load condition and 'water' represents that fact that the front surface of the horn was immersed in water to a depth of 17 mm. The results show that the vibration velocity amplitude ratios are close under the water load and no-load conditions. This indicates that the amplitude of an anti-node or that of

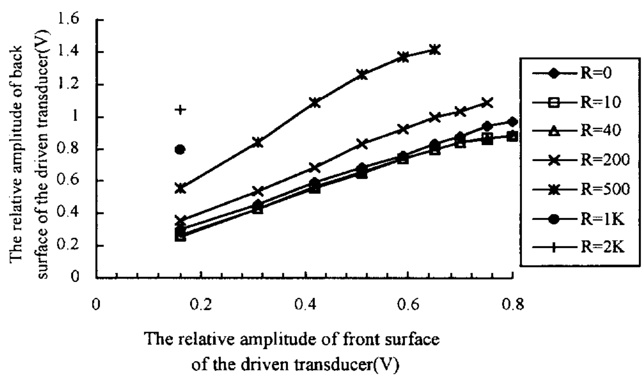

Fig. 3. Vibration velocity amplitude relations of the front and back surface of the driven transducer in a clamped transducer system versus amplitudes and loads.

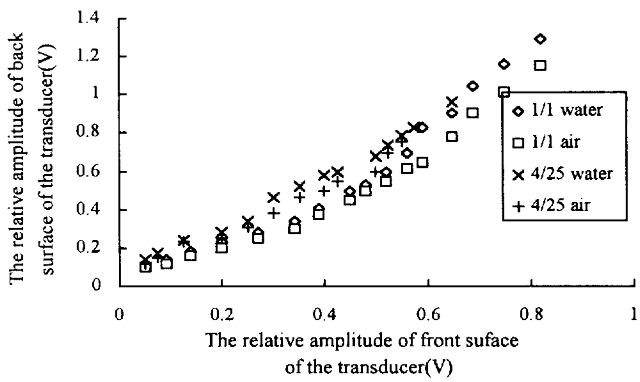

Fig. 4. Vibration velocity amplitude relations of the front and back surface of the transducer in a transducer horn system (4:25 and 1:1) versus amplitudes and loads.

a radiation surface can be measured at another antinode. Fig. 5 shows the experimental errors for measuring the output acoustical power of a clamped transducer system. The real output acoustical power was the power consumed by the electric resistance and the amplitude was that of the front surface of the driven transducer. Fig. 5 shows that the measurement errors of the wattmeter method are lower than 15% under the given load and amplitude conditions. The large errors in the light load conditions are mainly caused by the reading scale of the power meter.

3.2. Characteristics of the transducer system under certain input power conditions

With the wattmeter method, some valuable results about a power transducer system were measured. The variation of the efficiencies of the clamped transducer system with frequencies and loads are shown in Fig. 6. This figure indicates that the efficiencies increase with loads and the frequency bands are more narrow under light loads. The frequency (peak frequency) in which the efficiency is maximum is a little higher than the resonance frequency (under nonload condition, the resonance frequency = 19.72 kHz and the anti-resonance frequency = 20.24 kHz). The results above were measured at a constant input power of 20 W. Fig. 7 presents the relations of efficiencies of a clamped transducer system with the amplitudes of the front surface of the driven transducer and loads. The interesting result is that the electro-acoustic efficiencies hardly change with the amplitude. It also shows that the electro-acoustic efficiencies increase when the load becomes large, reach a maximum at a certain load, then decrease slowly with the load becoming larger. The results were measured at a constant frequency of 19.5 ± 0.02 Hz and the highest input electric power was 400 W.

Fig. 8 shows the frequency characteristics of the input electric impedance modulus of transducer–horn systems with area ratios 1:1 and 4:25. Fig. 9 gives the frequency characteristics of the electro-acoustic efficiency and indicates the obvious peaks of the efficiency of the transducer–horn systems. For a tapered system (4:25), the frequency band is more narrow and the peak frequency

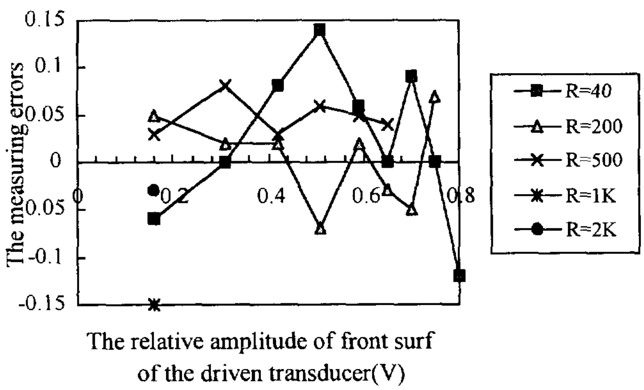

Fig. 5. Errors of the wattmeter method for measuring output acoustic power of a clamped transducer system versus amplitudes and loads.

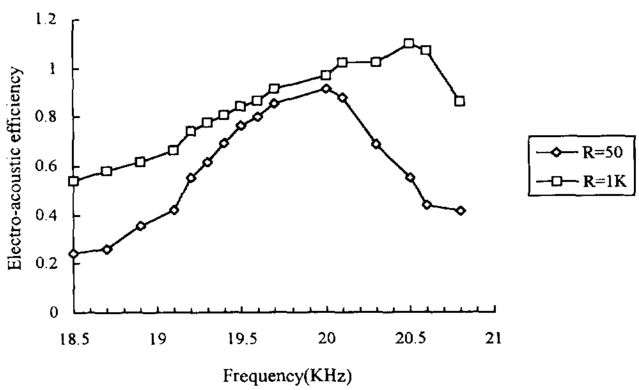

Fig. 6. Variation of electro-acoustic efficiencies of a transducer system with frequencies and loads.

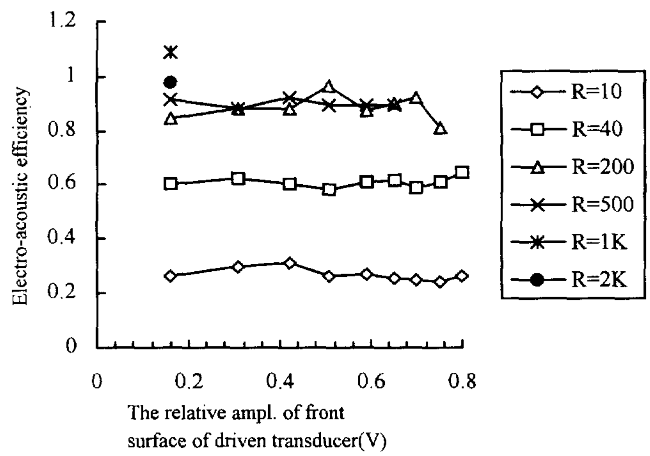

Fig. 7. Relations of the electro-acoustic efficiencies of a transducer system with the amplitudes of the front surface of the driven transducer and loads.

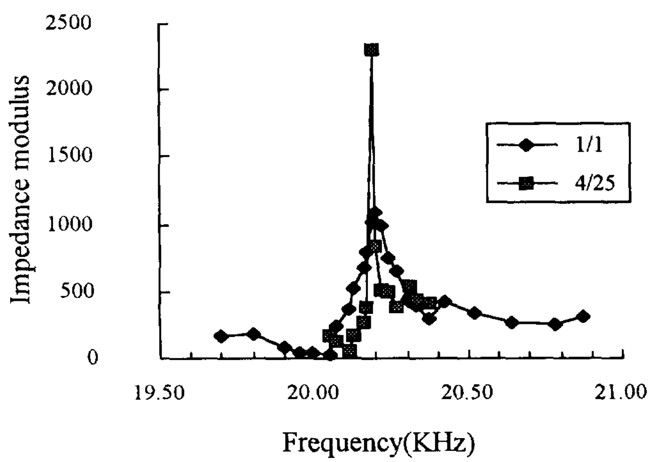

Fig. 8. Frequency characteristics of the input electric impedence modulus of transducer–horn systems.

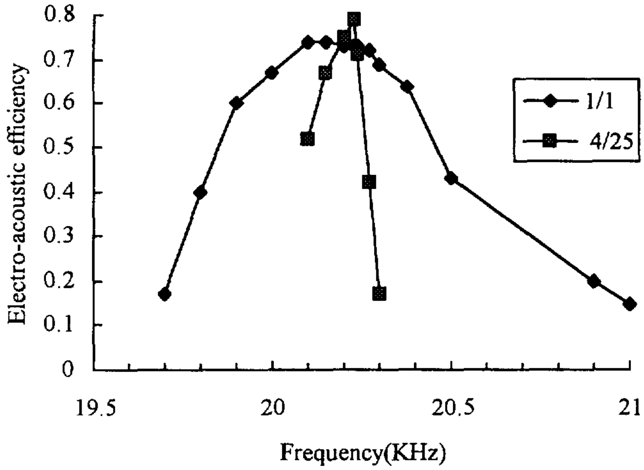

Fig. 9. Frequency characteristics of electro-acoustic efficiency of transducer–horn systems.

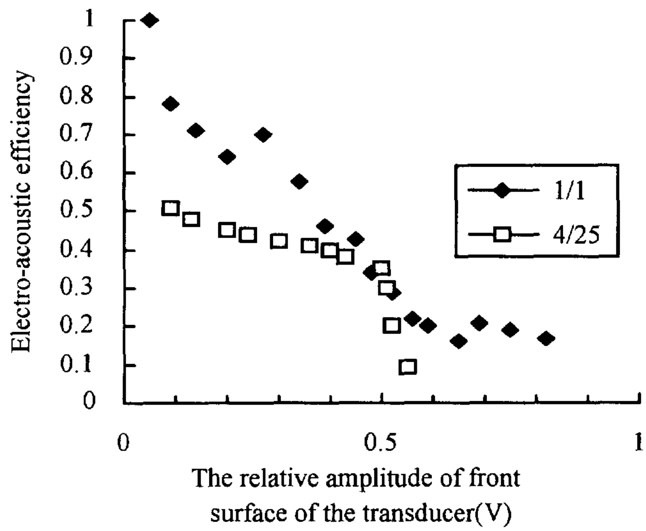

Fig. 10. Curves of the electro-acoustic efficiencies of transducer–horn systems varying with amplitudes of the front surface of the transducer.

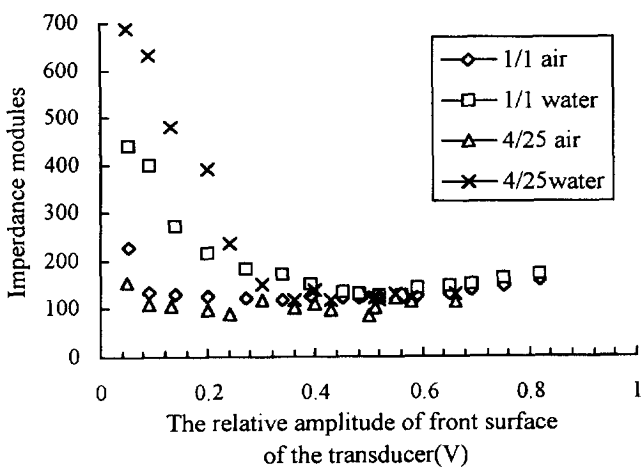

Fig. 11. Input electric impedence of transducer–horn systems under water at different amplitudes of the front surface of the transducer.

is a little higher than the resonant frequency (where the input electric impedance modulus is the lowest). Therefore, considering electric–acoustic matching, choosing a suitable working frequency is very important.

Fig. 10 displays the curves of the electro-acoustic efficiencies of the transducer–horn systems varying with the amplitudes of the front surface of the transducer. The interest is that the results are different from Fig. 7. The efficiency of the former decreases with growing amplitude; these results are explained by Fig. 11. The input electric impedance of the transducer–horn systems under water become small with growing amplitude, i.e. the loads become lighter because cavitation is emerging. The efficiencies of more than 100% in the figures were caused by the measuring errors. These results are predicted well in part (I) of this paper. On the other hand, it confirms the validity of the wattermeter method.

4. Conclusion

The vibration distribution of transducer systems changes with loads; this should be kept in mind in applying the wattmeter method. However, in a large range of load conditions, picking up the front surface vibration amplitude of the transducer, the wattmeter method is effective. Under light load conditions such as water, which includes most applications in sonochemistry, the convenience of the wattmeter method is that the amplitude of any anti-node can be picked up as a substitute for that of the front surface of the transducer. There are obvious efficiency peaks in the frequency for power transducer systems and the optimum frequency is usually a little higher than the resonance frequency. Carefully choosing the working frequency could make the electro-acoustic efficiency reach above 70% even under light load conditions for tapered horns. In ultrasonic liquid processing, the acoustic loads usually decrease with growing amplitude of the radiation surfaces of the ultrasonic vibration systems. This requires attention in the application of power ultrasonics, especially in sonochemistry.

Acknowledgement

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