Study on the multifrequency Langevin ultrasonic transducer

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Langevin ultrasonic transducers are widely used in high-power ultrasonics and underwater sound. In ultrasonic cleaning, a matching metal horn rather than a metal cylinder is used as the radiator in order to enhance the radiating surface and improve the acoustic matching between the transducer and the processed medium. To raise the effect of ultrasonic cleaning, the standing wave in the cleaning tank should be eliminated. One method to eliminate the standing wave in the tank is to use the multifrequency ultrasonic transducer. In this paper, the Langevin ultrasonic horn transducer, with two resonance frequencies, is studied. The transducer consists of two groups of piezoelectric ceramic elements: the back metal cylinder, the middle metal cylinder and the front matching metal horn. The vibrational modes of the transducer are analysed, and resonance frequency equations of the transducer in the half-wave and the all-wave vibrational modes are derived. According to the resonance frequency equations, transducers with two resonance frequencies are designed and made. The resonance frequencies, the effective electromechanical coupling coefficients and the equivalent electric impedances of the transducers are measured. It is shown that the measured resonance frequencies are in good agreement with the computed results, and the transducer can be excited to vibrate at two resonance frequencies, which correspond to the half-wave and the all-wave vibrational modes of the transducer.

Keywords: transducers; multifrequency Langevin ultrasonic transducers; resonance frequency; ultrasonic cleaning; vibrational modes

As new performance demands are placed on advanced electronic, optical and mechanical products, the need arises for different elements that have clean and non-destructive surfaces. This presents a new subject for ultrasonic cleaning. A solution to the problem is to utilize the technology of multifrequency ultrasonic cleaning.

In traditional ultrasonic cleaning[1–4], the transducer is operated on one resonance frequency, so that a standing wave is built in the cleaning tank. At the antinode of sound pressure, the effect of ultrasonic cleaning is perfect, while at the node of sound pressure, the effect of ultrasonic cleaning is not good; therefore, the elements to be cleaned should be mechanically moved to the antinode. This is somewhat cumbersome and so it is difficult to improve the cleaning quality of the elements. However, in the case of multifrequency ultrasonic cleaning, the situation is different. As there exist waves with different frequencies in the cleaning tank, the standing wave is destroyed and the difference between the nodes and antinodes is decreased. Therefore, mechanical movement is no longer needed and the cleaning quality can be improved. However, to produce ultrasound with different frequencies in the tank, a multifrequency ultrasonic transducer should be used.

In this paper, the Langevin ultrasonic horn transducers with two resonance frequencies are analysed, the vibrational modes are studied, and the resonance frequency equations are derived, which can be used to design ultrasonic transducers with different dimensions and resonance frequencies.

Theoretical analysis of the Langevin ultrasonic horn transducer with two resonance frequencies

Figure 1 shows the transducer with two resonance frequencies. In this figure, L_1, L_2 and L_3 are the lengths of the back metal cylinder, the middle metal cylinder and the front metal horn, respectively, each having a circular cross-section. Two groups of piezoelectric ceramic driving elements, whose length is L_0, are separated by the middle metal cylinder. To simplify the theoretical analysis, one-dimensional theory is used so that the lateral dimensions must be much smaller than the longitudinal dimensions. According to traditional experience, it is necessary that the lateral dimensions should be smaller than a quarter of the longitudinal wavelength. Based on the one-dimensional equivalent circuit of the longitudinal transducer, the equivalent circuit of the Langevin ultrasonic horn transducer with two resonance frequencies is shown in *Figure 2*, where Z_{BL} and Z_{FL} are the back and front load impedances of the transducer.

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