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A multimodal double-parabolic-reflectors transducer for dual-frequency ultrasound

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1. Introduction

Acoustic cavitation effect has been widely used for high-intensity focused ultrasound (HIFU) treatment[1)]. However, for traditional array transducers, the cavitation bubbles will influence the ultrasound's propagation path and shift the focus point. Heat may be generated in an unexpected region and damage healthy tissue. In this case, our group has proposed a double parabolic reflectors wave-guided ultrasonic transducer (DPLUS) to overcome this problem[2)], because the focused ultrasound is output from the waveguide tip, minimally invasive treatments become possible.

In addition, strong sound intensity is necessary for high-frequency cavitation due to the large threshold, while the nonlinear propagation with high intensity decreases the negative pressure and limits the cavitation efficiency. It has been proved a dual-frequency ultrasound can increase the negative pressure and cavitation effect[3)]. In this study, a multimodal DPLUS is proposed and designed for dual-frequency ultrasound to realize efficient cavitation and minimally invasive HIFU treatments. A resonant frequency control method with a series inductor is discussed for resonant frequency matching for two vibration modes[4)].

2. Design of multimodal DPLUS

2.1 Multimodal DPLUS Structure

The designed multimodal DPLUS structure is as shown in **Fig. 1**, including a double parabolic reflectors structure (Al2017) and two hard-type piezo rings (NGK SPARK PLUG CO., MT18K).

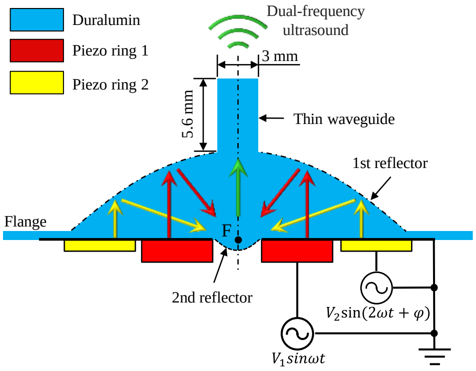

Fig. 1 Multimodal DPLUS with two piezo rings.

Under MHz frequency driving, the transducer's vibration is dominated by the piezo rings' thickness modes. In this case, the thickness modes resonant frequency ratio of the piezo rings is designed to be 1:2 by changing the rings' sizes. Two ultrasonic waves with different frequencies can be generated by the piezo rings and focused by two parabolic reflectors. Finally, a dual-frequency ultrasound is generated and output from the waveguide tip.

2.2 FEM Simulation

FEM (finite element method) simulation was carried out to design the transducer's parameters with Femtet, the results are shown in **Fig. 2**. The inner diameter, outer diameter and thickness for ring 1 are 5, 22 and 1 mm, respectively. And for ring 2 are 23, 40 and 0.5 mm, respectively. The harmonics analysis results for the piezo rings shows two thickness modes resonant frequency ratio is close to 1:2 (2.06 and 4.09 MHz), as shown in **Fig. 2(a)**. According to the velocity frequency response shown in **Fig. 2(b)**, large velocities occour near the piezo rings' resonant frequencies, indicating a dual-frequency ultrasound can be generated with this structure.

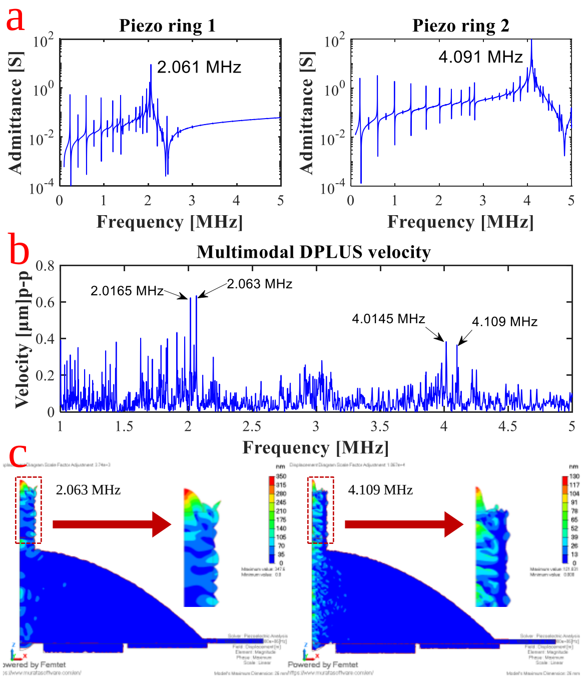

Fig. 2 Simulation results: a) thickness modes of two piezo rings; b) DPLUS waveguide velocity; c) target modes' vibration shapes.

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3. Resonant frequency ratio control

The resonant frequency ratio is affected by fabrication errors and boundaries, resulting in performance degradation. This problem can be solved through a resonant frequency control method with a series inductor.

3.1 Equivalent circuit analysis

The influence of the additional series inductor can be analyzed with the transducer's equivalent circuit, as shown in **Fig. 3**. The thickness mode is expressed as the *LCR* branch connected in parallel with the capacitor C_d. Because the mechanical power can be calculated by the current at the *LCR* branch ($I_{\mathrm{mechanical}}$) and *R*, this current can evaluate the vibration. With the series inductor L_s, the resonant frequency at the *LCR* brunch will be changed.

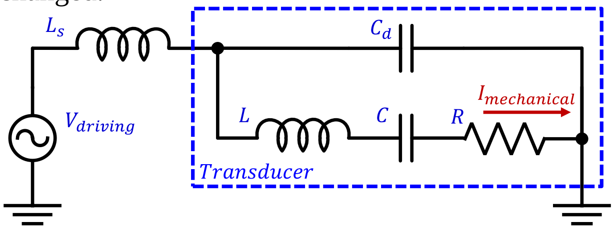

Fig. 3 Equivalent circuit for the piezo ring(transducer) connected with a series inductor.

This circuit was stimulated with the software LTspice. The parameters L,C,R and Cd come from a DPLUS prototype with one piezo ring, working with the thickness mode at 1.64 MHz. An impedance analyzer (Agilent, 4294A) was employed to get these parameters. As is shown in **Fig. 4**, by connecting a series inductor, the resonant frequency of *LCR* brunch was changed. When the Ls increased to 2 μH, the resonant frequency decreased from 1.641 MHz to 1.613 MHz.

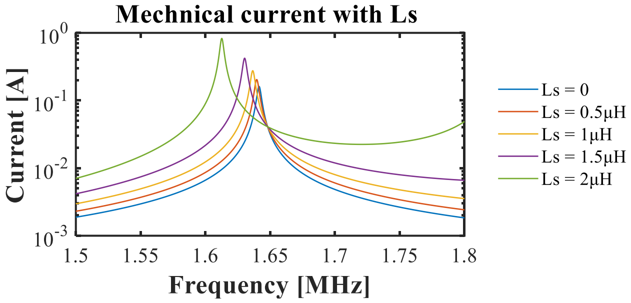

Fig. 4 Equivalent circuit calculation results.

3.2 Experimental results

The experiment has been carried out to confirm this method for resonant frequency control, results are shown in **Fig. 5**. The velocity frequency response of the transducer was measured by a laser Doppler vibrometer(OnoSokki, LV1800) and a frequency response analyzer(NF, FRA5097), with a driving voltage of 1Vpp. When an inductor (1.33 μH) was connected in series with the piezo ring, a vibration mode's resonant frequency decreased from 1.62 MHz to 1.6 MHz, which preliminarily verified this resonant frequency method.

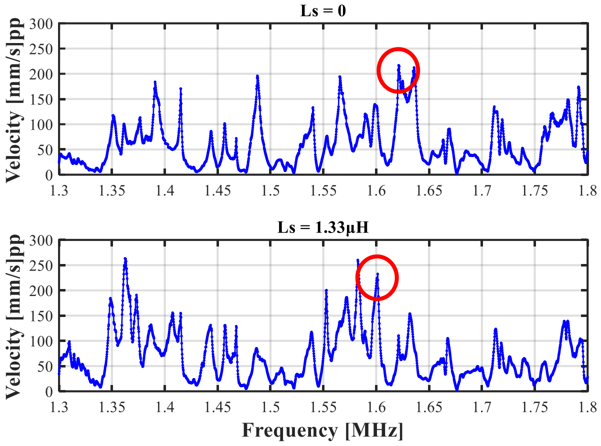

Fig. 5 Velocity change with the series inductor.

4. Conclusions and future work

In this study, a multimodal DPLUS is proposed and designed. FEM simulation proved the feasibility to generate dual-frequency ultrasound. A resonant frequency control method with a series inductor is discussed for resonant frequency matching for multiple vibration modes. In the experiment, a series inductor (1.33 μH) was connected to a DPLUS with one piezo ring, and a vibration mode's resonant frequency decreased from 1.62 MHz to 1.6 MHz.

In future work, the multimodal DPLUS prototype will be fabricated and tested, and the cavitation generated by a dual-frequency ultrasound will be further studied.

Acknowledgment

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