2P4-2

Study on the characteristic parameters of the radially composite cylindrical ultrasonic transducer

Jie Xu†, Shuyu Lin (Shaanxi Key Laboratory of Ultrasonics, Institute of Applied Acoustics, Shaanxi Normal Univ., Xi'an, 710119, China

1. Introduction

Cylindrical ultrasonic transducers have attracted much more attention. In the preparation of biodiesel, the introduction of cylindrical ultrasonic transducers increases the efficiency of the biodiesel production by 10 times and shorts mixing time $1/10-1/20$. In the field of secondary oil recovery, when the high-power cylindrical transducer is excited in the well of kilometers for several hours, the fuel injection increases from $2-8$ tons/ day to $10-30$ tons/ day. In the liquid, when high-power cylindrical transducers are excited, cavitation bubbles are generated. The sound field energy is concentrated and released quickly. At the same time, a high temperature of $5000\mathrm{K}$, a high pressure of $5.05\times10^{2}\,\mathrm{MPa}$ with strong shock waves and a micro-jet of $400\,\mathrm{km/h}$ are produced. In this case, a special physical environment is created, where chemical reactions can be accelerated and controlled. Therefore, the cylindrical ultrasonic transducer is widely applied in the field of substance synthesis, catalytic reaction, water treatment, waste degradation, nanomaterials and ultrasonic chemistry.(1)

In this paper, a radially composite cylindrical transdcuer is studied. The composite transducer consists of a piezoelectic ceramic cylinder polarized in the thickness direction and an outer metal cylinder. When the electrical signal is applied on the upper and lower surfaces of the piezoelectric cylinder, the vibration of piezoelectric cylinder is excited. The vibration of the metal cylinder is drived. The composite cylindrical transducer has the higher electroacoustic efficiency and the temperature stability.

Traditional analyses of the radially composite cylindrical transducer are based on the one-dimensional theory. However, when the height is comparable with the radius, the one-dimensional theory is no longer applicable. In our previous paper, three-dimensional theory is used to investigate the coupled vibration of the radially composite ultrasonic transducer. The equivalent electromechanical circuit and resonance frequency equations are obtained.

Further, power ultrasonic vibration system is a key part of power ultrasound technology.(2,3) In the field of power ultrasound, characteristic parameters of the transducer are attentioned. In this paper, on the basis of the resonance frequency equations for the composite cylindrical transducer, the effects of the radius ratio on the resonance frequency and the effective electromechanical coupling coefficient are acquired. The experiment is carried out to verify the effective of the analyses.

2. Theoretical basis

Fig.1 is the diagram of the radially composite cylindrical ultrasonic transducer. A piezoelectric ceramic cylinder $(b<r<c)$ is polarized along the thickness direction. The electrodes are deposited on the upper and lower surfaces. The metal cylinder $(a<r<b)$ is located on the outer of the piezoelectric cylinder. The lengths l are the same.

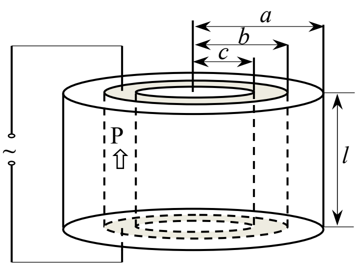

Fig.1 The diagram of the radially composite cylindrical ultrasonic transducer

The coupled vibration of the radially composite cylindrical ultrasonic transducer was analyzed. The resonance frequency equations are obtained. (4)

3. Analyses and discussions

According to the resonance frequency equations, the resonance frequencies and the effective electromechanical coupling coefficient are acquired.

For the cylindrical ultrasonic transducer, the radii $b=10\mathrm{mm}, c=5\mathrm{mm}$ and the length $l=10\mathrm{mm}$ are fixed. The radiu a is changed. A radius ratio $\tau=(a-b)/(b-c)$ is defined. The dependency of the characteristic parameters on the radius ratio is investigated. Figs. 2-4 are the relationship between characteristic parameters and the radius ratio.

jiexu2014@sina.com

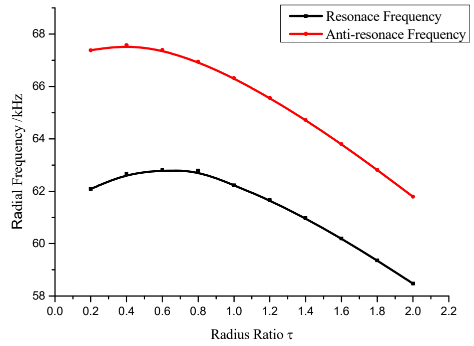

Fig. 2 The relationship between radial frequency and the radius ratio

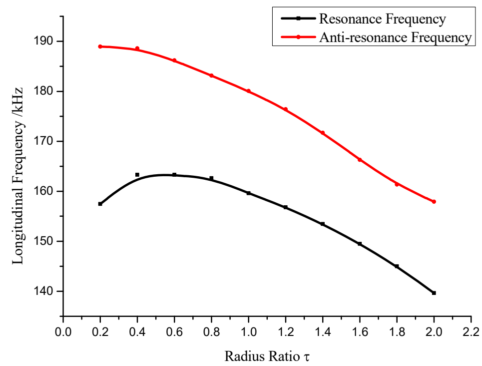

Fig. 3 The relationship between longitudinal frequency and the radius ratio

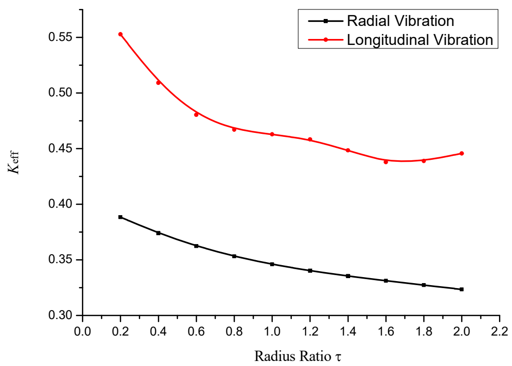

Fig. 4 The relationship between the effective electromechanical coupling coefficient and the radius ratio

From Figs. 2 and 3, the radius ratio is large while the radial and longitudinal resonance /anti-resonance frequencies are small. At the radius ratio $0.4 < \tau < 0.8$, the the radial and longitudinal resonance frequencies are large.

From Fig. 4, it is convenient to acquire the larger effective electromechanical coupling coefficient, as the radius ratio is small.

4. Experiment

We verify the effective of the above analyses via the experiment by measuring the resonance /anti-resonance frequencies of the two radially composite cylindrical transducers. Precision Impedance Analyzer WK6500B is used. The piezoelectric material is PZT-5A, the metal materical is Aluminum. The geometrial dimensions are $a_1 = 14\text{mm}$, $a_2 = 12\text{mm}$, $b = 10\text{mm}$, $c = 5\text{mm}$ and $l = 10\text{mm}$, as shown in Fig. 5.

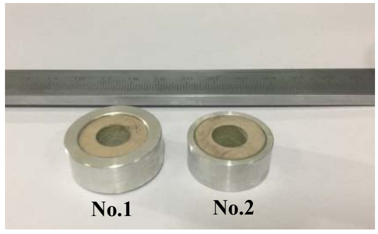

Fig. 5 The prototypes of the radial composite cylindrical ultrasonic transducer

The analytical radial resonance frequency $f_{r1} = 62786\text{Hz}$, $f_{r2} = 62671\text{Hz}$, and longitudinal resonance frequency $f_{z1} = 162633\text{Hz}$, $f_{z2} = 163297\text{Hz}$ agree well with the experimental radial resonance frequency $f_{rm1} = 63113\text{Hz}$, $f_{rm2} = 63105\text{Hz}$, and longitudinal resonance frequency $f_{zm1} = 159206\text{Hz}$, $f_{zm2} = 159449\text{Hz}$.

5. Conclusions

Based on the resonance frequency equations of the radially composite cylindrical ultrasonic transducer, the characteristic parameters of the transducer is investigated. The parameters optimization conclusions are obtained: (1) When the radius of the metal cylinder is slightly smaller than that of the piezoelectric cylinder, the resonance/ anti-resonance frequencies are larger. (2) The smaller radius ratio is beneficial to the larger effective electromechanical coupling coefficient.

Acknowledgment

This work was supported by National Natural Science Foundation of China (11374200, 11474192, 11674206) and the Fundamental Research Funds for the Central Universities (2016TS043)

References

1. Takuya Kambayashi, Tomonori Saeki and Ian Buchanan: Jpn. J. Appl. Phys. **56** (2017) 07JE04-1.
2. Atsuyuki Suzuki, Shota Ikeoka, and Jiromaru Tsujino: Jpn. J. Appl. Phys. **55** (2016) 07KE12-1.
3. Hiroki Yokozawa, Jens Twiefel, Michael Weinstein, and Takeshi Morita1: J. Appl. Phys. **56** (2017) 07JE08-1.
4. Jie Xu and Shuyu Lin: J. Acoust. Soc. Am. **143** (2018) 1206.