Finite element analysis of double resonance bender disk low frequency transducer

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Abstract. A bender disk transducer can generate low-frequency sound in a small size and light weight. But traditional bender disk transducer only works at single frequency by using first order bending mode and emits moderate levels of power. In this work, a double resonance bender disk low frequency transducer is investigated by using finite element model. The double resonance bender disk transducer consists of two segmented 3-3 mode piezoelectric ceramic disk on the both side of hollow metal disk, which could generate larger displacement in order to increase power radiation. A simple elastic mass system placed inside the hollow metal disk is introduced in the system to produce other lower resonance modes. Through the FEM calculations, it is found that the transmitting voltage response (TVR) of bender disk transducer could enhance 4dB in the first order bending mode resonance frequency, which is compared with traditional bender disk transducer with the same size. The TVR of lower resonance mode which is produced by additional central simple support elastic mass system in segmented bender disk transducer is more than 130dB. Through the optimization of finite element simulation, a double resonance bender disk transducer is designed, and its resonance frequency is 600Hz and 1kHz, respectively. The value of TVR is 130dB and 134dB corresponding to two resonance frequency. The double resonance bender disk transducer is compact dimension, low weight and it is a high performance low frequency transducer.

1 Introduction

The use of a bending vibration mode can allow an underwater acoustic transducer to achieve ideal low frequency radiation performance under a relatively small volume. The bender disk transducer has been continuously developed from the 1960s to the 21st century, when American R. S. Woollett [1] first gave a perfect theory of the bender disk transducer in early period, and then British John L. Delany [2] proposed a new bender disk transducer. At present, the bender disk transducer has been widely applied in underwater acoustic equipment that has certain requirements for the volume and weight of a transducer.

Currently, the bender disk transducer usually works at a single frequency, for which the working bandwidth is narrow and the transmission power is low. Therefore, the bender disk transducer that is structured based on the mosaic piezoelectric ring is designed and optimized by using the finite element software COMSOL, which aimed at improving the low frequency radiation power of the transducers. At the same time, a second elastic mass vibration structure is introduced into the transducer to enable the bender disk transducer to achieve double-frequency transmission and to expand the working bandwidth of the transducer.

2 The basic structure of transducer

The bender disk transducer is often designed with a structure shown in Figure 1. The transducer is composed of two pieces of piezoelectric ceramic disks that are polarized in the thickness direction and the hollow metal disk. The piezoelectric ceramic disks are bonded to the upper and lower surfaces of the metal disk, and are polarized in opposite directions and electrically connected in a parallel manner.

Fig. 1. Fundamental structure of typical bender disk transducer.

When a voltage is applied in the polarization direction of the piezoelectric ceramic, the strain of the ceramic can be indicated by the following equation [3]

$$\begin{aligned} S_1 &= s_{11}^E T_1 + s_{12}^E T_2 + d_{31} E_3 \\ S_2 &= s_{12}^E T_1 + s_{22}^E T_2 + d_{31} E_3 \\ D_3 &= d_{31} T_1 + d_{32} T_2 + \epsilon_{33}^T E_3 \end{aligned}$$

From above equations, it is evident that when the transducer is under the working conditions, the strain of the ceramic depends on the electric field E_3 , which is applied in the polarization direction of the ceramic, and the piezoelectric coefficient d_{31} . These results in the low

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electromechanical coupling coefficient and low radiated sound power of the transducer.

At the same time, for the low frequency bender disk transducer, the central position of the piezoelectric ceramic original of the transducer has the largest amplitude under the maximum voltage excitation so that the dynamic stress of the ceramic at this position can easily exceed the allowable stress limit of the material, which may reduce the reliability of the transducer for a long-term operation and restrict the transmission power of the transducer. Secondly, the low frequency mode that is available for the bender disk transducer is only the one-order bending vibration, which only enables the bender disk transducer to work at a single frequency.

A new structure of the bender disk transducer as shown in Figure 2 is proposed to improve the deficiency of the existing bender disk transducer. In the new bender disk transducer, the mosaic piezoelectric ceramic disk takes the place of the thickness-polarized piezoelectric ceramic disk that is used in traditional bender disk transducer; meanwhile, an elastic-mass vibration structure is added in the metal cavity.

Fig. 2. The structure of new bender disk transducer.

3 The finite element simulation

3.1. Finite element model of transducer

The finite element model of the new bender disk transducer is established by using of the commercial finite element software COMSOL. The transducer has a diameter of 160mm and the overall thickness of 34mm. The mosaic piezoelectric ceramic disk has an inner radius of 30mm and an outer radius of 80mm as well as a thickness of 4mm. It is made up of 80 wedge-shaped piezoelectric ceramic strips jointly.

Fig. 3. The finite element model of new bender disk transducer.

The piezoelectric material is PZT-4 piezoelectric ceramic. The metal disk of the cavity has a radius of 160mm; the cavity has a diameter of 152mm and a height of 18mm and it is made of 6063 aluminum alloy. The metal disk of the central support inside the cavity has a radius of 57mm and a thickness of 3mm. It is made of 6063 aluminum alloy. The central support disk is connected with a circular mass block that is made of brass. The mass block is 5mm-wide and 3mm-thick. Due to the symmetrical characteristics of the transducer, the

calculation and analysis is based on the 1/4 finite element model, as shown in Fig.3.

3.2 Mode and electrical admittance in air

The characteristic frequency analysis module of the software is used to calculate the mode of the transducer in the air, as shown in Figure 4. The low frequency mode is due to the introduction of the elastic-mass vibration structure of the central support. The mode is the bender mode of the elastic-mass vibration structure of the central support with the frequency of $f=650\text{Hz}$. Meanwhile, same as the traditional bender disk transducer, the new bender disk transducer has the one-order bender mode with the frequency of 1.6kHz.

(a) Bender mode of elastic-mass vibration structure: $f=650\text{Hz}$

(b) one-order bender mode: $f=1.6\text{kHz}$

Fig. 4. The mode of the new type bender disk transducer.

The voltage excitation load is applied for the finite element model of the transducer, and the electric admittance curve of the transducer in air is obtained by use of harmonic analysis technology, as shown in Fig.5.

Fig. 5. The electric admittance curve for transducer in air.

It can be seen from the electric admittance curve that the conductance curve has its maximum values at 700Hz and 1.62Hz, which means that the tangential voltage load applied to the piezoelectric ceramic ring of the transducer could excite the vibration mode, as shown in Fig.4.

3.3 Electroacoustic characteristics in water

The finite element model of the transducer for underwater electro-acoustic performance simulation is established. The electric admittance curve and the transmission voltage response curve of the transducer in

water are obtained through the harmonic analysis, as shown in Fig.6 and Fig.7.

Fig. 6. The electric admittance curve for transducer in water.

Fig. 7. The transmission voltage response curve.

Fig. 8. The comparison of transmission voltage response curve.

The resonant frequency of the transducer in water is 600Hz and 1kHz; the maximum conductance values are respectively 0.42mS and 0.32mS. The maximum transmission responses are 130dB and 134dB. The transmission voltage responses of the new bender disk transducer and the thickness-polarized bender disk transducer with same structure and size are compared, as shown in Figure 8. The transmission voltage response of thickness-polarized piezoelectric ceramic bender disk transducer, which is produced by the bender vibration mode of the elastic-mass structure with the central support, is 110dB. It is 20dB lower than the new bender disk transducer, so it cannot meet the requirements for real applications. The transmission voltage response that is produced by the one-order bender vibration mode is

130dB, which is also lower than the new bender disk transducer by 4dB.

4 Conclusions

A new mosaic bender disk transducer with the resonant frequency of 600Hz and 1kHz in water is designed by use of the finite element simulation in this paper. The transmission voltage response of the transducer at 600Hz is 130dB and the transmission voltage response at 1kHz is 134dB. It is shown by the calculation result of the finite element simulation that the bender disk transducer with the mosaic piezoelectric ceramic ring can improve the radiated acoustic power of the bender transducer. Adding an elastic-mass vibration structure to the inside of the metal cavity of the bender disk transducer can further reduce the operating frequency of the bender transducer. Meanwhile, it can enable the bender disk transducer to obtain the capability of dual-frequency transmission.

References

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