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Performance Simulation and Fabrication of PZT Piezoelectric Composite Ring

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Abstract: High-frequency wideband omnidirectional transducer is the development direction of the research of underwater acoustic transducer, PZT piezoelectric composite ring is not only capable of horizontal omnidirectional transmitting and receiving underwater acoustic signal. Meanwhile, it also makes the bandwidth of the transducer is expanded. Using the ANASYS finite element simulation software, the modal simulation of the ring structure of the 2-2 type piezoelectric composite is carried out, and the relationship curve of the bandwidth and the structure size is obtained. Based on the simulation, a design scheme is formed, cutting circular piezoelectric ceramics along the axial direction, there is epoxy resin in the groove. Thus the 2-2 type piezoelectric composite circular tube is formatted. The piezoelectric composite circular tubes suitable for horizontal omnidirectional broadband transducer.

Keywords: 2-2 Piezoelectric Composite, Simulation, Fabrication, Properties

1. Introduction

Composite materials are multiphase materials, which are made of piezoelectric phases (such as PZT) and polymer phases. It overcomes the shortcomings of the single-phase piezoelectric material and retains the strong piezoelectric property of piezoelectric phase material with a lower Qm value. The bandwidth of the transducer element is inversely proportional to the Qm value of the material, so the piezoelectric composite material is especially suitable for making the wide band transducer [1-6]. The typical piezoelectric composite material is made by cutting the ceramic and casting polymer. This method makes planar array composites that the piezoelectric ceramic is cut into the ceramic column array and the flexible polymers (such as epoxy resin, rubber, etc.) are added in the ceramic column array.

Chen Junbo et al. Of the No. 715 Research Institute of China Shipbuilding Heavy Industry Group made a piezoelectric composite piston transducer and the same size piezoelectric ceramic transducer [3]. The composite exhibits a single thickness resonance that the frequency is 180 kHz and the 3dB bandwidth is 15kHz. However, the piezoelectric ceramic presents multi-peaks resonance and the maximum resonance bandwidth is only 5kHz. The bandwidth of piezoelectric composite is 3 times that of single phase piezoelectric ceramic.

1-3-2 type piezoelectric composite broadband underwater acoustic transducer [7] was developed by Xian Xiaojun et al, who are in the institute of applied acoustics in Shanxi Normal University. The transducer is placed in anechoic test pool to test Water emission voltage response. The maximum response voltage of 1-3-2 type piezoelectric composite ceramic material underwater acoustic transducer is 183dB, and -3dB bandwidth of nearly 40kHz. Its bandwidth is much larger than that of the ceramic.

British S. Cochran used the 1-3 single crystal piezoelectric composite and matching layers to produce a bandwidth of doubling frequency of the underwater acoustic transducer [8]. Turkey I. Ceren Elmash has made a wide bandwidth and wide beam acoustic transducer based on 1-3 piezoelectric composites. The transducer can be applied to the field of underwater acoustic communication [9]. South Korea's Tian Zhi Fabricated a wide band ring transducer which is based on piezoelectric composite material with a matched layer [10].

At present, most of the curved transducers use piezoelectric ceramics as the sensitive material, because its Q value is much larger than that of the composite material. that is, the bandwidth of the material is less than that of the composite material. Therefore, if the composite material is made into a curved surface, the bandwidth of the transducer is bound to expand and the large open-angle beam radiation Sonic can be realized.

2. Performance Parameters of PZT-52 Piezoelectric Ceramic Ring with Different Thickness

The structure of the piezoelectric ceramic ring is shown in Figure 1. The Outer diameter is $2r_2$, Inside diameter is $2r_1$, The height is h, The thickness is t= r_2-r_1, The four kinds of piezoelectric ceramic ring has been tested which Outer diameter is 25mm, the height is 3mm, the inner diameter is 16mm, 17mm, 18mm, 19mm, The instruments used in the test are Agilent 4294A (40Hz-110MHz), Test results are shown in Table 1.

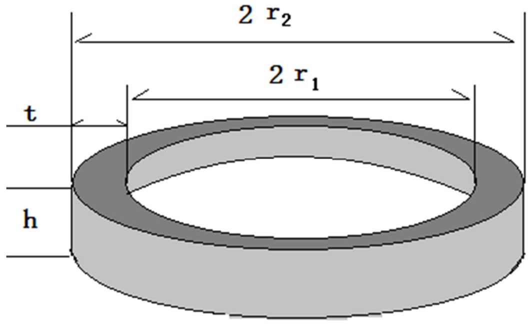


Fig. 1. *The geometry of Piezoelectric ceramic ring.*

Table 1. *Performance parameters of PZT-52 ceramic ring with different thickness.*

Model:	**Number (PZT-52)**									
φ25×φ16×3	**1#**	**2#**	**3#**	**4#**	**5#**	**6#**	**7#**	**8#**	**9#**	**10#**
resonant frequency *f* (kHz)	313	314	313	313.8	314.5	314.5	313.8	314.5	315.8	313.8
Bandwidth (kHz)	3.3	3.09	2.86	2.76	3.82	3.3	2.6	3.3	2.52	2.6
Q value	94	101	110	113	81.7	94.8	120.9	93.7	126.5	118
peak value of conductance G/mS	41	43	45	44.5	37.8	41.23	45.2	41.54	42.3	45.8
Model:	Number (PZT-52)									
φ25×φ17×3	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#
resonant frequency *f* (kHz)	341	340	343	342	343	345	343	342	342	342
Bandwidth (kHz)	3.8	3.7	3.5	3	3.6	3.6	3.5	4	4	2.9
Q value	89.7	89	96	114	93	95	98	83	84	115
peak value of conductance G/mS	49.5	50	54	55	50.7	48.5	52.9	46	46	55
Model:	Number (PZT-52)									
φ25×φ18×3	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#
resonant frequency *f* (kHz)	373	373	372	374	372	375	374	374	374	374
Bandwidth (kHz)	5.6	4	3.8	4.1	4.5	4.1	4.4	3.7	3.8	4.5
Q value	65	93	95	90	81	91.7	84	100	97	81.3
peak value of conductance G/mS	51	62	64	61	59	57.7	55	59	62.5	57.7
Model:	Number (PZT-52)									
φ25×φ19×3	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#
resonant frequency *f* (kHz)	408	405	404	407	405	405	403	4.6	403	405
Bandwidth (kHz)	5	4.2	4.75	5	4.8	4.9	4.3	5	5.9	4.8
Q value	81.6	95	85.9	80.9	83	81.5	93.6	80	68	83
peak value of conductance G/mS	68.4	78.9	71	65.2	69.3	68	77.7	67	64	69.5

From the table1, we can see that the resonant frequency decreases with the increase of the thickness, the bandwidth decreases with the increase of the thickness, the Q value increases with the increase of thickness, and the peak value of conductance decreases with the increase of thickness.

3. PZT Piezoelectric Composite Ring Design and Simulation

The geometry of the piezoelectric composite ring shows in Figure 2. Composite rings are made by cutting ceramic ring - pouring epoxy - Sample polish - coated electrode process. A piezoelectric ceramic ring is cut by Accurate control of the knife gap and step to make composite ring arranged in a uniform array.

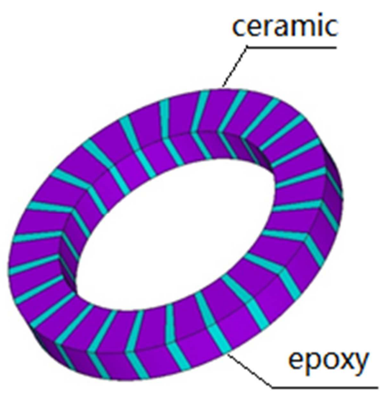


Fig. 2. *The geometry of Piezoelectric composite ring.*

Ring structure parameters include the volume percentage of the composite piezoelectric ceramic V, the radius of the circle R, the thickness of the ring T and the height of H. The volume percentage of the composite piezoelectric ceramic directly determines the electromechanical coupling coefficient Kt and Qm value of the composites.

In a cylindrical coordinate system modeling and simulation, it makes the piezoelectric ceramic that the height is h, the inner radius is r1, the outer radius is r2 and the polar angle is from 0º to 8º. Then it makes the epoxy resin that the height is h, the inner radius is r1, the outer radius is r2 and the polar angle is from 8º to 10º. The entity is copied 36 parts by the method of rotational symmetry to make the entire annular composite ring. The thickness of the composite ring is 4mm, The height of the composite ring is 3mm, the inner radius of the composite ring is 17mm. By simulation, the resonance frequency is 372KHz. As shown in figure 3.

By changing height h, thickness t, and the inner and outer ring radius, the ring resonant frequency and bandwidth are obtained with the variation in the size of its structure as shown in Figure 4.

From Figure 4, we can see that the ring resonant frequency decreases with the increase of the ring thickness t and the height h, and does not change with the change of the radius; The ring bandwidth BW also decreases with the increase of thickness t and height h, and does not change with the change of radius.

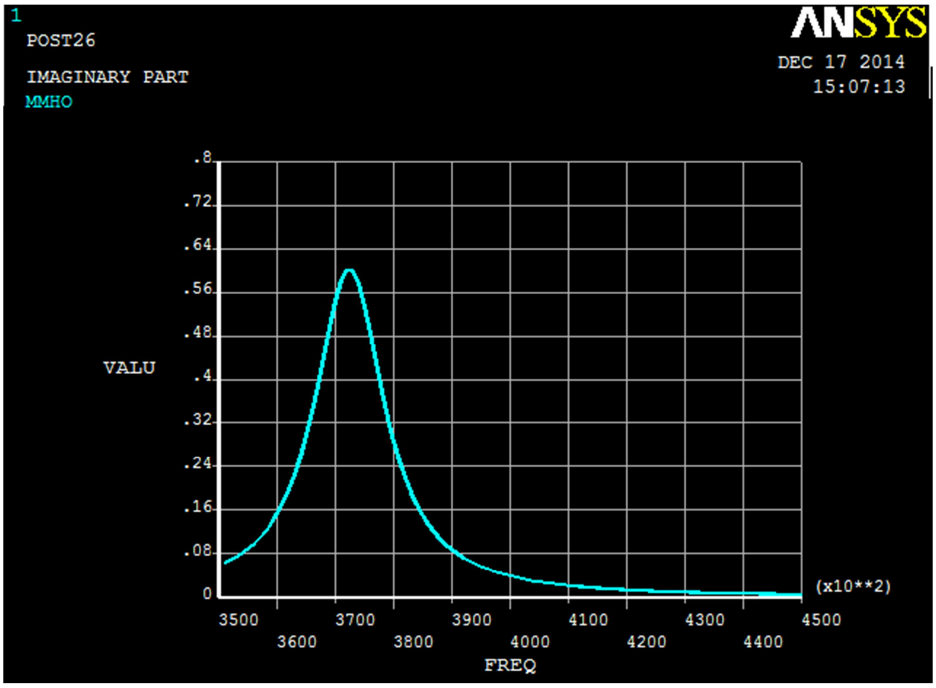
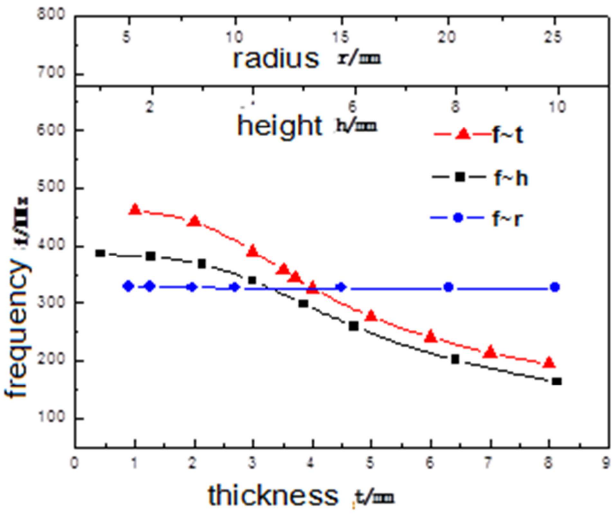
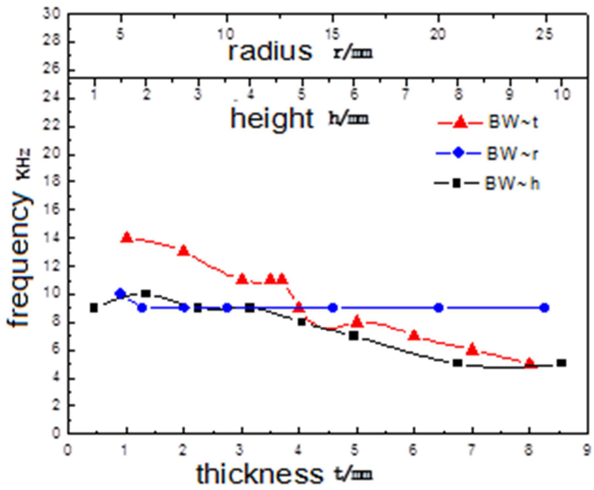


Fig. 3. *The harmonic response analysis of the ring.*



a) The law of the resonant frequency f with the parameters of the ring



b) Bandwidth BW with different parameters of the ring

Fig. 4. *The resonance frequency and bandwidth of the composite ring are changed with the parameters of the ring.*

4. Preparation of PZT Piezoelectric Composite Ring

On the basis of the conventional cutting - casting process, Composite rings are directly made by cutting ceramic ring - pouring epoxy - Sample polish - coated electrode process. Man continues to explore the preparation process. Especially a piezoelectric ceramic ring is cut by Accurate control of the knife gap and step to make composite ring arranged in a uniform array. the preparation and technical route of the composite ring is shown in figure5.

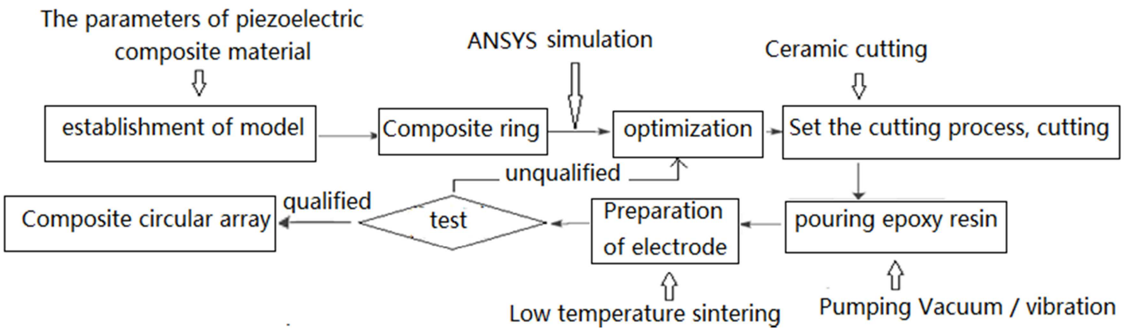


Fig. 5. *The fabrication of composite ring array.*

Fig. 6. *Preparation of composite ring array.*

The piezoelectric ceramic ring is PZT-5 production produced by the acoustics Institute of Chinese Sciences Academy. The bottom surface of the piezoelectric ceramic ring is placed on 1cm thick square plates and is fixed with melted paraffin. After the paraffin solidification, the steel plate together with the ceramic ring are placed into the cutting positions in the disco automatic grinding wheel dicing machine of the Japanese company (model DAD321). Then setting programs in the cutting machine and cutting the ring into 36 parts. Epoxy resins are produced fluid, and the epoxy resins are poured in the ceramic skeleton. At the same time, the bubble is evacuated and the epoxy resin is evenly filled. After Curing at room temperature, the composite material is obtained. Finally Polishing rough shaping makes a composite material ring, and the inner and outer surface is plated electrode to make a piezoelectric composite ring.

Due to the preparation process of the polarization of the piezoelectric ceramic under normal temperature and atmospheric pressure, the effect of the electrode of the piezoelectric ceramic is little. So the polarization of the composite material is omitted. The composite material is made into a kind of ring as shown in figure 6.

5. Performance Test of the Piezoelectric Composite Ring

The dielectric and piezoelectric properties of the composite ring are tested. When the test frequency is 100Hz, the piezoelectric constant d33 of the piezoelectric composites is measured by the piezoelectric constant tester (model: ZJ-3D) ;Vibration displacement of composite materials (Polytec Scanning Vibrometer) was tested by laser scanning vibration instrument; The low frequency capacitance and frequency characteristics of the composite material are tested by a precision impedance analyzer (4294A Agilent).

The sample parameters were measured, such as Piezoelectric constant, the vibration displacement (5V voltage drive), the relative dielectric constant, the speed of sound, acoustic impedance and so on. As is shown in table 2.

Table 2. *Properties of 2-2 composite.*

Material	d_{33} (pC/N)	Shift (pm)	ε_r	Dielectric loss	f_s(kHz)	f_p (kHz)	Bandwith (kHz)	v (m/s)	ρ (kg/m^3)	Z (Mraly)
2-2 type piezoelectric composites	480	89.5	859	0.04	388	489	11.2	3200	5018.7	18.05

From table 1, we can see that the piezoelectric ceramic ring bandwidth is 3.6KHz， from table 2, we can see that the piezoelectric composite ring bandwidth is 11.2KHz with the same dimensions of the ring. It is showed that the bandwidth can be increased by adding epoxy resin to the piezoelectric ceramic as a 2-2 type piezoelectric composite material.

The impedance characteristic of the piezoelectric composite ring is shown in figure 7. The main vibration resonance of the composite material is much larger than other vibration, and the bandwidth is larger than that of the ceramic. These characteristics can improve the bandwidth and frequency selectivity of the transducer, so the design of the transducer array is easy to implement.

The test and simulation results are compared. The test resonant frequency f is 388KHz and the bandwidth Bw is 11.2kHz. The simulation resonance frequency f is 372kHz and the bandwidth Bw is 9kHz. The highest frequency difference is 4.3%, and the bandwidth difference is 24.4%.

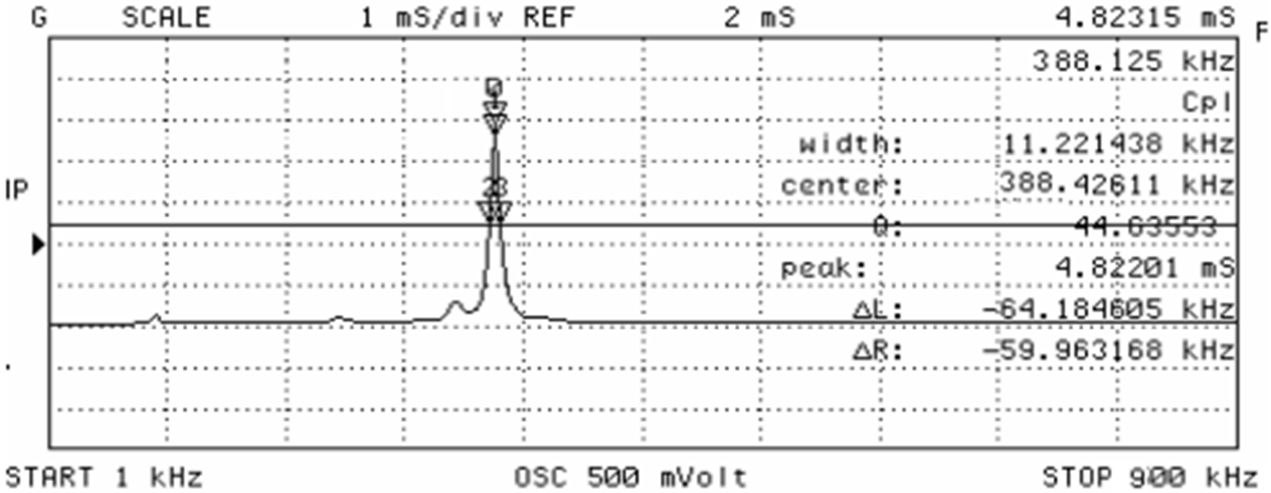


Fig. 7. Impedance characteristic curve of the ring of 2-2 type piezoelectric composite material.

The reason of the difference between the actual and the simulation bandwidth:

(1) The piezoelectric composite ring in the actual test has the internal energy loss of the material (his is due to the full compatibility of the ceramic and epoxy phases in the process, and the air is not fully discharged). Thereby that is more than the results of the simulation to expand the bandwidth.

(2) When the piezoelectric composite material is measured in the air, the air damping causes the energy loss of the transducer and also expands the bandwidth.

Above two reasons, the first is the main factor. At present, the bandwidth difference is up to 24.4%. This shows that we should pay attention to fully mixing and exhaust in the epoxy pouring process.

6. Conclusion

The preparation technology of plane composite material is mature. Coated electrode can be fabricated by the flat screen printing technology, but curved surface electrode is difficult to be printed by the flat screen printing technology. So it is difficult to realize the Curved surface composite material and limits the beam angle of the transducer. In this paper, Composite ring array is directly made by the process of cutting ceramic ring - pouring epoxy - sample grinding - curved screen coated electrode. By test, the resonant frequency is 388KHz, the bandwidth is 11.2kHz, the material piezoelectric constant d33 is 480 pC/N, the vibration displacement is 89.5pm, the sound speed is 3200m/s, the Acoustic impedance is 18.05Mraly, and the relative dielectric constant is 859. The piezoelectric constant d33 and the vibration displacement of the 2-2 type composite can reach the performance of the piezoelectric ceramics, and the sound speed and the acoustic impedance are greatly reduced, the bandwidth is increased. If you want to further broaden the bandwidth, it can be two different frequencies of single-tube composite rings stacked to produce a coupling that can further broaden the Bandwidth.

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