Acoustic field calculation for a compact barrel-stave flextensional transducer array

Zhengyao He and Chao Sun

Institute of Acoustic Engineering, Northwestern Polytechnical University, 710072 Xi'an, China
hezhengyao@163.com

The boundary element method together with the finite element method is used to calculate the radiated acoustic field of a compact array of barrel-stave flextensional transducers. At first, the surface vibration displacement distribution of one barrel-stave transducer is obtained by the finite element method using the commercial software ANSYS. The calculation results are then imported into the boundary element calculation software SYSNOISE. At the frequency of 1400Hz, the radiated acoustic field and radiation impedance are calculated by the boundary element method for a planar array which is composed of three identical barrel-stave flextensional transducers uniformly distributed on a circle with spacing much less than half wavelength. The calculation results show that the mutual interactions among elements are significant for the compact array. The mutual radiation resistance between two transducers is close to the self-radiation resistance of the transducers. And the transmitting source level of the 3-element array is 8.7dB higher than that of one transducer if the surface vibration velocities of the transducers in the array are the same as that of one transducer. The proposed technique can be used to predict the performance of a transmitting transducer array at the stage of preliminary design.

1 Introduction

The low-frequency, high-power underwater acoustic projectors have become a high priority technique for active sonar application. The barrel-stave flextensional transducer has low weight and volume, its structure and shape is suitable for constituting transducer arrays, and its resonant frequency can be very low, thus it is widely noticed all around the world. The detailed characteristics of the barrel-stave flextensional transducer are as follows: low resonant frequency, omnidirectional, high power, high efficiency and low weight and volume, further its limit working depth underwater is deeper because of its concave shell which can increase the prestress when the working depth increases [1,2].

The finite element method can be used to model and calculate the transducers. The resonant frequency, surface vibration displacement and vibration velocity distribution of the transducers can be calculated. The admittance curves, frequency response and radiation directivity curves can all be obtained [3-6]. When the surface vibration velocity distribution of the transducer has been obtained, the boundary element method can be used to calculate the radiation characteristics of the transducer and array [7-10].

In this paper, the finite element method and the commercial software ANSYS is used to model the barrel-stave transducer, and the surface vibration displacement and velocity distribution is obtained. Then, these are used as boundary condition and imported into the boundary element calculation software SYSNOISE. At last, the boundary element method is used to calculate the acoustic radiation characteristics of the barrel-stave flextensional transducer and array.

2 Acoustic radiation of single transducer

Because the barrel-stave flextensional transducer is symmetric up and down, only the upside half-part of the transducer is modeled in the three-dimensional boundary element model and meshed. Fig. 1 shows the three-dimensional boundary element model and mesh of the upside half-part of the transducer. The transverse direction is the X-axis direction, the longitudinal direction is the Z-axis direction and the origin point O is the center of the transducer. The diameter of the most concave part of the concave vibration shell of the transducer is 65mm. The height of the concave shell is 125mm. The diameter of the two end mass blocks on the upside and downside of the transducer is 90mm, and the height is 40mm. The harmonic response analysis of the transducer is conducted using the finite element method in the ANSYS software. The surface vibration displacement distribution when the transducer vibrates underwater is obtained. The result is then imported into SYSNOISE software exerting on the boundary element model of the transducer. Thus, the surface vibration velocity distribution of transducer is obtained by the SYSNOISE software. Further, the boundary element method is used to calculate the acoustic characteristics of the transducer. In the calculation, the driving voltage of the transducer is 1000V, and the analysis frequency is 1400Hz. Fig. 2 shows the radiated sound pressure amplitude of the 1/4 circle which is 1m from the center of the transducer in the Y=0 plane. The X-axis direction is 0°, and the Z-axis direction is 90°. The range of the calculated sound pressure level is from 190.44dB to 190.40dB. It is shown that the vertical directivity of the transducer is uniform and the fluctuant amount is within 0.04dB. Fig.3 shows the radiated sound field distribution of the transducer in the Y=0 plane. Fig.4 represents the radiated sound pressure level of the field points on the X-axis. The sunk part of the curve is the structure size of the transducer, where the sound pressure is zero. It is shown from Figs. 3~4 that the sound pressure is maximal on the most concave part of the transducer, the sound pressure of the field points decreases when their distance to the origin point increases, and the far-field sound pressure decreases like spherical wave. The maximal

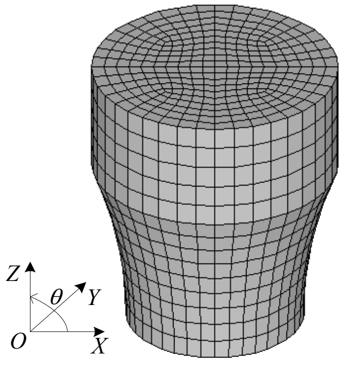

Fig.1. Boundary element model and mesh of upside half-part of the transducer. (Leftside is the sketch map of coordinate. The origin point is the center of the transducer.)

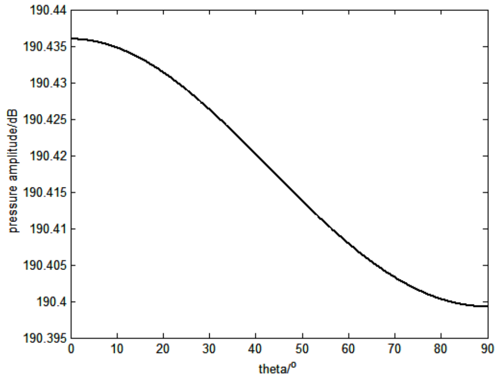

Fig.2. Radiated sound pressure amplitude of the 1/4 circle which is 1m from the center of the transducer in the Y=0 plane.

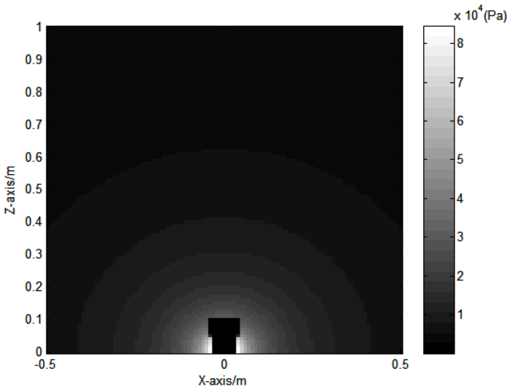

Fig.3. Radiated sound field distribution of the transducer in the Y=0 plane.

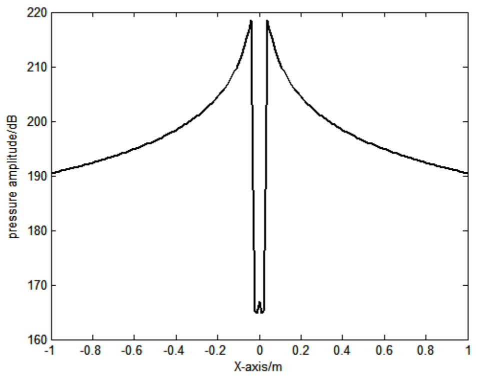

Fig.4. Radiated sound pressure amplitude of of the field points on the X-axis.

sound pressure level on the surface of the transducer is 218.6dB. The calculated source level of the transducer is 190.44dB, which is the radiated sound pressure level at the distance of 1m from the origin point in the X-axis direction.

3 Acoustic radiation of compact transducer array

The three-dimensional boundary element model and mesh of the upside half-part of the transducer array which is composed of three identical barrel-stave flextensional transducers is shown in Fig. 5. The three transducers are the same as the single transducer mentioned above. The maximal diameter of one transducer is 90mm. The three transducers are uniformly distributed on a circle. The diameter of the circumscribed circle of the array is 250mm. The transverse direction is the X-axis direction, the longitudinal direction is the Z-axis direction and the origin point O is the center of the circle which is passing the centers of the three transducers. The same surface vibration velocity distribution as mentioned above is exerted on the corresponding nodes of the three transducers, then the acoustic radiation characteristics are calculated using the boundary element method in SYSNOSIE software. The analysis frequency is also 1400Hz. Fig. 6 shows the radiated sound pressure amplitude of the 1/3 circle which is 1m from the origin point in the Z=0 plane. Because the three transducers are uniformly distributed on a circle, only the sound pressure in the range of 0° to 120° directions is calculated. The X-axis direction is 0°, and the Y-axis direction is 90°. The range of the calculated sound pressure level is from 199.15dB to 199.18dB. It is shown that the horizontal directivity of the array is uniform and the fluctuant amount is within 0.03dB. Fig. 7 shows the radiated sound pressure amplitude of the 1/2 circle which is 1m from the origin point in the Y=0 plane. The X-axis direction is 0°, and the Z-axis direction is 90°. The range of the calculated sound pressure level is from 199.15dB to 199.61dB. It is shown that the vertical directivity of the array is also uniform and the fluctuant amount is within 0.46dB. Fig.8 shows the radiated sound field distribution of the transducer in the Y=0 plane. Fig. 9 represents the radiated sound pressure level of the field points on the X-axis. The sunk part of the curve is the structure size of the transducers, where the sound pressure is zero. It can be shown from Fig. 8 and 9 that the radiated sound pressure level in the middle of the three transducers is maximal, which is higher than that on the surface of the transducers, and the far-field radiated sound pressure of the array decreases like spherical wave. The maximal sound pressure level in the middle of the array is 224.5dB, and the maximal sound pressure level on the surface of the transducers is 220.7dB. The former is 3.8dB higher than the latter. The calculated source level of the array is 199.15dB, which is the radiated sound pressure level at the distance of 1m from the origin point to the center of one transducer direction in the Z=0 plane. It is shown that the transmitting source level of the array composed of three transducers is 8.7dB higher than that of single transducer. It is because that the space between every two transducers is much less than half of the wavelength, and the acoustic mutual interactions among transducers are significant. The mutual radiation resistance between every two transducers is close to the self-radiation resistance of the transducers. The radiation power of the transducer and array is proportional to the square of their volume velocity. When the surface vibration velocity of the transducers in the array keeps the same as that of single transducer, the volume velocity of the array becomes 3 times as that of single transducer. Therefore, the radiation power of the array becomes nearly 9 times as that of single transducer.

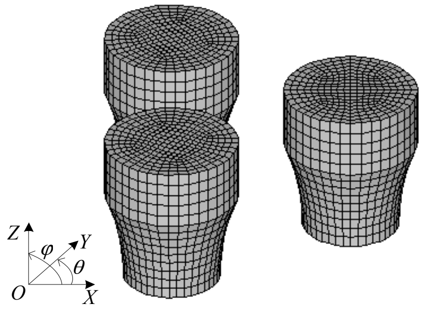

Fig.5. Boundary element model and mesh of upside half-part of the transducer array. (Leftside is the sketch map of coordinate. The origin point is the center of the circle passing the centers of three transducers.)

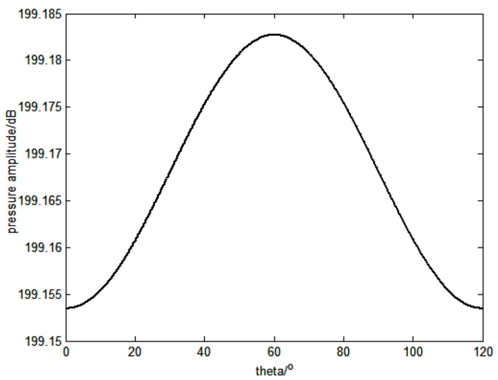

Fig.6. Radiated sound pressure amplitude of the 1/3 circle which is 1m from the origin point in the Z=0 plane.

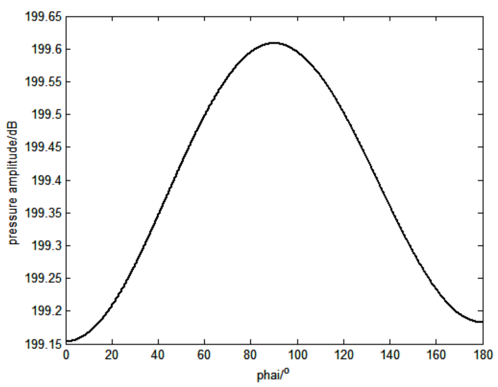

Fig.7. Radiated sound pressure amplitude of the 1/2 circle which is 1m from the origin point in the Y=0 plane.

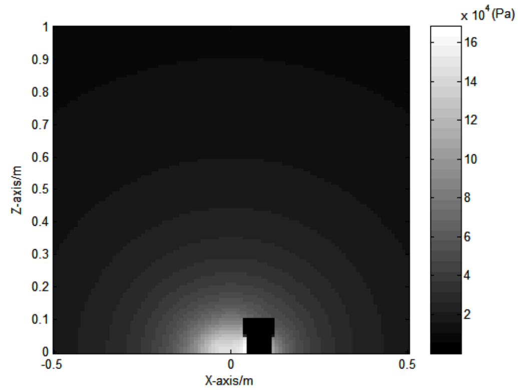

Fig.8. Radiated sound field distribution of the transducer array in the Y=0 plane.

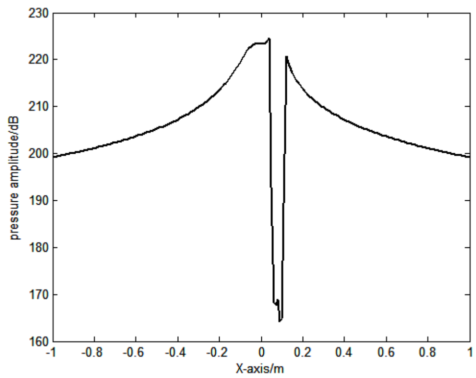

Fig.9. Radiated sound pressure amplitude of of the field points on the X-axis.

4 Conclusions

In this paper, the acoustic radiation characteristics of a single barrel-stave flextensional transducer and a compact array which is composed of three identical barrel-stave flextensional transducers are calculated using the boundary element method together with the finite element method at the frequency of 1400Hz. The calculation results show that the acoustic mutual interactions among elements are significant for the compact array where the space between every two transducers is much less than half of the wavelength. The mutual radiation resistance between every two transducers in the array is close to the self-radiation resistance of the transducers. The transmitting source level of the 3-element compact array is 8.7dB higher than that of single transducer when the surface vibration velocity of the transducers in the array keeps the same as that of single transducer. The proposed technique can be used to predict the performance of a transmitting transducer array and direct the design of the compact array.

Acknowledgments

This work was supported by the National Natural Science Foundation of China under Grant No. 10734030.

References

[1] Jones D.F., Abboud N.N., “Performance analysis of a low-frequency barrel-stave flextensional projector”, Proceeding of ONR Transducer Materials and Transducers Workshop,1-4 (1996).

[2] Jones D.F., Christopher D.A., “A broadband omnidirectional barrel-stave flextensional transducer”, J. Acoust.Soc.Am.,106, L13-L17 (1999).

[3] Hamonic B.,Debus J. C., “Analysis of a radiating thin-shell sonar transducer using the finite-element method”, J.Acoust.Soc.Am.,86,1245-1253 (1989).

[4] Jarng Soon Suck, “Comparison of barrel-stave sonar transducer simulations between a coupled FE-BEM and ATILA”, IEEE Sensors Journal, 3,439-446 (2003).

[5] Allik H. , Webman K. M., “Vibrational response of sonar transducers using piezoelectric finite elements”, J.Acoust.Soc.Am.,56,1782-1791 (1974).

[6] Smith R.R., Hunt J.T., “Barach D.. Finite element analysis of acoustically radiating structures with applications to sonar transducers.”, J.Acoust.Soc. Am.,54, 1277-1288 (1973).

[7] Harry A. Schenck, “Improved integral formulation for acoustic radiation problems”, J.Acoust.Soc.Am.,44, 41-58 (1968).

[8] Cunefare K.A., Koopmann G., Brod K., “A boundary element method for acoustic radiation valid for all wave numbers”, J.Acoust.Soc.Am.,85,39-48 (1989).

[9] Christan Audoly, “Some aspects of acoustic interacttions in sonar transducer arrays”, J.Acoust.Soc.Am., 89,1428-1433 (1991).

[10] He Zhengyao, Ma Yuanliang, “Calculation of baffle effect and mutual interaction between elements for an underwater acoustic conformal array with application to the optimization of projecting beampattern”, Chinese Science Bulletin, 52, 2584-2591 (2007).