The investigation on sound source identification in semi-space by NAH

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Abstract: The near field acoustic holography (NAH, hereafter) theory model in semi-space has been reconstructed on the foundation of NAH theory in full-space. The technique of semi-space acoustic field reconstruction by NAH has been developed on Fast Fourier Transforms Algorithm. This method has considered the water surface as soft boundary condition. The equivalent free sound field can be acquired if the measured sound field has been dealt with by the principle of the mirror. This method can overcome the disadvantages of the boundary element method which can be used to resolve the problems of sound source identification in semi-space, such as the use of the semi-space Green function, complex transformation matrix calculation, more time consummation and singularity solution existence. This method has been verified by numerical calculation and experiment respectively. The experimental frequency is at the range from 3 to 10 kHz. The distance between the hologram plane and source plane is 3 cm. The results show that it's an efficiency way to deal with the problems of sound source identification in semi-space.

1 Introduction

In recent tens of years, the technique of near field acoustic holography has already been developed into an important technology of investigating the noise source identification and sound field radiation[1-5]. However, most research has been done on sound radiation of vibrating structures in no boundary space (free field). In fact, the vibrating structures usually radiates sound field in semi-space. For example, the radiated sound fields from the vibrating structures in the air when placed on the ground, and from the submarines near the water surface, etc, are all sound field in semi-space. On these conditions, sound pressure measured in the holograms is the summation of incident sound pressure and reflected sound pressure. The radiation properties of the whole sound field can't be predicted accurately by using the NAH in full space, where is free field. Of course, we can use the semi-space green function in the Helmholtz integral equation to deal with the boundary surface's effect. But if so, we have to adopt BEM instead of FFT, and it will consume more time to do the same work. Based on the technique of NAH in full space, the theoretical model of NAH technique in semi-space is founded in this paper, and the FFT has been introduced into it. The method has utilized the absolutely soft boundary condition of water surface efficiently. The theory model has been validated both by numerical simulation and experiment.

2 The principle and realization

2.1 The basic principle

The sound pressure of point p in sound field can be expressed by the Helmholtz integral equation.

$$\alpha p(\vec{r}_P) = \iint_S [p(\vec{r}_Q)\cdot\frac{\partial G(\vec{r}_P,\vec{r}_Q)}{\partial n} - \frac{\partial p(\vec{r}_Q)}{\partial n}\cdot G(\vec{r}_P,\vec{r}_Q)]dS(\vec{r}_Q) \quad (1)$$

where, the value of α is related with the place of the field point, and its values selected as follow:

$$\alpha = \begin{cases} 4\pi & (\vec{r} \text{ is out of } S) \\ 0 & (\vec{r} \text{ is in } S) \\ 2\pi & (\vec{r} \text{ is on } S) \end{cases} \quad (2)$$

where, $\vec{r_p}$ denotes the point on S surface, $\vec{r_q}$ denotes the point out of S surface, $G(\vec{r_p},\vec{r_q}) = \dfrac{e^{-jkR}}{4\pi R}$ is the Green function, $R = \left|\vec{r_p} - \vec{r_q}\right|$ denotes the distance between the node $\vec{r_p}$ of source surface and the field point $\vec{r_q}$.

If the source surface and the hologram are two paralleling planes, and the green function is selected properly, the equation (1) can be simplified into

$$p(\vec{r}) = \iint_S p_S(\vec{r}_S)\cdot G_D(\vec{r},\vec{r}_S)ds(\vec{r}_S) = p(\vec{r}_S)\otimes G_D(\vec{r},\vec{r}_S) \quad (3)$$

Both sides of the equation (3) are carried out by two dimensional Spatial Fast Fourier Transforms. Then equation (3) in wave number field is rewritten as

$$p\left(k_x,k_y,z_H\right) = p\left(k_x,k_y,z_S\right)\cdot G_D\left(k_x,k_y,d\right) \quad (4)$$

where,

$$G_D\left(k_x,k_y,d\right) = \begin{cases} e^{-jd\sqrt{k^2-kx^2-ky^2}} & \left(k \ge \sqrt{k_x^2+k_y^2}\right) \\ e^{-d\sqrt{kx^2-ky^2-k^2}} & \left(k < \sqrt{k_x^2+k_y^2}\right) \end{cases} \quad (5)$$

From equation (4), the sound pressure of source surface S can be reconstructed by the sound pressure of measured surface H .

$$p\left(k_x,k_y,z_S\right) = p\left(k_x,k_y,z_H\right)/G_D\left(k_x,k_y,d\right) \quad (6)$$

or

$$p\left(k_x,k_y,z_S\right) = p\left(k_x,k_y,z_H\right)\cdot G_D^{-1}\left(k_x,k_y,d\right) \quad (7)$$

The above deduction shows that the sound pressure field on source surface can be reconstructed by the outer radiated sound field.

Similarly, on the absolutely hard boundary condition, the normal velocity can be predicted from equation

$$u_n(k_x,k_y,z_S) = p(k_x,k_y,z_H)\cdot G_N^{-1}(k_x,k_y,d) \quad (8)$$

Equation (8) shows that the normal velocity on source surface can be reconstructed by the sound pressure field of outer surface.

2.2 The realization in semi-space

If the sound field in semi-space with absolutely soft condition (for example, the water surface for the sound field underwater) is to be predicted, the equations above cannot be used directly. But the equivalent free field in three dimensional space can be obtained according to the absolutely soft (or hard) condition by dissymmetrically (or symmetrically) mapping the sound field underwater about the absolutely soft(or hard) surface [6]. After the equivalent free sound field is constructed, the sound field on the source surface can be reconstructed by using the expressions in section 2.

3 The numerical simulation

3.1 Case A: single source

It is assumed that the point sound source is placed at the coordinate origin. The two planes are hologram H and source plane S respectively. H is located at the place $Z = Z_h$; S is located at the place $Z = Z_S$. The hologram and source plane are paralleling, meanwhile, their size is equal. The direction paralleling to the water surface is x axis, while the vertical direction is y axis, see Fig 1.

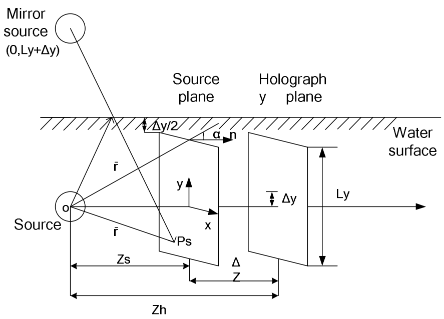
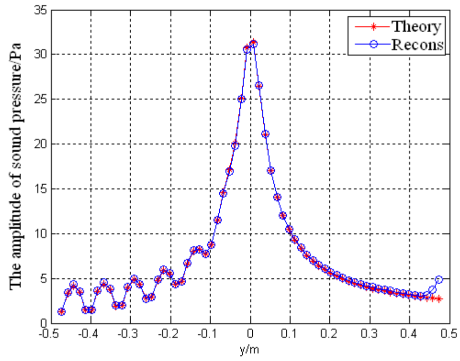


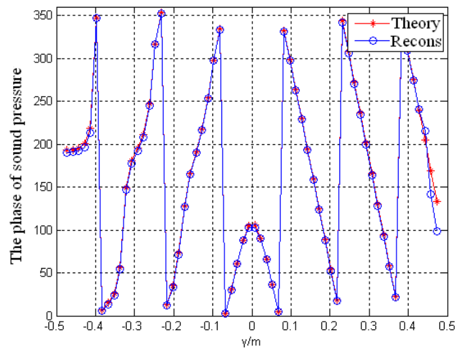
Fig.1 The plane to plane holographic transforms model for single source

The parameters of the model are as follows. The frequency of the point sound source is $f = 10000$ Hz. The wavelength is $\lambda = 0.15$ meters. The size of source plane and hologram is equal, $L_x = L_y = 6.3\lambda$. The Z axis coordinate of source plane is $Z_S = \lambda / 5$. The Z axis coordinate of hologram is $Z_H = \lambda / 3$. The distance between the sampling points both on source plane and hologram is $\Delta x = \Delta y = \lambda / 10$.

The comparison between the reconstructed sound pressure field using equation (7) and the sound field in the same position obtained from the point source formula are shown in figure 2. The figure 2-(a) is the comparison of sound pressure amplitude values. The figure 2-(b) is the comparison of sound pressure phase. The sound field distribution at the 32nd row of source plane is plotted in the figure. The abscissa is y , which is at the range from -0.4725 m to 0.4725 m. The y axis denotes sound pressure amplitude values in figure 2-(a), while y axis denotes phase and is at the range from 0 to 360 degrees in figure 2-(b). The curves in Fig. 2 show that the reconstructed sound field from equation (7) on source plane agrees well with that from point source formula.



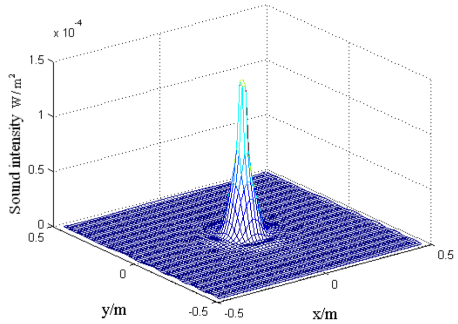
(a)



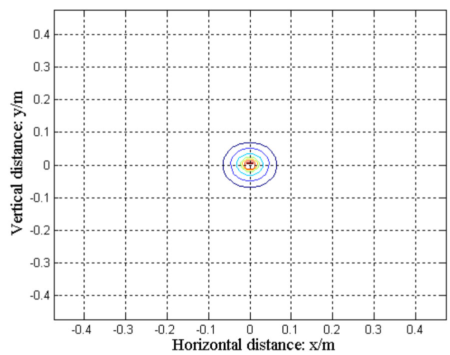
(b)

Fig. 2 The comparison between the reconstructed sound pressure field from equation (7) and that from point source formula on source plane.

The sound intensity distribution in the source plane is also reconstructed and shown in figure 3.



(a)The three-dimensional diagram



(b) The isoline diagram

Fig.3 The three dimensional diagram and isoline diagram of reconstructed sound intensity distribution in source plane

From figure 3-(a), it can be seen clearly that the sound source located in the center of source plane. The sound intensity in other positions is very little. The point where the sound intensity value is maximum is at the point (0, 0), which is shown clearly in figure 3-(b).

3.2 Case B: multi-sources

In the analysis of practical problems, there also exist the conditions of many coherent sound sources. In the sound field generated by multi-sources in semi-space, the reconstruction of multi-sources can also be accomplished similarly as above. The simulation of multi- sources' sound field is analyzed in the following.

The two point sound sources of contrary phase are located in the symmetric places of x axis. The distance between two sound sources is $d_{12} = 2\lambda/3$. The hologram H is put at the place $Z = Z_h$. The source plane S is put at the place $Z = Z_S$. The hologram is paralleling with the source plane, meanwhile, their size is equal. The direction paralleling water surface is x axis, while the vertical direction is y, see Fig 4.

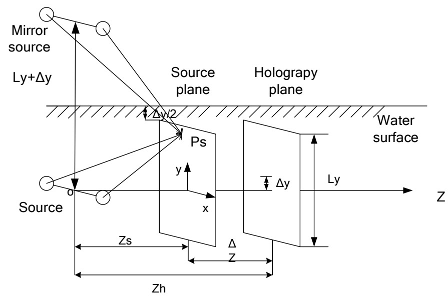
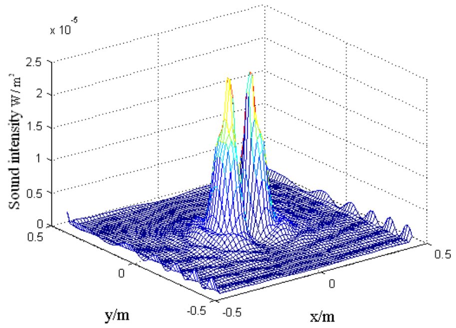
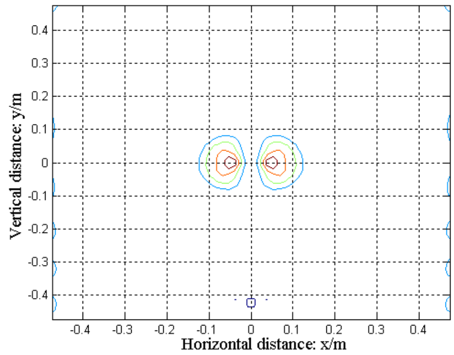


Fig.4 The plane to plane holographic transforms model of two sound sources

The parameters of the model are as follows. The frequency is $f = 10000$ Hz and the wave length is $\lambda = 0.15$ m. The size of source plane and hologram is equal, $L_x = L_y = 6.3\lambda$. The z axis coordinate of source plane is $Z_S = \lambda/5$. The z axis coordinate of holography plane is $Z_H = \lambda/5$. The distance between sampling points on source plane and hologram is $\Delta x = \Delta y = \lambda/10$. The simulated sound intensity distribution in the source plane is shown in figure 5.



(a)The three-dimensional diagram



(b) The isoline diagram

Fig.5 The three-dimensional diagram and isoline diagram of reconstructed sound intensity distribution in the source plane.

4 Experiment

The experiment is carried out in the muffling pool. The experimental equipments connection is shown in figure 6. A hydrophone array with 10 elements is used in the experiment. The distance between two adjacent hydrophones is 0.12 m. The measured dimension is 1.17×1.17 square meters. The data of sound pressure distribution is a matrix, which is 40 lines multiplying 40 rows.

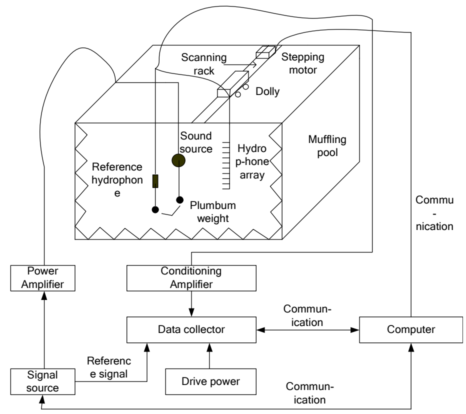
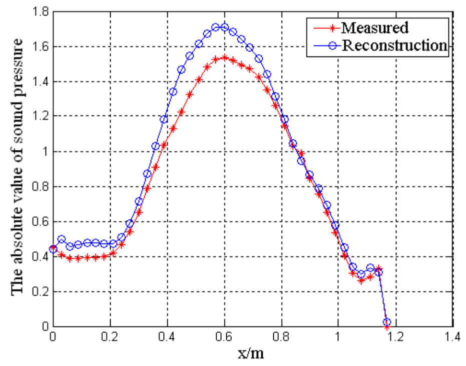
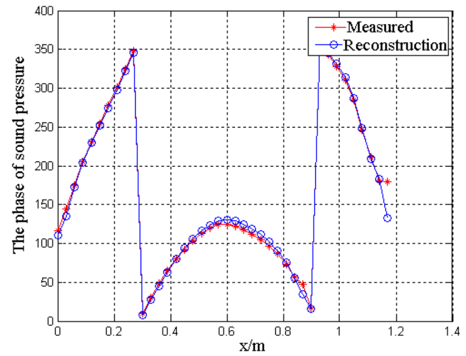


Fig.6 The disposal diagram of experimental system.

The condition of single sound source experiment is listed only. A single transmitting transducer is taken as the study object and then analyzed. The sound field is reconstructed by the measured sound pressure on the hologram. The experimental condition is as follows. The transmitting transducer is put 0.3 m deep underwater. The distance between the source plane and transmitting transducer is 0.1 m. The distance between the hologram and transmitting transducer is 0.13 m. The amplitude and phase comparison between the reconstructed sound pressure on the 18th row on the source plane and that by measured directly are shown in figure 7, where the frequency is 3 kHz.



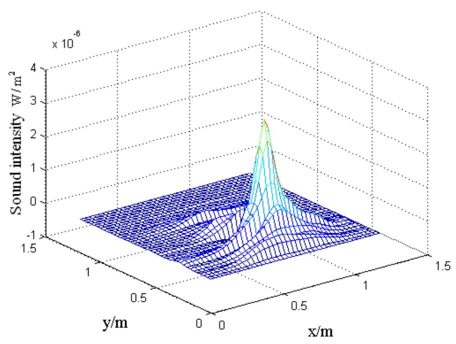
(a)The amplitude



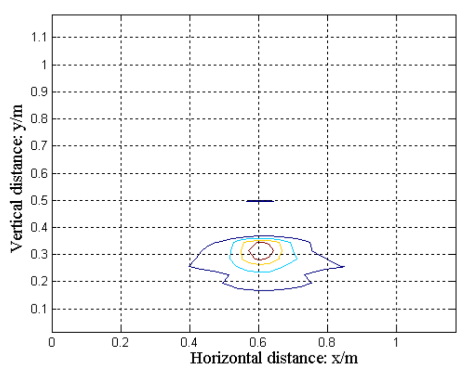
(b) The phase

Fig. 7 The sound pressure comparison between the reconstruction and measured value at the frequency of 3 kHz.

The reconstructed sound intensity on source plane at the frequency of 3,8,10 kHz is shown in figure 8, 9, 10 respectively. The x , y coordinates of sound source location is (0.6,0.3), which is shown obviously in the figures. The reconstructed location of sound source is just as the location placed before the experiment.

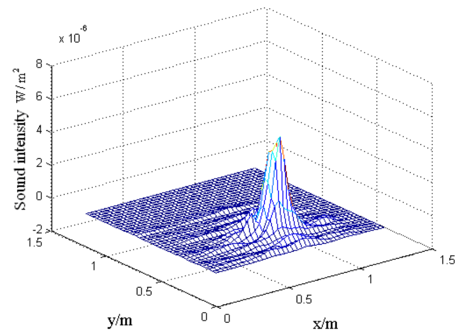


(a) The three-dimensional diagram

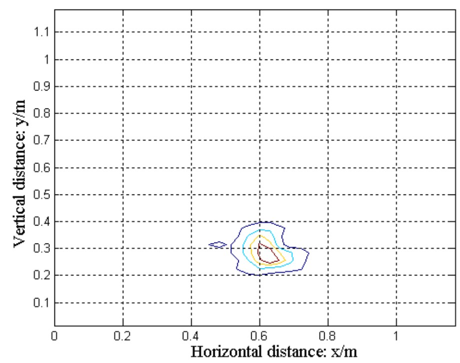


(b) The isoline diagram

Fig. 8 The three dimensional diagram and the isoline diagram of sound intensity distribution in the source plane at the frequency of 3 kHz

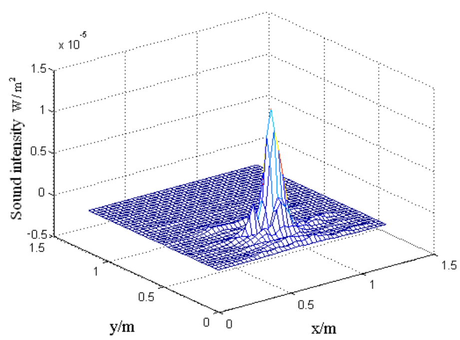


(a) The three-dimensional diagram

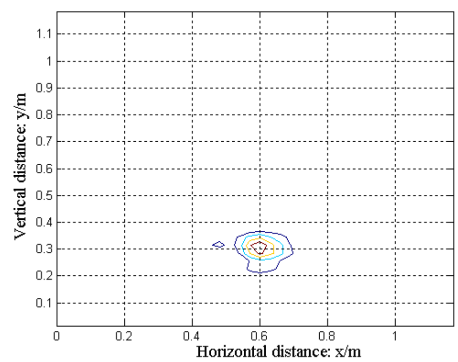


(b) The isoline diagram

Fig. 9The three dimensional diagram and the isoline diagram of sound intensity distribution in the source plane at the frequency of 8 kHz



(a) The three-dimensional diagram



(b) The isoline diagram

Fig. 10 The three dimensional diagram and the isoline diagram of sound intensity distribution in the source plane at the frequency of 10 kHz

5 Conclusions

The equivalent free field in three dimensional space can be obtained according to the absolutely soft (or hard) condition by dissymmetrially (or symmetrically) mapping the sound field about the absolutely soft (or hard) surface. Based on this assumption, the equivalent free sound field can be constructed, and then the sound field on the source surface can be reconstructed by the traditional NAH technique. The numerical and experimental results show that this method is very good for reconstructing the sound field from objects near very hard or soft boundary surface. Further, it can also be used for noise source identification in semi-space.

Acknowledgments

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