Design of High Frequency Acoustic Transducer Calibration System Based on Near-field Acoustical Holography

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***Abstract*—The demand for efficient and accurate devices used for calibration has been put forward in recent years. The near-field measurement technology is a convenient and operability method to calibrate an acoustic transducer. The calibration of high frequency acoustic transducer has a bigger error due to the limit of the calibration equipment. A high frequency acoustic transducer calibration system is designed in this paper. The fiber grating hydrophone array, the mechanical scanning mechanism, the control system and the design of the interface are included in the system. The simulations have been carried out to verify the correctness of the system. As a result, the design principle and implementation scheme is reliable.**

Keywords*—*Near-field Acoustical Holography (NAH), high frequency transducer, calibration

I. INTRODUCTION

With the development of underwater acoustic technology, more and more underwater acoustic equipment has been developed in recent years. The demand for efficient and accurate devices used for calibration has been put forward.

Most of the underwater acoustic equipment work at a higher frequency. The calibration of high frequency acoustic transducer with a big size needs a large volume of water and an expensive facility when using the conventional far-field measurement technology [1]. Though the near-field measurement technology solves the problem above, it is still not perfect. The traditional hydrophone can't meet the requirement to calibrate the high frequency acoustic transducer with a high precision because of its size and performance.

Compared with the traditional hydrophone, the fiber optic hydrophone has many advantages such as high sensitivity, strong ability of anti-electromagnetic interference, all optical transmission, small volume, light weight, and easily networking [2]. The fiber grating hydrophone is a kind of fiber optic hydrophone which has a small volume and a strong multiplexing capability [3].

The calibration system in this paper uses the fiber optic hydrophone to measure the near-field sound pressure of transducer and calibrate the transducer with the theory of NAH.

II. THEORY OF NAH

A. Basic Theory

NAH is a kind of technology rebuilding the field of acoustic source plane from the acoustic field of the holographic plane with the help of the transforming relation between the source plane and the holographic plane through measuring the acoustic pressure of the holographic plane.

$\boldsymbol{r_H}$ is a point in the hologram plane. Its coordinate is (x_H, y_H, z_H) and its complex sound pressure is $p_H(r_H)$. r_0 is a point in the sound source plane. Its coordinate is (x_0, y_0, z_0) and its complex sound pressure is $p_0(r_0)$. The relationship between $p_H(r_H)$ and $p_0(r_0)$ can be represented as:

$$p_H(r_H) = \iint_S p_0(r_0)\, g_D(r_H, r_0)\, dS \qquad (1)$$

$\boldsymbol{S}$ is the acoustic source plane. $g_D(r_H, r_0)$ is the transfer function which is related to the Green's function from r_H to r_0. It can be represented as:

$$g_D(r_H, r_0) = (z_H - z_0)(1 - jkR)\frac{e^{jkR}}{2\pi R^3} \qquad (2)$$

$\boldsymbol{R}$ is the distance between r_H and r_0:

$$R = \sqrt{(x_H - x_0)^2 + (y_H - y_0)^2 + (z_H - z_0)^2} \qquad (3)$$

Make a two-dimensional Fourier transform to (1), we can get:

$$P_H\left(k_x, k_y, z_H\right) = P_0\left(k_x, k_y, z_0\right) G\left(k_x, k_y, z_H - z_0\right) \tag{4}$$

G(k_x, k_y, z_H-z_0) is the two-dimensional Fourier transform of $g_D(r_H, r_0)$. $G(k_x, k_y, z)$ can be represented as

$$G\left(k_x, k_y, z\right) = e^{j z \sqrt{k^2-k_x^2-k_y^2}} \tag{5}$$

k is the wavenumber， k_x and k_y is the horizontal axis and the vertical axis of the sampling point in the wavenumber domain. The complex sound pressure of any point in the sound source plane can be represented as:

$$p_0\left(r_0\right) = F^{-1}\left[\frac{P\left(k_x, k_y, z_H\right)}{G\left(k_x, k_y, z_H - z_0\right)}\right] \tag{6}$$

$F^{-1}[*]$ is the inverse operation of two-dimensional Fourier transform.

The transmitting voltage response, the acoustic power, and the directivity are the main parameters to be calibrated. They can be gotten through the calculation of the complex sound pressure. So the complex sound pressure of far-field is the key of this paper.

How to get the complex sound pressure of the sound source plane from one of the holographic plane is discussed in the preceding part of this paper. But the complex sound pressure of the sound source plane is not cared about, if the complex sound pressure of the far-field plane can be gotten directly in the practical engineering.

Set the sound source plane z_0 is located at z=0. Set the holographic plane z_H and the far-field plane z parallel to the sound source plane, and their coordinates of z axis meet the conditions that $z_0 < z_H < z$. r is a point in far-field plane. Its coordinate is (x, y, z) and its complex sound pressure is $p(r)$. It is not difficult to get:

$$P\left(k_x, k_y, z\right) = P_H\left(k_x, k_y, z_0\right) G\left(k_x, k_y, z - z_0\right) \tag{7}$$

Combine (4) and (7)，we can get：

$$p\left(r\right) = F^{-1}\left[P_H\left(k_x, k_y, z_H\right) G\left(k_x, k_y, z - z_H\right)\right] \tag{8}$$

The derivation is based on the assumption that the sound pressure signal is zero or on a negligible levels out of the limited holographic plane.

B. Discretization Model

Due to that the continuous complex acoustic pressure can't be measured, a limited and discrete sequence of the complex acoustic pressure is used to approximate the continuous acoustic field.

Carve up the plane z_H and the plane z to $N\times N$ small blocks, whose size are $\triangle x\times\triangle y$, as shown in Fig.1. It is assumed that the acoustic pressure field of each sub-block is a constant field. The acoustic pressure of the constant field is the average of the acoustic pressure on the sub-block.

The complex acoustic pressure is measured in the center of each sub-block in the holographic plane. Take the acoustic pressure values of each midpoint to approximate the constant field. Then, the $N\times N$ limited and discrete holographic acoustic pressure array is gotten.

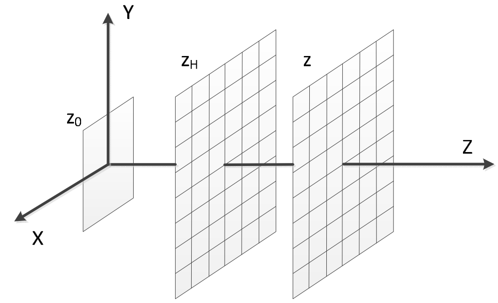

Fig.1 Acoustic Pressure Plane Diagram

$$p\left(r\right)\Big|_{N\times N} = F^{-1}\left[\begin{matrix} P_H\left(k_x, k_y, z_H\right)\Big|_{2N\times 2N}\times \\ G\left(k_x, k_y, z - z_H\right)\Big|_{2N\times 2N}\end{matrix}\right]\Bigg|_{N\times N} \tag{9}$$

III. DESIGN OF SYSTEM

By using the fiber grating hydrophone array, mechanical scanning mechanism and electronic control system, we can get the high frequency transducer near-field acoustic pressure distribution. Through the calculation of electric-acoustic parameters， we can get the acoustic field of the measuring plane, which is used to calculate the parameters of the transducer for the far-field. The whole structure of the system is shown in Fig.2.

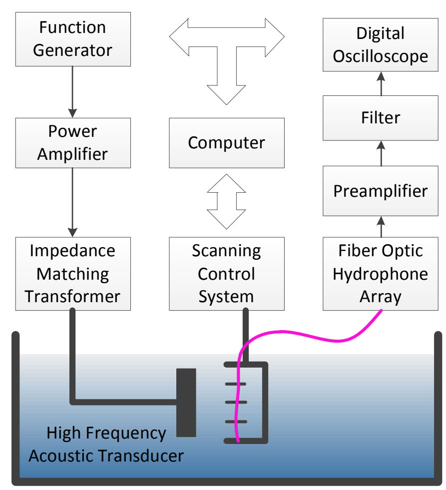

Fig.2 System Schematic Diagram

A. *Fiber Grating Hydrophone Array*

Acoustic intensity can be measured by the fiber grating hydrophone array. The central wavelength of the grating varies with the parameters change of environment. The fiber grating hydrophone can get the acoustic intensity from the change. It can be expressed as:

$$p = -\frac{\Delta\lambda_B}{\lambda_B}\frac{E}{(1-Pe)(1-2\mu)} \tag{10}$$

μ is the Poisson's ratio of the optical fiber core materials. ***E*** is the young modulus. ***p*** is the acoustic intensity. ***Pe*** is the valid elastic-optic coefficient of fiber optic.

The production method of the fiber grating hydrophone in this paper is different from the rest. The fiber grating hydrophone has many advantages which are the compact structure, the small size, the good spatial resolution, the high pressure sensitivity and the good amplitude and phase consistency. Besides, its preparation method is simple and it is easy to implement.

A single hydrophone can be chosen to measure the acoustic pressure of each point. A focal plane array of hydrophone can also be chosen to measure the acoustic pressure. The former problems is that the measurement cost a long time. The latter requires a lot of hydrophone, whose cost is higher. Using linear array of hydrophone as a compromise is a more reasonable method in application

Make measurement bracket as shown in Fig.3 and fix the fiber grating hydrophone arrays and transducer on the mechanical scanning auxiliary equipment.

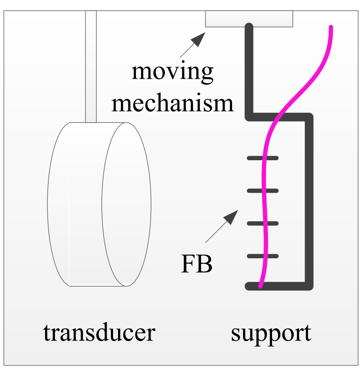

Fig.3 Measurement Bracket

B. *Mechanical Scanning Mechanism*

In order to measure the near field acoustic pressure, a mechanical scanning mechanism is designed in this paper. Fig.4 is the schematic diagram of mechanical scanning mechanism.

The transducer and the fiber grating hydrophone array are fixed on two platforms respectively. The platform of the transducer is called Z1, and the he platform of the fiber grating hydrophone array is called Z2. Z1 can move in the vertical direction. Z2 can move in the three direction which are horizontal, vertical and forward or backward. Z1 and Z2 are driven by motor to measure the near field acoustic pressure.

The size of the motor's step is related to the size of the discrete small block. The size of the discrete small block refer to the operating frequencies of transducer.

The step motor has the problem of lost step. To solve the problem, the servo motor is chosen to apply in this system.

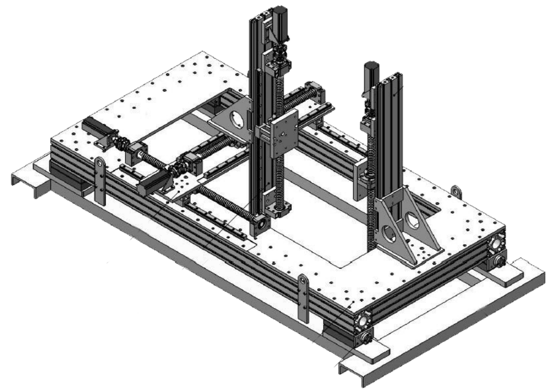

Fig.4 Mechanical Scanning Mechanism

C. *Electronic Control System*

The scanning control system and the data acquisition control system are the two parts of the electronic control system.

The motion control card is used in the scanning control system. The servo motor is controlled by the pulse and direction signals through the drive. The drives and its power supply circuit integrated on a scanning control chassis, as Fig.5.

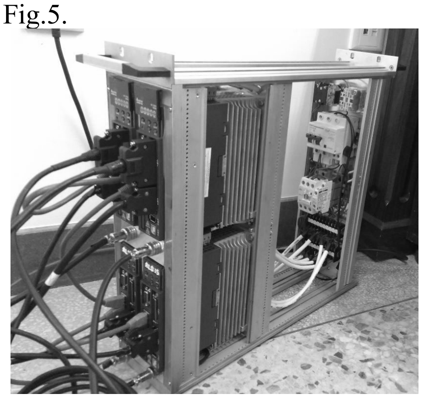

Fig.5 Drive Case

The initialization, the power-on and power-off of the motor, the off edge of each axis, acceleration and the deceleration time control of each axis, the motion speed control, the point-to-point motion control, the motion state real-time display of each axis and etc. can be achieved through using LabVIEW to call DLL dynamic link library function method [5].

A data acquisition card is used for data acquisition. The software tool MAX(Measurement &Automation Explorer) is used to configure and manage the data acquisition card.

Ten channels for data collection is available in this system. Data acquisition can be chosen to not store or store in a binary format in the computer disks for data processing [6].

The mechanical scanning and data acquisition can be completed by means of the system control interface in the computer control of the whole system. The system control interface is shown in Fig.6.

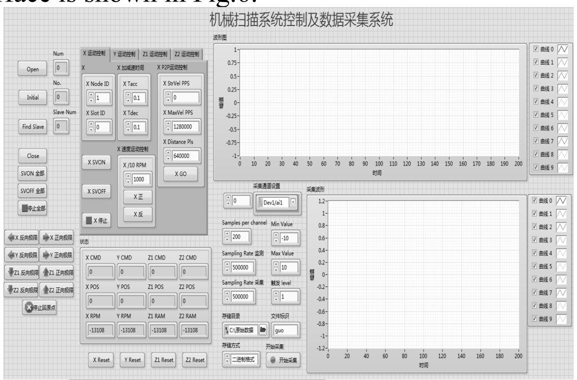

Fig.6 Control interface

IV. SIMULATION

A round surface radiation transducer is built as an example to verify the correctness of the theory and the discrete algorithm.

The center of the acoustic source surface is located in the origin of coordinates, and its radius is 0.05 m. select a plane located in z_H=0.04m as the holographic plane. The size of the holographic plane is L×L = 0.64×0.64 m^2. Discrete it into the grid cells whose size is 64 ×64 equal a square. Take the midpoint of each grid cell as the holographic acoustic pressure sampling point.

Get the holographic plane of each sampling point theory solution of the acoustic pressure amplitude, first. And then, calculate the acoustic pressure amplitude of each sampling point on the far field plane, which is shown in the Fig.7. Compare it with the theoretical value, at last, which is shown in the Fig.8.

The frequency of the acoustic source signal is 50 kHz, the velocity of water is c=1500m/s, the density of water is ρ =1000kg/m^3, $\Delta x \times \Delta y$=0.01×0.01m^2 in the simulation.

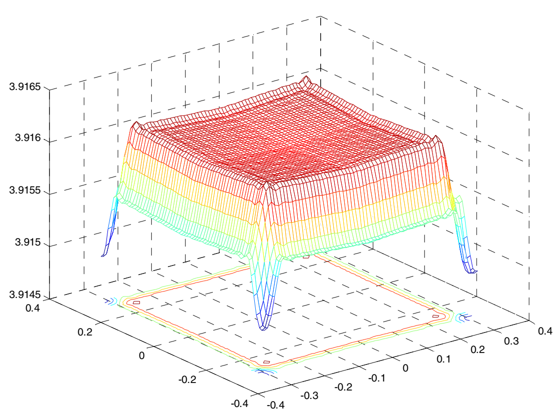

Fig.7 Acoustic Pressure Amplitude

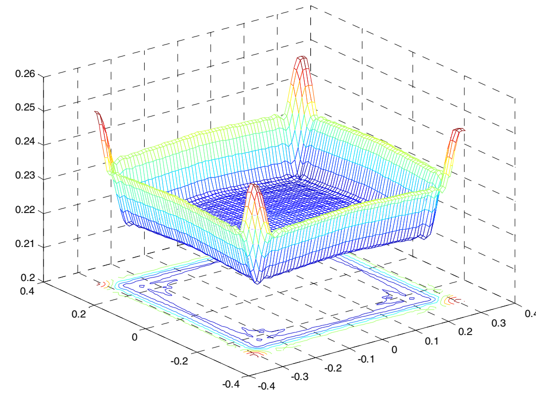

Fig.8 Percentage Error

The maximum error of acoustic pressure is 0.25%, the average error was 0.22% in the above example. It is seen the maximum error appeared on the edge.

There is a requirement that the attenuation of acoustic pressure is large enough around the holographic plane to apply the near field holographic technology [4,7,8]. The influence of the error on the edge is very small to the accuracy of rebuild the far field, if the error in the middle part is small.

The area has a big influence which is in the middle. The ultimate precision of the acoustic pressure of the far field plane can be guaranteed as long as the error of the middle area controlled in a certain range.

V. SUMMARY

The theory of near-field acoustical holography, the fiber grating hydrophone array, the mechanical scanning mechanism, the control system and the design of the interface are discussed in this paper. The simulation have been carried out to verify the correctness of the system. As a result, the design principle and implementation scheme is reliable.

However, it is still not reliable without the experiments. The pool experiment and the field experiment will be carried out when the whole system is completed. The pool experiment is easy to implement, but it can't reflect the real situation in the distance. The field experiment is strongly influenced by environmental factors. The solutions will be taken into account to overcome it, which is needed to consider next.

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