Calibration system design for multi-beam sonar

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Abstract—A set of calibration system for multi-beam sonar is designed by the principle and method of underwater acoustic metrology. Using the multi-dimensional operation control device, the calibration for acoustical index is completed in the anechoic pool, including the sound source level and beam width. The calibration for geometrical index is carried out in the large scale and deep-water prototype pool, including the bathymetric accuracy. Components and method of the calibration system are introduced, as well as the expanded uncertainty of the calibration system is presented. By comparing the calibrating value and the indicating or nominal value of the detected multi-beam sonar, test results show that the sound source level error is less than 0.7dB, the beam width indication error is less than 10% and the bathymetry value error is less than 0.2%.

1. Introduction
Multi-beam sonar has become the main sonar equipment for high precision bathymetry detection by its high efficiency and full coverage. The performance improvement, the frequency range extension and the type increase of sonar equipment put forward many new requirements for underwater acoustic measurement. In order to ensure the accuracy of ocean measurement data, it has practical research and application value to measure its detection performance regularly. Sound source level and beam width are the basic acoustic parameters of multi-beam sonar. They are closely related to the backscattering intensity and bathymetry accuracy. The above two parameters should be the acoustical indexes of multi-beam sonar calibration. Bathymetric accuracy affect the quality and efficiency of underwater topographic survey. The above parameters should be the geometrical indexes of the multi-beam sonar calibration. K.G. Foote et al. [1] developed the protocols for calibrating multi-beam sonar by means of the standard-target method. A calibration procedure to determine high resolution, three dimensional transmit and receive beam patterns of a Reson SeaBat 7125 MBES was performed using the fresh water calibration tank at the University of New Hampshire[2].

2. Methods
This part describes the calibration system design, including the experimental tank, rotary and lifting device, standard measurement Instrument. Calibration method for acoustical index and geometrical
index of multi-beam sonar is also validated in this part.

2.1. Calibration System Design

The multi-dimensional operation control device for acoustical index is mounted on the anechoic water tank, which can realize precise rotation, lifting, horizontal displacement and other functions. It is the main actuator of water acoustic measurement experiment. Multi-beam sonar transducer and standard hydrophone can be installed in the multi-dimensional operation control device (Figure 1), the angle and distance between them can be precisely controlled for the calibration of acoustic indicators. The maximum permissible error of angle control is ±0.05°, and the maximum permissible error of displacement control is ±0.1cm.

![Fig.1 Diagram of multi-dimensional operation control device and auxiliary equipments on anechoic tank. 1-Transducer;2-Rotary bracket; 3-Lifting bracket; 4-Standard hydrophone; 5- Pre-amplifier;6-Signal collector; 7-Display control computer; 8-Anechoic material.](image1)

The multi-dimensional operation control device for geometrical index is mounted on the prototype deep-water port pool. Multi-dimensional operation control device on the prototype deep-water pool (Figure 2) can install the multi-beam sonar transducer, and it can accurately control the distance between the transducer and the standard reflecting wall, which is used for the calibration of geometric index. The maximum permissible error of angle control is ±0.1°, and the maximum permissible error of displacement control is ±0.5 cm.

![Fig.2 Prototype deep-water pool and calibration equipment](image2)

2.2. Calibration Method

The experimental procedure for acoustic index is briefly described as follows:

(1) The tested transducer is installed at the bottom of the bracket of the multi-dimensional operation control device. Make its launching fan parallel to the water surface, and adjust the working parameters of sonar equipment to make sure it transmit pulse signal normally and stable.

(2) The standard hydrophone is connected to the signal collector. The signal collector records the open circuit voltage amplitude of the hydrophone in real time. The transmitting transducer is placed at the same depth underwater as the receiving hydrophone and meet the far field distance [3].

(3) Vertical direction test. Adjust the hydrophone to the lowest end, the transducer is measured roughly alignment the direction of the hydrophone and emit an acoustic signal with certain pulse width. The transducer remained stationary, and the hydrophone bracket is lifted at 1cm. Record the open
circuit voltage of the hydrophone at the same time. In the process of moving hydrophone, a voltage peak appears, which is the horizontal plane of acoustic axis of multi-beam sonar.

(4) Horizontal test. After finding the horizontal plane of the acoustic axis, fix the hydrophone. At this time, rotate the tested transducer in the horizontal plane through the precision rotary device, and control the servo motor to rotate the transducer at 0.1° angular spacing. After one revolution, an open circuit voltage of hydrophone can be collected at each angular position, and the emission directivity pattern is drawn. In the process of rotating the transducer, the position where the maximum voltage is found is the direction of the transducer's acoustic axis. At this point, the direction of the acoustic axis is found and pulse signals received.

(5) After the signal is filtered, the effective value of open circuit voltage for steady state part of pulse is calculated. According to the relation curve of sensitivity and frequency of standard hydrophone, the corresponding voltage sensitivity of each detection frequency range can be found. Combined with the voltage sensitivity M of the standard hydrophone, the free field sound pressure at each position can be calculated. The performance parameters such as sound source level and beam width are analyzed and calculated.

![Fig.3 Calibration Principle of Bathymetry](image)

The calibration process of bathymetry is as follows: the transducer of multi-beam sonar is installed on the connecting flange at the lifting rod of the multi-dimensional operation control mechanism, making the angle of multi-beam sonar transducer between 90°±0.1°. Adjust the turning mechanism to place multi-beam sonar transducer at 4 m underwater and 4 m offshore through the multi-dimensional operation control mechanism. Underwater transverse ranging is replaced by vertical bathymetry. A sound velocity profiler is used to measure the standard sound velocity at the water interface of the multi-beam sonar transducer. Input this sound velocity value into the multi-beam sonar display and control software. A straight line is arranged with the calibrated total station, and it is perpendicular to the surface of the short side wall of the pool. A point on the line is selected as the backsight point of total station measurement. Total station measures the horizontal distance between the control point and the standard reflector \( L_0 \), the horizontal distance between the control point and the multi-beam transducer array \( L_T \), and difference of two distances \( L_0 - L_T \), is regarded as the standard value of multi-beam sonar bathymetry. By rotating the transmitting angle of the transducer, all beams in the transmitting sector of the multi-beam sonar are irradiated to the reflection plate. Collect and analyze the data of multi-beam sonar, and make the difference between the standard value and the sounding indication value. Calculate the bathymetric indication error of all beam points. The principle schematic of bathymetry calibration is shown in Figure 3.
3. Results

Table 1 shows the test results of iBeam8120 multi-beam sonar made in China underwater acoustic experiment. The multi-beam operating frequency of this model is 200 kHz. The beam Angle is 1.5°×1.5°, and the maximum angle of the beam sector is 160°. Here's what needs to be said: the first 1.5° refers to the emission directivity of the multi-beam sonar along the track line, the second 1.5° refers to the receiving directivity along the vertical track line, and 160° refers to the emission directivity in the direction of the vertical track line.

| Equipment Model       | Sound Source Level | Beam Width (2θ₃dB) |
|-----------------------|-------------------|-------------------|
|                       | Nominal Value     | Test Value        |
| iBeam Multi-beam      | 220dB              | 219.350dB         |
| sonar                 |                   |                   |

Along track direction is 1.5°. Vertical track line direction (reception) is 1.5° (center beam). Vertical track line direction (emission) is 160°.

The abnormal water depth was eliminated according to Dixon’s Criterion. According to the requirements of IHO Standards for Hydrographic Surveys [4] and JJJG 139-2017 Multi-beam Echo Sounder – Shallow Water, the indication error of multi-beam sonar is evaluated. Seabat8125 multi-beam sonar is used as the equipment been tested. At the position 116.41m, central beam No.120 collects 50 ping bathymetric data. The minimum value is 116.22m, the maximum value is 116.41m, the range is 0.19m, the average is 116.32m, and the standard deviation is 0.05m. The calibration results of bathymetry are shown in Table 2, and the maximum relative error is better than 0.2%.

Table 3. Comprehensive analysis for the components of along-track beam width uncertainty

| Source                                      | Standard Uncertainty Component /Hz | Sensitivity Ratio |
|---------------------------------------------|------------------------------------|-------------------|
| Measuring repeatability                    | 0.003                              | /                 |
| The uncertainty component introduced by lifting devices | /                                  | 0.02              |
| The uncertainty component introduced by installation error | /                                  | -1.00             |

Combined standard uncertainty is,

\[ \mu_c = \sqrt{(0.01^2 + 0.06^2 + 0.01^2)} = 0.062^\circ \]  

(1)

Expanded uncertainty of beam width cross-track direction. Coverage factor \( k=2 \).
Uncertainty evaluation of bathymetric measurement.

Comprehensive analysis of uncertainty component is in Table 5.

| Standard uncertainty component | Source of uncertainty                          | \( \mu(x) \) | Sensitivity ratio |
|-------------------------------|-----------------------------------------------|---------------|-----------------|
| \( \mu(L_{th}) \)             | Repeatability and resolution of multi-beam sonar | 10mm          | 1               |
| \( \mu(L_0) \)                | Total station error                           | 25mm          | -1              |
| \( \mu(\Delta L) \)           | Sound velocity meter error                    | 5mm           | 1               |
| \( \mu(\Delta L_2) \)         | Instrument installation error                 | 12mm          | 1               |
| \( \mu(\Delta L_3) \)         | The uneven reflection wall deviates from aiming point | 17mm          | 1               |

Because each standard uncertainty component is not related, so combined standard uncertainty is:

\[
U = \sqrt{\mu^2(I_{th}) + \mu^2(L_0) + \mu^2(\Delta L) + \mu^2(\Delta L_2) + \mu^2(\Delta L_3)} = 34\text{mm}
\]  

Coverage factor \( k = 2 \), the extension uncertainty is,

\[
U = 2 \times \mu_L = 68\text{mm}
\]  

The total station measurement result is 65.141m, the arithmetic mean of 10 water depth data measured by multi-beam sonar is 65.123m. The calibration value of multi-beam sonar is,

\[
L = L_0 + \Delta L = 65.123m + 0.018m = 65.141m, \quad U = 68\text{mm}, \quad k = 2 .
\]  

Conclusions

Calibration system design of multi-beam sonar refers to JGJ 139-2017 Multi-beam Echo Sounder—Shallow Water. It can realize the calibration of multi-beam sonar source level, beam width and bathymetry, the measurement uncertainty of each calibration parameter meets the requirements of regulation. By comparing the calibrating value and the indicating or nominal value of the detected multi-beam sonar, test results show that the sound source level error is less than 0.7dB, the beam width indication error is less than 10% and the bathymetry value error is less than 0.2%.

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