Method to Determinate Surveying Ship Dynamic Draft and Error

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Abstract. In order to improve the accuracy of the MBES (multi-beam echosounding system), and determine the dynamic draft and error magnitude of the surveying ship, the multi-beam sonar detection method and GPS dynamic positioning are used for the water depth and GPS elevation data at different ship speeds in the same area. The method measures the dynamic draft correction magnitude, and the calculation with the error, which verifies the feasibility of the method, provides reliable dynamic draft and error magnitude for multi-beam data post-processing, and improves data accuracy.

1. Introduction

MBES (multi-beam echosounding system) is the main technical method of seafloor measurement, and the analysis and evaluation of its measurement error is an important part of quality control. The dynamic draft also seriously affects the measurement accuracy of the MBES. Both "Specifications for Hydrographic Surveying" [1] and " Hydrographic Surveys Specifications And Deliverables " [2] of NOAA in the United States make specific requirements for the accuracy of dynamic drafts. In actual operations, the calculation of the dynamic draft correction is often ignored, which is an important correction item. In the follow-up accuracy evaluation, it appears in the form of systematic error and the source of the error cannot be determined.

At present, the advanced fixed installation measuring ship can monitor the dynamic draft of the measuring ship in real time through the pressure sensor. Chunchun Z[3] obtained the draft correction through fitting and directly used it for data post-processing to control the measurement accuracy in the vertical direction. The portable measuring vessel with multi-beam transducers can adopt rod measurement method, level method method, GPS dynamic measurement positioning method and sonar sounding method. Bingzhao W[4] analyzed the applicable scope and typical values of the three measured statistical methods, and Jingwen W[5] designed and verified the measurement plan of the GPS dynamic measurement positioning method. Xinli Li[6] used the sonar detection method to simulate the dynamic draft correction for the multi-beam sounding system. Matte P[7] combined the GPS positioning PPK (dynamic post-processing) data with ADCP’s tilt data, and applied the least square method for dynamic draft correction. However, for multi-beam measurement, how to accurately determine the magnitude of dynamic draft correction and its error magnitude is lack of actual verification and analysis.

This paper intends to determine the dynamic draft correction magnitude by the multi-beam sonar detection method and GPS dynamic positioning method at the same time, and carry out error analysis to provide a reference for the refined processing of multi-beam sounding operations.
2. Dynamic draft measurement method

According to the state of the measuring ship, the draft $H_D$ can be divided into static draft $D_t$ and dynamic draft correction $\Delta D$. The static draft can be obtained by the daily average method before and after the voyage, the daily measurement method, and the displacement method[8].

The static draft can be obtained by formula (1), through the bow draft $D_f$, the stern draft $D_e$, the distance from the transducer to the bow mark $a$, the distance $b$ from the stern mark to the transducer, and the distance $d$ from the transducer surface to the bottom of the keel. The surface is positive underneath, and the ship's tilt angle $\theta$ is calculated by the ratio of the left and right draft to the ship's width.

$$D_t = \left( \frac{aD_e + bD_f}{a + b} + d \right) \cos \theta$$

(1)

2.1. Multi-beam sonar detection method

The multi-beam sonar detection method is also called the same-track comparison method. The specific principle is shown in Figure 2. By comparing the measured instantaneous sea surface difference at the same position, the influence of the tide level change is stripped, and the dynamic draft correction magnitude caused by the ship speed change is calculated. The measurement area should be a relatively flat seabed with no drastic changes in water depth, and the water depth is about 7 times the static draft of the measuring ship. The dynamic draft correction is also known as the navigation subsidence, which is affected by the combined effects of many factors such as ship load, ship type, speed, heading, sea conditions, and water depth.

First obtain the sound velocity profile in this area for the post-measurement sound velocity correction; measure the speed of the ship sailing downwind or downstream in an unpowered state, and obtain the data under this track including GPS positioning data and ship attitude data (roll $R$, pitch $P$, heading $A$, heave $H$), multi-beam bathymetry data and tide level data, through the draft value at speed in the
unpowered state, eliminating the influence of wind current on the ship's attitude in actual operations. Measure along the same track and heading at different speeds and record the same type of data; After sound speed correction and tide level correction, the next water depth coordinate point at unpowered speed and the next water depth coordinate point at different speeds can be obtained. If there is a water depth point position matching, the coordinates of the same position point coincide, a point position can be obtained the instantaneous sea surface difference between different ship speeds.

\[ \Delta z_m = z_{0m} - z_{nm} \]  \hspace{1cm} (2)

The tidal level difference between stripping and unpowered measurement is \( \Delta H_{\text{tide}} \), and the dynamic draft correction \( \Delta D_v \) at different speeds \( v_x \) is obtained.

\[ \Delta D_v = \Delta z_m - \Delta H_{\text{tide}} \]  \hspace{1cm} (3)

### 2.2. GPS dynamic positioning measurement method

The principle of GPS dynamic positioning measurement method is shown in Figure 3.

![Figure 3](https://example.com/figure3.png)

Figure 3 Schematic diagram of the principle of GPS dynamic positioning measurement.

When Sailing downwind or downstream under unpowered conditions, at a speed of \( v_0 \), at time \( t_0 \), the tide level is \( \text{tide}_0 \), the on-board GPS receiver measures the ground height \( \text{GPSH}_0 \), and the attitude meter obtains the attitude data at that time, and \( H_{i0} \) indicates the induced ascent under the influence of roll and pitch. The sink value is calculated by formula (4):

\[ H_i = -x \sin P - y \sin R \cos P + z(1 - \cos P \cos R) \]  \hspace{1cm} (4)

\((x, y, z)\) indicates the position of the shipboard GPS receiver in the hull coordinate system. Then the average sea surface \( L_0 \) measured at time \( t_0 \) is:
In the same way, the average sea surface measured $L_n$ at speed $v_n$ and time $t_n$ is:

$$L_n = GPSH_n - H_{in} - Heave_n - tide_n$$  

Then, at time $t_n$, the dynamic draft $\Delta D_n$ is:

$$\Delta D_n = L_n - L_0$$

### 3. Dynamic draft data processing method

In order to more accurately determine the dynamic draft correction magnitude of the surveying ship, it is necessary to select the appropriate environment and speed as much as possible, that is, the terrain is relatively flat (the water depth does not change much); the directional speed is fixed, and the acceleration period is reduced to reduce the data noise. However, in actual measurement, the above situation can only be avoided as much as possible and cannot be completely eliminated. Therefore, when extracting the measurement data, the overall mean extraction method is used as the extraction method. Its purpose is to eliminate the influence of accidental errors caused by the measuring instrument itself.

#### 3.1. Population mean extraction

Under the conditions of correct measurement operation and normal operation of the equipment, after removing gross errors, it can be considered that the measurement data does not contain systematic errors. The errors are caused by accidental errors in the measurement of the measuring equipment. According to statistical principles, they conform to the normal distribution. When a random event is large enough, its true value can be represented by its measured mean (its expectation). The formula is:

$$\Delta D_{\text{mean}} = \bar{\Delta D} = \frac{\sum \Delta D_i}{n}$$

$\Delta D_{\text{mean}}$ represents the average value of the dynamic draft correction, and $n$ is the number of points extracted.

#### 3.2. Hommer fitting method

The dynamic draft correction magnitude can also be calculated by Hommer formula [43]. Its expression is:

$$\Delta D = KV^2 \sqrt{Dz_m}$$

It can be seen from the formula that the dynamic draft correction magnitude is proportional to the square root of the ratio of the measured ship’s speed, the static draft, and the depth of the survey area. The K value can be obtained from the reference table of common surveying ships, or the measured dynamic draft correction magnitude can be based on the Hommer formula, and the K value of the surveying ship can be fitted by the least square method to obtain the dynamic draft correction of the surveying ship Scale or dynamic draft correction curve graph for data post-processing calculation.

#### 3.3. Dynamic draft correction error calculation

The error sources of the dynamic draft correction $\Delta D$ are two parts: one is the deviation of different measurement and extraction methods of $\Delta D$, and the other is the dynamic draft correction error caused by the speed measurement error. According to formulas (2)-(8), it can be approximated that the errors of the two parts are relatively independent. According to the law of error propagation, the draft correction error $\sigma_{\Delta D}$ is:

$$\sigma_{\Delta D}^2 = \sigma_{\Delta Dm}^2 + \sigma_m^2$$
\( \sigma_{\Delta m} \) represents the dynamic draft correction error caused by the speed measurement error of the measuring ship, and \( \sigma_m \) represents the internal coincidence error during the fitting of the dynamic draft correction, which is represented by the mean of the difference between the two methods. Among them, the velocity measurement error is based on the working principle of the multi-beam sounding system, and its error comes from the plane position measurement error and the time measurement error. Because the time synchronization of the 1PPS signal is at the nanosecond level at present, the time measurement error part is ignored and the main source of error is the measurement error in the plane position depends on the accuracy of the equipment used and the processing method, and its magnitude is different.

4. Experiment

4.1. data preparation

The data is selected from the data measured in Dalian in July 2020. The MBES adopts Geobean200[9], the positioning and attitude system adopts POS MV WaveMaster II[10], adopts PPK (post-differential processing) operation mode, and uses AML Minos• X[11] for sound velocity measurement Sound velocity profiler.

After the preliminary installation and measurement, the static draft is 1.335m. Select the cross survey line No. 1, 2, 3, and 4 of this survey. After the standard water depth processing correction process, the track line and water depth are obtained as shown in Figure 4. The water depth range is 9.9~11.1m.

Figure 4 Sketch map of track and water depth.
In Figure 5, the survey line No. 1 is when the measuring ship is in an unpowered state, the survey line No. 2 is for the survey ship to maintain a speed of 5 knots, the survey line 3 is for the survey ship to maintain a speed of 8 knots, and the survey line No. 4 is for the survey ship to keep 10 knots.

4.2. Dynamic draft correction calculation

4.2.1. Multi-beam sonar detection method

According to formulas (2) and (3), match the water depth points of the survey line 2, 3 and 4 with the survey line in the unpowered state (No. 1) at the same position, and strip off the survey line in the unpowered state (No. 1), the water depth difference of the point at the same location is shown in Figure 6.

Calculations have verified that the distribution of difference points conforms to the statistical characteristics of the normal distribution of random errors, and the overall mean correction magnitude is calculated to obtain the total mean dynamic draft correction magnitude as shown in Table 1.

| Source | NO.1&2 | NO.1&3 | NO.1&4 |
|--------|--------|--------|--------|
| Points | 966661 | 921930 | 914216 |
| Parameter | Δv (m/s) | ΔD (m) | Δv (m/s) | ΔD (m) | Δv (m/s) | ΔD (m) |
| Total mean | 2.27 | 0.018 | 3.49 | 0.038 | 4.02 | 0.049 |
4.2.2. GPS dynamic positioning measurement method

According to the formulas (4)-(7), the dynamic draft corrections are calculated for the survey lines 2, 3, and 4 and the unpowered survey line (No. 1) respectively, and the distribution of scattered points is shown in Figure 7.

The calculation has verified that the distribution of each scattered point conforms to the statistical characteristics of the normal distribution of random errors, and the calculation results of the total mean correction magnitude are shown in Table 2.

### Table 2  Correction value based on GPS dynamic positioning measurement method.

| Source   | NO.1&2 | NO.1&3 | NO.1&4 |
|----------|--------|--------|--------|
| Points   | 6363   | 4445   | 4173   |
| Parameter | \( \Delta v \) (m/s) | \( \Delta D \) (m) | \( \Delta v \) (m/s) | \( \Delta D \) (m) | \( \Delta v \) (m/s) | \( \Delta D \) (m) |
| Total mean | 2.319  | 0.019  | 3.510  | 0.036  | 3.978  | 0.044  |

4.2.3. Error analysis of dynamic draft correction

The dynamic draft corrections obtained by the sonar measurement method and the GPS dynamic positioning method are respectively performed according to the Hommer formula (11), and the total least squares fitting is performed, and the result is shown in Figure 8.

![Figure 8](image8.png)  
**Figure 8** Fitting diagram of correction for total dynamic draft.

![Figure 9](image9.png)  
**Figure 9** Dynamic draft correction and error.
It can be seen from Figure 8 that the dynamic draft corrections measured by the sonar detection method and the GPS dynamic positioning method are similar in value, and the two measurement methods are reflected in the distribution of the increase in the dynamic draft correction as the speed increases. Affected by the distribution of the mean data, when the speed reaches 2.65 m/s, the dynamic draft correction magnitude of the two methods is equal to 0.023m. It can be considered that the accuracy at this speed is higher, and the solution error can be verified later. When the speed reaches 5 m/s, the difference between the fitting estimation of the two measurement methods and the fitting is 0.005m and 0.004m, which are far smaller than the error of multi-beam sounding and GPS height measuring instrument itself, so the results are believed to be true and credible. This experiment uses the POS MV WaveMaster II positioning system, PPK (differential post-processing) correction method, the accuracy can reach 0.1m, and the real-time plane positioning error in sbet correction can also be used.

In summary, substituting the velocity measurement error $\sigma_{Av}$ into the fitting function, it can be expressed as the fitting mean value of the dynamic draft correction magnitude of the velocity measurement error at the speed. The correction magnitude and error of the dynamic draft of this experiment are shown in the figure9.

As shown in Figure 9, when the speed reaches 5 m/s, the error of the overall mean method accounts for 7.3% of the total correction magnitude. When the speed reaches 2.65 m/s, the relative minimum error is 0.0002m, which verifies that the accuracy of the fitting intersection point is better.

In summary, the above experiments prove that both the sonar detection method and the GPS dynamic positioning method can be used to determine the dynamic draft correction magnitude. The data is extracted by the total mean method, and the Hommer formula is used to perform the least square fitting. This method is reliability and effectiveness.

5. Conclusion

In this paper, the measurement and error analysis of the dynamic draft corrections in the key steps of the MBES data processing are carried out. The sonar detection method and GPS dynamic positioning method are used to measure the dynamic draft corrections. The data is extracted by the total mean method. The least square fitting is performed based on the Hommer formula; the source of the error of the correction magnitude of the dynamic draft is analyzed, and the accuracy within the correction magnitude is given. The experimental results prove that the sonar detection method and the GPS dynamic positioning method can be effectively measured the error analysis method is reliable and effective for measuring the ship's dynamic draft correction. Therefore, it is recommended to use the total mean method as the extraction method in future surveys, and use the sonar detection method and GPS dynamic positioning method to determine the correction magnitude and error of the ship's dynamic draft. The measurement and error analysis of the dynamic draft corrections are the key technical support for MBES accuracy assessment, and provide a theoretical basis for determining the error source of MBES.

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