Using high accuracy geodetic measurements to fix the main bases of the ship in shipbuilding and ship-repairing

P O Palkin¹, A A Kuzin¹

¹ Saint-Petersburg Mining University, 21 Line, 2, Saint Petersburg, 199106, Russian Federation
E-mail: kuzin_aa@pers.spmi.ru

Abstract. The article presents the coordinate method of determination and fixes the courses of main bases of the ship. All the methods that are used according to regulatory documents were analyzed, and their advantages and drawbacks were described. The real measurements were made using a total station and a laser tracker. The accuracy of this method was determined. Based on this analysis, it was concluded that surveying methods, among others, could be used to fix the course of main bases of the ship.

1. Introduction
One of the important conditions of safety and effective use of the ship is observation of its geometry while building or reconstructing and position of the gear which is established on the ship.

To provide the right position of the gear it is necessary to measure all the main bases of the ship, to fix them [1].

Traditionally to solve these problems, to measure the mutual position of the gear, to observe and fix the vector of centerline gyro-theodolite and the ruler are used. But this method is possible only in case of quiescence of the ship in the dry dock. If it is necessary to work in the depositing dock or on the float it is impossible to use traditional methods.

It is impossible to measure anything without the line of sight while using these methods; that is why it takes much time to prepare ship for measurement. It is necessary to make temporary openings to provide visibility.

But at the modern stage of developing the geodetic methods the coordinate method is the most precise and universal one that helps to solve the problems of the mutual position of objects, definition of the object’s form, etc. [2,3].

2. Method
Usually gyro-theodolite (or gyro-attachment) is used to determine and fix the centerline. Gyro-theodolite (fig. 1) is an optical electronic instrument to measure the direction angle and to determine astronomic bearing. The principle of the work of the gyro-attachment is based on features of the gyroscope and the daily rotation of the Earth.
Figure 1: Gyro-attachment GMT with total station Leica

Gyro-theodolites are high precision instruments. Their accuracy is from 10 to 60 seconds. Nowadays GPS systems take a leader position in surveying instruments. But there are some objects where it is impossible to use it. So we cannot stop using gyro-theodolites or gyro-attachments [4].

The course of centerline is fixed on the shipbuilding ways. It is fixed by 2 reference points. To move this course on a ship it is necessary to measure astronomic bearing. To make these measurements the gyro-theodolite is based between 2 points in line. Then some series of measurements are started and results of the bearing are obtained. After measurements it is necessary to count the average value of the astronomic bearing. This value is astronomic bearing of course of centerline.

After these measurements it is possible to fix the course (2 reference points) on the ship or in the installation of the ship. All the courses on the ship (centerline, parallel to centerline, perpendicular to centerline) are fixed with center marks (fig. 2) [5,6].

Figure 2: The center mark on the ship
All these methods with measurements with gyro-theodolite are possible only in the dry dock.

Advantages of traditional method is high accuracy of measurement. Drawbacks are the following: high cost of gyroscopes, danger of mechanical impact, and measurements are possible only in a dry dock.

If ship is reconstructed or it is necessary to make measurements of a float or in the depositing dock the coordinate method should be used. Coordinates of points, mutual position of objects and elements, determination of difficult forms can be measured with coordinate determine systems [7]. These systems are high precise total stations or absolute laser trackers (fig. 3).

![Figure 3: Absolute laser tracker](image)

These instruments are powered by SpatialAnalyzer. It is a metrology and geodetic software solution for large-scale applications. This software makes possibility to: inspect parts, build, analyze data, report, reverse design, automate complex operation to improve measurement and inspection efficiencies.

Advantages of using coordinate determine method are the following: less of preparation works, high accuracy of measurements, independent of position of the object, possibility of noncontact measurements, possibility of measurement on the objects that are afloat, moving or static (for example, in a dry dock). Drawback of using absolute laser tracker is a high price of instruments and software.

3. Results

Coordinates are solved be polar method or resection. Accuracy of measurement and fixing the course depends on accuracy of measurement of horizontal, vertical angles and distance. The Polar method is usually used to determine points’ coordinates. Coordinates of points are computed by the formulas:

\[ X = S \cos \nu \cos \beta \]
\[ Y = S \cos \nu \sin \beta \]
\[ H = S \sin \nu \]

where \( S \) stands for the distance, \( \beta \) stands for the horizontal angle, \( \nu \) stands for the vertical angle.

| Table 1. Specifications of Leica AT403 Laser Tracker [8] |
|-----------------|-----------------|
| Characteristics  | Value            |
| Measuring range (diameter) | 320 m          |
| Measurement angle               | Horizontal ±360° and vertical ±145° |
| Measuring accuracy (angle)      | 0.5"           |
| Measuring accuracy (distance)   | 0.015 mm + 0.006 mm/m |
All the measurements were made by Leica AT403. It is a compact and wireless mobile tracker system with the following specifications:

The accuracy of measurements of the spatial network or of the fixing of main ship’s bases is calculated according to the following formulas [9]:

\[
m_X = \sqrt{\left(\cos v \cos \beta\right)^2 m_S^2 + \left(\cos v \sin \beta - \sin v \cos \beta\right)^2 \left(\frac{m_v}{\rho}\right)^2 + \left(\cos v \sin \beta + \sin v \cos \beta\right)^2 \left(\frac{m_\beta}{\rho}\right)^2},
\]

\[
m_Y = \sqrt{\left(\cos v \sin \beta\right)^2 m_S^2 + \left(\sin v \sin \beta + \cos v \cos \beta\right)^2 \left(\frac{m_v}{\rho}\right)^2 + \left(\sin v \sin \beta - \cos v \cos \beta\right)^2 \left(\frac{m_\beta}{\rho}\right)^2},
\]

\[
m_H = \sqrt{\sin^2 (v) m_v^2 + \left(\cos v \cos \beta\right)^2 \left(\frac{m_v}{\rho}\right)^2 + \left(\cos v \sin \beta\right)^2 \left(\frac{m_\beta}{\rho}\right)^2},
\]

\[
m_{XYH} = \sqrt{m_X^2 + m_Y^2 + m_H^2},
\]

where \( m_S \) stands for the error of measurement of distance, \( m_\beta \) stands for the error of measurement of horizontal angle, \( m_v \) stands for the error of measurement of vertical angle, \( S \) stands for the distance, \( \beta \) stands for the horizontal angle, \( v \) stands for the vertical angle.

\( m_S \) stands for the error of measurement of the distance. It depends on the distance and can be computed by the following formula [10]:

\[
m_S = 0.015 \ mm + 0.006 \ mm \cdot L,
\]

where \( L \) stands for the distance in meters.

Cause space in the places of the ship is limited, so the max value of the distance will be 10 meters, and \( m_S = 0.08 \) mm.

The conditions of real measurement with laser tracker were simulated according to the data that are in tables 1, 2 and 3.

According to the data in tables 2-4 the accuracy of determination of the point’s coordinates is not to exceed 0.09 mm.

But it is not only passport characteristics that makes influence on accuracy of measurements. Also influence temperature, pressure, humidity affects on accuracy.

That is why it is necessary to create methodology that reduce all the influences. The methodology is the following:

- install the instrument;
- turn off its compensator;
- measure all the points of spatial network;
- locate the instrument in the right position;
- fix points of centerline with spatial attachments and reflector (fig. 4);
- determine the coordinates of the main bases of the ship in the framework;
- repeat these actions in all essential positions and stations.
Table 2. Accuracy calculation of determination of point’s coordinates with different horizontal angles and distance of 10 m, vertical angle of 0 degrees

| Distance, m | Vertical Angle, ° | Horizontal Angle, ° | Error of measurement of vertical angle, mm | Error of measurement of distance, mm |
|------------|-------------------|--------------------|------------------------------------------|-----------------------------------|
| 10         | 0                 | 0                  | 0.5                                      | 0.08                             |
| 10         | 0                 | 45                 | 0.5                                      | 0.08                             |
| 10         | 0                 | 90                 | 0.5                                      | 0.08                             |

Table 3. Accuracy calculation of determination of point’s coordinates with different horizontal angles and distance of 10 m, vertical angle of 30 degrees

| Distance, m | Vertical Angle, ° | Horizontal Angle, ° | Error of measurement of vertical angle, mm | Error of measurement of distance, mm |
|------------|-------------------|--------------------|------------------------------------------|-----------------------------------|
| 10         | 30                | 0                  | 0.5                                      | 0.08                             |
| 10         | 30                | 45                 | 0.5                                      | 0.08                             |
| 10         | 30                | 90                 | 0.5                                      | 0.08                             |

Table 4. Accuracy calculation of determination of point’s coordinates with different horizontal angles and distance of 10 m, vertical angle of 60 degrees

| Distance, m | Vertical Angle, ° | Horizontal Angle, ° | Error of measurement of vertical angle, mm | Error of measurement of distance, mm |
|------------|-------------------|--------------------|------------------------------------------|-----------------------------------|
| 10         | 60                | 0                  | 0.5                                      | 0.08                             |
| 10         | 60                | 45                 | 0.5                                      | 0.08                             |
| 10         | 60                | 90                 | 0.5                                      | 0.08                             |
To make measurements by the polar method in different parts of the ship it is necessary to make a frame. Then to determine the position of instrument in different parts the spatial geodetic network should be create in every place, where it would be necessary to measure and determine coordinate points and fix the course of centerline. The spatial geodetic network of the ship is shown in Figure 5.

The spatial geodetic network that was created on the ship N consists of more than 200 points. In conditions of fixing course of centreline with accuracy less than 1 mm the accuracy of creating spatial network should be less than 0.5 mm. This result was achieved. RMS of the network that was computed with the help of SpatialAnalyzer is 0.37 mm.

The results of the work are in Figure 6. There are 3 main bases of the ship that were constructed with the help of SpatialAnalyzer and the frame that based on them. Then there are points of spatial geodetic network and fixed points of centerline.
4. Conclusion
Modern problems show us that geodetic works should be performed not only on the static object, but also on objects, which are in motion. That’s why traditional methods cannot be used.

In this article new method that was certified is described. Accuracy that is necessary for these types of works was achieved.

The coordinate determine method allows one to skip all the advance preparation and solve a problem both afloat and in a dry dock during a short period of time and at a low cost.

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