中国光学
Chinese Optics

文章编号　1674-2915(2011)06-0583-05

Correction method of heading calibration for calibration theodolite

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Abstract: To precisely and effectively complete the heading calibration of a theodolite, this paper analyzes the effect of single error on the heading calibration, and builds a correct model of the heading calibration when the collimating and orientation errors are involved at the same time according to the heading calibration principle. It provides the specific correction and verification methods. Experimental and measurement results indicate that the orientation error measured by positive and inverse pointing methods is equivalent to the error between orientation error and collimating error. The research in this paper proves the feasibility and effectiveness of the correction method and disciplines the method of heading calibration at the dock, which will make sure TT&C complete mission successfully.

Key words: calibration theodolite; heading calibration; single error; correction method

标校经纬仪航向标定修正方法

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摘要:为了准确有效地完成经纬仪航向标定,本文根据标校经纬仪坞内航向标校原理,分析了各单项误差对航向标定的影响,建立了照准差和定向误差同时影响下的航向标定修正模型,给出了具体的修正方法。实验及检测结果表明,用正倒镜法测得的定向误差数值等于定向误差与照准差的差值。文章验证了修正方法的正确性和有效性,规范了坞内航向标定方法,为测量船完成测量任务奠定了基础。

关　键　词:标校经纬仪;航向标定;单项误差;修正方法

中图分类号:TP391.4; V556　　**文献标识码**:A

收稿日期:2011-09-08;**修订日期**:2011-11-18

1 Introduction

Calibration theodolite is an important device for the heading calibration of spacecraft TT&C (Telemetry, Track & Command). It is used for precision calibration when the spacecraft is at a dock or a deport[1-2]. During the manufacture of spacecraft, the reflection mirror is put into the inertial navigation hanging cular, which stands for the straight north of inertial navigation. The azimuth datum mirror is put onto the theodolite platform, then we make the two mirrors' normal direction in parallel to stand for spacecraft TT&C's heading direction. When the theodolite is imported onto the ship, we need to make the calibration theodolite's azimuth encoder zero angle line and the azimuth datum mirrors' normal direction alignment before we do other measurement work. However, in practice, there are single errors. We can only get the precision heading data until all the single errors have been corrected. With the precision heading data, we can build the ship's azimuth datum to ensure fulfillment of the measurement mission.

2 Heading calibration system for spacecraft TT&C theodolite

The spacecraft TT&C theodolite's heading calibration system can be described as Fig. 1[3-4].

The whole system consists of a calibration theodolite, a theodolite platform, a hanging cular and a inertial navigation system. The hang cular reflection mirror is put into the hang cular of inertial navigation, and the mirror's normal direction stands for the direction of inertial navigation. The azimuth datum mirror is equiped on the theodolite platform, which makes its normal direction parallel with the reflection mirror's normal direction. During the calibration process, the azimuth datum mirror's normal direction is considered as the ship's azimuth direction. When the theodolite is imported onto the ship, we use one 0.2″ collimator tube and two reflex light-tubes to align the hang cular reflection mirror, azimuth datum mirror as well as calibration theodolite's azimuth zero angle line[3-5].

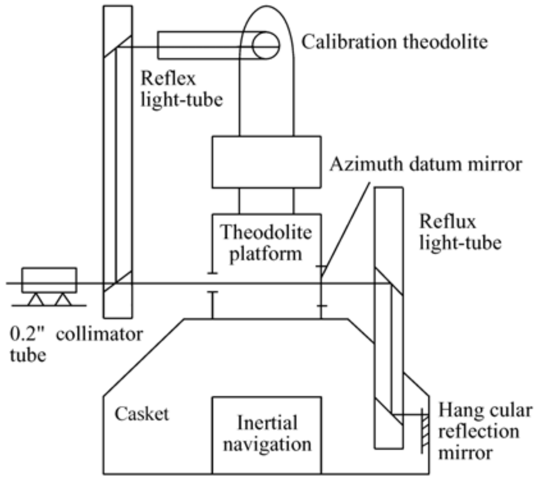

Fig. 1 Heading calibration system and optical path of calibration theodolite

3 Influence of theodolite single error on azimuth measurement

The calibration theodolite uses the horizontal structure which has three main axes: horizontal, vertical and collimating. Since the limitation of manufacture and adjustment using factors, the three axes are not vertical with each other. So there is an angular measurement error, and we called it axis error, including horizontal error, vertical error as well as collimating error[6-7]. They all have influence on the azimuth measurement. In this paper, we just only focus on the influence of collimating error, and neglect others.

3.1 Collimating error

The theodolite's collimating axis is not vertical to the horizontal axis and it will form an angular measurement error which is called sighting error and standed by C. The theodolite uses a positive and inverse mirror to point on the horizontal object to measure sighting error C. By setting the positive azimuth angle reading as $A_{positive}$, and the inverse azimuth angle reading as $A_{inverse}$, then we get the sight error as Eq. (1):

$$C = \frac{A_{positive} - A_{inverse} \pm 180°}{2}. \quad (1)$$

It can be proved that the influence of a sight error on the azimuth measurement is[6-7]:

$$\Delta A_C = C(\sec E_n - 1), \quad (2)$$

where E_n is the elevation angle of measurement object.

3.2 Orientation error of azimuth encoder

When the theodolite's optical axis points on the orientation direction (usually, we use the north as the orientation direction), the angle between azimuth encoder zero angle line and orientation line is azimuth encoder reading, and we call it orientation error, and use the g to stand for it[6-7]. In practice, we use ground azimuth flag to orient, and set the ground azimuth flag relative to equipment's azimuth angle as A_0. We make the theodolite point on this flag, and the azimuth encoder's reading is A_i, that is:

$$g = A_i - A_0. \quad (3)$$

The orientation error reveals that the azimuth encoder's zero angle line and the set zero angle line is inconsistent. That is to say the start line of azimuth angle is not precision. And the orientation error g is an constant which can only be measured and corrected but not be eliminated[7].

The orientation error g is measured by the positive and inverse mirror method[7]. Provided that there is a horizontal object in the straight north, with the positive pointing reading as $A_{positive}$, and inverse pointing reading as $A_{inverse}$, and then the orientation error is:

$$g = \frac{A_{positive} + A_{inverse} \pm 180°}{2}. \quad (4)$$

4 Heading calibration mathematic model and heading correction method

In the third part, we talk about the sight error, azimuth encoder orientation error and their measurement methods as well as their influences on azimuth measurement. The above analysis based on the hypothesis shows that there is one item error without other errors.

However, in practice, the equipment's three axes are closely related with each other, as for a specific equipment, these item errors are in existance simultaneously.

In this part, we focus on the heading correction mathematic model and correction method with sight error C and orientation error considered.

The spacecraft TT&C's heading calibration system is shown in Fig. 1. During the manufacture, the azimuth datum mirror's normal direction has been already considered as the orientation direction N. When the calibration theodolite is imported onto the ship, we use one 0.2″ collimator tube and two reflex light-tubes to make the azimuth datum mirror's normal direction and the theodolite's optical axis aligned. By clearing the azimuth encoder reading to zero, at this time g is equal to zero.

However, in practice, the equipment's orientation error will be changed with time. With the spacecraft TT&C at a dock, we use the above calibration tools to make optical axis point on the azimuth datum mirror's normal direction, then get the orientation error according to the formula (3), and set it as g. With the positive and inverse mirror method, we get the sight error, and denote it to be C. And their relationship is shown in Fig. 2.

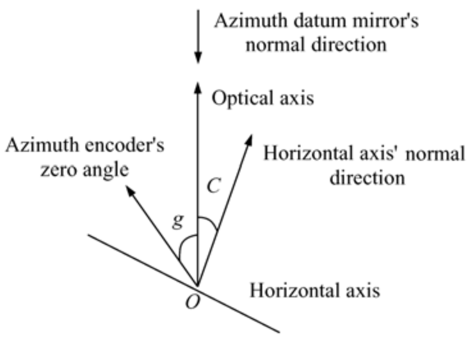

Fig. 2　Calibration relationship at dock

In actual measurement, the theodolite has sight and orientation errors. The two item errors are all needed to be corrected[8-9].

Setting the azimuth measurement reading as A_{ce}, and the corrected data as $A_{correct}$, we consider the sight error C and orientation error g (since the influence of transfer error from a reflex light tube is known and has been discussed precisely. So we neglect it.), then the correction model is:

$$A_{correct} = A_{ce} - g - C(\sec E - 1) . \quad (5)$$

With formula (5), we correct the sight error and analyze influences of orientation error on azimuth measurement and complete the heading calibration work[8-9].

On the spacecraft TT&C, we usually use positive mirror pointing method to measure the orientation error, and the analysis is as follows:

Provided the theodolite has a sight error C, with positive mirror pointing method, we get the orientation error g, and their relationship is shown in Fig. 3.

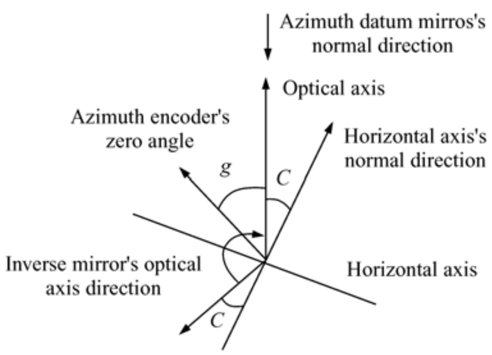

Fig. 3 Measurement of orientation error with positive and inverse methods

When the optical axis points on the azimuth datum mirror's normal direction, the azimuth encoder's reading is:

$$A_{inverse} = g . \quad (6)$$

Then inverse the system, the theodolite needs to be turned $180° - 2C$, then points on azimuth datum mirror's normal direction, that is:

$$A_{inverse} = 180° - 2C + g . \quad (7)$$

According to the formula (4), we can get the orientation error g', then

$$g' = \frac{A_{positive} + A_{inerse} \pm 180°}{2} =$$

$$\frac{g + 180° - 2C + g - 180°}{2} = g - C. \quad (8)$$

From the formula (8), we arrive that considering sight error and orientation error, the result of orientation error measurement by using the positive pointing method is equal to $g - C$.

If we use positive pointing method to measure orientation error, the heading calibration correction model is:

$$A_{correct} = A_{ce} - g' - C\sec E =$$
$$A_{ce} - (g - C) - C\sec E =$$
$$A_{ce} - g - C(\sec E - 1) . \quad (9)$$

Compared with the formula (5) and formula (9), they are the same. That is to say the two correction models are equal with each other.

5 Experiments and measurement results

With the 2010's heading calibration measurement at the dock, and the azimuth datum mirror as the azimuth datum, we got the measured and computed data which are shown in Tab. 1.

Tab. 1 Measurement and computing results

		Measurement data	Computing results
Positive pointing	A	359°59′49″	Sight error: $C = 3″$
	E	359°59′57.3″	Orientation error: $g = -11″$
Inverse pointing	A	179°59′43″	Zero angle error(negelect)
	E	180°0′1.3″	
Azimuth encoder's zero angle		359°59′49″	

With the positive and inverse pointing to compute the orientation error:

$$g' = \frac{A_{\text{positive}} + A_{\text{inverse}} \pm 180°}{2} = \frac{359°59'49'' + 179°59'43'' - 180°}{2} = -14''. \quad (10)$$

At this time,

$$g - C = -11'' - 3'' = -14''. \quad (11)$$

The measurement and computing results reveal that the two methods are consistency and reasonability.

6 Conclusion

In this paper, we focus on the heading calibration at the dock. The principle and method of heading calibration have been discussed in detail and the following main results are obtained:

(1) The heading correction mathematic model is built by considering theodolite's sight and orientation errors;

(2) Two methods for measuring the orientation error is presented. One is positive and inverse pointing method and the other is positive mirror pointing method. We analyze the differences and relationships of two methods, and develop the two correction formulas;

(3) The consistency and reasonability of two correction methods in different situations are proved.

The research in this paper can be used as spacecraft TT&C heading calibration at the dock, and it provides a constructive reference for other calibrations.

参考文献:

[1] PAN L. *The Position Measurement Technology for Space Instrument Ships*[M]. Beijing: National Defence Industry Press, 2009. (in Chinese)

[2] JIAN S L. *The Introduction of Maritime Tracking Technology for Space Instrument Ships*[M]. Beijing: National Defence Industry Press, 2009. (in Chinese)

[3] *Rules for the Implementation of Calibration for Space Instrument Ships at Dock*[M]. No. 23 Base, 2001. (in Chinese)

[4] *The Layout Calibration Scheme for Space Instrument Ships at Dock*[M]. No. 23 Base, 2007. (in Chinese)

[5] ZHANG S L. *The Data Process Method for Space Instrument Ships*[M]. Beijing: National Defence Industry Press, 2009. (in Chinese)

[6] WANG J Q. *The Layout Design of the Optical Instruments*[M]. Changchun: Changchun Institute of Optics Fine Mechanics and Physics, Chinese Academy of Sciences, 2003. (in Chinese)

[7] WANG J Q, ZHAO X Y, LI Y C. *Optical Measuring in Shooting Range*[M]. Beijing: Academy of Equipment Command & Technology, 2001. (in Chinese)

[8] WANG M, HU S L. *Range Data Processing and Error Analysis*[M]. Beijing: National Defence Industry Press, 2008. (in Chinese)

[9] HE Z C, HU G A. *Optical Measurement System*[M]. Beijing: National Defence Industry Press, 2002. (in Chinese)

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