Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 21(2011) s589−s593
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Change monitoring of earth rotation parameter with Maglev gyroscope precessional torque

YANG Zhi-qiang, GONG Yun, SHI Zhen, LI Yun

Geological Engineering and Geomatics Institute, Chang'an University, Xi'an 710054, China

Received 19 June 2011; accepted 10 November 2011

Abstract: Through analyzing the relationship between gyro dynamic torques produced by the changes of earth rotation parameters (ERP), a method of measuring the earth rotation parameters was proposed and explored by using gyroscope. The preliminary experiments were carried out using GAT Maglev Gyro Station (which is self-developed by China). Considering the measurement and expanding-application of the earth rotation parameters, some ideas and opinions about the structure design, measurement methods and data processing of gyro were proposed, and some outlook of the expanding-application of the gyroscope in geodetic and geophysical fields were done. The experimental results show that using the high-precision gyroscope to determine the changes of ERP is feasible, with the emergence of ultra-high precision gyro; it is possible for determining the earth rotation parameters by gyro in stead of by current complex space surveying technology.

Key words: Maglev gyroscope; earth rotation parameters (ERP); precessional torque; pole motion; length of day

1 Introduction

The earth rotation parameters (ERP) usually refer to the pole motion (pole motion) and length of day (LOD). It along with precession, nutation together makes up the earth orientation parameters (EOP). It is of great significance to confirm these parameters for precisely determining the orbit of the satellite and navigation and the establishment of the high-precision ground control nets, global plate motion and regional crustal deformation monitoring.

Currently, people monitor the variations of the earth rotation parameters mainly depending on calculating by the VLBI, SLR and GPS and other surface-to-air measurement methods, due to the influence of tidal wave, atmosphere and ocean currents, the earth rotation parameters change in different degrees on Sunday and sub-Sunday [1]. Now IERS releases a calculation results through the network. By contrast, using gyroscope to measure. The earth rotation parameters has good independence, does not require large-scale ground-to- air measurement, and can reflect the variation of the earth rotation parameters from the changes of itself sensitive data.

Early in 1852, FOUCAULT put forward the idea that the rotation of the earth would lead to the high-speed movement of the gyro effect [2]. He considered that no any astronomical observation or geomagnetic observation, as long as the gyroscope observation could draw any site meridians position. But due to the limit of the condition of technology at the time, FOUCAULT's idea didn't get the desired effect through experiment [2]. But in the 20th century, with the development of the gyro technology, people successfully developed gyro compass for marine navigation directional equipment, gyro theodolite for mine surveying, etc., proving the correctness of FOUCAULT from the fundamental idea.

Since the earth's rotation movement can influence the motion of gyro, it shows that there exists certain contact between the gyro's movement and the earth's rotation movement, though the analysis of the motion of gyro can reflect some of the characteristics of the earth rotation movement.

There is no related research about monitoring ERP by using Maglev gyroscope at home and abroad. Maglev gyroscope is used to monitor ERP which has been applied to the national invention patent: A method of determining the earth polar motion by gyroscope, a

Foundation item: Project (41074006) supported by the National Natural Foundation of China
Corresponding author: YANG Zhi-qiang; Tel: +86-29-82334032; E-mail: Yang_gps@chd.edu.cn

method of determining the rotation angular velocity of the earth by gyroscope.

2 Influence of ERP variation on gyroscopic precession moment

2.1 Relationship between gyroscopic precession moment and ERP

The reason why high speed rotating gyroscopic can determine the position of meridian line for arbitrary point is gyroscope with stable spin axis and precession, which moves around the meridian line under the effect of the earth rotation.

As shown in Fig. 1, l is the direction of any meridian. O is the position of gyroscope; the direction of $\boldsymbol{\omega}_e$ is as the same as the rotational angular velocity of the earth, it is exact as the direction of the earth spin axis; ω_1 is the zenith direction heft of the rotational angular velocity of the earth on the station. If the latitude of the station is φ, the intersection angle between ω_1 and ω_e is φ. The horizontal projection of $\boldsymbol{\omega}_e$ is the direction of meridian line. According to the intersection angle between gyroscope axis and meridian line, the horizontal component is broken down into ω_2 along the direction of the gyroscope axis and ω_3 for the vertical component of the gyroscope axis.

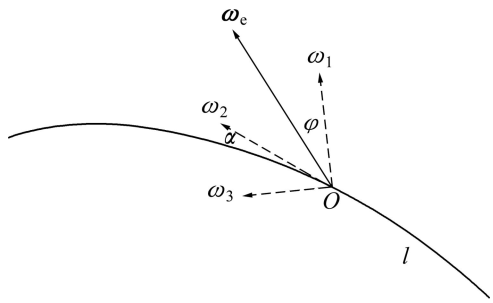

Fig. 1 Sketch map of earth rotation angular momentum decomposition

In the decomposition of the three components of earth's angular velocity, based on moment vector product rule $\boldsymbol{M}=\boldsymbol{H}\times\omega$, ω_2 along the rotation axis gyro does not produce torque on the gyro effect; ω_1 and ω_3 will produce torque on the vertical and horizontal directions.

$$\boldsymbol{M}_1 = \boldsymbol{H} \times \boldsymbol{\omega}_e \sin\varphi \tag{1}$$

$$\boldsymbol{M}_3 = \boldsymbol{H} \times \boldsymbol{\omega}_e \cos\varphi \sin\alpha \tag{2}$$

In practical application, as the measurement of $\boldsymbol{M}_1$ will be impacted by the weight-torque of the gyroscope, often by measuring the $\boldsymbol{M}_3$ to reverse all the rest physical quantity. According to Eq. (2), we can know that the moment results from the effect of rotation of the earth on the gyro, including earth's rotation rate $\boldsymbol{\omega}_e$ and latitude φ. The angle α reflects the angle of surface composed by the site of gyro at a moment and the earth's spin axis, and gyro spin axis is a real physical quantity and has close relationship with the gravity direction of the test site. So, we can use the change of $\boldsymbol{\omega}_e$, φ and α to reflect the change of the parameter of the earth [6−10].

2.2 Decomposition of polar motion changes

Daily length of rotation of the earth is caused by the influence of rotational angular velocity $\boldsymbol{\omega}_e$ of the earth. It can directly reverse by Eq. (2). Earth changes in the spin axis position can be gotten by φ and α.

As shown in Fig. 2, gyro station is located in point T , and the latitude is φ. Assuming the earth spin axis moves from AA' to DD', AD can be resolved into AB and AC, AC is on the meridian line which has the station T, $AB \perp AC$. The earth spin axis' movement in the direction of AB will cause the change of axis gyro deflection angle α. The earth spin axis' movement in the direction of AC will cause the change of gyro station latitude φ. The angular displacement of the two directions can be converted into distance changes of the pole.

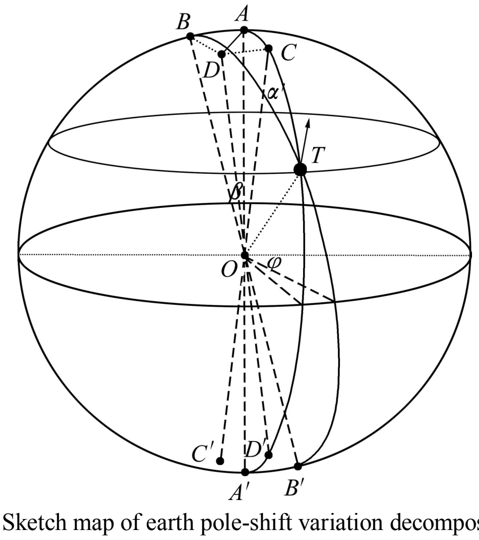

Fig. 2 Sketch map of earth pole-shift variation decomposition

$$\begin{cases} \overline{AB} = R \cdot \arccos[\sin^2\varphi + \cos^2\varphi \cdot \cos(\alpha_1 - \alpha_2)] \\ \overline{AC} = R \cdot (\varphi_1 - \varphi_2) \end{cases} \tag{3}$$

where R is earth radius; α_1 and α_2 are axis gyro deflection angle, respectively; φ_1 and φ_2 are gyro station latitude, respectively. And combining AB and AC based on the vector relation, the polar motion vector AD can be gotten. If taking the measurement of multi-angle embattling and joint decoding in the global scope, the precision of the computed results can be improved.

3 Test cases and data analysis

As the international community has no precedent of measuring the earth rotation parameters by gyroscope, and does not have a dedicated gyro equipment, to validate this method, the GAT high-precision Maglev gyro station is used, which is independently developed by China to test the above inference. The instrument uses magnetic bearing technology to replace the traditional gyro suspension with supporting technology; the measurement is applied to the optical non-contact torque feedback control technology, in order to make the sensitive part of the gyro to stay static. By means of collecting the 20000 group current values from the torquer's stator and rotor to determine the size of precessional torque below the sensitive part of gyro, and according to Formula (2) to calculate the north declination of axis gyroscope, using the RDC (Resolver digital converter) angle to measure device and the total station survey to observe the target line direction, finally, the azimuth is determined by gyro [11−13].

Through the indoor test to verify the accuracy, GAT magnetic declination rotation axis gyroscope measurement accuracy is 2.3 s (which contains the RDC and the rotation accuracy of the measurement). In this experiment, the study of the earth rotation rate and latitude measurement are included [14−15].

3.1 Test case

The national geodetic original point in Yongle Town of Jingyang, in Shanxi Province is chosen as the test place. This place has a good observing environment and the observations are stable. The measured area latitude is N34°32″, the collecting data of every observation set are as shown in Fig. 3. Blue expresses the rotor current value of the first position, and green expresses the rotor current values of the second position. The measurement results are as shown in Tables 1 and 2.

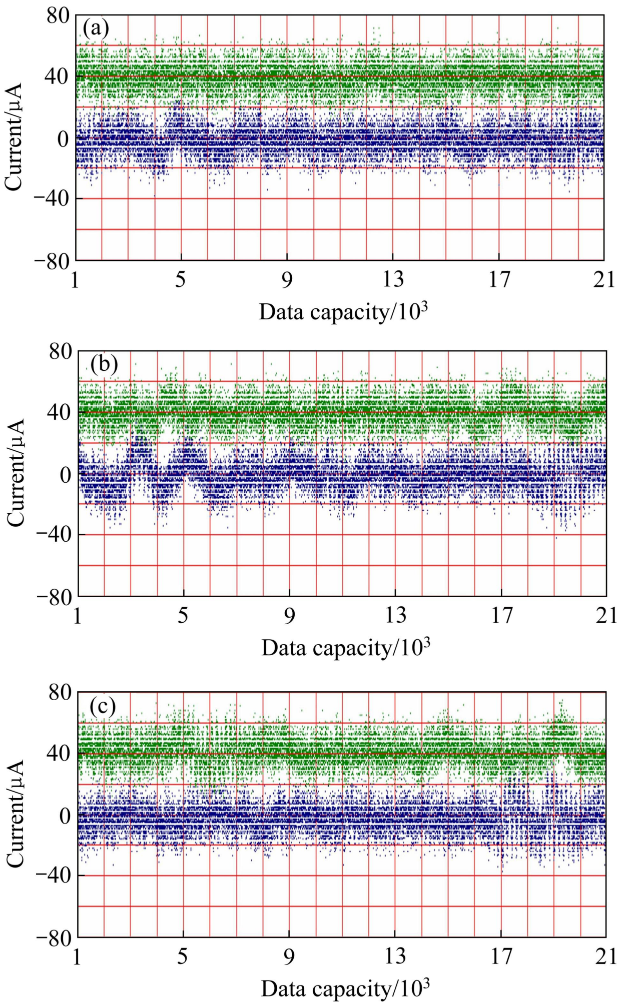

Fig. 3 Test data scatter plot chart: (a) 1°25′36″; (b) 1°25′35″; (c) 1°25′37″

Table 1 Testing length of day by gyro

Input Latitude/(°)	Known azimuth	Electronic tachometer reading	Gyro axial orientation (including constant correct)	Rotational angular velocity of earth	Time/s
34.5	316°07′07″	314°41′59″	1°25′36″	0.000 072 5	86 665
			1°25′35″	0.000 072 1	87 145
			1°25′37″	0.000 072 2	87 025

Table 2 Latitude by gyro

Rotational angular velocity of earth	Known azimuth	Electronic tachometer readings	Gyro axial orientation	Latitude/(°)
0.000 072 7 Radian/SEC	316°07′07″	314°41′59″	1°25′36″	30.271 061 4
			1°25′35″	30.838 884 1
			1°25′37″	30.690 827 5

3.2 Test analysis

1) Analyzing the dispersion. It shows that the data collected in this experiment have high quality. But from the view of the data scatter, the construction environment still has some impact on the data collection of gyroscope. There is still further possibility to improve the accuracy of the result.

2) The known azimuth in this test is the gyroscope azimuth obtained by correcting with a apparatus constant. So, the measurement error of apparatus constant and the RDC error may bring systematic errors to the result.

3) Tables 1 and Table 2 show that no matter the day length measurement or the latitude measurement, the orientation of gyroscope spin axis should be made as close as possible to north to reduce measurement error when gyroscope is set up initially.

4) The day length measurement error of this test is about 5 min and this is not enough to meet the needs to measure changes in day length.

5) For the latitude measurements, though the gyroscope currently can not meet the needs of the shift measurements, it can obtain the approximate latitude of a region.

4 Conclusions

In order to use gyro to measure the earth rotation parameters, the accuracy of gyro measurement is needed to further improve, which has to take the following three aspects into account:

1) The structural design of the gyroscope should be improved, a gyroscope specifically for measuring the earth's rotation parameters is needed to design. Gyroscope used for directional measurements' sensitive department cannot do much because of the need to consider transportation, placement and other issues. The gyro's angular momentum is often limited, which makes the ability of gyro torque to overcome outside interference will accordingly be limited. The gyroscope used to measure the earth's rotation parameters cannot consider such issues as transportation of equipment, so the size of the sensitive department of the gyro can be properly increased to enhance the ability to resist outside interference of the gyro. In the meantime, support system of the gyro is needed to take into the re-consideration because of the increase of the sensitive department of the gyro. When the size of the sensitive department of gyro is larger, the quality is bigger, the floating liquid, magnetic as well as traditional means of hanging can be taken into consideration generally in order to make the sensitive department of the gyro stay in a steady state of freedom. In addition, the effect of using instrument constants on measure error and the contribution RDC angular measurement error should be considered in the design of the structure.

2) The measurement of the gyro is improved, so as to design a specially gyro measurement system to measure the earth's rotation parameters. It's only to know α in the gyro Eq. (2) to measure the direction. The α, φ and $\boldsymbol{\omega}_e$ are known when we measure the earth's rotation parameters. So, we can build up the system to measure the earth's rotation parameters by three gyros. One is used for the gyro spin axis to the delineation north α, one is used for the measurement of latitude φ, and the last one is dedicated to measuring the earth's ratation angular velocity $\boldsymbol{\omega}_e$. Results pass through the iterative data to measurement of earth rotation parameters in real-time.

3) Improving the algorithm of the data. A special software is designed to process the mass data collected by gyro. It is necessary to select the correct method to process the massive data which are collected by gyro in a reasonable and appropriate basis of measurement structure. Gyroscope is sensitive equipment through which the sensitive earth's rotation state and the real state of the Earth's movement are reflected.

4) Compared with VLBI, GNSS, etc, it's relatively simple, and low cost to measure earth rotation parameters by gyro, without the need for large-scale joint air-ground measurements. However, since it appeared in the 19th century, gyro measurements are most used in underground engineering oriented technology. Gyro does not play its greatest value. By extension, in human studies about the future deep space exploration, we can reflect any state of the planet's rotation through the gyro.

References

[1] STEIGENBERGER P, TESMER V, MACMILLAN D, THALLER D, ROTHACHER M, FRITSCHE M, RÜLKE A, DIETRICH R. Subdaily earth rotation models estimated from GPS and VLBI data [R]. Vienna, Technische Universität München, 2008.

[2] ZHANG Guo-liang. Mining geodesy [M]. Beijing: China Mining University Press, 2005: 15−20. (in Chinese)

[3] YANG Zhi-qiang, YANG Jian-hua, SHI Zhen, YANG Shuai. The new magnetic levitation gyro station: China, 201020110125.7 [P]. 2010−10−06. (in Chinese)

[4] YANG Zhi-qiang, LI Zhi-gang, SHI Zhen, YANG Shuai. A method of determing the earth polar motion by gyroscope: China, 201010174339.5 [P]. 2010−09−01. (in Chinese)

[5] YANG Zhi-qiang, LI Zhi-gang, SHI Zhen, YANG Shuai. A method of determing the rotation angular velocity of the earth by gyroscope: China, 201010174931.5 [P]. 2010−09−15. (in Chinese)

[6] FANG Fang. The comprehensive analysis of movement rules and orientation error [M]. Tianjin: Tianjin University Press, 2003: 5−8. (in Chinese)

[7] YANG Zhi-qiang. The research report of GAT high-precision magnetic levitation gyro station [R]. Xi'an: Geomatic and Space Information Research Institute of Chang'an University, 2008. (in Chinese)

[8] XIAN Gui-suo. The research of key technique of automaticly searching north by Gyro theodolite [D]. Tianjin: Precision Instruments and Photoelectron Engineering Institute of Tianjin University, 2006: 6−9. (in Chinese)

[9] LIN Ming-chun. The research of key technique of Gyro theodolite's digitization and automation [D]. Tianjin: Precision Instruments and Photoelectron Engineering Institute of Tianjin University, 2006: 8−12. (in Chinese)

[10] XU Shao-quan, ZHANG Hua-hai, YANG Zhi-qiang. The principle and application of GPS [M]. Wuhan: Wuhan University Press, 1998: 19−21. (in Chinese)

[11] Tangshan Gyro Theodolite Group of Coal Science Research Institute. The basic principle, structure and orientation of gyro theodolite [M]. Beijing: Coal Industry Press, 1982: 33−36. (in Chinese)

[12] YU Lai-fa. Gyro's directional measurement [M]. Beijing: Liberation Army Press, 1988: 12−18. (in Chinese)

[13] LIU Jin-nan. The progress of GPS [J]. The Global Positioning System, 2000, 17(2): 25−29. (in Chinese)

[14] GUO Xiu-zhong, YU Bo, CHEN Yun-xiang. The principle and application of Gyro [M]. Beijing: Aviation Industry Press, 1987: 4−6. (in Chinese)

[15] GUO Xiu-zhong. The theory of gyro inertial navigation system [M]. Beijing: Defense Industry Press, 1996: 23−35. (in Chinese)

(Edited by CHEN Can-hua)