Comparison of Absolute Gravity Measurements Obtained with FG5/232 and FG5/214 Instruments

XING Lelin  LI Hui  LI Jiancheng  HE Zhitang

Abstract  This paper introduces the comparison of absolute gravity measurements in China during 2006-2008, and analyzing the survey and comparing the results, it shows that there is no obvious system error between the gravimeter of FG5/214 and FG5/232, the surveying accuracy is very high and repetition is good, and their inner surveying accuracy is about 2-3 microGal.

Keywords  comparison; absolute gravity surveying; gravity change; earthquake

CLC number  P223

Introduction

Absolute gravimeter cannot be calibrated except for components such as atomic clock and laser, so the determination of gravity datum is needed to compare absolute gravity measurement to get a highly accurate absolute gravity value.

The two comparisons of absolute gravity measurement between the Institute of Seismology and the Shaanxi Surveying and Mapping Bureau in mainland China was performed during Nov. 11-14, 2006 and Jan. 22-24, 2008 at 3053# and Jiufeng absolute gravity datum station. To maintain a better environment for the comparison, three-day observation without jamming noise was carried out successfully.

The results were compared and analyzed by processing the original data and analyzing some factors that contributed to the observation. Then the application and prospect of high accuracy absolute gravity measurement in the field of crust vertical deformation was probed. On the basis of the comparison, the determination of high accuracy absolute gravity datum by FG5 gravimeter surveying has become truth and served as a solid foundation for monitoring earthquakes and doing research in the related geodynamics.

1  Absolute gravity meter and comparison results

The FG5 (XE “FG5:Concept”) absolute gravimeter is a transportable instrument with high precision, high accuracy that measures the vertical acceleration of gravity. The operation of the FG5 is simple in concept: A test mass is dropped vertically by a mechanical device inside a vacuum chamber, then allowed to fall a distance of about 20 cm. A laser interferometer is used to determine accurately the position
of the test mass as a function of time during its free-fall. The acceleration of the test mass is calculated directly from the measured trajectory.

The interferometer (XE “Laser Interferometer”) generates an optical interference fringe each time the test mass falls 1/2 the wavelength of the laser light. These fringes are counted and timed with an atomic clock to obtain precise time and distance pairs. A least-squares fit to these data are used to determine the value of \( g \). This method for measuring gravity is absolute because the determination is purely metrological and relies on standards of length and time. The distance scale is given by a frequency stabilized helium neon (HeNe) laser built in the interferometer. A rubidium atomic time-base (XE “Atomic Time Base”) provides the time scale used for accurate timing. The value of gravity obtained with the FG5 can be used without the loop reductions and drift corrections normally required when using relative instrumentation.

Fig.1 shows how gravity is measured with an FG5. A test body, containing a corner cube retro-reflector, is dropped from the top of the dropping chamber. The laser light is split to reflect off the falling corner cube and a fixed corner cube which serves as a reference. The mass accelerates to the bottom of the chamber, and the raw fringe signal is detected by the photodiode as the dropped object falls. The optical fringes in the raw fringe signal are timed to create calibrated time and distance pairs. The lower part of the figure demonstrates the increase in the fringe signal frequency as the test body accelerates.

The FG5 is now a firmly established standard in the fields of geophysics and metrology. As of 2006, over 45 instruments have been constructed and are employed throughout the world.

To test the capability and surveying accuracy of FG5/232 absolute gravimeter, after the checking and acceptance in September 2006, several observations have been done from September to November. To get the value of ground point, the correction of vertical gravity gradient must be done, so we surveyed the gradient by two relative gravimeters (LCR-G853, G854), the average gradient of two meters as the final result for both 3053# and Jiufeng station. The vertical gradient was determined between the pier and the plane which is 1.3 m high, the observation order was plane-pier-plane or pier-plane-pier, the observation data was processed with the tidal correction and zero drift correction to make the error within \( \pm 3 \times 10^{-8} \) ms\(^{-2}\).

For the comparison between FG5/214 and FG5/232, the observation method is 25 sets, 100 drops/set, 10s/drop. The surveying time is 25 hours and the method was done to eliminate the effects of earth tide, ocean load and atmospheric pressure. FG5 observations are computed by g7 software with the parameters of coordinate, height, gravity gradient, instrument reference height, polar motion coordinate \( X \), \( Y \) and reference voltage of laser peak. According to the method described above, the observation results are shown in Table 1 and Fig.3(2006.11).

Table 1 shows the information of absolute gravity value including the set scatter, gravity vertical gradient and others. Fig.4 gives the processed set values and set scatter. Table 1 and Fig.2 show an obvious high accuracy of surveying results, set scatter of each time is better than \( \pm 1.5 \times 10^{-8} \) ms\(^{-2}\); the two gravimeters show that the gravity value at 3053# station has a descending trend; the two gravimeters in 2006 and 2008 have no system errors by comparison, the difference of gravity value is less than \( 2.5 \times 10^{-8} \) ms\(^{-2}\) especially for the
ground values. We can conclude that the two stations are stable as absolute gravity datum stations.

Table 1  Absolute gravity results at 3053# and Jiufeng station

| Station | Gravimeter | Measurement time | Set number | Processed number | 1.3m height (10^{-8}ms^{-2}) | Floor value (10^{-8}ms^{-2}) | Set scatter (±10^{-8}ms^{-2}) | Vertical gradient of gravity (10^{-8}ms^{-2}/cm) |
|---------|------------|-----------------|------------|------------------|-------------------------------|-------------------------------|-------------------------------|----------------------------------|
| 3053#   | FG5/232    | Sep.25-26,2006  | 29         | 29               | 979 350 581.2                 | 979 350 956.9                 | 1.18                          | -2.890                           |
|         | FG5/232    | Oct.18-19,2006  | 25         | 25               | 979 350 576.2                 | 979 350 952.0                 | 1.43                          | -2.890                           |
|         | FG5/232    | Nov.13-14,2006  | 25         | 24               | 979 350 577.7                 | 979 350 953.4                 | 1.08                          | -2.890                           |
|         | FG5/214    | Nov.11-12,2006  | 24         | 24               | 979 350 575.5                 | 979 350 951.4                 | 1.44                          | -2.890                           |
|         | FG5/232    | Jan.23-24,2008  | 25         | 25               | 979 350 572.1                 | 979 350 951.7                 | 1.38                          | -2.921                           |
| Jiufeng | FG5/214    | Jan.22-23,2008  | 26         | 26               | 979 350 572.5                 | 979 357 752.1                 | 1.49                          | -2.921                           |
|         | FG5/232    | Nov.15-16,2006  | 25         | 21               | 979 350 519.2                 | 979 357 758.7                 | 1.04                          | -2.619                           |
|         | FG5/214    | Nov.15-16,2006  | 26         | 26               | 979 350 518.3                 | 979 357 757.7                 | 1.24                          | -2.619                           |

Fig.3  Gravity value and set scatter information

There are so many factors that can affect the absolute accuracy and precision; besides the temperature, vertical gravity gradient has the great contribution to the accuracy of the gravity value, so the operators heed to be careful and earnest while surveying the gradient. In theory, it will be a stable gravity value if surveyed for a long time at the same station, in fact, while processing the original observation data through $g_7$ software, ETGTAB-CSR 3.0 is used for the model of tidal correction. In the ETGTAB tide model, whose factor is 1.16, the real tide is not equal to the theory tide and the pressure correction adopts 0.30 microGal/mBar as scale factor, which also has some effect on the real gravity value[1].

2  Application and its future

Currently, the precision of high accuracy FG5 absolute gravimeter is 1-2 microGal[2], provided that there is no mass movement, 1cm crust vertical uplift causes about $3\times10^{-8}$ms^{-2} gravity change, that is about 5-10 mm crust vertical uplift can be monitored by the FG5 absolute gravimeter. Therefore, it is a fast and economic method for monitoring crust vertical movement using the FG5 absolute gravimeter.

Some countries have indicated to monitoring crust vertical movement using high accuracy FG5 absolute gravimeters. Scientists are studying the field of geodynamics using these cherished gravity data [3]. Some significant projects are formulated, especially in the field of international cooperation. Professor Hwang in Taiwan used repeat absolute gravity surveying to monitor the ground fall in the Yunlin area; the results are in accordance with the leveling results. In China, professor WANG Yong monitored the gravity change in Yunnan-Sichuan area and at Lasha point using repeated absolute gravity surveying. It shows that the gravity changed obviously after the Lijiang earthquake. He computed the gravity change at Lasha point using dislocation model, comparing with the leveling and absolute result, and the results are popular. The Shaanxi Mapping and Surveying Bureau is studying the relationship between gravity and ground water using repeat absolute gravity survey combined with GPS and leveling.

In a word, many departments in China, such as earthquake, mapping and surveying, gravity research and etc., are establishing the high precision absolute
gravity network using absolute surveying to monitor non-tidal gravity change, to study the sea level surface height variation and crust vertical movement caused by earthquakes, volcano eruptions or earth structure and their mechanisms\cite{14, 5}. The absolute gravimeter is a good tool for detecting the earth’s gravity field; it provides us a special method to understand the unique earth. It has more functions in the field of sea level monitoring, geoid determination, ground water change and mineral resources detection.

3 Conclusion

Absolute gravity measurements for comparison have been successfully conducted at 3053\(^{\circ}\) and Jiufeng station during two instances. The observation results show that set scatter is better than \(\pm 1.5 \times 10^{-5} \, \text{ms}^{-2}\). It is reasonable that the acquiring parameters are 25 hours, 1 set/hour, 100 drops/set. Absolute gravity surveying requires a stable site and temperature without environment noise. A good surveying period starts from night until the following morning. The vertical gradient of gravity contributes a lot in deducing gravity. Operators must survey carefully with relative meters adopting the best program. The nominal temperature for absolute gravimeter measurement is 15°C-25°C. To maintain the temperature, the temperature change amplitude should be not more than ±2.5°C, or the results will not be satisfactory.

The comparison results show that there is no system error between FG5/232 and FG5/214, the difference of gravity results is less than 2 microGal in 1.3 m height. The value in 2008 at 3053\(^{\circ}\) station drops about 4.5 microGal comparing with the result of 2006. As we know, the earth’s gravity field is a time variation physics field; perhaps hydrology effect correlates with the change mush.

Recent gravity studies at the Institute of Seismology, CEA, were based on gravity monitoring nets, gravity nets based on the precision of absolute gravity datum, since the average accuracy of absolute determinations is 1-2 microGal which is higher than the accuracy of relative meter \cite{6-7}. Therefore, FG5 is intended to serve as a basis for geodynamic studies to unify non-tidal gravity change. Repeated absolute gravity determination will enable us to evaluate variations of the gravity field over a long period of time because the measurements are independent of internal variations of the instrument (for instance, changes in scale factors). Moreover, the reference datum provided by absolute gravity sites will permit distinguishing between local and regional effects, resolving the internal ambiguity associated with relative networks. The comparison of absolute gravimeters reveals that there is no obvious system error between FG5/232 and FG5/214, so the data and results can be exchanged and shared with each other. It makes a solid condition for the high accuracy gravity measurement to monitor vertical crustal movement.

Recently, a new absolute gravimeter (A10) has been imported by the School of Geodesy and Geomatics, of Wuhan University. So far, there are a total of four absolute gravimeters in China. Perhaps, the comparison among the four Chinese absolute gravimeters will be conducted soon.

References

\[1\] Xing Lelin, Liu Dongzhi (2007) Comparison of FG5 absolute gravimeter surveying[J]. Journal of Geomatics, 32(2): 27-29

\[2\] Wang Yong, XU Houze, Zhang Weimin (1998) Observation results of high precision absolute gravity in central and western China in 1996[J]. Acta Geophysica Sinica, 11(6): 818-824

\[3\] Zhang Weimin, Wang Yong, Zhan Jingang (2005) High accuracy absolute gravity observation in Chinese mainland during 1996-2003[J]. Progress in Geophysics, 20(1): 204-210

\[4\] Liu Dongzhi, Xing Lelin (2007) Experimental observation results with FG5/232 absolute gravimeter[J]. Journal of Geodesy and Geodynamics, 27(5): 88-93

\[5\] Sun Hepin, Zhang Weimin (2006) Comparison of the absolute gravity measurements obtained with China and Japan instruments[J]. Science of Surveying and Mapping, 31(6): 33-34

\[6\] Liu Dongzhi, Li Hui, Xing Lelin (2007) The analysis of absolute gravity surveying result of China earthquake gravity network[J]. Journal of Geodesy and Geodynamics, 27(5): 88-93

\[7\] Xing Lelin, Liu Dongzhi (2007) Fg5 absolute gravimeter and its survey in 3053 station[J]. Journal of Geomatics, 32(2): 27-29