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Calibration of the superconducting gravimeter TT70 #016 at Syowa Station by parallel observation with the absolute gravimeter FG5 #203

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Abstract: For the purpose of calibration of the superconducting gravimeter model TT70 #016 at Syowa Station, Antarctica, we carried out parallel observations with the absolute gravimeter FG5 #203 from December 29, 2000 to January 25, 2001. During the FG5 measurements, the laser stability was sometimes not good and this caused irregular data. We carefully examined the relation between laser stability and gravity values, and took it into account for the removal of abnormal data. We applied linear regression to the selected SG and FG5 data set, and obtained the value of -58.168 μGal/V to an accuracy of 0.10% for the scale factor of TT70 #016. The difference of the obtained scale factor from the previous value of -57.965μGal/V is about 0.35%.

key words: superconducting gravimeter, scale factor, calibration, FG5, laser stability

1. Introduction

Since superconducting gravimeters (hereafter abbreviated as SGs) have high sensitivity and long-term stability, SG observations have significant importance for studies of earth tides, ocean tides, earth rotation, free core nutation, and various other disciplines. In order to utilize SG data for these geophysical studies, precise determination of the scale factor, which transforms the SG output voltage signal to gravity acceleration, is important. Theoretical solid earth models are considered so accurate that, at present, the discrepancies of observed gravity from those models are generated by other phenomena, *e.g.,* ocean loading or earth's inelasticity. Because solid earth tide accounts for most of the tidal signal and the rest is a few percent at most, precise determination of the scale factor is necessary to study these phenomena accurately (Baker and Bos, 2001). The Global Geodynamics Project (GGP; see Crossley *et al.,* 1999) recommends periodic calibration with an accuracy of better than 0.1%.

There are two principal methods for calibration of the SG. The first method, so called absolute calibrations, involve applying artificial acceleration to the gravimeter using, for instance, a vertically-oscillating platform (Richter *et al.,* 1995). However, this method requires a special instrument and it is practically impossible to conduct it in Syowa Station.

The second method, so called relative calibrations, is performed by parallel observation of the SG and a reference, *i.e.,* an absolute gravimeter or a "calibrated" relative gravimeter. The scale factor can be obtained by comparing the gravity signals measured by the SG with those by the reference. Due to error propagation, the overall accuracy of calibration is limited by the accuracy of the reference; the accuracy of the standard FG5 absolute gravimeter is within 0.1% (Francis, 1997). Moreover, absolute gravity measurements give us useful information on the long-term drift of the SG and/or the real gravity change at the observation point.

The SG model TT70 #016 (hereafter abbreviated as TT70 #016) observation at Syowa Station has been in use since March, 1993. Calibration of the TT70 #016 has been carried out twice so far. The first calibration was performed using one year registration of LaCoste&Romberg gravimeter D73, and the value of $-57.965\,\mu$Gal/V was obtained (Kanao and Sato, 1995; Sato *et al.,* 1995). The second calibration was performed by parallel observation with the absolute gravimeter FG5 (Aoyama *et al.,* 1997). However, due to instrumental troubles (for details, see Yamamoto (1996)), a reliable scale factor was not obtained. Hence the value from the first calibration has been used for the scale factor of TT70 #016 up to now, even though the accuracy is not satisfactory.

During the 42nd Japanese Antarctic Research Expedition (JARE-42), absolute gravity (hereafter abbreviated as AG) measurements have been carried out using the FG5 #203 in the same gravity room, and we obtained parallel observation data for both the SG and the AG, of enough duration and quality to determine the precise scale factor. In this paper, we report the determination of the scale factor of the TT70 #016 using the parallel observation data and discuss some related problems which have to be solved for future measurements.

2. Observation and data processing

2.1. Absolute gravity measurements

From December 29, 2000 to January 25, 2001, AG measurement using the FG5 #203 was carried out in the gravity room of Syowa Station (Kimura, 2002), at the IAGBN (International Absolute Gravity Basestation Network) category A #0417 stations (Boedecker and Fritzer, 1986). We obtained more than 100000 single measurements (drops) for the AG data.

During the AG measurement, the iodine stabilized He-Ne laser frequently became unstable and the gravity values became also unstable and scattered consequently. The real-time data collecting software of FG5 has an option which allows the system to detect the locked laser peak when the drop is initiated. This option requires a table of the nominal laser output voltages for each laser peak. The software of the FG5 detects the laser peaks to be locked by comparing measured laser voltage during a drop with the voltages in the table stored in the software, and the gravity values are calculated using the corresponding wavelengths of the locked laser peaks. Thus, if the laser output voltages are unstable, the laser peak detection may fail, and false wavelengths will be used for calculation of the gravity. Note that a false laser lock detection between one adjacent line pair causes about a $27\,\mu$Gal gravity difference.

To check the false detection of the laser peaks, we plotted the output voltages of the iodine laser and the corresponding gravity values with respect to the laser peaks which were automatically detected. Figure 1 shows 6360 data obtained from January 6 to January 7, 2001, as an example. In Fig. 1a, pluses(+), crosses(×), squares(□) and stars(★) show gravity values which were calculated by assuming the corresponding wavelengths of ID, IE, IF and IG peaks, respectively. Note that the operation system of the FG5 only uses laser peaks either between ID and IG or between IH and IJ. The solid circles in Fig. 1b indicate laser output voltages and the four level lines indicate the nominal laser output voltages at the ID, IE, IF and IG peaks. These voltages were measured and recorded in the software table. The gravity values look stable only when the laser outputs are around 0.24 V (ID) and/or −0.08 V (IE). Therefore, we decided to use only data which were locked on the ID and IE peaks.

The removal of the false FG5 data due to laser instability greatly reduced systematic errors, but there still remained some outliers due to unspecified reasons. To remove those data, we took the following two steps: first remove data over $\pm 500\,\mu$Gal from the median value; second remove data over $\pm 300\,\mu$Gal from the average value of the data which remained after the first step.

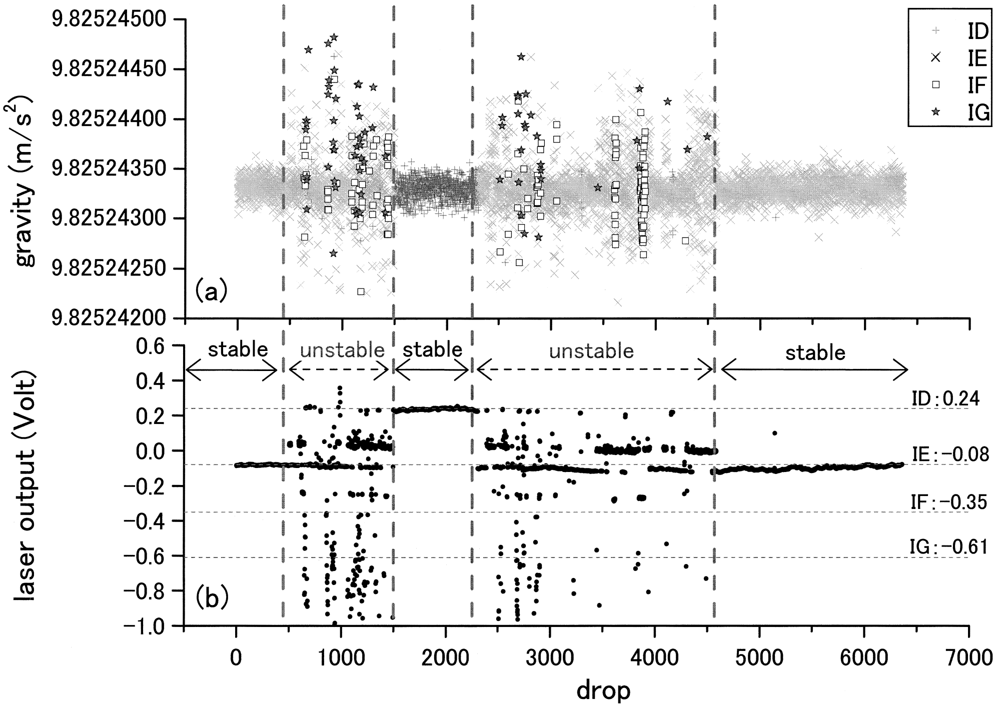

Fig. 1. This figure shows 6360 data obtained from January 6 to January 7, 2001. (a) The FG5 gravity values. The pluses(+), crosses(×), squares(□) and stars(★) show gravity values which were calculated by using the corresponding wavelengths of the ID, IE, IF and IG laser peaks, respectively. (b) The iodine stabilized He-Ne laser output. The solid circles indicate laser output and the four level lines indicate the laser output of ID, IE, IF and IG peaks which were measured and recorded in the software table.

2.2. *Comparison of AG and SG data*

Figure 2 shows a time series of the AG and the SG data (1 second sampled GGP-1 data) from December 29, 2000 to January 13, 2001. During the observation period, several maintenance procedures were taking place in the gravity observation room at the same time. This caused noise on the observed gravity data. Especially, helium liquefier which started on January 13, 2001, resulted in increased noise on both the AG and the SG data. Thus we did not employ those data though the observations continued until January 25, 2001. Note that several earthquakes occurred during the observation period, as shown in Fig. 2. We also removed data which were scattered under the influence of those earthquakes (see Fig. 2).

For calibration of the SG scale factor with the AG data, simultaneous pairs of SG and AG data are necessary. Before preparing the data set, the SG data were corrected for the time lag (8.16 s delay) of the GGP-1 filter which is an on-board anti-aliasing low-pass filter recommended by the GGP. After pre-processing to remove the false FG5 data mentioned above, and after the time lag correction for the SG data, the SG data which correspond in time with the AG data were picked up.

We note a step in the SG data on January 5, 2001. We separate the whole period into two sections, namely (A) before the step and (B) after the step. We carried out linear regression analysis for data of the (A) section, (B) section and (C) the data for the whole period. After removing data outside of three times the standard deviation,

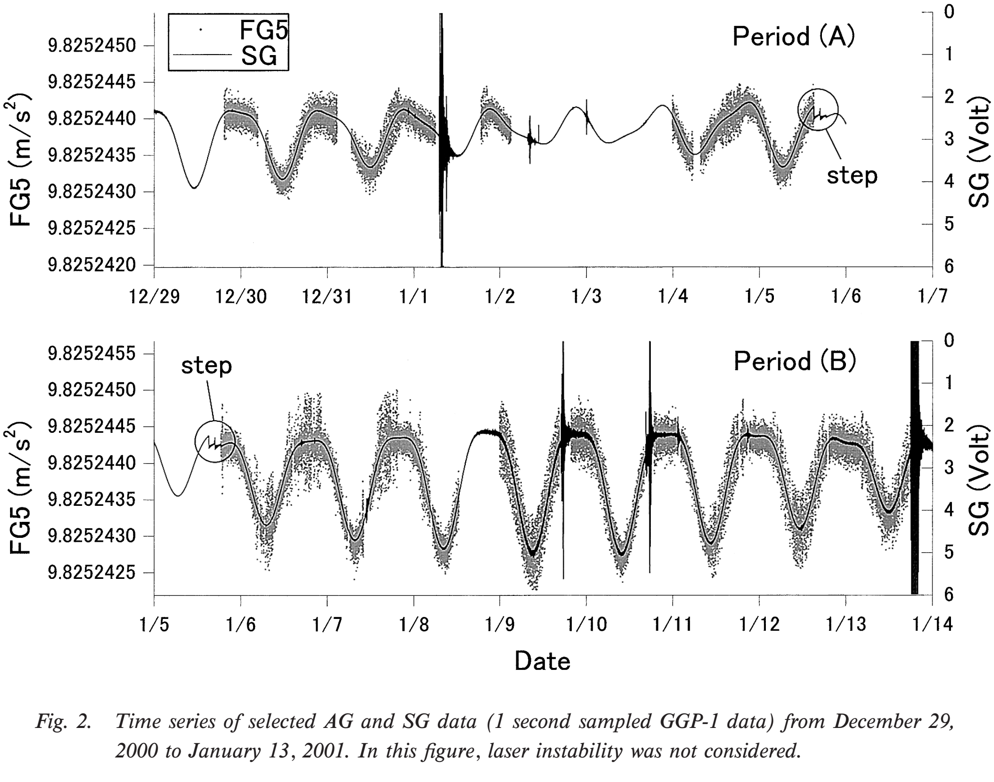

Fig. 2. Time series of selected AG and SG data (1 second sampled GGP-1 data) from December 29, 2000 to January 13, 2001. In this figure, laser instability was not considered.

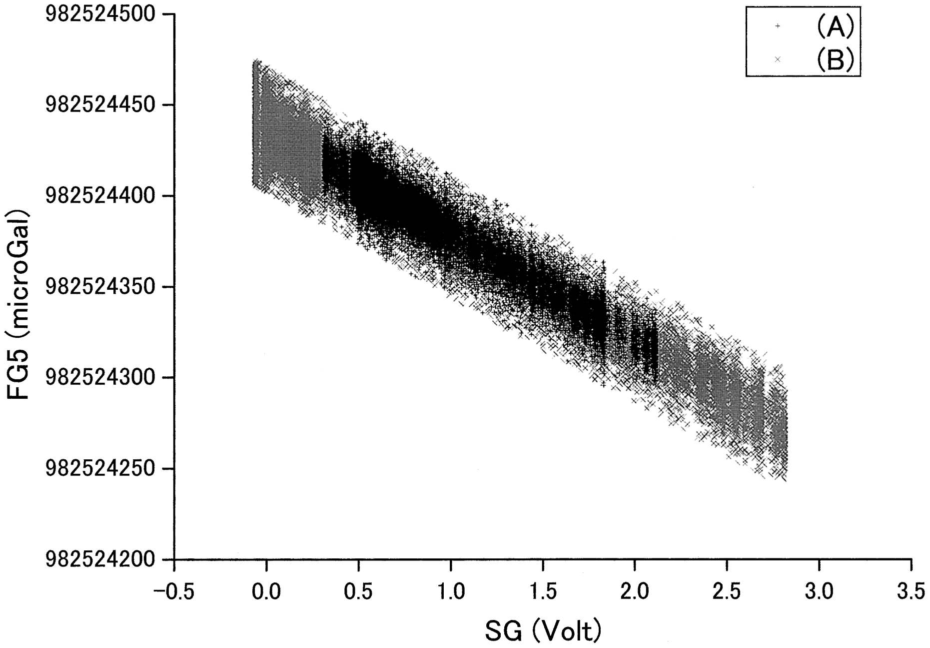

Fig. 3. Selected pairs of AG and SG data from (A) December 29, 2000 to January 5, 2001 (before the step) and (B) January 5, 2001 to January 13, 2001 (after the step). The SG step of January 5, 2001 was corrected. The total number of data is 55743.

the regression analysis was repeated twice to obtain the final result. Figure 3 shows selected pairs of AG and SG data throughout the whole duration.

3. Result

The scale factors calculated are summarized in Table 1 and plotted in Fig. 4. In the figure the current scale factor by Kanao and Sato (1995) is also plotted.

A remarkable difference of the scale factor between (A) and (B) resulted from the difference of the tidal amplitude (see Fig. 2). In period (A), the tidal amplitude was small and the estimation error of the scale factor was large, and vice versa in period (B).

Table 1. The scale factor of TT70 #016.

Period*	Scale factor (μGal/V)	(%)	Number of the data
(A)	−57.811±0.120	(0.21)	23026
(B)	−58.239±0.075	(0.13)	32882
(C)	−**58.168**±0.061	(0.10)	55743
Previous	−57.965	(about 1)	

*Period
(A) December 29, 2000–January 5, 2001
(B) January 5, 2001–January 13, 2001
(C) December 29, 2000–January 13, 2001

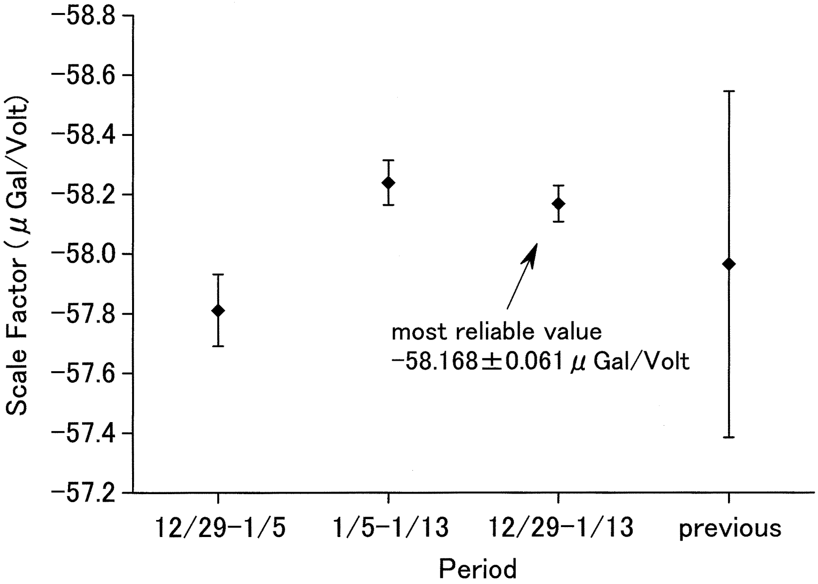

Fig. 4. The scale factor of TT70 #016 obtained in this study. The currently adopted value by Kanao and Sato (1995) is also plotted. Note the magnitude of the error bar reduced to one-tenth for our measurements.

Although the scale factor obtained for (A) differs from that for (B), we cannot find any systematic errors in period (A) when the estimation errors are taken into consideration, so there is no reason to remove the data for (A). Undoubtedly the increase in number of data improves the estimation error statistically. Therefore, we concluded that the value of $-58.168 \pm 0.061\,\mu$Gal/V is the most reliable value for the scale factor of TT70 #016.

4. Concluding remarks

A new type of SG model CT has been installed in Syowa Station and TT70 #016 will soon been replaced. Prior to the instrument replacement, precise calibration of the scale factor of TT70 #016 was really desired so as to utilize these 10 year data most effectively. We succeeded in determining improved accuracy and obtained the scale factor of TT70 #016 to an accuracy of 0.10%. The obtained value is consistent with the previously adopted scale factor by Kanao and Sato (1995), but it is about ten times more accurate than the previous one.

Finally, we make some suggestions for future calibration studies and/or FG5 measurements. We believe that one of the biggest error sources degrading FG5 data is variation of the room temperature. The recommended operation temperature of the FG5 is between 15°C and 25°C within the variation of ±2.5°C . However, during our parallel observation, the actual temperature varied from 19.6°C to 29.0°C; this large variation must have caused the laser instability. This should be taken into consideration in future work.

Owing to the short summer season of Antarctica, various works and observations tend to be concentrated in the two months December and January. FG5 observations during winter are needed to avoid the large artificial noise that is inevitable in summer.

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