Polar Geosci., **18**, 49–57, 2005

Installation of the superconducting gravimeter CT(#043) at Syowa Station, Antarctica

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(Received February 2, 2005; Accepted June 10, 2005)

Abstract: During the wintering period of the 44th Japanese Antarctic Research Expedition (JARE-44: February 2003 to January 2004), a new superconducting gravimeter CT(#043) with a cryocooler was installed and tested to replace the former TT70(#016) at Syowa Station, Antarctica. The CT(#043) has design sensitivity of 1 nGal (1×10^{-11} m/s^2) to study the Earth's dynamics in tidal and longer-period bands. A new type of diaphragm was used to effectively isolate the vibration from the refrigerator cold-head and to prevent solid air contamination from entering the Dewar. A real-time remote monitoring system including a Web camera for diagnostics from Japan has also been installed.

key words: superconducting gravimeter, GM refrigerator, diaphragm, monitoring system, Syowa Station

1. Introduction

Since superconducting gravimeters (SGs) have high sensitivity and long-term stability, SG observations have significant importance for studies of Earth tides, ocean tides, Earth rotations, free core nutation, and various other disciplines. This high sensitivity will enable the Global Geodynamics Project (GGP; *e.g.* Crossley *et al.*, 1999) to search for internal gravity waves in the Earth's liquid core and "slow or silent" earthquakes, especially for long-term gravity variations and the influence of environmental effects on gravity. The stability of the SG approaches a few μGal (1×10^{-8} m/s^2) per year, which makes it invaluable for geodetic purposes, such as monitoring sea-level changes and tectonic deformations (Richter *et al.*, 1983).

In 1993 the SG TT70(#016) was introduced to Syowa Station (69°00′S, 39°35′E), Antarctica, for the first time by JARE-34 (Sato *et al.*, 1993, 1995). Since then, the SG TT70(#016) has been continuously running for 10 years without severe interruptions (Shibuya *et al.*, 2003). The first evidence of incessant excitation of the Earth's free oscillations is especially noted as an important contribution from the Syowa SG observations (Nawa *et al*., 1998, 2000).

Although the SG TT70(#016) produced many scientific results, it required on-site helium liquefaction. Transport of gaseous helium (99.9999%) cylinders and operation of the liquefier twice a year for refilling the gravity Dewar was a burden to the responsible JARE-members. Therefore, from February 5, 2003 through January 31, 2004, a new-type SG CT(#043) with an integrated cryocooler was installed to replace the former TT70(#016). Since parallel observation and comparison with TT70(#016), and calibration of the CT(#043) by an FG5 absolute gravimeter are discussed in the accompanying paper by Fukuda *et al.* (2005) in this volume, we are going to focus on the design of mechanical properties.

2. Superconducting gravimeter

Figure 1 schematically shows components of CT(#043). This SG consists of two basic components: 1) the gravimeter sensing unit which includes the superconducting magnets and sphere, circuitry for energizing the coils, etc., and 2) the liquid helium Dewar and refrigeration system which keeps the gravimeter sensing unit close to 4.2 K to maintain the superconducting state. We follow Warburton and Brinton (1995) for explanation of the principle of the SG.

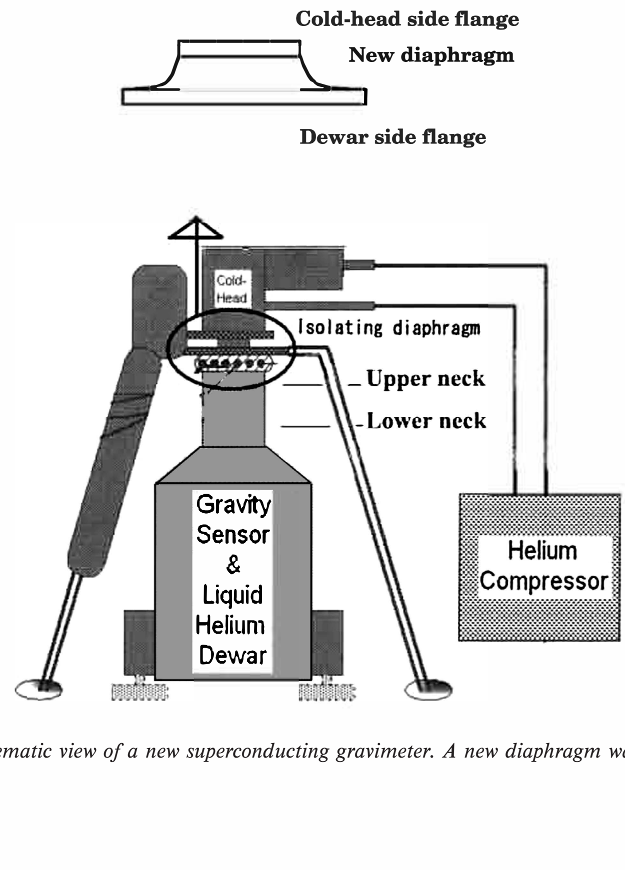

Fig. 1. Schematic view of a new superconducting gravimeter. A new diaphragm was integrated.

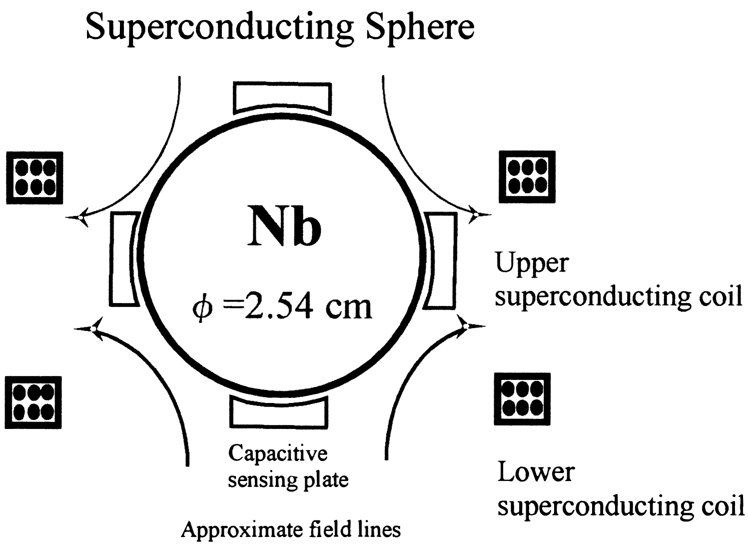

Fig. 2. Superconducting sphere in the gravity-sensing unit.

As shown in Fig. 2, the gravimeter sensing unit contains a 2.54 cm diameter spherical proof mass. The sphere (Nb) is levitated by the forces produced by magnetic fields generated from a pair of superconducting coils called the Upper and Lower coils. It behaves as a perfect diamagnetic so that surface currents are generated which exactly cancel and exclude any applied magnetic field from its interior. It is the interaction between the sphere's surface currents and the applied magnetic field that produce the levitation force. The vertical magnetic gradient ("spring constant") can be made very weak by adjusting the ratio of currents in the two field coils. The use of trapped persistent super-currents accounts for the long-term stability of the SG in comparison to mechanical spring type gravimeters.

A capacitance bridge network consisting of three spherical capacitor plates positioned around the sphere senses the position of the sphere. The sphere capacitive couples the excitation signals to the center plate of the bridge. When the sphere is equidistant from the upper and lower plates, the drive signals cancel and the resulting signal on the center plate is zero. When changes in gravity cause the sphere to move from its balancing position, it produces an error signal that is linear in displacement. During operation, the position of the sphere is held close to its null position by a feedback circuit, which applies a magnetic force through a separate feedback coil. Since the force from the feedback coil varies linear by with the current, measuring the current through the feedback coil provides measurement of the change in the Earth's gravity.

The gravity sensor is surrounded by a superconducting magnetic shield to eliminate the effect of changes in the external magnetic field. It is also enclosed in a vacuum can and temperature regulated to a few mK. This makes the sensor insensitive to environmental effects such as changes in external temperature and humidity.

According to the GWR Instruments Manual (GWR Instruments Ltd., 2002), the

Dewar refrigeration system consists of a newly designed Dewar interfaced with a two-stage (lower and upper stages) cryocooler which is capable of obtaining temperatures below the vaporization point of liquid helium. The system is based on the Coolpower 4.2 LAB cryocooler manufactured by Leybold Vacuum Products Inc. This Gifford-McMahon (GM) type cryocooler delivers a maximum cooling power of 4 Watts at 60 K to its upper stage and 0.25 Watts at 4.2 K to its lower stage, and consumes no liquid helium. It may operate without maintenance for more than 5 years.

3. Setup and initial cool-down

In February 2003, the new SG CT(#043) was brought into the gravity observation hut of Syowa Station, and the setup procedure was started. Figure 3 shows the initial cool-down curve for the CT(#043), where the red, blue and green curves correspond to the temperatures at the upper neck (nearby the first stage of the refrigerator; see Fig. 1), lower neck (near the second stage of the refrigerator; see also Fig. 1), and the Dewar bottom, respectively. The temperature distribution along the neck tube was measured by using a carbon resistance thermometer.

We used liquid nitrogen for pre-cooling, and transferred liquid helium for final cooling. During the pre-cooling stage, the Dewar bottom showed 77 K of the filled liquid nitrogen temperature. The spike increase from 77 K to 130 K indicates the transient stage of the coolant replacement for the liquid helium, and the Dewar bottom gradually (in 3 hours) approached 4 K. When the GM-refrigerator began operation on February 6, the neck tube temperature gradually decreased to about 60 K at the upper neck (1st stage) and 4K at the lower neck (2st stage), which indicates almost the temperature as the Dewar bottom. This means an increasing level of liquid, and the Dewar became 88% full on March 17, 2003.

We started the levitation procedure subsequently on March 18, using upper and lower superconducting coils. It took almost one month to fine-adjust the position of the levitated sensing sphere, after careful micrometer adjustment of the tilt-compensation system. After this fine-adjusting the position of the sensing sphere, we finally started the data recording from April 18, 2003.

4. Comparison of the data of TT70(#016) and CT(#043)

We carried out parallel observations of the TT70(#016) and CT(#043) for about 7 months from April to November 2003. We estimated and compared the irregular terms and drift rates between them, by selecting sample data from August 1 through September 4, 2003. Figure 4 shows BAYTAP-G (Tamura *et al.*, 1991) decomposed time series of these irregular terms and drift rates. The level of less than $\pm 1\,\mu$Gal for the irregular term from CT(#043) shown by black curves is smaller by a factor of 5–10 as compared with $\pm 3\,\mu$Gal of those from TT70(#016) shown by red curves. The reduced level of short-period noises may be a benefit from calm mechanically driven piston as compared to the previous gas driven cryocoolers. As compared with $\pm 5\,\mu$Gal long-period (1–7 days) fluctuation of the TT70(#016) drifts by blue curves, the drifts of CT(#043) by green curves are characterized by less pronounced fluctuations but a larger

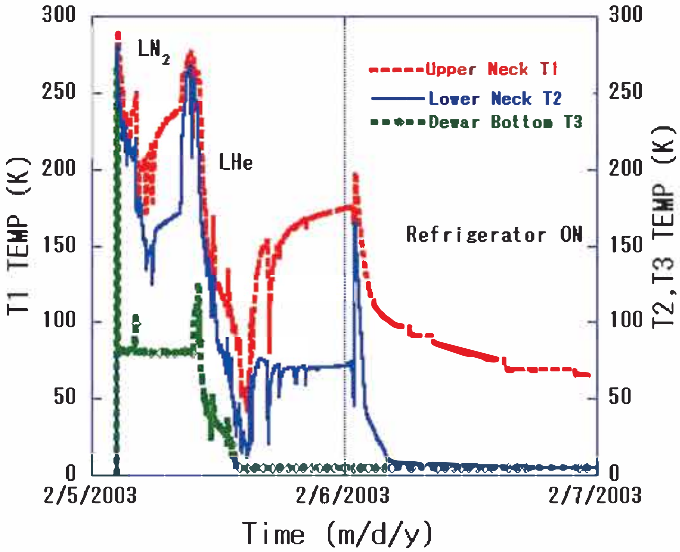

Fig. 3. Initial cool-down curve for the superconducting gravimeter CT(#043). For details of cool the down procedure, see text.

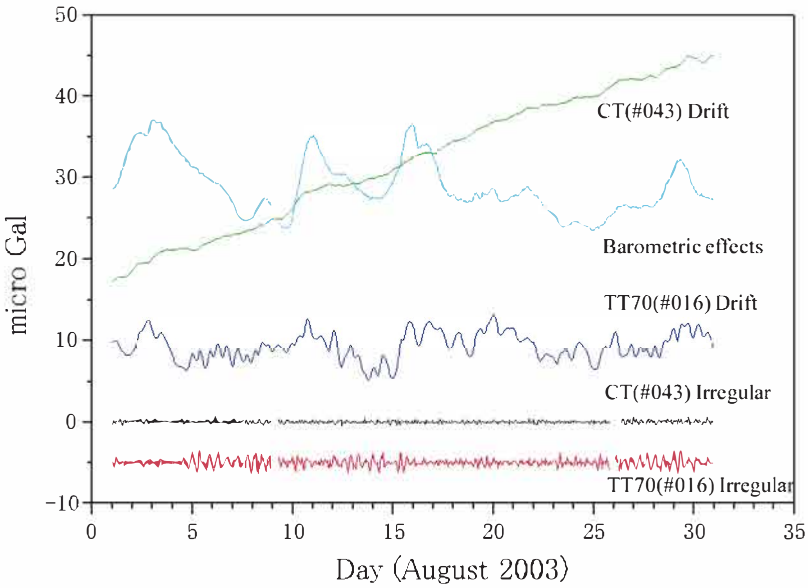

Fig. 4. Comparison of the BAYTAP-G decomposed irregular noise and drift terms between TT70 (#016) and CT(#043).

Fig. 5. A new superconducting gravimeter CT(#043) was placed to the pillar site for routine operation.

linear trend of 24μGal/month (see Fukuda *et al*., 2005). The reason for this rather large drift trend of the CT(#043) is not known yet.

5. A new type diaphragm

Figure 5 illustrates the CT(#043) setting to the pillar site for routine operation. As schematically shown in Fig. 1, the isolation bellows (see open circle part) provides a seal which isolates the Dewar from vibrations of the cold-head. The original diaphragm in CT(#043) is made of rubber and attaches to the gravimeter head on one side while the cold-head support plate is on the other side. However, a rubber diaphragm passes through air molecules as well as helium molecules at room temperature. This inevitably resulted in solid-air growth within the Dewar for the long-term running of the refrigerator. There appeared such solid-air induced vibrating noise from the refrigerator from July 13 after 2 months' operation of the CT(#043). Therefore, instead of the rubber diaphragm, we tried a new type of aluminum-coated polyurethane diaphragm. This material does not pass through helium nor air molecules at any operating temperature. We confirmed that this new diaphragm effectively isolated the vibration noise from the refrigerator cold-head, and that this prevented contamination of solid air into the Dewar for eleven months. Details are discussed in Ikeda *et al.* (2004).

6. Remote monitoring system

The communications satellite (INTELSAT) data receiving system using a 7.6

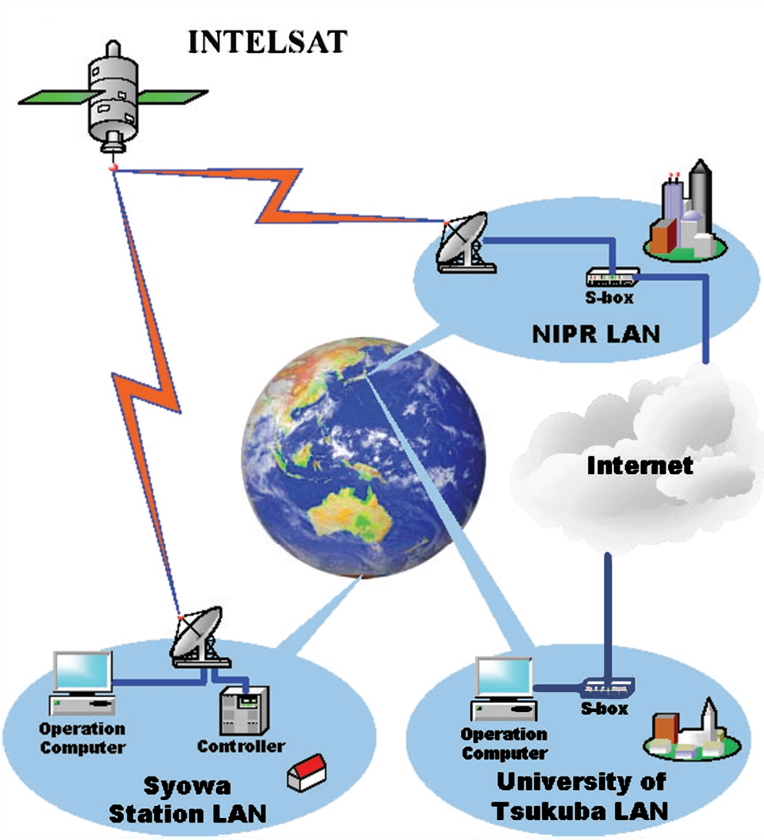

Fig. 6. *Data communication link from Syowa Station to Japan by virtual private network (VPN) using an S-Box.*

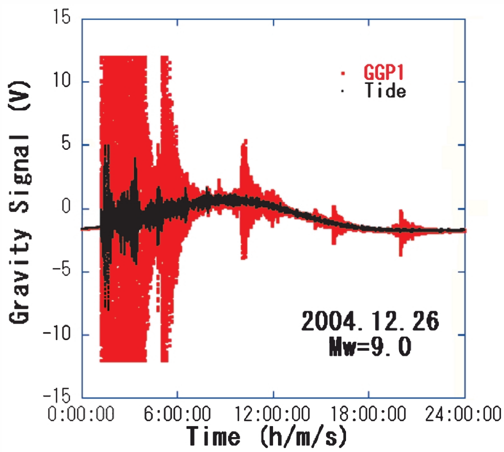

Fig. 7. *Real-time remote monitoring system of CT(#043) recorded the Sumatra Earthquake of December 26, 2004.*

m-diameter parabolic antenna was installed at Syowa Station in February 2004. Figure 6 shows a communication link from Syowa Station to Tsukuba University by virtual private network (VPN) using an S-Box. From August 26, 2004, we started real-time remote monitoring of the CT(#043) diagnostics data such as neck temperatures, tilt compensations, sounds of the cold-head, etc. from Japan by using the above VPN designed by Iimura and Nakashima (1999). Figure 7 shows the GGP1 (Crossley *et al.*, 1999) and tide signals from the Sumatra Earthquake of December 26, 2004; this gives another milestone for successful replacement of TT70(#016) with CT(#043).

7. Conclusions

We succeeded in the installation of a new SG CT(#043) with a cryocooler to replace the former TT70(#016) at Syowa Station, Antarctica. Although the helium gas boils off from the liquid helium bath stored inside the Dewar, the 4K cryocooler can re-condense it. In this manner, the Dewar operates as a closed cycle system without losing coolant so long as electric power is supplied to the refrigerator. We tested an aluminium-coated polyurethane diaphragm instead of the standard rubber one; it proved to well isolate the vibration noise from the refrigerator cold-head, and to prevent the solid air contamination into the Dewar. In addition, a real-time remote monitoring system with Web camera for diagnostics from Japan has also been established.

Acknowledgments

We would like to thank JARE-44 members for kindly supporting our installation work.

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