On-Board Test on the Performance of a Surface Ship Gravity Meter NIPRORI-1

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船上重力計 NIPRORI-1 型の船上における性能試験

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要旨： 1980年に新しく製作した船上重力計 NIPRORI-1 型の性能試験のため，同年9月から10月にかけて砕氷船「ふじ」の内地巡航に同乗した．この試験により，NIPRORI-1 型重力計が南極で使用するに足る十分な性能を保有することが確かめられた．

Abstract: A surface ship gravity meter NIPRORI-1 which was built in 1980 was tested on board the icebreaker FUJI during her cruise around the Japanese Islands from September to October 1980. This test has verified that performance of the new gravity meter is satisfactory as a device to be used for the measurement in the Antarctic region.

1. Introduction

The NIPRORI gravity meter Model-1 is a newly designed surface ship gravity meter which has a main mission of surveying the Antarctic region. Because this gravity meter was developed in 1980 through co-operation between the National Institute of Polar Research (NIPR) and the Ocean Research Institute, University of Tokyo (ORI), it was named 'NIPRORI'. Major points of this meter lie in the gravity sensor and the stabilized platform, the former being a conversion of a precise servo accelerometer for inertial navigation and the latter consisting of a frictionless vertical gyroscope and a follow-up platform (SEGAWA *et al.*, 1981). This meter was tested on board the icebreaker FUJI from September to October 1980, and soon after the test cruise the FUJI set sail for Antarctica with this gravity meter installed.

2. System of the NIPRORI Gravity Meter

Figure 1 shows a total assembly of the NIPRORI gravity meter. This meter

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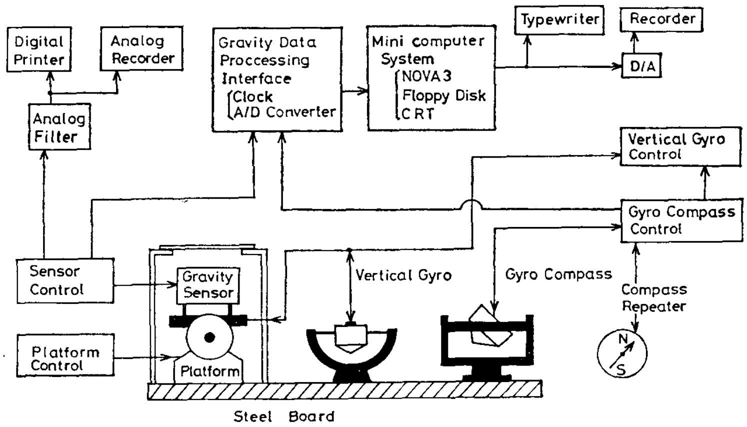

Fig. 1. Total assembly of the NIPRORI gravity meter.

consists of a gravity sensor mounted on a stabilized platform, a vertical gyroscope that controls the platform, a gyrocompass whose signal is used for the latitude correction of the vertical gyroscope and calculation of the Eötvös correction, a mini-computer and an analog filter that process the output from the gravity sensor and record the results. The vertical gyro, the gyro-stabilized platform and the gyrocompass are placed on a steel board in order that they are firmly fixed mechanically.

The gravity sensor used is a servo accelerometer housed in a cylindrical metal vessel about 110 mm long and 50 mm in diameter (Fig. 2). A cylindrical proof mass is attached to a horizontal beam that can swing vertically about one end acting as a flexible pivot. When gravity and/or vertical accelerations cause the beam to deviate from the neutral position, electric current flows into the coils wound around the cylindrical proof mass, and a force produced by electromagnetic interaction between the coils and the magnet acts on the beam so that it returns to the neutral position. Deviation of the beam is sensed by a pickup transformer whose inductance is changed by the movement of a small metal plate attached to another end of the beam. In this way gravity is converted into electric current in the coils, making it possible to measure the gravity through the measurement of the electric current or voltage. This gravity sensor is characterized by linear

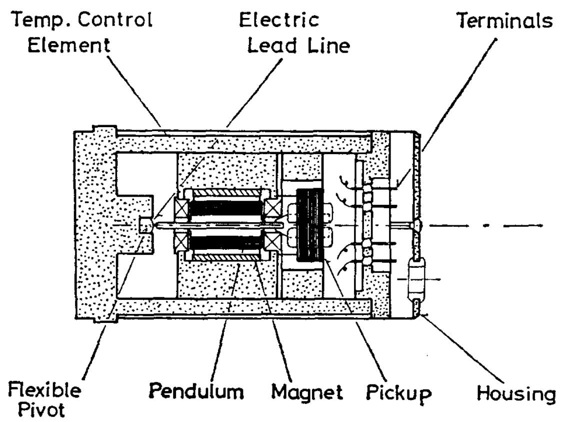

Fig. 2. Servo accelerometer housed in a cylindrical metal vessel.

response and ruggedness. Relative deviation from linearity is less than 10^{-6} under acceleration of ± 300 gals that is caused by the ship's motion. The sensor can stand under the acceleration of ± 10 G and work in any posture.

The stabilized platform (Fig. 3) has an aluminum frame on which the gravity sensor and its electronics are placed. This frame is rotated by a pair of DC torque motors and the angle of rotation is monitored by a pair of 16-bit shaft encorders. The vertical gyroscope shown in Fig. 4 has an accuracy of ± 1 min of arc in verticality in the rolling as large as ± 30 degrees. To the two axes of the vertical gyroscope are attached synchro transmitters which send signals of the ship's inclination to the stabilized platform. According to the signals from the synchros the platform control drives the DC torque motors to keep the platform vertical. Performance of the vertical gyroscope can be seen from Table 1, which was obtained from a laboratory test using a simulator of the ship's motion. Follow-up

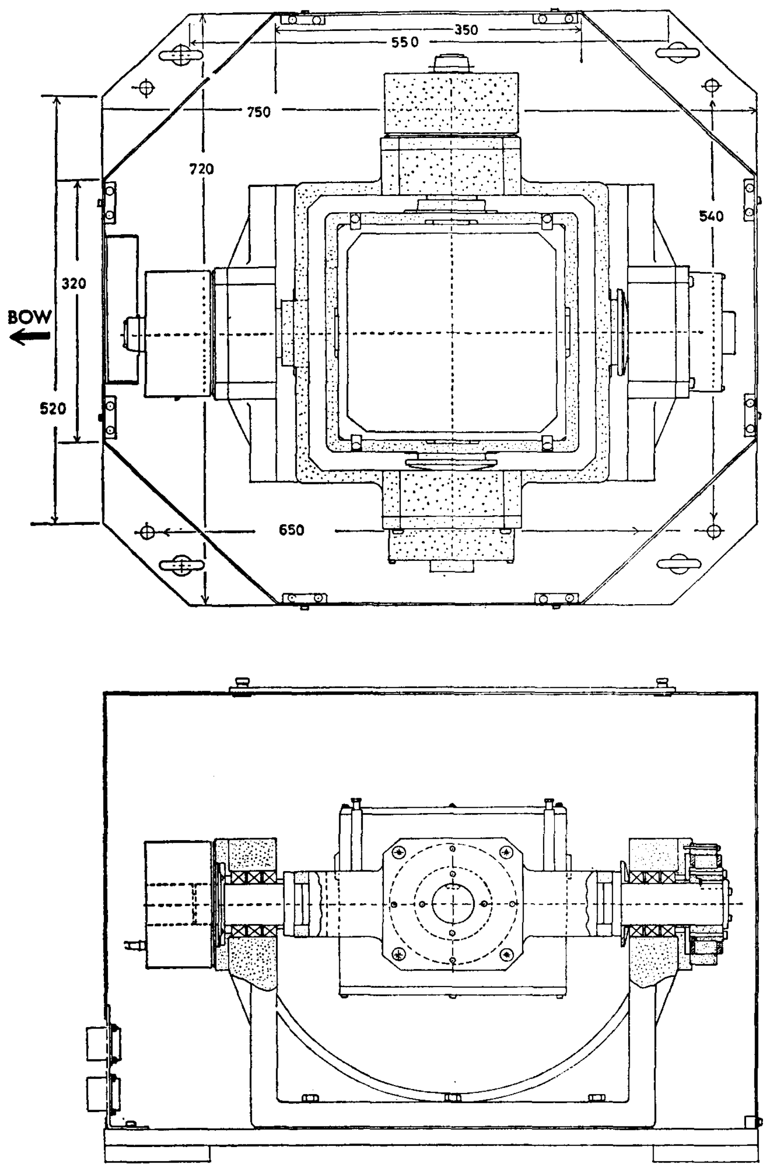

Fig. 3. Stabilized platform.

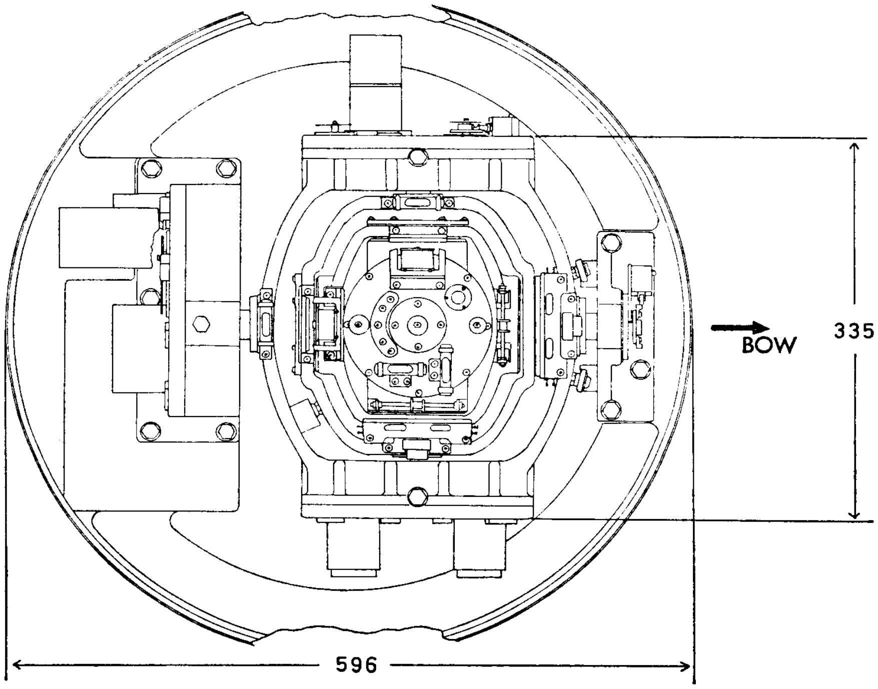

Fig. 4. Vertical gyroscope.

Table 1. Laboratory check on the platform performance. Error means the amount of angle deviation of the platform from the preset angle.

Pitch axis		Roll axis	
Setting angle	Error	Setting angle	Error
−7°	−0.01°	−27°	0.00°
−6	−0.01	−25	0.00
−5	−0.01	−20	0.00
−4	−0.01	−15	0.01
−3	−0.01	−10	0.01
−2	−0.01	− 5	0.01
−1	−0.01	0	−0.01
0	0.00	5	−0.01
1	−0.01	10	−0.01
2	−0.01	15	−0.01
3	−0.01	20	−0.02
4	−0.01	25	−0.02
5	−0.01	27	−0.02
6	−0.01		
7	−0.01		

error of the platform is, in this case, less than ±0.01 degree (±0.6 min of arc).

Signals from the gravity sensor are processed in two ways. The voltage output of the servo accelerometer is introduced into two different lines; one signal is directly sent to a passive RC low pass filter that has a time constant of about

100 s, and the other to a 7-figure digital voltmeter which converts the output voltage into a digital form at every 0.2 s. The analog data are recorded on a strip-chart recorder with a full scale of 200 mgal continuously. The digital data are read and processed by a mini-computer (NOVA 3 system) and filtering of noise acceleration as well as correction for the Etövös effect are conducted. The final output from the computer is displayed on a CRT display, and at the same time it is printed and punched on paper tapes at intervals of 1 or 2 min.

3. Test on Board the Icebreaker FUJI

The NIPRORI gravity meter was set on board the icebreaker FUJI in September 1980. The place where the gravity meter was installed is shown in Fig. 5, and its photographic view is shown in Fig. 6. During the test cruise the icebreaker FUJI which started from Yokosuka, Japan went around the southwestern part of Japan, while visiting Naha, Hosojima, Tokuyama and Hibi, and back to Yokosuka.

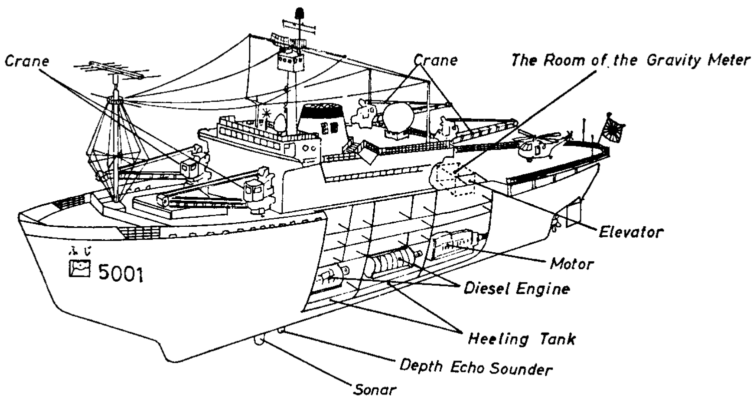

Fig. 5. The icebreaker FUJI showing the place where the gravity meter was installed.

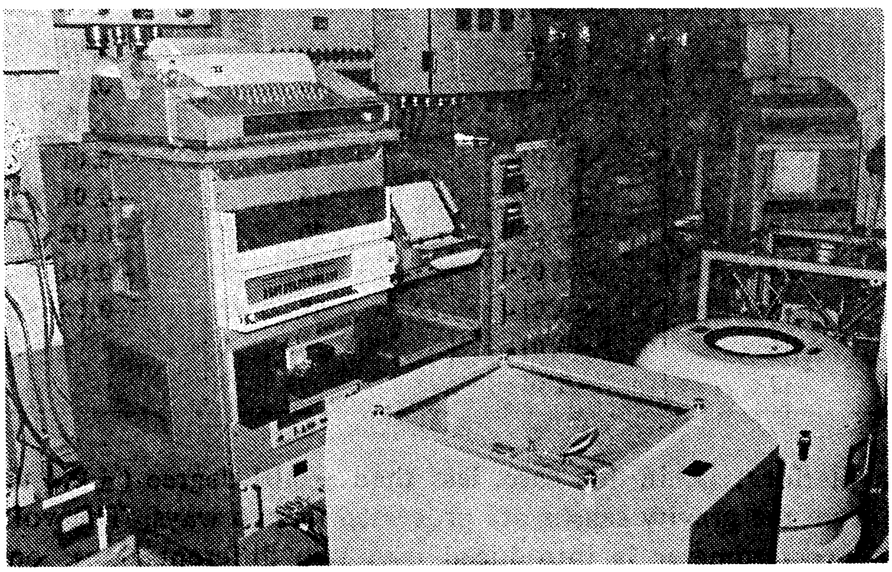

Fig. 6. Photographic view of the NIPRORI gravity meter.

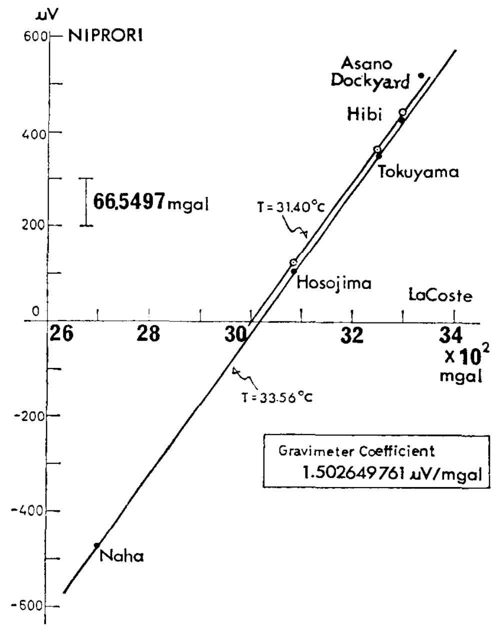

Fig. 7. Scale factor (μV/mgal) of the NIPRORI gravity meter is obtained from the relationship between the output from the NIPRORI and the reading from the LaCoste & Romberg land meter. The scale factors were checked for two different temperature points T=31.40° C (open circles) and 33.56° C (solid circles), and it was found that the ambient temperature did not affect them.

It was found that during the cruise the gravity value was significantly affected by ambient temperature, although the gravity sensor itself was regulated at 60 ±0.01°C. The relationship between the gravity readings and the ambient temperature can be expressed as follows:

$$dG/dT = 0.2497156(T-54.3418)\ \mathrm{mgal/°C}.$$

This formula shows that the temperature coefficient depends on the temperature and that it becomes zero at the temperature of 54.3418°C. At normal temperature (25°C) the coefficient is −29.6 mgal/°C, and the temperature effect decreases as temperature rises until it reaches 54.3418°C. Therefore, in order to avoid this effect the electronic circuit that is closely connected to the sensor was also regulated in temperature. This improvement was very successful.

The scale factor of the gravity meter is seen from Fig. 7, which was obtained by comparing sea gravity meter readings with readings of a LaCoste & Romberg gravity meter Model G at the piers where the ship was moored. From this experiment a scale factor 1.502649761 μV/mgal was obtained. This factor does not change with the change of the ambient temperature.

Drift characteristics of the meter during this test cruise were not definitely found, because the scale factor of the gravity meter had not been accurately known beforehand. However, as seen from Fig. 7, the linear relation between the readings of the sea gravity meter and those of the land gravity meter was fairly well, suggesting that there was little drift of the meter, or else that there occurred

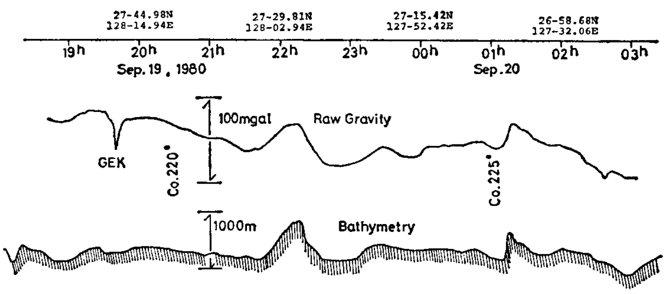

Fig. 8. An example of the measurement of gravity using the NIPRORI gravity meter. This measurement is part of the data obtained along the track of Fig. 9 between the Amami-Ohshima and the Okinawa Islands. A spike-like change marked by GEK shows an apparent change of gravity caused by the Eötvös effect in case of current measurement conducted using a Geoelectric Kinematograph. Marks Co. 220° and 225° indicate ship's heading.

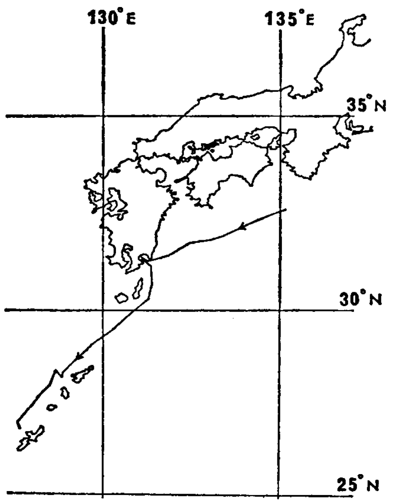

Fig. 9. Ship's track on which gravity was measured.

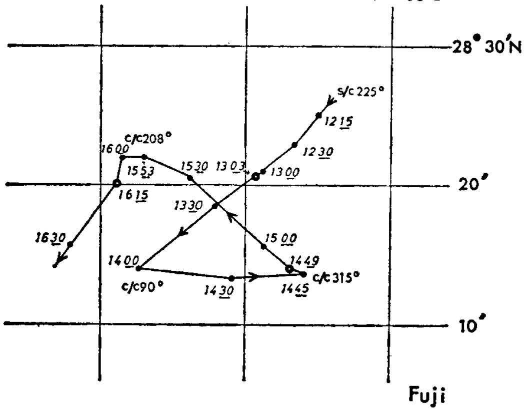

Fig. 10. Ship's track when gravity measurement was checked at the crossing of the track.

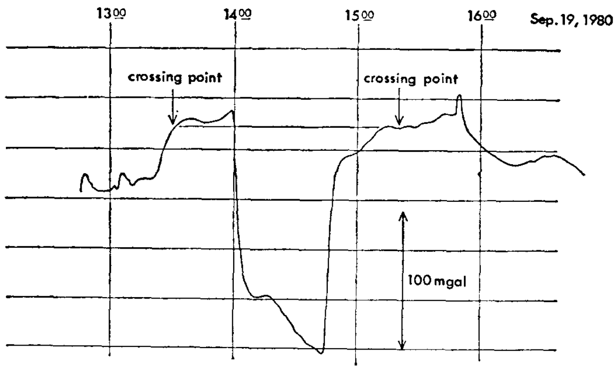

Fig. 11. Gravity change measured along the track shown in Fig. 10.

entirely linear drift with time. This problem has remained to be investigated further.

Figure 8 shows an example of measured gravity and bathymetric profiles that are selected from the results obtained in the track of Fig. 9. Since this is a raw gravity which includes effects from the Eötvös, bathymetric and latitude changes, they have to be removed before obtaining gravity anomalies. These changes, however, are evidence showing normal performance of the gravity meter.

In order to check repeatability of the meter the measurements were compared at a crossing of the ship's tracks shown in Fig. 10. This crossing is expected to be the same point where gravity was measured twice. The gravity change near this crossing is shown in Fig. 11. When two points of gravity that correspond to the measurements at the crossing of the tracks are compared, it is found that the coincidence of the two values is perfect. The results from this experiment will assure that the performance of the present gravity meter is satisfactory.

Acknowledgments

The authors' thanks are due to the staff of the National Institute of Polar Research, particularly to Director and Professor Takesi NAGATA and Professor Yoshio YOSHIDA, who encouraged us constantly during the development of the present gravity meter.

Reference

SEGAWA, J., KAMINUMA, K. and KASUGA, T. (1981): A new surface ship gravity meter "NIPRORI-1" with a servo accelerometer. J. Geod. Soc. Jpn., **27**, 102–130.

(*Received December 12, 1981; Revised manuscript received February 24, 1982*)