DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Record 1973/72

SOVIET GRAVITY TIE FROM MOSCOW TO SYDNEY 1972

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P. Wellman, J.C. Dooley, and B.C. Barlow

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SUMMARY

Scientists from the Soviet Union made a successful gravity tie between Moscow and Sydney in December 1972 using five sets of pendulum apparatus. The pendulums used are of Soviet design, and are among the most accurate in existence.

1. INTRODUCTION

Absolute determinations of gravity in terms of the fundamental units of time and distance are difficult and time-consuming to make with great accuracy. They have been made at only a dozen sites throughout the world, in Europe, North America, Colombia in South America, and Sydney in Australia. These absolute gravity measurements define the adopted datum of the unit of acceleration. Differences in acceleration can be measured accurately using less sophisticated relative pendulum apparatus. For relative pendulums, the physical lengths are unknown but constant, and the periods at two sites (T1, T2) can be used to calculate accurately the difference between the gravity at the sites (g1, g2) as $g1/g2 = T2^2/T1^2$. Relative pendulum apparatus can be used to compare absolute determinations of gravity, and can be used to construct an acceleration scale by establishing acceleration at group sites that range in gravity. A third type of gravity measuring instrument, the gravity meter, does not help to define the scale and datum, but is quick to use and has a relatively high precision. Gravity meters can be used to check acceleration scales for consistency, and to connect these scales so as to form a world network of gravity stations of known scale and datum. The more accurately known points on this world network comprise the First Order World Gravity Network (FOWGN).

The absolute measurement of gravity at Sydney was carried out by staff of the National Standards Laboratory, Sydney, within the laboratory building (Bell et al., 1973). The method used was free rise and fall of a metal corner reflector through horizontal planes defined interferometrically. To evaluate this absolute gravity measurement, the gravity difference between the National Standards site and sites in Europe must be measured, and this can be done most accurately by use of relative pendulum apparatus. The Soviet Geophysical Committee has been systematically tying sites to the Moscow site. The tie would have the additional value that it would strengthen the First Order World Gravity Network in an area in the eastern hemisphere where it was weak. This Record describes the logistics and apparatus of the 1972 Moscow-Sydney relative pendulum tie made by the Soviet Union.

2. DESCRIPTION OF THE SOVIET PENDULUM PARTY VISIT TO SYDNEY

The pendulum party consisted of six Russians (only one speaking English), who had five sets of pendulum apparatus with a total weight of about 1000 kg. The party arrived in Sydney on 15 December 1972, and left for Moscow on 26 December with the Australian part of the work complete. The equipment is expected to measure the gravity difference between the

Moscow and Sydney absolute gravity sites with a standard deviation of 0.04 mGal. Results will be sent to the Bureau of Mineral Resources when available.

Special transport arrangements for the personnel and equipment were made. When travelling by air, the Russians carried within the first-class section of the aircraft cabin (on rubber matresses) the quartz crystal oscillators, and the pendulums clamped in swinging chambers. From the beginning to the end of the survey, the pendulums were under vacuum (0.5-1 mm Hg) and kept at constant temperature. Ni-Cd batteries supplied enough heating power for three days' travel. The less sensitive electronic equipment was carried as excess baggage. Personnel travelled economy class. Satisfactory ground transport was provided in Sydney by a two-ton walk-through truck with drived provided by the Department of Stores and Transport.

Customs clearance was facilitated by prior application for pre-release of the scientific equipment under section 40AA of the Customs Act. The equipment was released on production of this document, and 'entry' of the equipment on 18 December was quick. There was no check ng of the equipment on exit, as at a later date a government officer could sign that the equipment had left the country.

The Russians were in Sydney for eleven days. During the first half of the period equipment was set up and tested, and during the second half measurements were made. The equipment suffered only minor damage in travelling from Moscow to Sydney, and the Russian spare parts were adequate. The National Standards Laboratory basement site was satisfactory as regards area, vibration, and temperature. There were no power failures, and only two short air-conditioning failures. Four pendulums gave good results and the fifth gave slightly anomalous results, possibly because of slight movement of the floor support. A Russian scientist was with the equipment day and night during the whole visit, and the National Standards Laboratory chief considered it necessary for an officer of the Bureau of Mineral Resources (BMR) to be in the building with them at all times.

The Russian party and two or three supporting BMR personnel stayed the eleven days at International House, a student hostel of University of Sydney, about one kilometre from the National Standards Laboratory. Everyone considered that the convenience of being in easy walking distance of the work site more than offset the inflexibility of the student hostel. The Russians visited the N.S.W. Art Gallery, the Zoo, two beaches, BMR, the Division of National Mapping, and the Soviet Embassy. Relations between the Russian scientists and Australians were good at all times, and the Soviet Embassy was helpful. While the work was in progress there were short supervisory visits by J.C. Dooley and B.C. Barlow of BMR.

The most serious problem throughout the whole survey was communication with the Russians, even though one Russian spoke some English, a Russian speaking BMR scientist was in the group during most of the work, and an NSL interpreter was available during normal working hours. Problems associated with the arrival of the Russian party were that BMR was not notified of their final arrival flight and the arrangements required for transport of their equipment. On the Russians' departure, problems arose from their departing during the Christmas/New Year public holidays, from a misunderstanding about how they wanted their equipment sent out, from lack of confirmation of the Aeroflot reservations on their tickets, from the rigid international flight embarkation procedures, and from the long time the Russians needed to load their equipment personally.

3. PERSONNEL

Arrangements for the visit were made by:

Dr Yu. D. Boulanger

Vice President
Soviet Geophysical Committee
Academy of Sciences of the USSR
Molodezhnaya 3, Moscow B-296.

Soviet personnel making the pendulum tie were:

Dr Y.A. Slivin (leader)
Mr N.A. Gusev
Mrs A.G. Goidysheva
Mr N.N. Korolev
Mr I.A. Sas
Mr A.P. Metlin

Central Scientific Research Institute of
Geodesy, Aerosurvey and Cartography,
Board of Geodesy and Cartography
4-B, V-Pervomayskaya
Moscow, E-264.

Australian supporting personnel from the Bureau of Mineral Resources were:

Dr. P. Wellman
Mr W. Anfiloff
Miss R.B. Jones

Australian supporting personnel from National Standards Laboratory were:

Dr D.L.H. Gibbings
Mr A. Sorokin

4. IMPORTANT FEATURES OF THE SOVIET RELATIVE PENDULUM APPARATUS OVM

The OVM pendulums appear to give better results than any other pendulum apparatus in the world. This is thought to be due to the many good and unique features of the apparatus. Several features of the apparatus make it look antiquated (valve electronics, binary counting, and quartz crystal clocks) but these features do not detract from its operation.

Good features of the design are:

(a) Hysteresis effects are avoided by never removing the pendulums from the swinging chambers, which are kept evacuated and at constant temperature.

(b) Humidity effects on the agate flats and knife edges are avoided by the same procedure. Note the unusual choice of agate as the knife edge material.

(c) The knife edges are never lowered onto the flats when the pendulum is vertical; the pendulum bob is always drawn to one side (ready to start swinging) and then lowered.

(d) After the swing has started the amplitude is allowed to decrease before measurement of period commences so that that portion of the knife edge which has been lowered on to the flat is not used during the measurement.

(e) Period is always measured over the same range of amplitude of swing; or at least the starting amplitude is always the same with only minor variation in the final amplitude.

(f) Period is always determined for the same number of swings (4096?).

Features of the apparatus which are poor, but which do not appear to effect the results are:

(a) Use of agate for knife edges.

(b) Period is timed between a single starting instant (pendulum mirrors parallel) and a single final instant (pendulum mirrors again parallel).

5. TRANSLATION OF PAMPHLET ON SOVIET RELATIVE PENDULUM APPARATUS OVM

Pamphlet issued by:

Central Scientific Research Institute of Geodesy, Aerosurvey and Cartography (TsNIIGAIK),
Directorate of Geodesy and Cartography,
Soviet Ministry of USSR.

Translation by J.C. Dooley

Designation

The vacuum pendulum apparatus OVM is intended for relative measurements of the force of gravity at control gravimetric points of a high degree of accuracy, and to set up calibration ranges for gravity meters.

Distinctive features of the OVM apparatus are:

- use of two quartz-metallic pendulums with tungsten bobs;
- the pendulums are kept at constant temperature by thermostatting, not only at the gravimetric stations but also during transport; the residual air pressure inside the apparatus is 0.5 to 1.0 mm of mercury;

- full automation of the controlling apparatus, with remote control from a special panel;
- use of an electronic counting device for determination of the periods and amplitudes of oscillation of the pendulums;
- high accuracy of lowering the pendulums on the supporting flats; this lowering is carried out with the pendulums in an inclined position;
- use of optical multiplication to increase the resolving power of the photo-recorder and for consolidation of the construction of the photo-electric transducer with the pendulum apparatus;
- use of a single reversible electric motor and a free-wheeling clutch to successively arrest, centre, set pendulum amplitude, and start the pendulums in antiphase.

The probable economic effectiveness from use of the apparatus on the supporting USSR gravimetric station network amounts on the average to 50,000 roubles per year for one set of apparatus.

Technical characteristics

Accuracy of measurement of the difference in the force of gravity between control and other stations by direct connexion using one set of equipment (consisting of three apparatuses) irrespective of distance and gravity interval $\pm$ 0.15 mGal.

Accuracy of the period of oscillation of a pendulum with the aid of the photo-electric recorder over 15-minute period 1.0×10^{-8} s.

Accuracy of a single determination of the amplitude correction 2×10^{-8} s.

Initial amplitude of oscillation of the pendulums $40' \pm 0.3'$

Temperature coefficient of the pendulums 20×10^{-8} s/degree

Air pressure coefficient 15×10^{-8} s/mm Hg

Accuracy of measurement of temperature inside the apparatus 0.03°

Accuracy of measurement of air pressure inside the apparatus 0.03 mm Hg

Constancy of landing of the knife of the pendulums on the flat
0.5 - 1.0 m

Stability of the quartz oscillator $(1-3) \times 10^{-8}$ s.

Coefficient of thermostabalization of the pendulum chamber
70

Total error of a single value of reduced period of oscillation, including error of arresting $\pm(2-4) \times 10^{-8}$ s.

Weight of apparatus (without packing)

pendulum apparatus	32 kg
photo-electric recorder	26 kg
control panel	13 kg

Weight of a set of equipment, consisting of three apparatuses
213 kg

Dimensions of the apparatus (without packing)

pendulum apparatus	380mm x 380mm x 560mm
photo-electric recorder	360mm x 480mm x 315mm
control panel	385mm x 270mm x 230mm

Area required for observation $8\ m^2$.

<u>Principle of action and brief description of the apparatus</u>

The OVM apparatus (Fig. 1) consists of a two-pendulum thermostatted evacuated apparatus, in which the oscillations of pendulums are recorded by the method of Vening-Meinesz with the use of an electronic counting device.

Arresting, centring, setting of amplitude of the pendulums, and starting them in opposite phases are accomplished in the required order with the aid of a single reversible electric motor. To achieve this objective, the rotor of the motor rotates anticlockwise and its rotation is transferred through a coupling with free play to the corresponding device. The pendulums are fastened in the clamping device with clockwise rotation of the rotor.

In order to ensure preservation of the pendulum knife-edges, the pendulums are lowered onto and raised from the supporting flats in an inclined position, so that at the moment of landing and uplift the angle of inclination of the pendulums is about twice the initial amplitude. Before arresting the pendulums are stopped by a special device.

The photo-electric transducer of the pendulum oscillations is fixed directly to the main base of the pendulum apparatus. Such compact dimensions became possible thanks to the application of optical multiplication of the angle of inclination of the pendulums (in Fig. 2 are shown four multiple reflections). The optical system (Fig. 2) enables the motion of the ray to be transferred from the illuminating lamp to the photo-multiplier FEU-31.

Three slits are located in the receiving diaphragm for measurement of the amplitudes and periods of the pendulums. In front of the diaphragm is located a shutter, closing off the control slit and opening the outer slits for measurement of amplitude of oscillation of the pendulums, and closing the outer and opening the central slit for determination of the period.

A bell-shaped impulse of duration 2-3 ms from the photomultiplier FEU is fed to the shaping cascade of the photo-electric recorder where it is formed into a starting sharp pulse of positive charge and duration about 10 s. An auxiliary outlet device takes off the positive charge from a two-channel amplifier-limiter and allows the next impulse to pass through to the main outlet device, which opens the two starting cascades. Two counting devices simultaneously begin to count: one counts the number of oscillations of the quartz oscillator, and the other the number of oscillations of the pendulum. The count is stopped at a predetermined number of pendulum oscillations. By dividing the corresponding indications of these two counting devices, the period of oscillations of the pendulums is determined.

For determination of the amplitude of oscillation of the pendulum, one of these counting devices measures the interval of time between two successive impulses originating from the passage of the light ray through the outer slits.

Instruments are located on the control panel by means of which constant temperature of the pendulums is maintained, reversing of the electric motor is achieved, the brightness of the illuminating lamp is regulated, and the residual pressure of the air and temperature in the thermostatted volume are measured.

The apparatus is levelled by an autocollimating level fixed on a special agate flat, which is in the same plane as the main flats of the apparatus.

Set of equipment

A set comprises three pendulum apparatuses, consisting of some identical pendulums and some pendulums of different types. Three constructions are available:-

Quartz-metallic pendulums with tungsten bobs, period 0.5s;

Quartz-bronze minimum pendulums with period 0.5s;

Quartz-bronze with tungsten bobs, with period 0.75s (lengthened).

For each pendulum apparatus is provided a photo-electric recorder of periods and amplitudes of oscillation of the pendulums, and a control panel. Also included in the set is an auto-collimating level, a vacuum pump, and a set of spare parts. Also required for operation are an electric oscillograph, a means of checking the frequency of the quartz oscillator feeding into the photo-electronic recorder, a source of mains power at gravity stations, and a portable power source during transport.

The apparatus was developed in the gravimetric laboratory of the Central Scientific Research Institute of Geodesy, Aerosurvey and Cartography and constructed in the experimental workshop of the optical-mechanical factory of TsNIIGGAIK. The experimental form was devised in 1965-1966.

The apparatus is covered by copyright Certificates, No. 172067, 163540, and 162329.

6. REFERENCES

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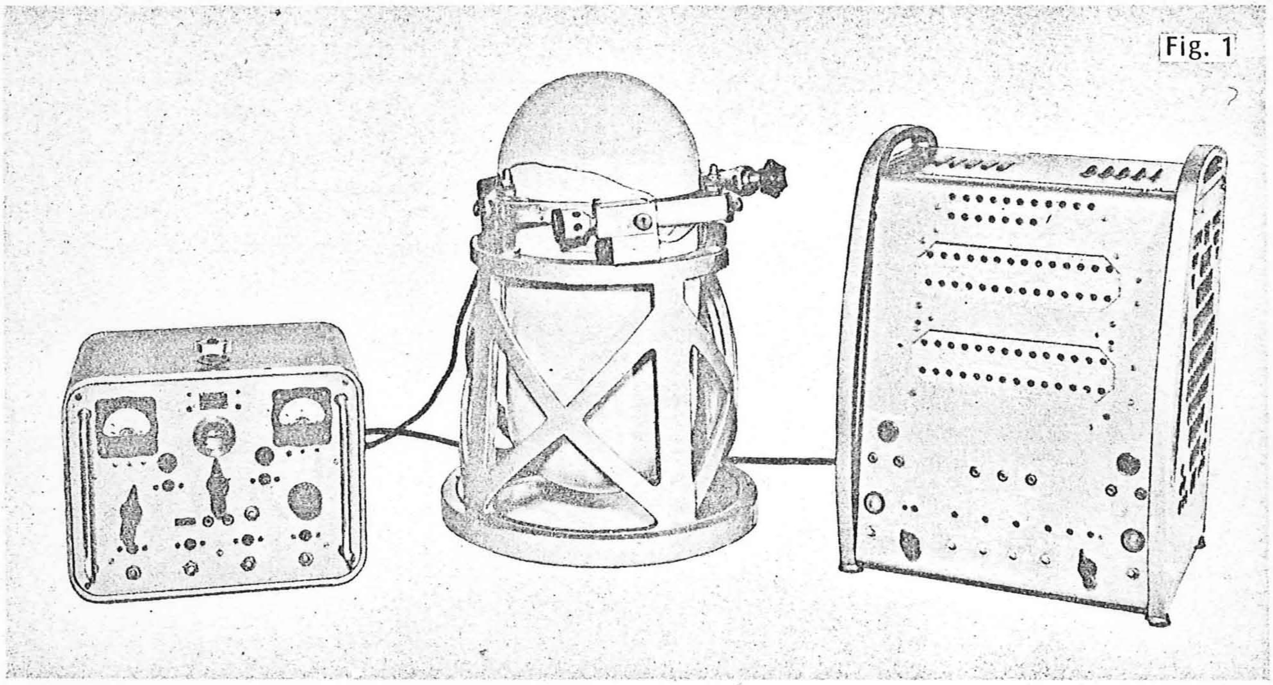

Fig. 1

BLOCK DIAGRAM

Fig. 2