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DETERMINATION OF GRAVITY ACCELERATION AT SYDNEY WITH PENDULUM APPARATUS

by

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Central Scientific Research Institute of Geodesy, Aerial Survey, and Cartography.

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FOREWORD

The absolute measurement of gravity at Sydney was carried out by the National Standards Laboratory, Sydney. In order to evaluate this absolute measurement and tie it to gravity stations forming the First Order World Gravity Network, six Russian scientists from the Soviet Geophysical Committee visited Australia in December 1972.

The Russian text of a report describing the operation and a translation into English were provided by Professor Yu. D. Bonlanger on his recent visit.

The Russian text is to be published elsewhere. The English translation (which has been subject to minor editing within the Bureau) is reproduced here as a BMR Record by agreement with Professor Boulanger.

INTERPRETATION OF GRAVITY ACCELERATION AT SYDNEY WITH PENDULUM APPARATUS

In accordance with obligations undertaken by the Soviet Union within the frame of the International Association of Geodesy, a program of research is being carried out jointly by the Soviet Geophysical Committee of the USSR Academy of Sciences and the Central Research Institute of Geodesy, Aerial Surveying and Cartography of the Chief Administration of Geodesy and Cartography of the USSR; the program includes, in particular, a determination of gravity acceleration in relation to Potsdam at such stations for which absolute gravity determinations have already been made.

The purpose of the work described in this paper was to get a more precise value of the correction in the Potsdam system on the basis of absolute determinations made at Sydney.

In December 1972, an expedition of the Central Research Institute of Geodesy, Aerial Survey and Cartography (TZNIIGAIK) carried out determinations of gravity acceleration at Sydney in relation to Potsdam with the help of a complete pendulum apparatus OVM.

The gravimetric connection described was accomplished in accordance with an agreement concluded in 1972 between Dr N.H. Fisher, Director of the Bureau of Mineral Resources of Australia, and Yu. D. Boulanger, corresponding member of the Academy of Sciences of the USSR, Vice-president of the Interdepartmental Geophysical Committee of the USSR.

1. Work organization

With the aim of simplifying the organization of the work, all measurements were made from Moscow (Ledovo) because Δg between Potsdam and Moscow (Ledovo) had already been determined with apparatuses of different types, and a mean square error $\pm$ 0.019 mGal had been obtained. Such a high accuracy of the determination of Δg Potsdam-Ledovo makes it possible to execute the measurements from Ledovo. In this case the accuracy of tying Sydney to Potsdam is essentially determined by the error of connecting Ledovo to Sydney.

The pendulum equipment was transported in passenger planes, and from airports to points of observations - in motor trucks. The equipment was mounted on porolon buffers, which safety measure prevented it being damaged by sudden jolts or blows.

During transportation, the thermostats of the equipment were continually connected to the electrical system of the aircraft or to accumulators, and during prolonged stops, connected to an alternating current source.

At Sydney, the observations were executed on the gravity station No. 5099-9905 located in room No. 37 of the National Standards Laboratory at Sydney University. At this same place absolute gravity determinations had been made in 1971 (6).

The following sequence of observations was accepted for establishing the gravimetric connexion: Moscow (Ledovo) I - Sydney - Moscow (Ledovo) II.

In order to raise the accuracy of measurements, a double program of observations was carried out at Station Sydney using all instruments of the set.

The measurements were executed during the following calendar periods:

Moscow (Ledovo) I	2- 5 December 1972,
Sydney	17-25 December 1972,
Moscow (Ledovo) II	29-31 December 1972.

The working group charged with the realization of this gravimetric connection included the following specialists:

Slivin, Yu.A	-	cand. techn.sci., head of the group,
Gusev, N.A.	-	senior engineer
Korolev, N.N.	-	engineer
Goydysheva, A.G.	-	engineer
Sas, I.A.	-	engineer
Metlin, A.P.	-	senior technician

When working at Sydney, the expedition obtained much assistance from the members of the staff of the Bureau of Mineral Resources, namely - Dr P. Wellman, W. Anfilof and Miss R. Jones; and also from Dr D. Gibbins and O. Sorokin - staff members of the National Standards Laboratory.

2. The equipment

All measurements were made with the pendulum equipment OVM (Fig. I) designed at the TZNIIGAIK. The principal peculiar features of these instruments are the following:

- a complete OVM instrument consists of five two-pendulum apparatuses equipped with quartz-metal pendulums of different construction and of different oscillation periods (S = 0.5 sec. and S = 0.75 sec.);

- the pendulums are permanently mounted within thermostatted and evacuated apparatuses;

- in order to raise the accuracy of registration of the periods and amplitudes of oscillation of the pendulums, optical multiplication of the deflection angle of a fictitious pendulum was used;

- arresting, centring, blocking for transportation, and fixing the amplitudes of the pendulums for successive automated starting are effected by means of a single small electric drive;

- setting of the pendulums down onto their respective supporting plates and raising therefrom is done in a tilted position of the pendulums; the centring and arresting devices ensure a uniform lowering of the pendulums onto their supporting plates with an accuracy higher than I mkm;

- the equipment is provided with an automated remote control from a special panel;

- a photo-electronic registration system is used, which permits both the period and amplitude of oscillations of a fictitious pendulum to be obtained with the help of a counting device.

When measuring the oscillation period of a pendulum, a pulse from a photo-electronic multiplier (FEU) is always generated at those moments of time when the phase of the pendulums is near 0° or 180°. The starting pulse opens the count of two counters (Fig. 2), one of which counts the oscillations of the pendulums and the other those of a quartz resonator (100 kHz). After a certain number of oscillations of the pendulum (preselected and set on the registering device), the next pulse from the pendulum stops the counter that counts the oscillations of the quartz resonator. Satisfactory accuracy of measurements (with photo-electronic registration), was ensured by using a special method of tying the starting pulse to the centre of the bell-shaped input pulse.

The accuracy of determination of any time interval between two output pulses from the pendulums is ± 14 μsec, which enables the oscillation amplitude of the pendulums to be determined with an error ± 0.6". In this case, the time intervals between two consecutive pulses are measured by the photoelectronic registering device; the said pulses correspond to the moments of deflection of the pendulums from their equilibrium position by the angles $+\alpha$ and $-\alpha$.

Tests carried out in laboratory conditions have shown that the period of ascillation of the pendulums can be determined with an accuracy ± 0.5 . 10^{-8} sec. in 20-25 minutes of time. The duration of one set of observations is 35 minutes (4096 oscillations).

As a standard of frequency, a group of quartz generators (1024 kHz) is used, the thermostats of which are continually connected with a dry storage battery.

The complete set of pendulum equipment includes also all necessary accessories, namely: a mechanical vacuum pump; an oscillograph for tuning up and checking the operation of the equipment, and a number of storage batteries.

3. Results of Measurements

The principal features of the pendulums used in this investigation are given in Table 1.

Pendulum instrument No.	Pendulums NN	Approximate period (sec.)	Barometric coefficient (10^{-8} sec./ mm Hg)	Temperature coefficient (10^{-8} sec./1°C)
1	2	3	4	5
6101	502.504	0.492	9.3 ± 0.3	8.9 ± 0.3
6102	T_1, T_2	0.495	8.9 ± 0.1	44.3 ± 0.2
6301	4a, 5a	0.483	10.0 ± 0.2	6.1 ± 0.5
6302	4, 5	0.739	21.3 ± 0.4	2.7 ± 0.8
6303	1, 2	0.485	18.9 ± 0.7	2.3 ± 0.4

The period of the fictitious pendulum was determined from the formula

$$S = S' + \Delta S_a + \Delta S_B + \Delta S_t + \Delta S_f + \Delta S_\delta + \Delta S_H + \Delta S_{☉☽}$$

where S' is the value of the oscillation period of the fictitious pendulum obtained with the help of a photoelectronic registering device.

ΔS_a - correction for amplitude

ΔS_B - correction for (barometric) pressure,

ΔS_f - correction for the variation of frequency of quartz standards,

ΔS_t - correction for temperature,

ΔS_δ - correction for lack of symmetry,

ΔS_H - correction for non-isochronism,

$\Delta S_{☉☽}$ - correction for tidal influence of the Moon and Sun.

We shall not dwell at length on the above corrections, which are well-known; instead we will mention only some special features of the method used for determining corrections for amplitudes and lack of symmetry. [1].

When adjusting the pendulum instruments OVM, constant initial conditions of observation are ensured, namely:

$$S_2 - S_1 = \pm 10^{-7}\ \text{sec}, \quad a_2 - a_1 = \pm 0{,}5,$$

$$\phi_2 - \phi_1 = 180° \pm 1°, \quad \lambda_2 - \lambda_1 = 1.10^{-6},$$

where S_1, a_1, ϕ_1, λ_1 and S_2, a_2, ϕ_2, λ_2 are, respectively, the periods, amplitudes, phases, and logarithmic decrements of damping of the first and the second real pendulums. Therefore, the correction ΔS_a was determined from measurements of the amplitude (a) of the ficititious pendulum only:

$$\Delta S_a = \frac{S}{64} a^2$$

As already stated above, the pulse from the FEU must be always generated at such moments of time when the phase of the pendulum is the same. With damped oscillations the pendulum phase at the end of measurements is not, in general, equal to that of the start. Therefore, a correction for lack of symmetry (i.e. for the non-symmetric location of points that correspond to the range of motion of the pendulum in relation to the entrance slit in the diaphragm) must be introduced into the measured period of pendulum oscillations. When adjusting the optical system of the instrument, the value of the indicated correction must be carefully checked at every one measurement of the oscillation period of the pendulum, so that it should not exceed $\pm$ 0.02.10^{-8} sec. In this case it may be neglected.

The conditions under which the observations of the periods are made have a great influence on the quality of the results obtained, and characterize the extent of elimination of various errors. Table 2 gives - for each program and each instrument - the mean values of amplitudes of the fictitious pendulum together with corrections for amplitude, temperature, and pressure of residual air within the instruments during the measurements. The differences of the mean values at the initial station and the station under observation are small, which in a large measure contributes to elimination of the influence of these factors on the results.

In order to decrease the influence of microseisms and various vibrations, no less than six periods of the fictitious pendulum were measured in each program of pendulum observations. In the intervals between measurements the pendulums were always arrested.

The mean values of periods obtained after introduction of the necessary corrections, and their mean-square errors, are shown in Table 3.

Table 4 gives the gravity increments for each instrument. Under every Δ g value the corresponding mean-square errors are written, being determined according to a method used by the TZNIIGAiK [5]. In the last column the weighted mean Δg value between Sydney and Moscow (Ledovo) determined with a mean-square error $\pm$ 0.06 mGal is given. Table 4 contains also the arithmetic mean value of gravity acceleration. The error of this mean value was, however, obtained only from internal consistency of the instruments during the current series of measurements.

The weighted mean was accepted as a final value of Δ g between the stations.

As a result of the measurements the following value of the gravity increment between Moscow (Ledovo) and Sydney was obtained:

$$\Delta g = -1879.54 \pm 0.06 \text{ mGal}$$

From these measurements the gravity acceleration at Sydney can be computed.

TABLE 2. CONDITIONS OF OBSERVATIONS

Stations and NN of programs	Amplitude minutes			Correction for amplitudes 1.10^{-8} sec.	Temperature ^0C	Pressure mm Hg
	Starting	Initial	Final			
			Instrument 6101			
Ledovo I	47.5	47.0	43.3	-531.5	39.95	0.87
Sydney I	47.4	47.0	43.2	-530.2	39.90	0.90
Sydney II	47.4	47.0	43.2	-530.1	39.95	0.91
Ledovo II	47.4	47.0	43.2	-529.4	39.85	0.92
			Instrument 6102			
Ledovo I	34.5	34.2	31.9	-285.7	40.12	0.92
Sydney I	34.5	34.2	31.7	-284.8	39.88	0.90
Sydney II	34.5	34.2	31.5	-284.4	39.92	0.92
Ledovo II	34.5	34.2	31.3	-283.8	40.00	0.92
			Instrument 6301			
Ledovo I	44.9	44.3	40.4	-456.6	40.07	0.91
Sydney I	44.9	44.3	40.3	-454.8	39.79	0.89
Sydney II	44.9	44.3	40.2	-453.9	39.86	0.91
Ledovo II	44.9	44.3	40.2	-453.3	39.79	0.86
			Instrument 6302			
Ledovo I	25.9	25.7	21.6	-219.9	40.07	0.89
Sydney I	25.8	25.7	21.4	-219.1	40.00	0.90
Sydney II	25.8	25.7	21.4	-219.1	40.00	0.92
Ledovo II	29.9	25.7	21.2	-218.2	40.05	0.89
			Instrument 6303			
Ledovo I	49.5	48.7	39.2	-501.5	40.00	0.89
Sydney I	49.3	48.6	38.8	-497.1	39.88	0.87
Sydney II	49.4	48.7	38.7	-497.2	39.95	0.89
Ledovo II	49.6	48.7	38.7	-497.4	39.83	0.90

TABLE 3. MEAN PERIODS OF PENDULUMS

Stations and NN of programs	Mean period sec.	M 1.10^{-8} sec.	Number of periods
	Instrument 6101		
Ledovo I	$0.4915\ 4391_6$	$\pm$ 0.61	6
Sydney I	$0.4920\ 1518_7$	0.25	7
Sydney II	$0.4920\ 1516_9$	0.66	7
Ledovo II	$0.4915\ 4384_5$	0.69	7
	Instrument 6102		
Ledovo I	$0.4949\ 3082_9$	$\pm$ 0.94	9
Sydney I	$0.4954\ 0528_5$	1.19	8
Sydney II	$0.4954\ 0526_9$	1.16	8
Ledovo II	$0.4949\ 3072_1$	0.95	8
	Instrument 6301		
Ledovo I	$0.4830\ 3540_9$	$\pm$ 0.39	8
Sydney I	$0.4834\ 9852_0$	0.51	10
Sydney II	$0.4834\ 9854_7$	0.56	10
Ledovo II	$0.4830\ 3541_3$	0.71	8
	Instrument 6302		
Ledovo I	$0.7393\ 9619_3$	$\pm$ 0.23	8
Sydney I	$0.7401\ 0519_0$	0.70	7
Sydney II	$0.7401\ 0519_7$	0.29	7
Ledovo II	$0.7393\ 9622_0$	0.29	6
	Instrument 6303		
Ledovo I	$0.4853\ 8836_2$	$\pm$ 0.55	8
Sydney I	$0.4858\ 5370_7$	0.44	7
Sydney II	$0.4858\ 5369_3$	0.96	7
Ledovo II	$0.4853\ 8830_2$	0.89	8

TABLE 4. GRAVITY INCREMENTS (mgl)

INSTRUMENTS					Mean	Weighted mean
6101	6102	6301	6302	6303		
1	2	3	4	5	6	7
-1879.56	-1879.39	-1879.49	-1879.68	-1879.45	-1879.51	-1879.54
± 0.16	± 0.22	± 0.12	± 0.12	± 0.15	± 0.05	± 0.06

As Δ g between Potsdam and Ledovo is 291.327 ± 0.019 mgl, we obtain for gravity acceleration at Sydney in relation to Potsdam (g_0 = 981,274.00 ± 0.00) :

$$G_{Sydney} = 979{,}685.79 \pm 0.06 \text{ mGal}$$

Gravity for the station "Sydney" was computed without introducing the Honkasalo correction [8].

Making use of the data kindly placed at our disposal by the Bureau of Mineral Resources, containing values of Δ g for the Sydney station, computed from absolute determinations in the systems IGSN and the Isogal Project, and utilizing the results obtained by Cooke [7] as well, we are able to make a comparison of all these values with those obtained here.

This comparison is shown in Table 5.

TABLE 5. VALUES OF g IN mGal

Determined with pendulum equipment OVM	Obtained from absolute measurements	In the system IGSN 71	In the system Isogal Project	Obtained by Cooke	Correction to Potsdam system (mGal)
979 685.79 ± 0.06	979 672.0 ± 0.20	979 671.85 ± 0.05	979 685.74 ± 0.05	979 685.80 -	13.79 ± 0.21

The g-value obtained with the instrument OVM differs from the one accepted in the system Isogal Project only by 0.05 mGal, and nearly coincides with the g-value obtained by Cooke.

Thus the correction of the Potsdam system deduced on the basis of absolute measurements carried out at Sydney and of relative measurements made using the pendulum equipment OVM is - 13.79 $\pm$ 0.21 mGal.

This value is in good agreement with other modern data.

The results of the measurements described indicate a high accuracy of determinations between two such distant continents.

In conclusion, the author wishes to express his most sincere gratitude to the management of the Bureau of Mineral Resources and the National Standards Laboratory of Australia for their assistance in organization of the measurements; we also express our thanks to our Australian colleagues who ensured trouble-free operation at the station and did their utmost to render the sojourn of the participants of the work in Australia both agreeable and interesting.

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Fig. 1

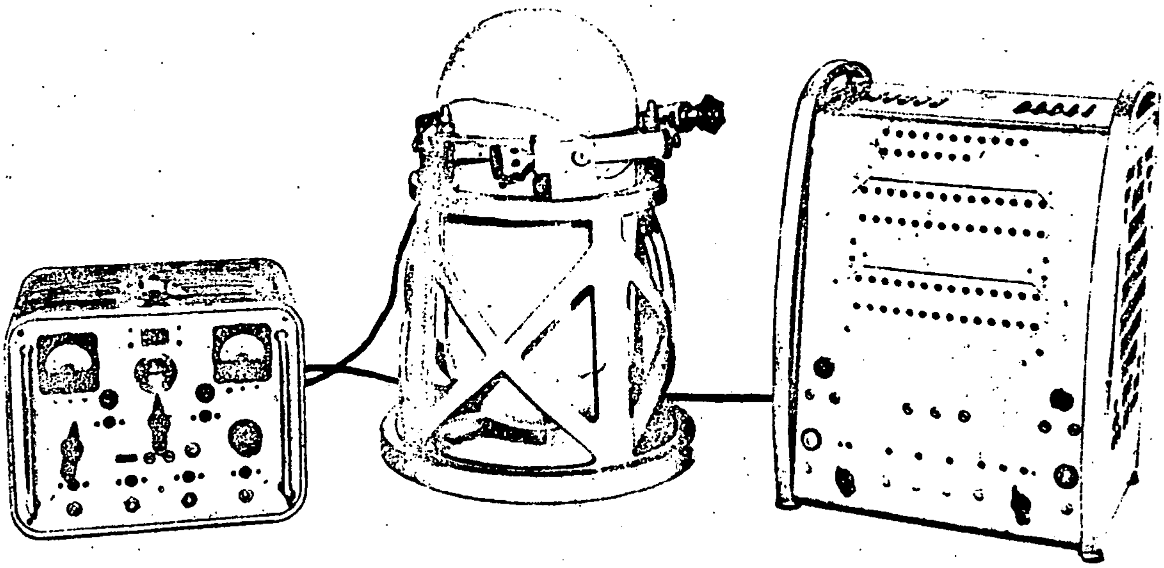

Fig. I.- A complete set of the Vacuum Pendulum Equipment O V M .

1. **Control panel**
2. **Autocollimation level**
3. **Pendulum apparatus**
4. **Photoelectronic registering device**

BLOCK DIAGRAM

Fig. 2

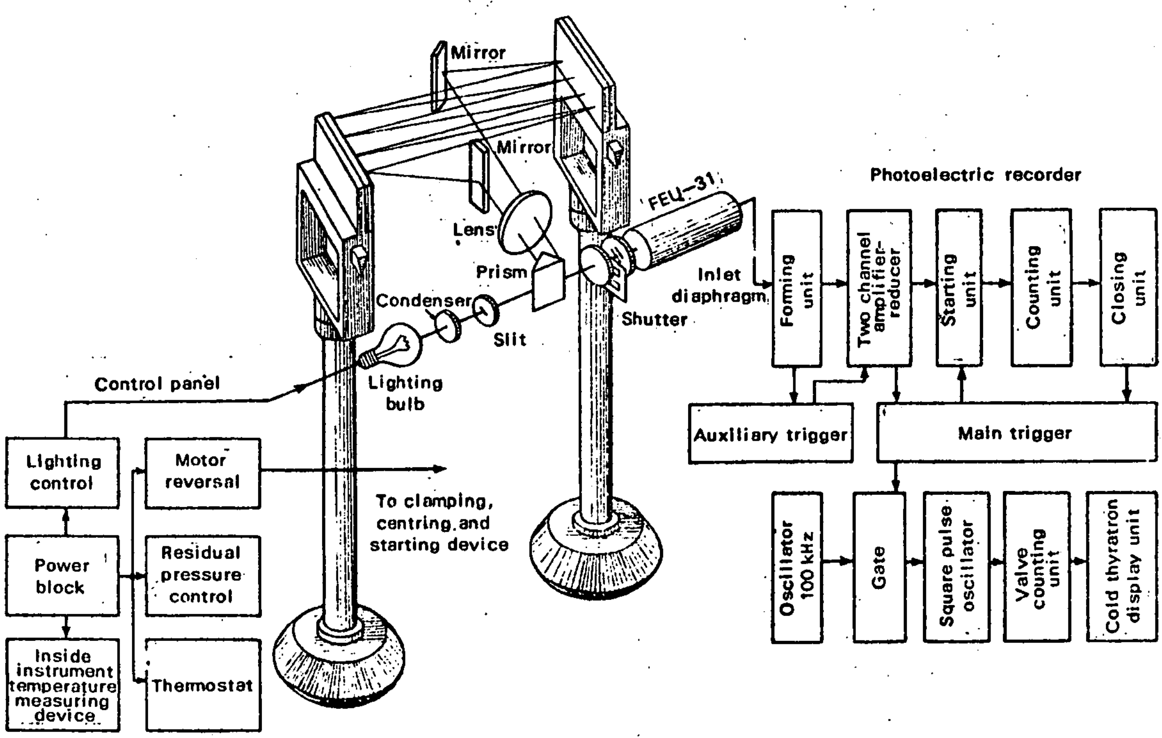

Fig. 2. - Block-scheme of the Vacuum Pendulum Apparatus O V M .