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# FIRST RESULTS WITH THE TRANSPORTABLE ABSOLUTE GRAVITY METER JILAG–3

## Abstract

*A transportable absolute gravity meter has been built at the Joint Institute for Laboratory Astrophysics* (JILA) *of the University of Colorado and delivered in January 1986 to the Institut für Erdmessung* (IFE), *Universität Hannover. Instrumental investigations, software improvements and absolute gravity determinations on* 15 *stations performed by* IFE *in 1986 are reported here. The main conclusion from one year experience with the instrument is that absolute gravity can be observed on a station within one day with a precision of a few* $\mu$gal *and an accuracy of about* 10 $\mu$gal .

## 1. Introduction

In January 1986, the Institut für Erdmessung (IFE), Universität Hannover, received an absolute gravimeter, which was the third one of a series of six instruments, developed and built during the past years at the Joint Institute for Laboratory Astrophysics (JILA), National Bureau of Standards and University of Colorado, Boulder, U.S.A. The gravimeter (called JILAG–3) was designed to be portable in order to be employed at geodetic, geophysical, geological, and geodynamical field applications (e.g. Faller et al., 1982, 1983). The basic principle of the instrument is the determination of the acceleration of a free falling triple prism due to gravity by simultaneous time and distance measurements in a laser interferometer (see *Figure 1*). Time and length standards are provided by a rubidium normal, and a frequency stabilized He-Ne-laser respectively. Much effort was made to reduce systematic and random errors in order to achieve an accuracy of few $\mu$gal ($1\ \mu\text{gal} = 10^{-8}\ \text{m} \cdot \text{s}^{-2} = 10^{-9}\ \text{g}$). With a dropping distance of about 0.2 m , this requires a precision of the distance observations of about 0.2 nm and a timing precision of about 0.2 ns .

Special features of the instrument are a servo controlled drag free chamber, following the dropped prism during the free fall and shielding it against residual air drag (vacuum about $10^{-6}$ mbar = $10^{-4}$ pa), and a long periodic isolation device against ground vibration, called super spring. By suspending the drag free chamber carrying the dropped prism on a steel belt, driven by a servo motor, the prism can be moved from the

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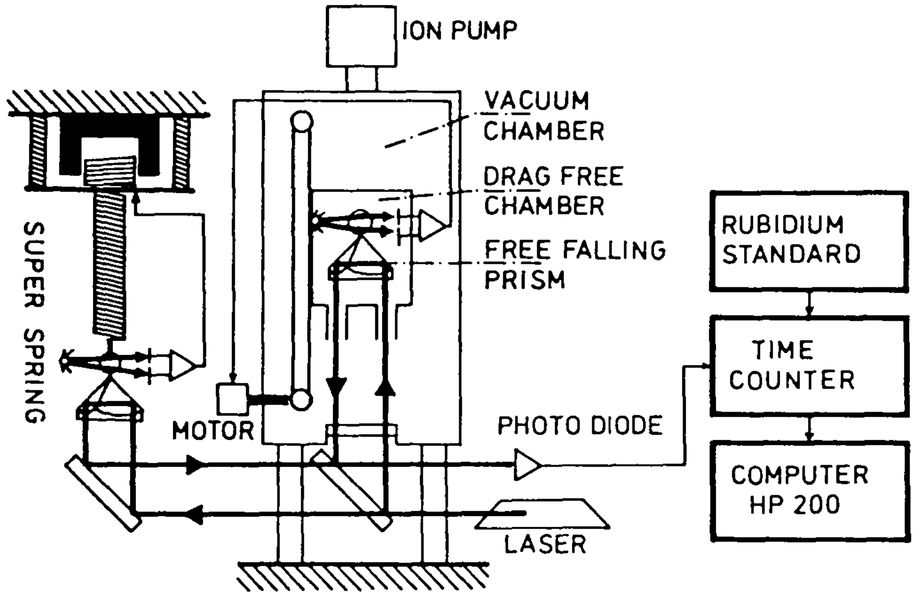

*Fig. 1 — Schematic of JILAG–3 absolute gravimeter*

bottom to the top of the vacuum chamber, released to free fall by a computer command, and softly catched at the bottom. During the free fall, the motor is controlled by a photo split diode monitoring the distance between the drag free chamber and the prism. Thus, the drag free chamber and the residual air molecules inside have the same speed as the prism. During its fall, the dropped prism is decoupled from ground vibration, whereas the other parts of the interferometer including the reference prism are not. Without using any isolation against ground vibration, the drop to drop scatter for the observed gravity values is about 2 . . . 5 mgal, which is about three orders of magnitude above the desired observation accuracy. By suspending the reference prism on a long periodic spring, the ground vibration induced noise can be reduced significantly. For the JILAG-3 gravimeter, a mechanical spring with a length of about 0.3 m (1 sec natural period) is used in an electronic feedback loop (super spring) in order to increase the natural period; the period and damping of the super spring can be adjusted easily by electronic means. With a period of about 30 sec, the drop to drop scatter is 20 . . . 200 $\mu$gal depending on station and weather (wind) conditions. Generally, the ground vibration induced noise is at lowest during the night and the weekend, and on stations far away from traffic.

The interference fringes produced by the dropped prism during the free fall are sensed by a high speed avalanche photo diode, generating a frequency modulated sine wave signal. After transformation of the photo diode signal into rectangular pulses by a zero crossing detector, the pulses are divided by 4000 and fed into a time counter. The time counter records the occurance of 200 divided pulses, thus observing time values at 200 equidistant positions of the dropped prism separated by about 1.25 mm (4000 times half the wavelength of the He-Ne laser of about 0.632 $\mu$m). This set of 200 time and distance observations is used in the HEWLETT-PACKARD series 200 microcomputer (HP 200) to compute one-line the initial position, initial speed and the acceleration (gravity value) of the dropped prism by a least squares adjustment; after applying the relevant corrections (see chapter 2), the observed gravity value is stored on a floppy disc. The drop takes about 2 sec including data transfer and the data evaluation another 8 sec; thus absolute gravity experiments can be performed every 10 seconds. Due to this high repetition rate, a set of 500 gravity observations can be collected within two hours, yielding a standard deviation of 1 . . . 10 $\mu$gal for the mean gravity value.

Because the control of the JILAG–3 absolute gravimeter and the data evaluation are carried out on-line by the HP 200 computer, gravity observations at a station are fully automatized. Thus, long observation series and observations during the night and the weekend can be performed without requiring permanent presence of an observer. The instrument can be disassembled into 8 transportation boxes, with a total weight of about 400 kg, and fits into a small van. It can be transported and operated by two observers; the set up of the instrument takes about 2 hours under normal conditions. However, the JILAG–3 absolute gravity meter is a highly developed and sophisticated instrument with a number of high technology components, and thus only well trained observers with sufficient experience can successfully operate it.

## 2. Instrumental Investigations and Software Improvements

For the accuracy of the absolute gravity determination, the calibration and stability of the He-Ne laser and of the frequency standard are essential. The EFRATOM model FRK *rubidium frequency standard* used in the instrument has an initial calibration of better than $5.10^{-11}$ and a long term stability of better than $10^{-10}$ per year and therefore will not need to be re-calibrated within the next years. The used frequency stabilized *He-Ne laser* LASEANGEL Co. model RB1 is a switchable double wavelength laser; the stability of the single wavelength is given by the manufacturer by $2 \cdot 10^{-9}$ per month, whereas the mean of both wavelengths is estimated to have a ten times better stability. Absolute gravity determinations with the JILAG-3 instrument are always carried out using both wavelengths, switching the laser by the HP 200 computer. After having received the instrument, the laser has been calibrated at PTB, Braunschweig, in February 1986. Compared to the initial calibration at JILA, Boulder, in September 1985, the mean of both wavelengths agreed within $2.10^{-9}$, whereas the individual wavelengths showed variations of about $10^{-7}$. The difference between the gravity determinations using both wavelengths (see *Figure 2*) shows an rms variation of $\pm 11$ $\mu$gal corresponding to $\pm 1 \cdot 10^{-8}$ rms laser wavelength variation, but no significant long time variation during the past year.

No significant *temperature dependence* of the observed gravity values could be detected between 17° C and 25° C for the JILAG-3 instrument; there exists only a slight temperature dependence of the mechanical friction in the dropping mechanism, causing some problems in the lift phase of the drag free chambers servo motor at temperatures below 17° C.

During a one day pumping phase after the repair of a broken wire inside the *vacuum chamber,* we took the opportunity to perform gravity observations at $10^{-2}$, $10^{-4}$ and $10^{-6}$ mbar pressure inside the vacuum chamber. From these results, an almost linear dependence of about $10^6$ $\mu$gal/mbar has been found, which gives about

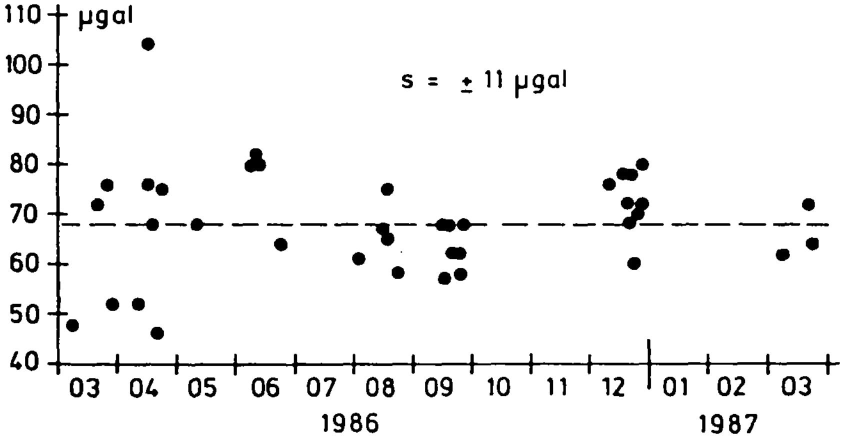

*Fig. 2 — Differences between gravity determinations on both wavelengths of JILAG–3 frequency stabilized laser*

1 $\mu$gal residual air drag influence at $10^{-6}$ mbar vacuum used for absolute gravity determinations. Depart from this repair, the vacuum could be maintained below $10^{-5}$ mbar during one year.

For the absolute gravity determination, some *reductions* have to be added to the raw result (velocity of light correction, earth tide correction, polar motion correction, air pressure correction, centering to the station marker). The earth tide correction was the only one applied in the original processing program, all other corrections had to be computed separately. In order to enable the computation of the final gravity value directly after having finished the observations, we decided to implement all necessary reductions in the on-line processing program. This was not an easy task, because at present the HP 200 computer connected to the absolute gravimeter can only be programmed in HPL language, which is a very simple and uncomfortable programming language.

Because of the *finite velocity of light* $c = 299792458 \text{ ms}^{-1}$ , the travel time of the light from the dropped prism to the avalanche photo diode varies by about 0.7 ns , which in our case causes a gravity correction of about $-14 \mu$gal . The easiest way to correct this effect is to add the term $z/c$ to the observed time values ($z$ = actual position of the dropped object with respect to the first observed position) , before the evaluation is carried out.

The subroutine TIDE1 used in the original processing program for the *earth tide correction,* computes the tidal potential by a shortened series development for the ephemeris of sun and moon with a tidal amplitude factor of 1.170 and a zero phase shift. In *Figure 3* the results of subroutine TIDE1 have been compared with those of an earth tide program using CARTWRIGHT–TAYLOR–EDDEN tidal potential development with 505 waves and observed tidal parameters for the station Hannover (Torge and Wenzel 1977). There can be seen errors up to 13 $\mu$gal ( ± 6 $\mu$gal rms) , which mainly result from the shortened series development. Therefore, the subroutine

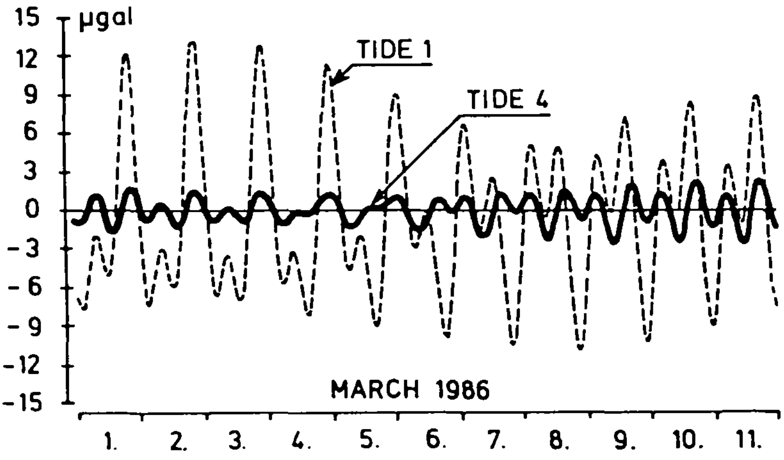

*Fig. 3 – Errors of earth tide corrections computed with subroutines TIDE 1 and TIDE 4 for station Hannover*

TIDE4 has been implemented in the on-line processing program, which uses an expanded series development with a tidal amplitude factor of 1.164 and a zero phase shift. The earth tide corrections computed with this subroutine have errors less than 3 µgal ( ± 1 µgal rms), see *Figure 3.* In order to fulfill the recommendations of the IAG standard earth tide committee (Rapp 1983) concerning the constant M0S0 tide,

$$\delta g\,[\mu gal] = -4.83 + 15.73\,sin^2\,\psi - 1.59\,sin^4\,\psi \tag{1}$$

with $\psi$ = geocentric latitude has to be added. The implementation of a subroutine which uses the CARTWRIGHT–TAYLOR–EDDEN tidal potential development and observed tidal parameters is not possible because of the restricted programming language.

The *polar motion* of the earth causes a time variation of the station's distance to the rotation axis and thus a time variation of gravity. The gravity correction due to polar motion (e.g. Wahr 1985) is

$$\delta g\,[\mu gal] = 1.164 \cdot 10^8\,\omega^2 \cdot a \cdot 2\,sin\,\varphi\,cos\,\varphi\,(x \cdot cos\,\lambda - y \cdot sin\,\lambda) \tag{2}$$

with x, y = pole coordinates in BIH system in radian. The gravity correction due to polar motion has a maximum variation of about ± 5 µgal with periods of 365.25 and 435 days. In order to obtain an on-line computation of the gravity polar motion correction during the absolute gravity determination, we have used a prediction of pole coordinates by means of the series development (e.g. Sheng 1982)

$$\begin{aligned} x\,[''] = 0.0512 + 18.15 \cdot 10^{-6} \cdot A - 0.0870\,sin\,B - 0.0453\,cos\,B \\ - 0.0473\,sin\,C + 0.1732\,cos\,C \end{aligned} \tag{3}$$

$$\begin{aligned} y\,[''] = 0.2845 - 3.87 \cdot 10^{-6} \cdot B + 0.0422\,sin\,B - 0.0732\,cos\,B \\ - 0.1756\,sin\,C - 0.0520\,cos\,C, \end{aligned} \tag{4}$$

with A = MJD (modified Julian Date) − 46431 ,

$B = 2\pi A/365.25$ , $C = 2\pi A/435.00$ .

The parameters of the series development have been fitted to the BIH final pole coordinates (Earth Orientation Bulletin, U.S. Naval Observatory) from 2.12.1983 to 27.10.1986 and allow the prediction of pole coordinates up to August 1987 with an accuracy of about 0.03″. The computed gravity correction (see *Figure 4*) have an accuracy of about 0.1 μgal.

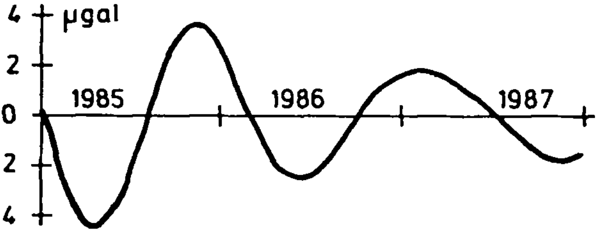

*Fig. 4 – Polar motion correction for gravity at station Hannover*

Time dependent variations of the *air pressure* cause variations of the air density and therefore variations of the gravitational attraction of the atmosphere. Additionally, the air pressure variations deform the earth's crust, the sea level and the ground water level. These effects cause a gravity variation of about – 0.3 ... – 0.4 μgal/mbar. By analyzing observations with the absolute gravimeter JILAG–3 in December 1986 and March 1987 at station Hannover 101 (see *Figure 5*), a linear regression coefficient of – 0.43 ± 0.15 μgal/mbar has been determined with ± 6 μgal standard deviation of the absolute gravity observations. This regression coefficient is in agreement with other determinations (e.g. – 0.34 ± 0.03 μgal/mbar by Sakuma 1983, – 0.41 ± 0.06 μgal/mbar by Torge and Wenzel 1977 from earth tide observations). The absolute gravity determinations discussed in chapter 3 have been corrected by adding

$$\delta g\,[\mu\text{gal}] = 0.30 \cdot (\text{Pa}\,[\text{mbar}] - \text{Pn}\,[\text{mbar}]) \qquad (5)$$

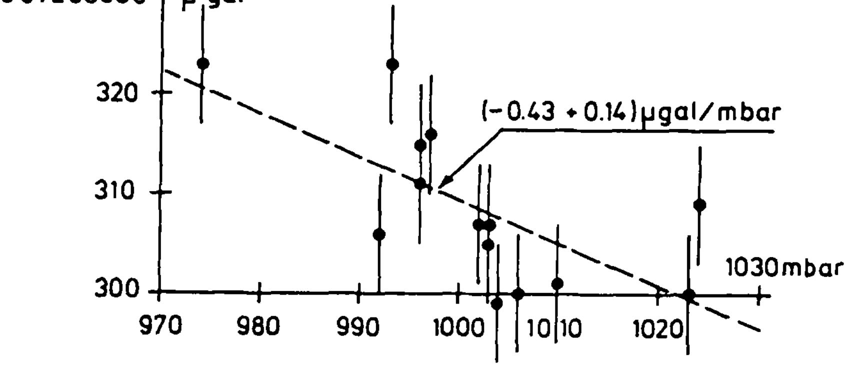

*Fig. 5 – Regression between air pressure and gravity observations with JILAG–3 absolute gravimeter at station Hannover*

according to IAG resolution No. 9 of Canberra 1979 with Pa = observed air pressure, Pn = normal air pressure computed from DIN 5450 standard atmosphere (e.g. Boedecker and Richter 1984) for the station elevation H by

$$\mathrm{Pn}\,[\mathrm{mbar}] = 1013.25 \cdot (1. - 0.0065 \cdot \mathrm{H}\,[\mathrm{m}] / 288.15)^{5.2559} . \qquad (6)$$

Finally, the absolute gravity value has to be *centered* to the station marker, which is normally a point on the floor. For the evaluation of absolute gravity by the adjustment of time and distance observations of the dropped prism, the gravity is assumed to be independent from elevation. Thus, the adjusted gravity value is referring to a fictitious point inside the vacuum chamber. The elevation of this fictitious point depends on the elevation of the center of mass of the dropped prism when the free fall begins, and of its position at the start and stop pulse for which the recorded time is used in the adjustment (e.g. Zumberge 1981). For the JILAG–3 instrument, the elevation of a visible edge of the drag free chamber above the station marker is measured at the release position; with the known distance of the center of mass of the dropped prism to this edge and its elevation at the start and stop pulse, the elevation of the fictitious gravity reference point is computed by the on-line processing program. After disassembling the absolute gravimeter, the vertical gravity gradient at the station is observed using at least two LaCoste-Romberg relative gravimeters equipped with an electronic feedback system (Schnüll et al. 1984, Röder et al. 1985) at ground level and at 1 m above ground. The accuracy of the observed gravity gradients is generally better than 2 μgal/m (e.g. Röder and Wenzel 1986).

## 3. Absolute Gravity Determinations

About two months after receiving the instrument, absolute gravity determinations on 15 different stations have been started in order to get experience in the transportation, disassembling and assembling of the instrument, and to test the gravimeter under different environmental conditions. Observations have been performed on 9 stations in Germany, on 3 stations at BIPM, Sèvres/France and on 3 stations in Denmark; the results of the observations are given in *Table 1*. The instrument has been transported in a VW-van; during transportation, the vacuum was continuously maintained by operating the ion pump from the car battery. Therefore, the observations could start immediately after having assembled and adjusted the gravimeter, which usually took about two hours. The number of drops collected on the stations in order to obtain a precision of a few μgal varied between 1000 and 8000, depending on the station and weather conditions and on the continuously increasing experience in handling the instrument. The performance of the gravimeter improved, whenever an error source was detected and eliminated. Especially, in July 1986 the super spring has been re-adjusted, yielding a lower drop to drop scatter, and in September 1986 the re-adjustment of the zero crossing detector for the fringe signal resulted in a non significant dependence of the signals amplitude. Additionally, software improvements have been performed in parallel. A sequence of 500 gravity experiments, recorded with the JILAG–3 instrument of present performance at station Hannover under normal conditions during week-day, is shown in *Figure 6* with a standard deviation of ± 54 μgal for the result of a single drop. A histogram for the same series is given in *Figure 7*.

The most severe problem which occured on some stations and is still unsolved, is a tilt of the interferometer base during the observations. In order to observe correct distances to the dropped prism during its fall, the laser beam in the vacuum chamber has

Table 1

Results of Absolute Gravity Determination with JILAG-3

| Station | Epoch | Drops | Gravity [µgal] | Stand. Dev. [µgal] | Gradient [µgal/m] |
|---|---|---|---|---|---|
| 101 Hannover | 86/03/08 | 6000 | 981263316 | 1 | 285 |
| 522 Clausthal | 86/03/20 | 1037 | 981115721 | 2 | 266 |
| 1 Hannover | 86/03/25 | 4000 | 981262381 | 2 | — |
| 151 Braunschweig | 86/03/27 | 3000 | 981252914 | 1 | 285 |
| 101 Hannover | 86/04/11 | 8000 | 981263312 | 2 | 285 |
| 482 Bad Harzburg | 86/04/15 | 2000 | (981165471) | 2 | 253 |
| 785 Bremerhaven | 86/04/16 | 3000 | 981356702 | 1 | 300 |
| 141 Hamburg | 86/04/17 | 3000 | 981363656 | 2 | 288 |
| 40 München | 86/04/20 | 2000 | 980723111 | 1 | 294 |
| 10 Wiesbaden | 86/04/22 | 3000 | 981036845 | 1 | 264 |
| 101 Hannover | 86/05/11 | 3900 | 981263303 | 1 | 285 |
| 123 Sevres A3 | 86/06/07 | 3000 | 980925913 | 1 | 295 |
| 125 Sevres A5 | 86/06/09 | 8000 | 980926556 | 3 | 253 |
| 127 Sevres A7 | 86/06/10 | 4000 | 980926623 | 1 | 259 |
| 101 Hannover | 86/06/22 | 6000 | 981263310 | 2 | 285 |
| 101 Hannover | 86/08/03 | 6000 | 981263321 | 3 | 285 |
| 600 Copenhagen | 86/08/20 | 1470 | 981495591 | 5 | 259 |
| 624 Tebstrup | 86/08/22 | 1470 | 981580495 | 4 | 260 |
| 623 Helsingör | 86/08/23 | 1500 | 981580386 | 5 | 264 |
| 101 Hannover | 86/08/27 | 1000 | 981263303 | 8 | 285 |
| 101 Hannover | 86/09/22 | 3800 | 981263306 | 6 | 285 |
| 101 Hannover | 86/12/20 | 11000 | 981263307 | 2 | 285 |
| 101 Hannover | 87/03/18 | 3000 | 981263308 | 2 | 285 |

**Remark:** Observation at station 482 Bad Harzburg is suspected to have a gross error.

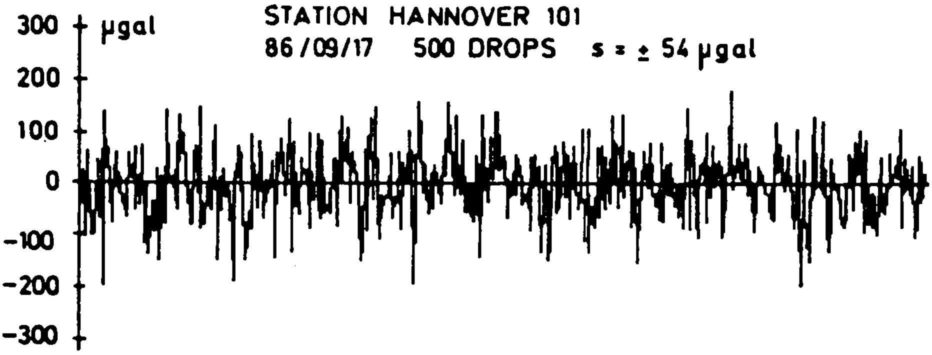

*Fig. 6 — Sequence of a typical set of gravity observations with JILAG-3 absolute gravimeter during week-day*

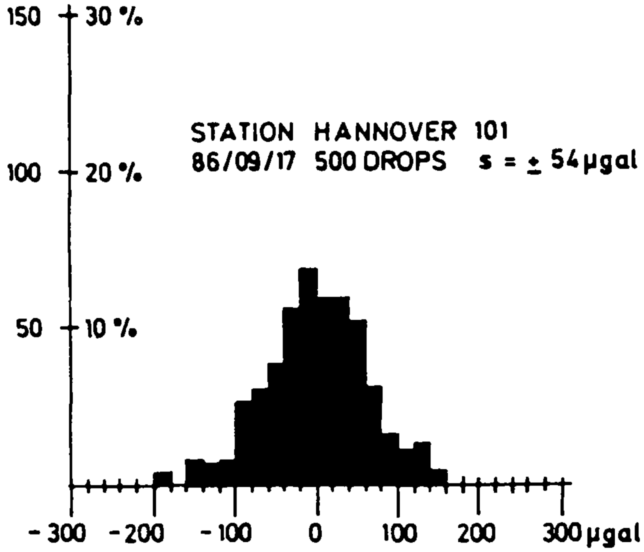

*Fig. 7 — Histogram of a typical set of gravity observations with JILAG–3 absolute gravimeter during week-day*

to be vertical with an accuracy of about 2″ . Before starting a set of gravity observations it is carefully adjusted by means of an oil pot as a liquid mirror, and checked afterwards. At some stations with soft floor, a large tilt of the interferometer base occured during the observations and thus they had to be repeated. A possible solution of this problem may be the installation of electronic levels on the interferometer base, which can be read during the gravity observations by the HP 200 computer and used to correct the observed gravity values. Another small problem was the air pressure observation by reading a THOMMEN barometer manually with an accuracy of about 1 mbar at the beginning and at the end of an observation set. On the one hand, the barometer drift of several mbar in half a year has to be checked from time to time against a mercury barometer, on the other hand there may occur some mbar air pressure variation during the gravity observations. This problem is currently being solved by reading a high quality air pressure sensor with a drift of about 0.1 mbar per year by the HP 200 computer during the observations.

After having completed a field campaign, the instrument has usually been set up in our gravity laboratory (station 101 Hannover) for check and maintenance purposes. Additionally, a number of observations have been performed there for instrumental tests. The absolute gravity determinations with the JILAG–3 gravimeter at station 101 Hannover given in *Table 2* show an rms variation of ± 6 μgal over a period of one year ; no significant influence of transportation and no significant long time variation can be detected.

From 6. to 11. June 1986, absolute gravity determinations have been carried out at Bureau International de Poids et Mesures (BIPM) , Sèvres/France, on station A3 , A5 and A7 . Unfortunately, only station A3 meets the requirements for high quality absolute observations, whereas stations A5 and A7 have a soft and unstable floor. In

Table 2

Stability of JILAG–3 Results at Station 101 Hannover

| Station | Epoch | Drops | Gravity [μgal] | Stand. Dev. [μgal] | Discrep. [μgal] |
|---|---|---|---|---|---|
| 101 Hannover | 86/03/08 | 6000 | 981263316 | 1 | - 6 |
| 101 Hannover | 86/04/11 | 8000 | 981263312 | 2 | - 2 |
| 101 Hannover | 86/05/11 | 3900 | 981263303 | 1 | + 7 |
| 101 Hannover | 86/06/22 | 6000 | 981263310 | 2 | 0 |
| 101 Hannover | 86/08/03 | 6000 | 981263321 | 3 | - 11 |
| 101 Hannover | 86/08/27 | 1000 | 981263303 | 8 | + 7 |
| 101 Hannover | 86/09/22 | 4000 | 981263306 | 6 | + 4 |
| 101 Hannover | 86/12/20 | 11000 | 981263307 | 2 | + 3 |
| 101 Hannover | 87/03/18 | 3000 | 981263308 | 2 | + 2 |
| | Average: | | 981263310 | | ± 6 |

parallel to the absolute gravity observations, vertical gravity gradients and gravity differences between stations A3 , A4 , A5 , A6 and A7 have been observed with three LaCoste-Romberg gravimeters equipped with electronic feedback systems (Röder and Wenzel 1986). Whereas the result of the JILAG–3 instrument on stations A3 and A5 agree within 5 μgal after having been transfered to station A1 , the result on station A7 is about 20 μgal lower. This is probably related to the unstable floor at A7 . In *Table 3* results of the JILAG–3 absolute gravity determinations are compared with those of other absolute instruments observed during the 2 . international comparison of absolute gravimeters in 1985 (Boulanger, Faller and Groten 1986). The average of the three JILAG–3 observations is in good agreement with the result of the French instrument (Sakuma) , but compared with results of other instruments, deviations between – 20 μgal and – 41 μgal are shown. These discrepancies seem not to be related to the type of measurements, because both the French and the Italian apparatus are using the rise and fall principle, whereas the other instruments make use of the free fall principle, but seem to be related to systematic errors in the individual instruments (e.g. Boulanger, Faller and Groten 1986).

JILAG–3 absolute gravity determinations on six stations have been compared in *Table 4* with absolute gravity observations carried out in 1976/1977 with the Italian IMGC instrument (Cannizzo et al. 1978). The discrepancies are between – 25 μgal and + 26 μgal, with + 2 μgal on the average and ± 17 μgal rms. At first glance the result of this comparison looks not bad, because a part of the discrepancies is suspected to be caused by real gravity changes during the ten years periode between both observation campaigns. On the other hand, there exist severe discrepancies up to 25 μlgal/m between gravity gradients observed by IFE and IMGC and used for the reduction of the absolute gravity observations to the station marker (see *Table 5*) . We are sure, that IFE gravity gradients have an accuracy of about 2 μgal/m , because they have been observed with at least two LaCoste-Romberg gravimeters equipped with electronic feedback systems, and the results and observation procedure have been verified in an international campaign at BIPM Sèvres/France, in 1985 (e.g. Becker 1985, Boulanger, Faller and Groten 1986) and again in 1986 (Röder and Wenzel 1986). Because gravity

### Table 3

### Comparison of JILAG–3 Observations at BIPM Sèvres with other Absolute Determinations

| Station | Gravity [µgal] | Stand. Dev. [µgal] | Discrep. [µgal] |
|---|---|---|---|
| 123 Sevres A3: 980925913 centered to A1: | 980925983 | ± 1 | |
| 125 Sevres A5: 980926556 centered to A1: | 980925978 | ± 3 | |
| 127 Sevres A7: 980926623 centered to A1: | 980925963 | ± 1 | |
| JILAG-3 Average: | 980925975 | ± 6 | |
| centric on A1: France : | 980925976 | ± 6 | - 1 |
| centered from A3: Italy : | 980925995 | ± 5 | -20 |
| centered from A5: USA (Faller) : | 980925999 | ± 8 | -24 |
| centered from A3: USSR : | 980926002 | ± 6 | -27 |
| centered from A6: USSR : | 980926002 | ± 6 | -27 |
| centered from A7: USA (Zumberge) : | 980926013 | ± 7 | -38 |
| centered from A4: China : | 980926016 | ±14 | -41 |

Reference Values taken from BOULANGER, FALLER and GROTEN 1986

### Table 4

### Comparison of JILAG–3 Observations with IMGC observations

| Station | JILAG-3 [µgal] | IMGC [µgal] | Discrep. [µgal] |
|---|---|---|---|
| 151 Braunschweig | 981252914 | 981252909 | + 5 |
| 141 Hamburg | 981363656 | 981363681 | -25 |
| 40 München | 980723111 | 981723116 | - 5 |
| 10 Wiesbaden | 981036845 | 981036847 | - 2 |
| 123 Sèvres A3 | 980925913 | 980925899 | +14 |
| 600 Copenhagen | 981495591 | 981495565 | +26 |
| | | Average: | + 2 |
| | | Rms Discrepancy: | ±17 |

IMGC observations taken from CANNIZZO et al. 1978

Table 5

Comparison of IFE and IMGC gravity gradients

| Station | IFE [μgal/m] | IMGC [μgal/m] | Discrep. [μgal/m] |
|---|---|---|---|
| 151 Braunschweig | 285 | 268 | 17 |
| 141 Hamburg | 288 | 274 | 14 |
| 40 München | 294 | 279 | 15 |
| 10 Wiesbaden | 264 | 239 | 25 |
| 123 Sèvres A3 | 295 | 273 | 22 |
| 600 Copenhagen | 259 | 238 | 21 |
| | Average: | | 19 |
| | Rms Discrepancy: | | ± 4 |

gradients are not significantly affected by time variations, except for strong mass variations in direct vicinity of the station, systematic errors must be suspected for the IMGC gravity gradients. Therefore, IMGC absolute gravity observations have been re-processed using IFE gravity gradients given in *Table 6*. The discrepancies between JILAG–3 and IMGC gravity determinations change to – 13 μgal on the average and ± 16 μgal rms. As for the comparison at BIPM, the JILAG–3 results are significantly lower.

Table 6

Comparison of JILAG–3 Observations with IMGC observations

(IMGC Observations Processed with IFE Gradients)

| Station | JILAG-3 [μgal] | IMGC [μgal] | Discrep. [μgal] |
|---|---|---|---|
| 151 Braunschweig | 981252914 | 981252923 | - 9 |
| 141 Hamburg | 981363656 | 981363692 | -36 |
| 40 München | 980723111 | 981723128 | -17 |
| 10 Wiesbaden | 981036845 | 981036867 | -22 |
| 123 Sèvres A3 | 980925913 | 980925917 | - 4 |
| 600 Copenhagen | 981495591 | 981495582 | + 9 |
| | Average: | | -13 |
| | Rms Discrepancy: | | ±16 |

In *Table 7*, gravity determinations with the JILAG–3 absolute gravimeter are compared with gravity values from Deutsches Schweregrundnetz 1976 (DSGN 76). The DSGN 76 is a relative gravity network, observed with four LaCoste-Romberg gravimeters in 1977 and adjusted to IMGC absolute gravity determinations at stations Hamburg, Braunschweig, Wiesbaden and München using own gravity gradient observations (e.g. Sigl et al, 1981, Boedecker and Richter 1984). The accuracy of the DSGN 76

## Table 7

## Comparison of JILAG–3 Observations with Deutsches Schweregrundnetz 1976 (DSGN 76)

| Station | JILAG-3 [μgal] | DSGN76 [μgal] | Discrep. [μgal] |
|---|---|---|---|
| 101 Hannover | 981262310 | (981262322) | (-12) |
| 1 Hannover | 981262381 | 981262404 | -23 |
| 151 Braunschweig | 981252914 | 981252943 | -29 |
| 482 Bad Harzburg | (981165471) | 981165520 | (-49) |
| 141 Hamburg | 981363656 | 981363679 | -23 |
| 40 München | 980723111 | 981723129 | -18 |
| 10 Wiesbaden | 981036845 | 981036864 | -19 |
| | Average: | | -22 |
| | Rms Discrepancy: | | ± 4 |

**Remarks: Station 101 Hannover is not a DSGN76 station, but connected to DSGN76 station 1 Hannover. JILAG-3 observation at 482 Bad Harzburg is suspected to have a gross error.**

gravity differences is in the order of ± 5 . . . 10 μgal . The discrepancies between JILAG–3 absolute gravity observations and DSGN 76 is – 22 μgal on the average and ± 4 μgal rms . In the comparison, the results on stations 101 Hannover and 482 Bad Harzburg have not been used, because station 101 Hannover is not a DSGN 76 station, but connected to it by relative observations, and a gross error is suspected in the JILAG–3 result for station 482 Bad Harzburg because of only 13° C room temperature during the observations. The rms discrepancy of ± 4 μgal is excellent, regarding the precision of the absolute gravity determinations of about ± 2 μgal , the precision of DSGN 76 gravity differences of ± 5 . . . 10 μgal , and the possibility of real gravity changes during the ten years periods between both observation campaigns.

In *Table 8* , JILAG–3 absolute gravity determinations on two stations of the Fennoscandian land uplift gravity line are compared with results from six LaCoste-Romberg gravimeters (Mäkinen et al. 1986). The discrepancy of 3 μgal for the gravity difference is remarkably small, regarding the precision of the absolute gravity determinations and the fact, that as usual they also could not be performed exactly on the stations themselves but had to be centered by means of relative measurements.

Concluding the different comparisons between JILAG–3 results with other gravity determinations, there has been found an excellent repetition accuracy of ± 6 μgal , an excellent agreement with relative gravity observations, but systematic discrepancies to other absolute gravimeters between – 1 and – 41 μgal . The reason could not yet be detected, and investigations concerning this problem are continued. Systematic errors may also exist in other absolute gravimeters being presently available, and international comparison campaigns may help to solve this problem in the future.

Table 8

Comparison of JILAG–3 Observations at Fennoscandian Land Uplift Gravity Line with Relative Observations

| Station | | Gravity [μgal] | Stand. Dev. [μgal] | Discrep. [μgal] |
|---|---|---|---|---|
| 624 Tebstrup : 981580495 centered +35 | : | 981580530 | ± 4 | |
| 623 Helsingör: 981580386 centered -22 | : | 981580364 | ± 5 | |
| JILAG-3 Difference | : | -166 | ± 6 | |
| Difference from 6 LCR Gravimeters | : | -169 | ± 2 | 3 |

Reference Values taken from MÄKINEN et al. 1986

## 4. Conclusions

From the first laboratory and field tests performed with the JILAG–3 absolute gravity meter in 1986, the following conclusions may be drawn :

– the instrument can be employed operationally under different environmental conditions delivering reliable results within one day, including assembling and disassembling,

– with 500 to 1500 drops, a precision (standard deviation) of a few μgal is obtained for the mean gravity value,

– from repeated measurements in the station Hannover, a stability of ± 6 μgal has been found over one year of operation,

– comparison with the results of other absolute gravity meters reveal systematic discrepancies up to 41 μgal , which are well known to occur between presently available absolute gravimeter systems. These discrepancies reduce to the 10 μgal level or less, when gravity differences are compared.

We can state, that the JILAG–3 gravity meter can be used for the rapid establishment of high-precision gravity control points, supporting gravity networks of global, regional, and local extension, especially with respect to the investigation of gravity variations with time. IFE will perform corresponding field projects in the next years. Further research is needed in order to explain and to remove the systematic discrepancies between different instruments.

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