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The Use of the A10-020 Gravimeter for the Modernization of the Finnish First Order Gravity Network

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Abstract. The A10 is the first absolute gravimeter that allows the rapid determination of gravity with high accuracy in field conditions. In many applications, an absolute gravity survey with the A10 thus becomes highly competitive with traditional relative gravity surveys, in terms of both efficiency and accuracy. In particular, it is very efficient in the modernization of gravity control and high precision gravity survey required in modern gravity networks.

In 2008 the Institute of Geodesy and Cartography received the outdoor free-fall gravimeter A10 No 020. Time series of gravity taken with it since September 2008 at the Borowa Gora Geodetic-Geophysical Observatory in Poland show that the A10-020 provides high quality measurements in laboratory as well as in field conditions.

In 2009–2010 the A10-020 gravimeter was used for the re-measurement of the Finnish First Order Gravity Network. Altogether 51 field sites were occupied, with a repeatability better than 4 μGal. For control, 9 Finnish absolute gravity stations were occupied with the A10-020 altogether 25 times. From preliminary computations, the offset of the A10-020 to the FG5-221 of the Finnish Geodetic Institute was negligible and the RMS difference was 3 μGal.

The polarization–stabilized laser and the rubidium frequency standard of the A10-020 were calibrated before and after the surveys at the Finnish National Metrology Institute MIKES to ensure the metrological quality of the measurements.

The results obtained confirm the applicability of the A10 absolute gravimeter to the modernization of gravity control networks.

Keywords: absolute gravity survey, A10 free-fall gravimeter, gravity control

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1. Introduction

Substantial progress in gravimetry is currently observed due to the growing use of free-fall gravimeters. Absolute-gravity measurements provide consistent reference values for areal gravity surveys for geodesy and geology. Repeated gravity measurements with precise absolute gravimeters are required for geodynamic research, and provide additional control for the vertical velocities in terrestrial reference systems, Absolute gravimeters are used for monitoring the non-tidal variation in gravity (due to e.g. hydrology or Glacial Isostatic Adjustment) together with permanently operating superconducting gravimeters. They also provide the calibration to superconducting gravimeters and other tidal gravimeters for improving Earth tide and ocean tide models.

A growing role is expected to be played by outdoor absolute gravimeters. The first modern outdoor absolute gravimeter, the A10, was introduced in 2000 by Micro-g Solutions, Inc. (now Micro-g LaCoste, Inc.). It has specifically been designed for field measurements under possibly harsh conditions. In many applications, the precision of the A10 and the gain in efficiency from eliminating the need to loop frequently to reference stations make the gravimeter superior with respect to the existing relative spring gravimeters. In accuracy the A10 cannot compete with the FG5 but depending on the purpose of the measurements this may be compensated by its lesser demands on the site and on the measuring conditions.

At present, the manufacturer specifies the A10 to have 10 μGal accuracy (absolute), and 10 μGal precision in 10 minutes on a quiet site (Micro-g LaCoste, Inc., 2008a). The publicity material of the manufacturer shows examples where precision better than 1 μGal is reached (Micro-g LaCoste, Inc., 2010). The results of gravity measurements with the A10 gravimeter performed during last decade by different research teams show a steadily improved performance (Liard and Gagnon; 2002; Duquenne et al, 2005; Schmerge and Francis, 2006; Kryński and Roguski, 2009; Bonvalot et al., 2009, Falk et al., 2009, Nielsen et al. 2010). Under laboratory conditions, the quality of the measurements is clearly better than that specified by the manufacturer. Also the results of recent field measurements are very promising.

The experiences with the A10-020 of the Institute of Geodesy and Cartography (IGiK) in Poland and in the re-measurement of the First Order Gravity Network (FOGN) of Finland are described in this paper.

2. Test measurements in Poland

In September 2008 the A10-020 was installed at the Borowa Gora Geodetic-Geophysical Observatory of the IGiK. Since then, a number of measurements with the A10-020 were conducted both in the gravimetric laboratories and in the field. In particular, regular gravity measurements are performed at two pillars (A-BG and BG-G2) of the Borowa Gora Gravimetric Laboratory. The gravity results with the A10-020 at the A-BG station and a comparison with those obtained with the JILAg-5 and four different FG5 gravimeters during the last 15 years are shown in Figure 1. The reduction due to hydrology was not applied to gravity data being compared.

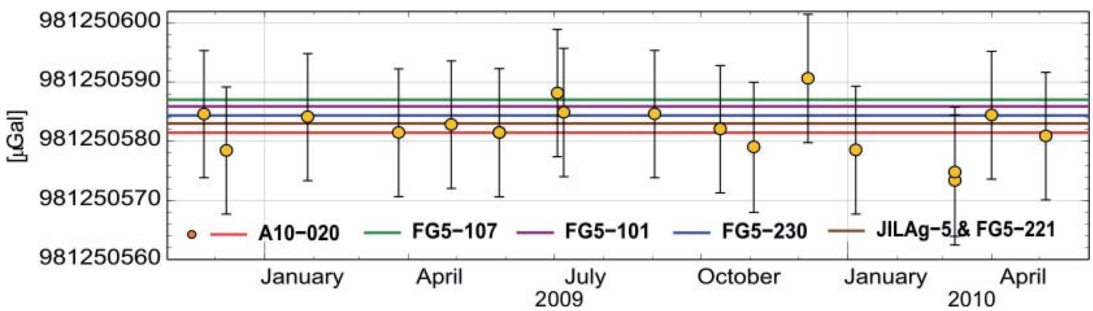

Fig. 1. Results of measurements with the A10-020 at the A-BG laboratory station in the Borowa Gora Observatory. The error bars are provided by the default settings in the "g8" acquisition and post-processing software provided by Micro-g LaCoste, Inc. The 10 μGal uncertainty from "System Type" is always the dominant contribution. The red line corresponds to the average of all measurements with the A10-020

The time series at BG-G2 (not presented here) shows the same consistency and repeatability.

From Figure 1 and Table 1, the standard deviation of a single station occupation with the A10-020 gravimeter in the laboratory conditions at Borowa Gora was 4.5 μGal. This is in fact pessimistic as some of the variation in the A10-020 results is probably due to a genuine variation in gravity at the observation site. It has also been noted that the differences between the FG5 results are nearly of the same order as the variation in the A10-020 results, and the mean of the A10-020 results is within 6 μGal of all FG5 (Kryński and Sękowski, 2010).

A routine gravity measurement with the A10-020 at the gravimetric laboratory of the Borowa Gora Geodetic-Geophysical Observatory was based on 12 hours of data. Experiments were conducted with data from 24 minutes' up to 18 hours' duration. Similarly to Schmerge and Francis (2006) no significant difference depending on data length was found in the determined *g*. Therefore a routine for field work where measurements in a single setup last only 24 minutes has been adopted. They consist of 8 sets with 120 drops each, with 1 second drop interval. Between sets the laser frequency is switched to a different side-lock (see Chapter 4). Last four measurements were performed in two independent set-ups of different orientation.

Gravity is regularly measured with the A10-020 also at the outdoor field station 156 Borowa Gora (Fig. 2). At that station, no independent absolute gravity measurement is available as yet.

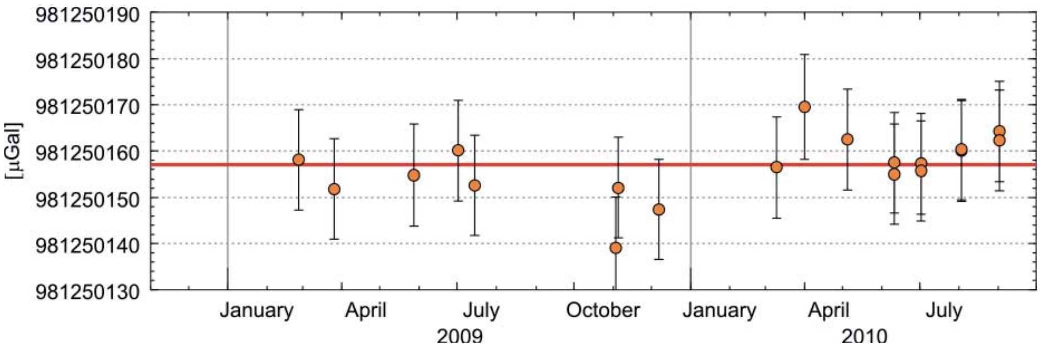

Fig. 2. Results of measurements with the A10-020 at the field station 156 Borowa Gora. The red line corresponds to the average of all measurements with the A10-020

The statistics of the results shown in Figure1 and Figure 2 is given in Table 1. The offset for the A10-020 at the A-BG station was computed with respect to the average of the results of 3 gravity determinations with the FG5-230 of the Warsaw University of Technology (WUT) during the last 4 years, i.e. the FG5 results closest in time to the A10-020 results.

Table 1. Statistics of measurements with A10-020 at two stations at Borowa Gora [μGal]

Station	No. of observations	Max - Min	Std. dev	RMS	Offset
A-BG	27	20.6	4.5	5.6	–3.4
156	20	30.5	6.7	NA	NA

It is not surprising that the scatter of the A10-020 results at the field station 156 Borowa Gora (Table 1) is substantially larger than at the laboratory station A-BG. The results confirm that the performance of the A10-020 fulfils and in fact significantly exceeds the specifications of the manufacturer on accuracy and precision. They are similar to those published recently by other research teams (cf. Introduction). In particular, they proved the usefulness of the A10 for the modernization of existing gravity control network (Sękowski and Kryński, 2010).

In July 2009 the IGiK and FGI conducted at various sites in Borowa Gora additional tests of the performance of A10-020 on unstable supports. The results (not shown here) were encouraging. Subsequently the bilateral project of the Finnish Geodetic Institute (FGI), Helsinki and the Institute of Geodesy and Cartography (IGiK) was set up on the re-measurement of the Finnish First Order Gravity Network (FOGN) with the A10-020.

3. Status of the Finnish First Order Gravity Network

The Finnish First Order Gravity Network (Fig. 3) was established in 1962–63 by the FGI to provide a reference for gravity surveys in Finland. At the time it consisted of 41 stations and it supplanted the earlier "base net" of 250 stations (Kiviniemi, 1964).

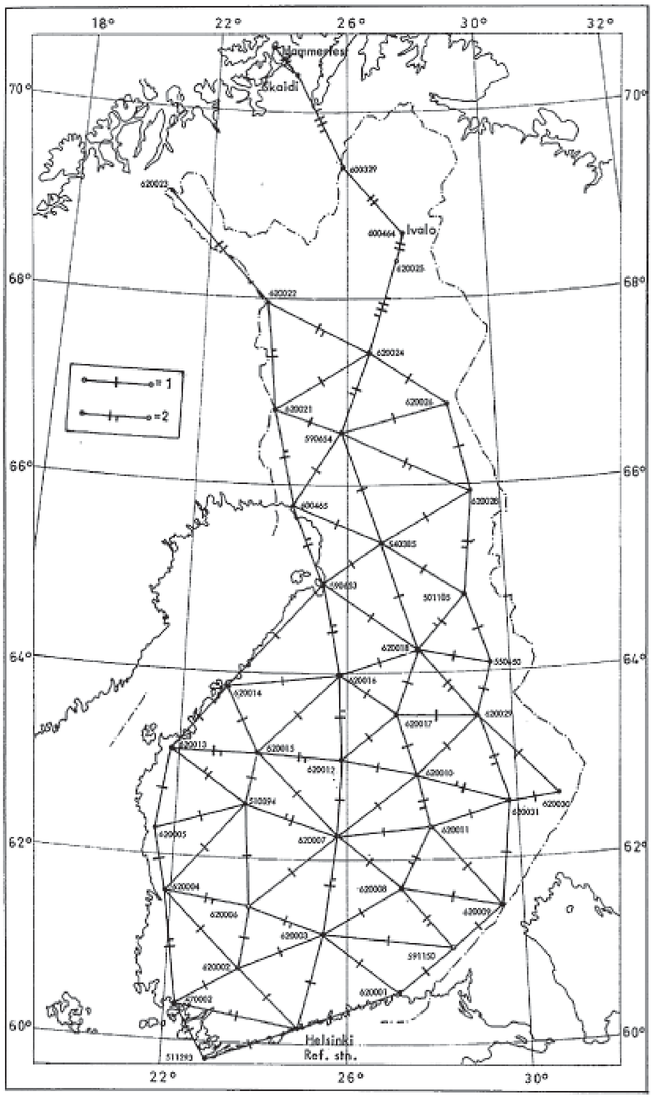

Fig. 3. The First Order Gravity Network of Finland measured in 1962–63 (Kiviniemi, 1964).The tags on the connecting lines indicate the number of measurements of the gravity difference. One cross-tag: measurement of the type ABA; one and a half cross-tags: measurement ABAB, etc.

To quote Kiviniemi (1964): "For easy access, the first order stations are placed as near as possible of traffic junctions. In order to ensure the permanence of the stations, they were attached to monumental buildings, in most cases churches. When no suitable buildings were available, the stations were placed on levelling benchmarks." Nearly all stations are outdoors. Typically on church stairs, they are easy to find even in the winter with plenty of snow, and are accessible at almost any time without prior arrangements. Changes at the stations have mostly come from reconstruction of the stairs, e.g. to allow wheelchair access. Of the original 41 stations 28 were intact in 2010.

The network was first measured in 1962–1963 by A. Kiviniemi with the Worden Master 227 gravimeter. The original gravity reference level and scale were obtained from the European Calibration System 1962 (Kiviniemi, 1964). The reference level and scale currently in use in the FOGN were derived by T. Honkasalo in 1971 from a local adjustment of the IGSN71 (Morelli et al., 1974). The FOGN is thus in the mean tide system of the IGSN71. No time-homogenization due to post-glacial rebound was applied to the observations but because of the short observation period the FOGN can be stated to have epoch 1963.0 (Kääriäinen and Mäkinen, 1997). The accuracy of the gravity differences (one-sigma) was estimated by Kiviniemi (1964) to be 0.03...0.06 mGal (one sigma).

A control measurement of the network was conducted by A. Kiviniemi in 1988 with the LaCoste & Romberg model G (LCR-G) gravimeters G-55 and G-600. The root-mean-square difference (1988 minus 1962-63) of gravity differences was 0.035 mGal without correction for land uplift. Comparisons of the FOGN values with absolute gravity measurements showed the consistency of the FOGN within its estimated accuracy, after system differences, i.e. the epoch and the treatment of the permanent tide were accounted for (Kääriäinen and Mäkinen, 1997).

Gravity values of some rebuilt sites were corrected on the basis of the 1988 measurements, otherwise the 1971 values were retained (Kääriäinen and Mäkinen, 1997). Some more recent patches are unpublished. New values for rebuilt sites have been deduced from ties within the FOGN, not from absolute gravity measurements. Thus the FOGN has formed a consistent reference for Finnish gravity surveys, and their results calculated in the FOGN can easily be transformed to other epochs and tidal systems.

4. Renovation of the Finnish First Order Gravity Network

4.1. Purposes and strategy

The principles for the renovation of the FOGN were worked out at the FGI in 2008–2009, mainly by J. Mäkinen. The purpose of the work is twofold: to provide the users (including the FGI itself) with new, more accurate reference values for their gravity surveys and other applications, and to facilitate the re-computation of old surveys to this new reference. Therefore it was decided to use the sites of the existing FOGN network where possible. Two alternatives then presented themselves: (1) relative network measurements with multiple gravimeters, similar to the scheme in Figure 3 and including laboratory-type sites measured with the FG5 absolute gravimeter, and (2) absolute measurements with an A10 outdoor gravimeter on the FOGN stations, and including occupations of FG5-sites for comparison purposes. The cooperation with the IGiK made it possible to adopt the latter alternative, using the A10-020 gravimeter.

The sensor heights of the relative gravimeters that will visit FOGN sites differ considerably. Even more differ the tripod heights adopted by various institutes in their field work. The typical FOGN station is on church stairs on a small hill. As a consequence, the vertical gravity gradient differs appreciably from the normal gradient and is in addition markedly non-constant. To avoid distortions both in the creation and use of the new FOGN values, it was therefore decided (i) to measure at all sites vertical gravity differences between three heights using relative gravimeters, (ii) to use this gradient information in the processing of the A10-020 observations, and (iii) to publish not only a single gravity value but gravity as a function $g = g(z)$ of elevation z above the station, up to $z = 1$ m. The drop in the A10-020 starts at 0.7175 m above the mounting surface and its nominal length is 0.0886 m. The nominal sensor heights for the measurement of the vertical gravity differences are 0.16 m, 0.50 m and 1.00 m. The first mentioned-height is nearly as low as we can get with the relative gravimeter used in the gradient measurement, a Scintrex CG-5 which has its sensor 0.089 m above the bottom of the gravimeter box (Scintrex Limited, 2008). The choice of the other heights is related to the form of the $g = g(z)$ expected on stairs and to the A10 dropping height, and will be discussed in detail elsewhere. At a few stations with a rough surface the interferometer was mounted on the stand provided by the manufacturer (Fig. 6) which raises the drop start by about 0.12 m. The sensor heights in the measurement of the vertical gravity differences are kept the same as on other stations.

4.2. Field practices

The measurement sequence previously adopted for field measurements in Poland was 8 sets of 120 drops each, with one-second drop interval and three-minutes set interval, giving a duration of 24 min for the whole series. The sequence was also applied in the FOGN, with an important addition: on all sites two independent sequences were measured, between which the A10-020 was dismantled and re-mounted in a different azimuth, if possible 180 degrees apart from the first one (Mäkinen et al., 2010b, 2010c).

This (i) facilitates the detection of gross errors in the setup and measurement process, (ii) provides data to estimate the accuracy/precision of the station occupation, (iii) improves accuracy as it allows some averaging over possible setup--specific errors, especially the instrument/pier response due to the drop recoil, (iv) provides data to evaluate the success of the "system response compensation" in the data acquisition and post--processing program (Micro-g LaCoste, Inc., 2008b), (v) eliminates any systematic error due to possible horizontal velocity of the dropped object ("the Eötvös effect"). Regarding the item (v), the A10 dropping mechanism does not have any preferred directions (e-mail information from D. van Westrum, Micro-g LaCoste Inc., on August 5, 2009). In fact the authors did not observe any effects of type (v) in the measurements (see Section 4.3), but the advantages (i)...(iv) stand.

The IGiK has constructed a mobile gravimetric laboratory for the A10-020 in a VW Transporter minibus. The dropper and the interferometer unit of the gravimeter are carried from their special transport boxes to the site taking advantage of the 15 m cables, while the electronics unit stays in the car (Fig. 4 and Fig. 5). The A10 needs protection against wind and sun. Therefore a tent was used in nearly all outdoor measurements. Now, mounting and stabilizing a tent on stairs could be problematic. Therefore, the tent type previously used by IGiK was improved at FGI by sewing sleeves to it, and boxes of weights placed on the sleeves maintain the tent in place. Wooden benches are used to make a platform for the tent, while the gravimeter is mounted on the stone/concrete step (Fig. 5).

Fig. 4. The A10-020 in the mobile gravity laboratory; left – dropper and interferometer unit in transport position, right – the electronics unit

Fig. 5. Views of a typical field station

The stairs provide a smooth horizontal surface such that both the dropper and the interferometer can be mounted directly on them. Some of the stations however are on bench marks in rock. Then the interferometer was set up on the stand provided by the manufacturer. For the dropper legs the IGiK developed special stands that allow the mounting on rough and inclining surfaces (Fig. 6). They proved very stable.

Fig. 6. Setup under rough field conditions, with the IGiK-constructed special stands for the dropper legs

The rapid tempo of the A10 measurements mean that there is very little time when the gravimeter could be running unattended and the team would be free to do auxiliary work at the site. Therefore only a sketch was drawn and photographs taken. The rest of the auxiliary measurements: levelling, measurement of vertical gradient, possible relative-gravity ties from an excentre, detailed documentation (photos, sketches), GNSS positioning etc. are done by a supporting team travelling separately from the A10 team.

4.3. Experiences and results

For reasons of workforce deployment, the measurements with the A10-020 were performed in four relatively short campaigns, in August 2009, May 2010, July 2010 and August 2010, by an expedition consisting of the first two authors. During them 19, 15, 9, and 8 field stations were measured in 17, 15, 12, and 11 campaign days, respectively. In addition, 9 laboratory-type absolute stations (i.e., measured with the FG5-221 of the FGI) were occupied altogether 25 times (Fig. 7).

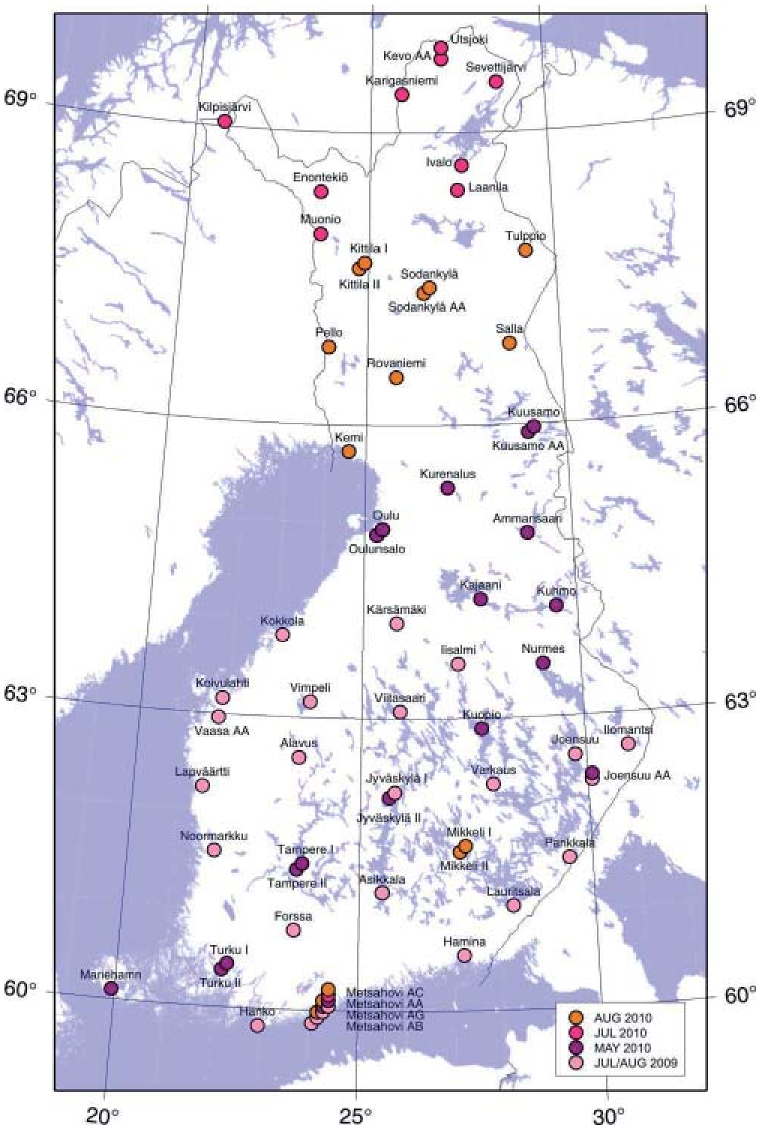

Fig. 7. Stations occupied with the A10-020 in 2009 and 2010. The FOGN network is slightly expanded and densified compared with the original in Figure 3. Some towns have more than one FOGN station; the roman numbers used here to distinguish the sites are not the official FOGN names. The laboratory-type absolute-gravity sites where comparisons with measurements by the FG5-221 were made have two letters after the name

If no problems were encountered, two hours were needed to occupy a field station, from arrival to departure: for identifying/selecting the point, testing its stability using a LCR-G gravimeter, setting up the tent, performing the measurements in two setups, making a detailed sketch and taking photos. In most instances, the usability of the FOGN station for the present work had not been reconnoitred in advance on-site. In the case that a station had been destroyed or was not suitable for an A10 measurement, some time was spent finding a replacement site. In the two last campaigns long distances were travelled as essentially only stations in Lapland were left. With the more usual 120–150 km distance between stations, two stations could be observed in one day. The minibus of the expedition travelled altogether 12 000 km during the campaigns.

About 50% of the auxiliary measurements needed were performed in 2010. The rest will be done in 2011. After the vertical gradients at the stations have been calculated, the final processing of the A10-020 observations can be performed. For the present analysis we mostly rely on the field calculations, where the normal vertical gradient of gravity is used at the FOGN stations, and the laser wavelength and the rubidium frequency (Chapter 4) available at the time of the survey were applied.

The accuracy of the A10-020 measurements can be estimated (a) at the laboratory stations, from comparison with values measured with the FG5-221, and (b) at all stations, from comparison of the results of the two independent setups.

At the laboratory stations the vertical gradients of gravity are known, and we have also calculated corrections for the drift in the laser frequency between calibrations. The FG5-221 measurement closest in time (one day to one year) to the A10-020 measurement was used. The mean difference of the A10-020 and FG5-221 results was 0.3 μGal and the RMS difference 2.5 μGal (N = 25). These figures are smaller than the authors expected.

Neither the missing information about the vertical gradient nor the long-term laser drift influence the comparisons between the two setups. At the laboratory sites, the RMS difference between the two setups was 4 μGal (N = 25). At the FOGN stations, the RMS difference was 7 μGal (N = 55). Assuming that the errors in the two setups are independent, this would imply a standard error of 7/2 or less than 4 μGal for the mean of the setups, i.e. for the result of the station occupation. While the two setups in fact share many error sources which do not show up in the difference, these are nevertheless very encouraging figures.

As mentioned in Section 4.2, the two setups were performed in opposite azimuths always when possible. The choice of the azimuths depended on practical considerations like space limitations. In 60 station occupations the azimuth difference is within the range 170–190 degrees. The travel lock of the Super Spring of the A10-020 was used as an azimuth index. Its direction is perpendicular to the plane of the two guide rods of the drag-free cart in the dropping chamber. In three directions: N-S, E-W, NE-SW there are enough azimuth pairs to allow a reliable estimation of the azimuth effect on measured gravity: n = 21, 20, 6, respectively. In all these cases the mean difference between the setups was less than 1 μGal, i.e. not significant.

The larger RMS between setups at the FOGN stations compared with the laboratory stations mostly seems to depend on the worse stability of the gravimeter support on them (step, floor etc. instead of pier). This manifests itself through large systematic residuals in the fit of the equation of motion to the (time, distance) observations of the free fall. Especially dangerous is low-frequency content in the residuals (Klopping et al., 1991). At stations with large residuals, or large differences between the first two setups we observed in additional setups. Some of these stations were in the end discarded and new sites selected instead. It is expected that careful modelling of the residuals using the “system response compensation” (Klopping et al., 1991; Micro-g LaCoste, Inc., 2008b) in post-processing will to some extent improve the agreement between the different setups at the instable stations.

The preliminary test of stability using an LCR-G and a colleague heaving or jumping on the stairs next to it turned out to be an excellent predictor of site quality for the A10-020.

5. Calibration of the laser and of the rubidium oscillator

The traceability of the free-fall determination of gravity to SI units derives from the wavelength of the laser that is used to track interferometrically the falling object, and from the frequency of the clock that is used in the timing of the distances along the trajectory. To ensure the metrological quality of the measurements with the A10-020 in the FOGN, both the rubidium oscillator and the polarization-stabilized laser of the gravimeter were calibrated before and after the field work at the Centre of Metrology and Accreditation (MIKES), which is the National Metrology Institute of Finland.

5.1. Calibration of the rubidium oscillator

The rubidium oscillator Symmetricom X72 of the A10-020 had initially been calibrated at Micro-g LaCoste, Inc., before the delivery to the IGiK. Subsequently, it has been calibrated three times at MIKES (MIKES 2009, 2010a, 2010b). In addition, the oscillator was calibrated at the BIPM (Sèvres, France) during the International Comparison of Absolute Gravimeters ICAG 2009. The authors have also on four occasions calibrated the oscillator themselves at the Metsähovi Geodetic Observatory, using the frequency of the hydrogen maser of the nearby Metsähovi Radio Observatory of the Helsinki University of Technology as a standard. The results are collected in Figure 8.

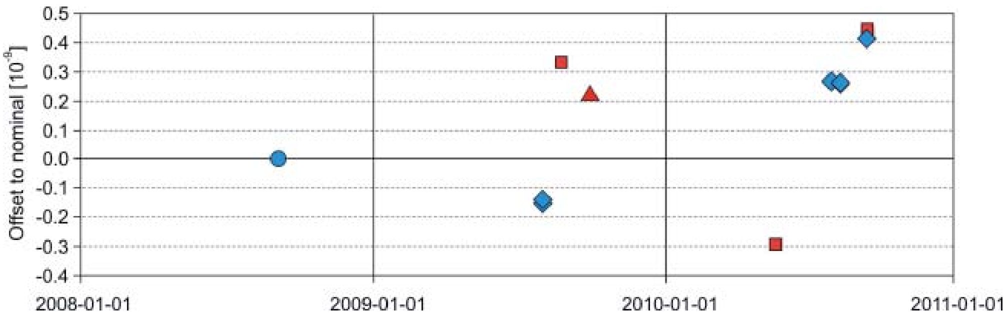

Fig. 8. The relative offset of the frequency of the rubidium oscillator of the A10-020. The nominal frequency of the oscillator is f = 10 MHz. The plotted number is $\Delta f/f$ where $f + \Delta f$ is the measured frequency. The blue circle is the initial calibration at Micro-g LaCoste, Inc. The blue diamonds are our own calibrations at the Metsähovi Geodetic Observatory. The red triangle corresponds to the calibration at BIPM. The red squares show the results of the calibrations at MIKES. Uncertainties are not plotted

The frequency offset of the rubidium oscillator of the A10-020 has varied in the range $\pm 0.5\times10^{-9}$ relative to the nominal frequency of 10 MHz (Fig. 8). The variation does not show any regular pattern and it is not clear with how much confidence we can interpolate corrections to the nominal frequency between the calibration dates. The redeeming feature is however that the observed relative variation an offset of $\pm 0.5\times10^{-9}$ in frequency corresponds to an offset of only ±1 μGal in measured gravity.

5.2. Calibration of the laser

The polarization-stabilized laser (model ML-1) of the A10-020 had initially been calibrated at the Micro-g LaCoste, Inc., before the delivery to the IGiK. It was then calibrated three times at MIKES (MIKES 2009; 2010c; 2010d). The laser can be stabilized at two frequencies about 700 MHz apart, usually called the red and blue side-lock (or mode). Gravity data are taken alternating between the two side-locks and the results averaged. This is done because the mean of the side-locks, the centre frequency, is much more stable than either of the side locks. Consequently, only changes in the centre frequency, not the side locks, count for the final result.

Figure 9 presents the calibration history of the A10-020 laser. From the linearity of the drift of the centre frequency so far, it can be seen that for best accuracy, the laser should be calibrated at least once a year. The final processing of gravity data will be performed interpolating the laser frequency for the epochs of the measurements.

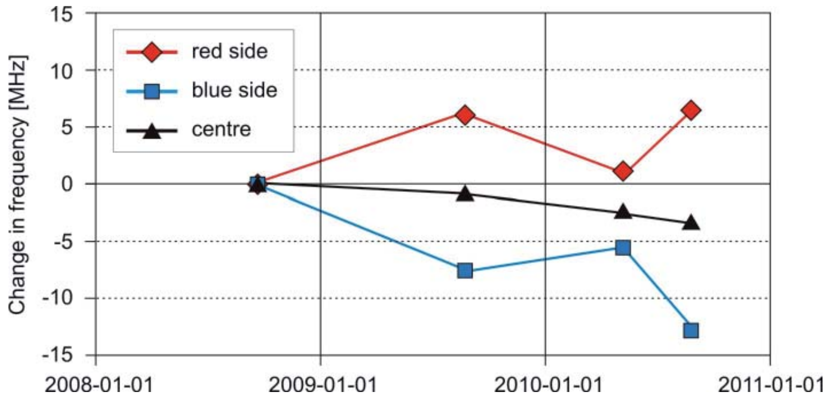

Fig. 9. The calibrations of the laser of the A10-020 for the two side locks and the centre frequency. The change in frequency is shown relative to the first calibration at Micro-g LaCoste, Inc. Subsequent calibrations were performed at MIKES. Uncertainties are not shown. A change of 1 MHz in the laser frequency corresponds to 2.1 μGal in measured gravity. The total drift of the centre frequency in two years was 3.1 MHz which, if neglected in the processing, would lead to an error of 6.4 μGal in measured gravity

6. Instrument tests

The laser calibrations at MIKES were performed by keeping the laser at each side-lock for an extended period of time. Therefore, additional test data was taken alternating the side locks in exactly the same way as in gravity measurements. More importantly, at MIKES the temperature was always within 0.1°C of 20°C. However, in field conditions the ambient temperature may vary tens of degrees. Though in the A10 the polarization-stabilized laser is mounted inside a temperature-controlled block within a heated enclosure, temperature-related effects in its frequency cannot be a-priori excluded (Mäkinen and Ståhlberg, 1998). Together with MIKES scientists, a 27-hour temperature test of the laser was therefore ran, varying the laboratory temperature between 16 and 25°C. At the Metsähovi Geodetic Laboratory, a test run with gravity was then performed, measuring gravity during 46 hours while the laboratory temperature was varied between 12 and 30°C. The results of these experiments will be published elsewhere.

7. Summary and conclusions

The A10-020 outdoor gravimeter of the IGiK has been used to measure improved gravity values at 51 field stations of the Finnish First Order Gravity Network. Comparisons of two independent set-ups at each station occupation indicate a repeatability better than 4 μGal for their mean. At 9 laboratory-type stations 25 comparisons of the A10-020 with the results of the FG5-221 of the FGI were made. The offset between the two instruments was negligible and the RMS difference between them less than 3 μGal. The work was completed in 55 days during 4 separate campaigns.

The difference between the A10-020 results and the relative measurements of 1962–63 and 1988 contains a contribution from the Postglacial Rebound (PGR), and its analysis may shed additional light on the relationship of gravity change and vertical motion in PGR (Mäkinen et al., 2010a, 2010d).

For best accuracy with the A10-020, it is important to select stations with a stable support for the gravimeter. The laser should be calibrated at least once per year.

The results confirm the advantages of the A10-020 for the measurement of gravity reference networks.

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Wykorzystanie grawimetru A10-020 do modernizacji fińskiej osnowy grawimetrycznej

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Streszczenie. Grawimetr A10 jest pierwszym grawimetrem absolutnym umożliwiającym precyzyjne wyznaczenie przyspieszenia siły ciężkości w warunkach polowych. Wyniki absolutnych pomiarów przyspieszenia siły ciężkości przy użyciu grawimetru A10 są w wielu przypadkach konkurencyjne w odniesieniu do tradycyjnych względnych pomiarów grawimetrycznych zarówno pod względem precyzji pomiaru, jak i jego efektywności. W szczególności grawimetr A10 jest bardzo przydatny do modernizacji osnowy grawimetrycznej oraz do precyzyjnych pomiarów grawimetrycznych wymaganych we współczesnych sieciach grawimetrycznych.

We wrześniu 2008 r. w Obserwatorium Geodezyjno-Geofizycznym Borowa Góra zainstalowano przenośny grawimetr balistyczny A10-020. Ciąg czasowy obserwacji grawimetrycznych od września 2008 r. wskazuje, że pomiary wykonywane grawimetrem A10-020 zarówno w warunkach laboratoryjnych, jak i polowych charakteryzują się wysoką jakością.

Grawimetr balistyczny A10-020 został użyty w latach 2009–2010 do ponownego pomiaru przyspieszenia siły ciężkości na punktach fińskiej osnowy grawimetrycznej. Przyspieszenie siły ciężkości pomierzono na 51 punktach osnowy z powtarzalnością lepszą niż 4 μGal. Dla kontroli wykonano dodatkowo 25 pomiarów przyspieszenia siły ciężkości na 9 grawimetrycznych punktach absolutnych w Finlandii. Ze wstępnych obliczeń wynika, że systematyczna różnica między rezultatami pomiarów A10-020 i FG5-221 jest zaniedbywalna, zaś błąd średni różnicy jest na poziomie 3 μGal.

Zarówno laser o stabilizowanej polaryzacji, jak i rubidowy wzorzec częstotliwości grawimetru A10-020 były kalibrowane przed i po pomiarach polowych w Fińskim Narodowym Instytucie Metrologii MIKES w celu zapewnienia metrologicznej jakości pomiarom.

Uzyskane wyniki potwierdzają przydatność grawimetru balistycznego A10 do prac związanych z modernizacją osnowy grawimetrycznej.

Słowa kluczowe: absolutne wyznaczenia przyspieszenia siły ciężkości, grawimetr balistyczny A10, podstawowa osnowa grawimetryczna