SURVEYING WITH THE A10-020 ABSOLUTE GRAVIMETER FOR GEODESY AND GEODYNAMICS – FIRST RESULTS

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ABSTRACT

The A10 is the first outdoor absolute gravimeter that allows to determine gravity with high precision. Absolute gravity survey with the A10 becomes highly competitive in terms of both efficiency and precision with traditional relative gravity survey.
The portable A10-020 absolute gravimeter has been installed at the Borowa Gora Geodetic-Geophysical Observatory in September 2008. Since then a number of test measurements was conducted. Under laboratory conditions the series of gravity determination was obtained at two independent pillars at Borowa Gora as well as in Metsahovi and the BIPM gravimetric laboratories. Also a number outdoor gravity measurements with the use of mobile gravimetric laboratory was performed at the stations of gravity control in Poland and in Finland. The results obtained indicate high quality of gravity determination with the A10 under laboratory conditions and unprecedented quality under field conditions. They confirm the applicability of the A10 absolute gravimeter to the modernization of gravity control and high precision gravity survey required in modern gravity networks, but also its usefulness in microgravimetry as well as geodynamics.
Some practical problems concerning the use of the A10 and its operational procedure are discussed.

1. INTRODUCTION

Absolute gravimeters together with permanently operating precise relative gravimeters, i.e. tidal gravimeters or superconducting gravimeters, are recently used for improving Earth tide models as well as for monitoring non-tidal variations of gravity field. Repeatable gravity survey with precise absolute gravimeter is required at the stations of the European Combined Geodetic Network, designed for the maintenance of long time stability of the terrestrial reference system with an accuracy of 10^{-9} for Europe, especially in vertical component (Ihde et al., 2005). Special role is expected to be assigned to the A10 portable absolute gravimeter, manufactured since late 1990. by Micro-g, that can successfully be used in the laboratory although it has specifically been designed for a field survey of gravity. Its efficiency and precision make the A10 gravimeter superior with respect to the existing relative gravimeters.
The A10 gravimeter provides a new standard in the absolute gravity measurements. It is optimised for fast data acquisition and portability in outdoor applications in World-Wide operating dynamic range with 10 μGal accuracy, 1 μGal precision (Micro-g LaCoste, 2008). The A10 provides absolute value of gravity with good precision in a very short time.

The results of measurements with the A10 gravimeter performed during last decade by different research teams are quite optimistic (Liard and Gagnon; 2002; Schmerge and Francis, 2006; Krynski and Roguski, 2009; Falk et al., 2009). The quality of laboratory measurements is clearly better than specified by the manufacturer. Also the results of field measurements with the A10 are very successful.
In 2008 the Institute of Geodesy and Cartography (IGiK), Warsaw, joined the family of users of the A10 gravimeter. In September 2008 the absolute gravimeter A10-020 was installed at the Borowa Gora Geodetic-Geophysical Observatory. Since then, a number of measurements with the A10-020 were conducted both in the gravimetric laboratories and in the field. Majority of the results obtained confirm those published by other research teams. Some practical problems concerning the use of the A10 and its operational procedure that arose in the practice so far of the team of the IGiK were indicated and they are discussed in the paper.

2. LABORATORY MEASUREMENTS WITH THE A10-020

Absolute gravity is systematically measured with the A10-020 gravimeter at two pillars A-BG and BG-G2 of the gravimetic laboratory of the Borowa Gora Geodetic-Geophysical Observatory since September 2008. The results of those measurements are shown in Figure 1 and Figure 2, respectively.

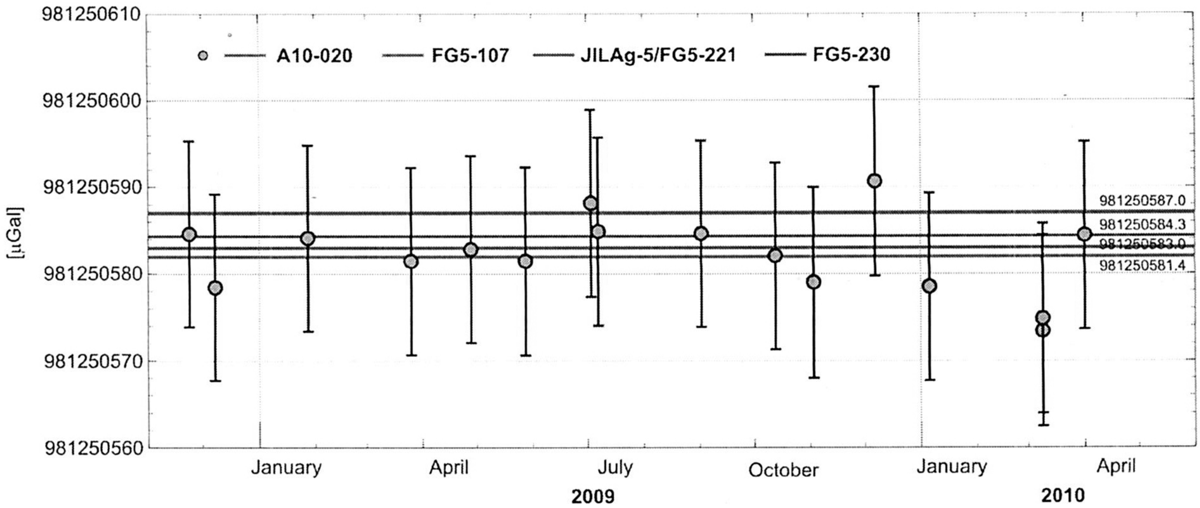

Fig. 1. Results of measurements with A10-020 at the A-BG laboratory station.

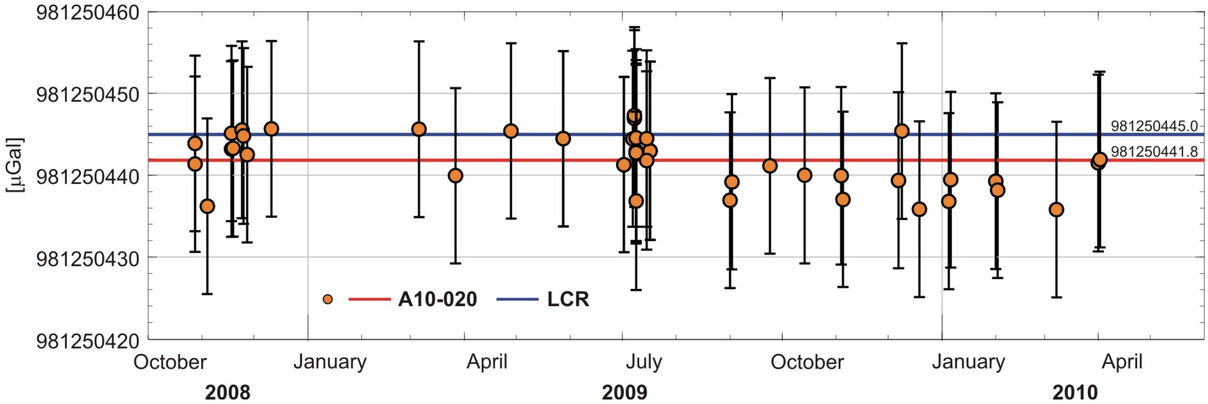

Fig. 2. Results of measurements with A10-020 at the BG-G2 laboratory station.

At the A-BG station the results of gravity survey with the A10-020 were compared with those obtained with the JILAg-5 and three different FG5 gravimeters within last 15 years. The gravity measured with the A10-020 at the BG-G2 pillar was compared with the absolute gravity value at A-BG used as reference when adjusting the Polish Gravity Control Network (POGK97) in 1990 (Krynski et al., 2003) transferred to BG-G2 using a set of 4 LaCoste&Romberg (LCR) gravimeters. With respect to that value the offset of the average gravity determination with the A10-020 was computed for the data from the BG-G2 station. The respective offset for the data from 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 last 4 years. The statistics of those measurements are shown in Table 1.

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

Station	No. of observations	Max - Min	Std. dev	Rms	Offset
A-BG	18	17.19	4.26	4.78	2.39
BG-G2	45	11.49	3.18	4.45	3.16

Although the routine gravity survey with the A10-020 at the gravimetic laboratory of the Borowa Gora Geodetic-Geophysical Observatory was based on 12h data, some experiments were conducted with data from 24 minutes up to 18 hours. Similarly to Schmerge and Francis (2006) no significant difference depending on data length was found in the determined g. Therefore the single setup for field measurements with the A10-020 has been assumed to take only 24 minutes. It consist of 8 sets with 120 drops each, with 1 second drop interval.

In 2009 the A10-020 was also used to measure gravity at two other gravimetric laboratories: the Bureau International des Poids et Mesures (BIPM) gravimetric laboratory in Sèvres, France during the International Comparison of Absolute Gravimeters ICAG-2009 (Fig. 3), and the gravimetric laboratory of the Finnish Geodetic Institute (FGI) in Metsahovi during the first campaign of re-surveying of the Finnish Gravity Control Network (FOGN).

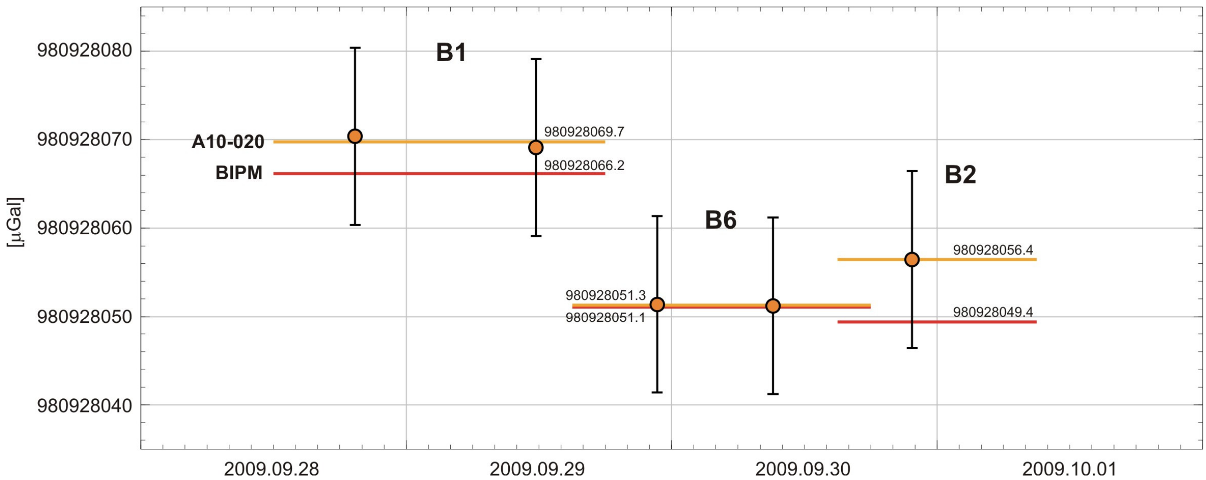

Fig. 3. Results of measurements with A10-020 at three pillars B1, B2 and B6 in the BIPM gravimetric laboratory.

In the Metsahovi gravimetric laboratory 8 measurements of gravity were performed with the A10-020 absolute gravimeter. The results obtained exhibit high quality in terms of repeatability and accuracy. Compared with the respective ones obtained using the FG5-221 gravimeter of the FGI their standard deviation equals to 4.4 µGal and the offset -1.1 µGal (Mäkinen et al., 2010b).
The results presented above show that the performance of the A10-020 gravimeter in the laboratory conditions is significantly better than it has been specified by the producer (Micro-g LaCoste, 2008). Its both precision and repeatability are almost as good as the ones of the FG5 data. For example, the standard deviation of gravity measurements with the FG5-230 in the gravimetric laboratory of the Jozefoslaw Astro-Geodetic Observatory of the WUT estimated from 40 surveys equals 2.6 µGal (Barlik et al., 2009).

3. FIELD MEASUREMENTS WITH THE A10-020

Mobile gravimetric laboratory has been set up at the Institute of Geodesy and Cartography, Warsaw, for field measurements with the A10-020 gravimeter (Fig. 4). The VW Transporter has been adapted for such laboratory. The A10 gravimeter is transported in two special boxes, together with the complete infrastructure of the measuring system. An additional equipment, such as a tent for protecting the A10 against external weather conditions during field measurements has been developed.

Fig. 4. Field survey with the A10-020 using mobile gravimetric laboratory.

Absolute gravity is systematically measured with the A10-020 also at the field station 156 Borowa Gora of the POGK97. The results obtained were compared with gravity value (LCR) obtained from the adjustment of the POGK97 (Fig. 5). The statistics of those measurements are shown in Table 2.

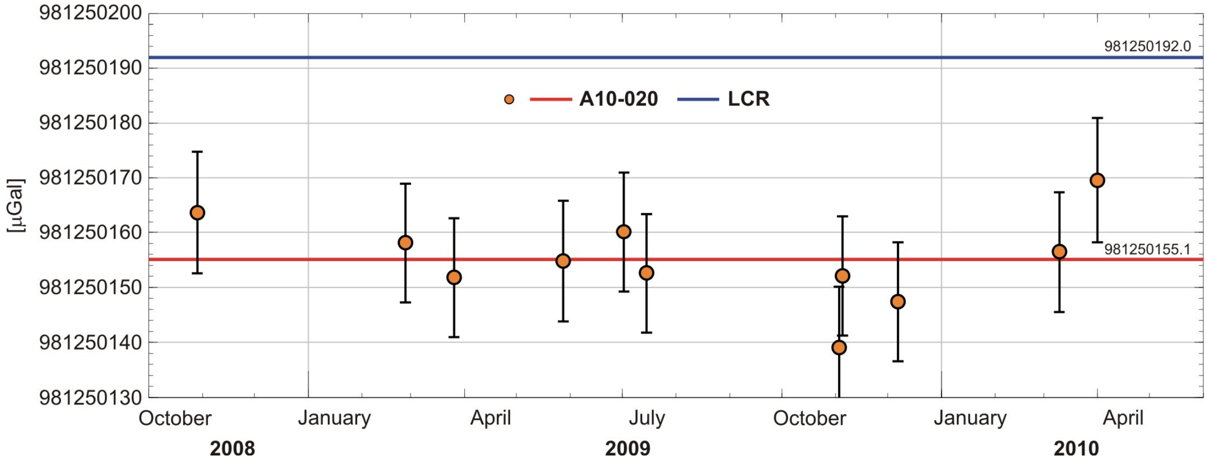

Fig. 5. Results of measurements with A10-020 at the field station 156 Borowa Gora.

Table 2. Statistics of measurements with A10-020 at field station 156 Borowa Gora [μGal]

No. of observations	Max - Min	Std. dev	RMS	Offset
11	30.47	8.13	37.34	36.94

It is not a surprise that the dispersion of gravity surveyed with the A10 at the field station (Table 2) is substantially larger then one obtained for gravity surveyed in the laboratory (Table 1). The offset of gravity determined at the field station 156 Borowa Gora with respect to the gravity value obtained from the adjustment of the POGK97 seems large (Table 2) when considering the accuracy of adjusted gravity of the POGK97 station estimated equals 10 μGal. It indicates the need for further modernisation of the existing gravity control in Poland.

During the 2009 campaign of re-measuring the FOGN absolute gravity was measured with the A10-020 at 19 field stations of the network (Mäkinen et al., 2010a; 2010b). Red circles in Figure 6 show the FOGN stations re-surveyed with the A10-020 in 2009. Some improvements in the additional equipment, like wooden benches to make platform for tent or sleeves sewn on tent with weights on them to keep tent in place, made survey with the A10-020 more efficient.

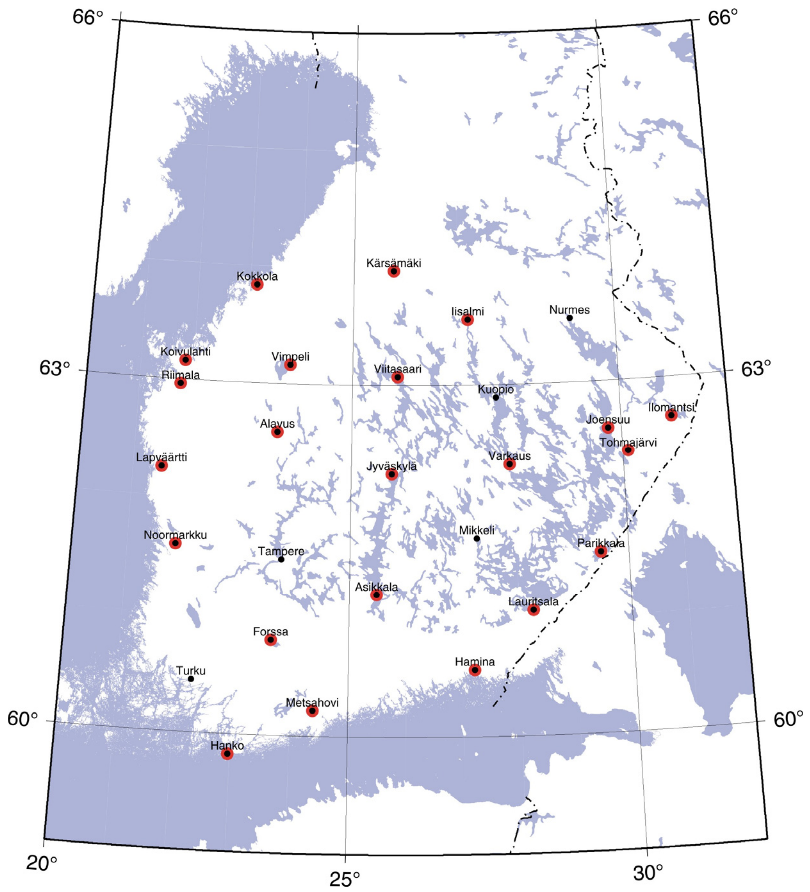

Fig. 6. Stations of the Finnish Gravity Control Network re-surveyed with the A10-020 in 2009.

The strategy of the field survey with the A10 developed for absolute gravity survey in the field in Poland was adopted for surveying the FOGN sites. Two independent setups, rotating the gravimeter by 180° in between were performed. The single setup is followed by 8 sets with 120 drops each, with 1 second drop interval; it takes only 24 minutes. There is practically no time when the gravimeter runs and the team is free to do supporting measurements, e.g. levelling, vertical gradient, a relative tie from an excentre, documentation (photos, sketches), GNSS positioning, etc. Practically, with 150 km between stations, only 2 stations per day could be surveyed. At 10 FOGN sites the results obtained with the A10-020 were compared with the respective ones obtained with the FG5-221 of the FGI. The mean difference equals 1 µGal while the standard deviation - 4 µGal (Mäkinen et al., 2010a; 2010b). The results obtained show that the performance of the A10 gravimeter also in the field conditions is better than it has been specified by the producer (Micro-g LaCoste, 2008).

4. SOME PRACTICAL PROBLEMS WITH THE USE OF THE A10-020

There are several practical problems encountered during the operational work with the A10-020 gravimeter. Most of them are related to the dependence of the parameters of the gravimeter on the ambient temperature and the local weather conditions.
As an instrument designed in particular to the measurements in the open air, i.e. under field conditions, the A10 has a thorough thermal insulation. However, there is a need to protect the instrument from the influence of direct exposure to the Sun as well as against wind and rain. A standard way to provide such protection is to use a tent

covering the whole instrument at the station. A standard, dome-shape, fishermen tent without floor, modified by adding stripes of cloth in its bottom part to allow easy setting with the extenders as well as to provide better wind protection was used in field work with the A10-020. The tent solution works fine, but the authors experience indicate that strong attention must paid, whether a temperature inside the tent does not increase significantly, what is very likely when it is set in the direct exposure to the Sun. In such conditions, it happened a lost of vacuum, because of overheating an ion pump. While the ambient temperature was about 20 C, the temperature inside the tent exceeded 40 C. This is certainly a problem of the A10 insulation and its resistance for high temperatures. The manual of the A10 provided by the manufacturer (Micro-g LaCoste, 2008) states that the gravimeter is able to operate in temperatures up to 35 C (internal temperature), but such temperature can be really easily, accidentally reached if there is no air conditioning system in the car transporting the A10 or the measurements are conducted in direct sunshine.

Another problem related to a temperature, concerns the time needed to achieve stable work conditions, especially in the fieldwork. According to the manual of the A10 (Micro-g LaCoste, 2008) the gravimeter needs at least 4 hours of heating up to achieve thermal equilibrium by the dropper and interferometer base chambers. However, it usually is very difficult to estimate the proper length of the heating up period during the fieldwork, where time is a very important factor, and where the gravimeter is being switched on all the time except for short periods of taking it out of the car. The length of that period depends also strongly on actual, local, weather conditions (ambient temperature, cooling breezes, etc). In addition, some kind of influence of the temperature on the mechanical parts of the gravimeter, which affects its levelling system was observed when surveying with the A10-020. The laser beam verticality checked directly after setting the gravimeter at the station has frequently been observed changed after some time. Therefore the verticality of the gravimeter should always be checked after completion of the survey at a site.

Further issue is a dependence of the red/blue laser modes separation on the temperature. It seems to grow up in lower temperatures. However, no indication on its possible influence on the results have been observed.

The strategy of two independent setups, rotating the gravimeter by 180 degrees in between, was adopted during the field survey. This was caused by two reasons. The first was to eliminate the possible influence of setting up orientation on the results, due to the particular construction features of the instrument. However, the experience with the A10-020 does not show any evidence of such influence. It shows on the other hand that the result of survey can sometimes be affected by a substantial bias with no evidence indicating its source. The second reason concerned the acceptance of the rules to repeat every single measurement is to eliminate any possible systematic errors.

There could be pointed out few less important issues, which make the measurements more difficult, like hard and heavy cables, and inconveniently placed connectors, which need to be handled with the highest care. Due to their hardness it is very important to protect the gravimeter from the vibrations transferred by the cables, e.g. not to leave the cables touching the wall of the protecting tent.

5. CONCLUSIONS

The precision and repeatability of gravity measurements with the A10 gravimeter depend on numerous factors, such as performance of the instrument, quality of the pier, ability of the operator to set up the gravimeter correctly, weather conditions, etc. To

prevent negative effects of weather in field measurements it is necessary to use additional equipment, such as a tent to protect the instrument against the wind and Sun.

Proper preparation of the A10 gravimeter before the data acquisition is extremely important. The stable thermal balance of the internal gravimeter devices: dropping chamber, rubidium oscillator, laser interferometer as well as the superspring device and verticality maintaining system is essential. It seems then reasonable to wait at least 30 minutes to 1 hour after setting up the instrument at the site, whenever it had to be switched off even for a very short period. To increase the reliability of gravity determination two independent surveys at each site are highly recommended.

Results obtained with the A10-020 gravimeter in test surveys under laboratory conditions proof their high quality in terms of both precision and repeatability, that is almost as good as the one of the FG5. The rms of the A10-020 data with respect to the FG5 data estimated in different laboratories does not exceed 5 µGal.

The field experiments performed and the results obtained show the usefulness of the A10 for the modernization of gravity control, in particular for its densification with absolute gravity points.

High quality of the A10 data make the gravimeter suitable for geodynamic research not only under laboratory conditions but also in the field in the regions of stronger geodynamic activity. It may successfully replace the expensive and time-consuming relative gravity surveys applied so far for such purpose.

Repeated observations at a gravity reference station are highly recommended in order to monitor instrument behaviour over a longer time span. Regular checks of the laser frequencies as well as frequency standard are necessary and enable significant enhancement of accuracy.

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