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Some Results of Calibration Factor Determination of LaCoste and Romberg Gravity Meters (Model D)

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Abstract. Contrary to the manufacturer's manual we observe a non-linearity of the calibration-factors of the D-8 and D-9 LCR gravity meters. By measuring on two local calibration-lines ($\Delta g_1 = 27$ mgal and $\Delta g_2 = 41$ mgal) and in various ranges of the measuring screw, we were able to prove the effects of non-linearity by experiments. The calculation of calibration factor functions is outlined and the quality of the approximation-model could be verified in terms of measurements on parts of the European Calibration line (ECL). The results show, that the effects of nonlinearity have to be considered with regard to high precision gravity measurements. By using the calibration factor as given by the manufacturer; errors up to 0.08 mgal will be observed.

Key words: Nonlinearity of gravity meters – Calibration factors – Calibration factor function – Accuracy of readings – LaCoste and Romberg gravity meter (Model D)

Introduction

LaCoste and Romberg model D gravity meters have a resolution in the µgal range, and at present they belong to the most sensitive field gravity meters in the world. The instruments D-8 and D-9 described here are used for both gravity and vertical gradient measurements in the Eastern Alps mainly (Götze et al. 1979; Steinhauser et al., 1980). Because of the elevation differences of several measuring points in this region it is necessary to measure in various reset ranges of the gravity meters with a range of approximately 200 mgal[1] (corresponding to 2,000 turns of the measuring screw) only.

The instruments D-8 and D-9 were calibrated quickly and easily by comparison of measurements with corresponding gravity differences Δg on calibration lines (sections of the European calibration line ECL). The following sections of the ECL were used:

D-8 gravity meter: Torfhaus G – Bad Harzburg G,
$\Delta g = 84.15$ mgal
D-9 gravity meter: Kufstein N – Stafflach X,
$\Delta g = 224{,}71$ mgal.

The calibration factors of LCR-D gravity meters are stated to be constant in the whole measuring range by the manufacturer. Different ranges of counter units had to be used during the calibrations, which have been performed on the calibration lines mentioned above during the last ten years, because of frequent reset displacements. Thereby systematic differences from the expected values of the corresponding gravity differences could be observed, which amounted to six counter units at the most corresponding to a gravity difference of 0.06 mgal. They were interpreted qualitatively as non-linearities of the calibration factors. Observations of this kind have been described by other authors too (e.g. Wenzel, pers. comm. 1973; Steinhauser, 1978; Torge and Kanngieser, 1980) and initiated an examination of the systematic effects concerning the LCR-D gravity meters mentioned above. This is particulary true for the experiments of Lambert et al. (1979).

The existing measuring results clearly show, that deviations from the expected values of gravity differences on calibration lines are not due to measuring errors, but a functional relation exists between the gravity differences (calculated by using a constant calibration factor) and the mean readings. Figure 1 shows the measured gravity differences on the calibration line Torfhaus G – Bad Harzburg G as a function of the mean position of the measuring screw for the gravity meter D-8. The gravity differences decrease with increasing mean positions of the measuring screw and deviate from the "true" value up to the amount of 0.08 mgal.

In case of the LCR D-9 the differences between the readings at the final points of a local calibration line in Vienna increase with the mean position of the measuring screw almost linearly (Steinhauser, 1978).

A significant nonlinearity of the measuring screw depending upon the reset screw position was also found in case of other LCR Model D gravity meters (Torge and Kanngieser, 1980; Dragert et al., 1981; Lambert and Liard, 1981).

Measurements and Nonlinearity Determination

The gravity differences on the sections of the ECL described above are too large for a reliable determination of the effects of non-linearity. Local calibration lines had to be used or to be installed for this purpose.

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[1] 1 mgal $= 10^{-5}$ ms^{-2}

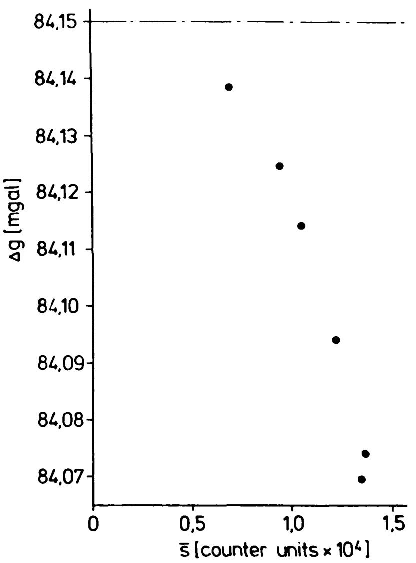

Fig. 1. Relationship between measured gravity differences and the mean measuring position, plotted for the LCR-gravity meter D-8; calibration line: Torfhaus G – Bad Harzburg G

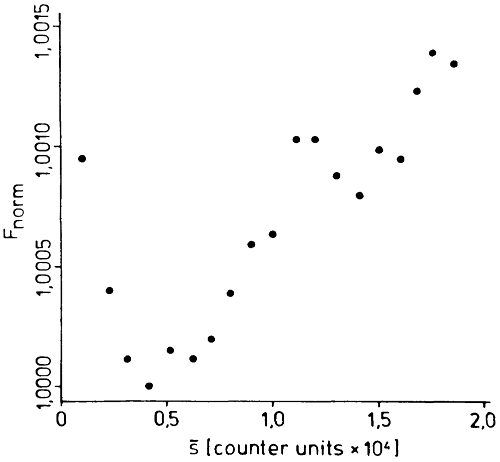

Fig. 2. Normalized calibration factor function F_{Norm} for the D-8 gravity meter on the local calibration line Clausthal – Osterode

Local Calibration Lines and Experimental Results

The following criteria are decisive for the selection of local calibration lines:

- Sufficient gravity differences for a reliable proof of nonlinearity effects. Starting from a reproducibility of 0.02 mgal of relative measurements the gravity difference of the local calibration line should amount to 30 mgal approximately. This relation corresponds to observations mentioned above, which show variations of 0.06 mgal at gravity differences of 84 mgal. Gravity differences larger than 30 mgal should not be used, as the extrema of the calibration factor function could not be resolved because of the integral effect of the measurements.
- Low noise at the gravity stations and sufficient short-term stability to ensure reliable repititions of the measurements.
- Short time intervals between the readings at the ends of the calibration lines to guarantee a favourable drift behaviour of the gravity meters.

For the examination of the LCR D-8 a local calibration line was installed between Clausthal and Osterode, meeting the requirements mentioned above. The gravity difference amounts to 27 mgal. On this calibration line the gravity difference was measured at 19 consecutive positions of the reset screw in the available measuring range of 200 mgal approximately. At the ends of the calibration line measurements were carried out 4 or 5 times in each reset position to guarantee reliable results; all readings were corrected with respect to instrumental drift. The time intervals between the readings at the ends of the line amounted to 10–12 min only. Figure 2 shows the results of 19 single measurements in normalized form, where the ratio defined by

$$F_{Norm} = d_m / d_i \tag{1}$$

d_m = maximal value of the differences between the readings

d_i = difference between the readings for $i = 1, .., 19$

is represented as a function of the mean readings $\bar{s}_i$ ($i = 1 .., 19$). Figure 2 evidently shows that the gravity difference of 27 mgal is sufficient to resolve local extrema of the calibration factor function. In Figure 1a corresponding trend, at best, is shown because of the limited resolution there.

The existing calibration line between Vienna Hohe Warte and Kahlenberg with a gravity difference of 41 mgal approximately was used for the examination of the instrument D-9 again. In addition to a better resolution by using further reset positions the temporal reproducibility of the nonlinearity effects should be tested. The end points of the calibration line were measured 3 or 4 times at each reset position; all readings were evaluated taking into account the tidal gravity variations and instrumental drift. The measurements were repeated at three reset positions. The time interval between the measurements at the end points of the calibration line was of the order of 20–25 min. The measuring results of 1979 and 1976 are shown in Fig. 3, also in normalized form. The temporal variation of the sensitivity of the LCR D-9, which was determined by yearly measurements on the profile section of the ECL between Kufstein N and Stafflach X using the same reset screw position every time, was considered here accordingly. The measurements of 1979 confirm the earlier results. This fact shows temporal stability of the observed effects. In the upper range of counter units a modification of the calibration factor function determined in 1976 has to be made, as the measurements of 1976 did not yield reliable information about the uppermost range.

Numerical Calculations

The determination of the calibration factor $Caf(r)$ as a function of the readout value (r) may be outlined with regard to the fact that the true gravity difference is (still) unknown on local calibration lines. Let Δg be the unknown gravity difference between the end points of the calibration line with the readings s_1 and s_2, we have

$$\Delta g = \int_{s_1}^{s_2} Caf(r)\, dr. \tag{2}$$

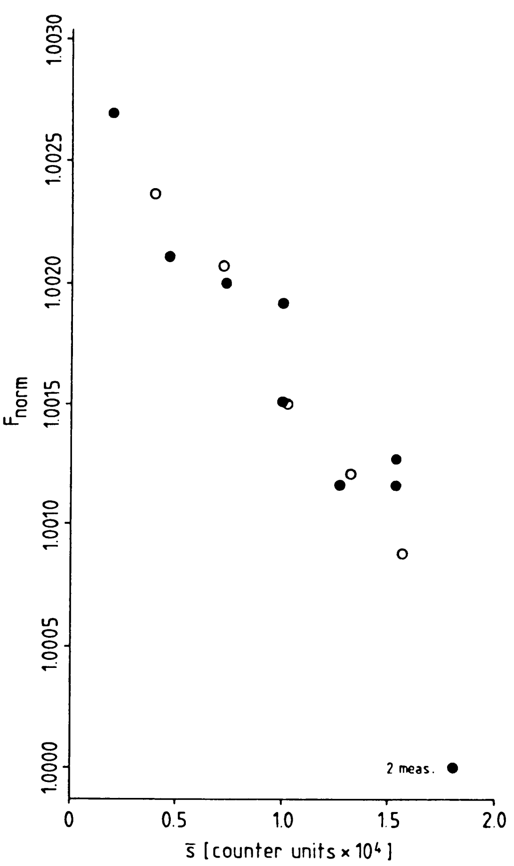

Fig. 3. Normalized calibration factor function F_{Norm} for the D-9 gravity meter on the local calibration line in Vienna: ○ 1976 measurements; ● 1979 measurements

Is the reading s_1 close to s_2, the Δg of gravity becomes

$$\Delta g = Caf(\bar{r})\cdot d, \tag{3}$$

with $d = s_2 - s_1$ and $\bar{r} = \frac{1}{2}(s_2 + s_1)$

after application of Newton's interpolation formula to solve the integral of Eq. (2). We now introduce F_{Norm}, the normalization factor of Eq. (1). Substituting this factor into Eq. (3) for the calibration factor function due to different readings $\bar{r}_i$ we obtain

$$Caf(\bar{r}_i) = F_{Norm}(\bar{r}_i)\cdot Caf(\bar{r}_m) \tag{4}$$

with i = index of the mean reading at various reset screw positions and m = index of the mean reading with maximal difference d,

because the product in Eq. (3) is a constant defined by Δ_g. Considering $Caf(\bar{r}_m)$ = const, we get from Eqs. (2) and (4) and according to a well-known $\Delta\tilde{g}$ from the observed differences on a calibration line:

$$Caf(\bar{r}_m) = \Delta\tilde{g}\left[\int_{s_1}^{s_2} F_{Norm}(\bar{r})\, d\bar{r}\right]^{-1}. \tag{5}$$

The calibration factor function $Caf(r)$ is determined after selecting a suitable approximating function to satisfy the discrete values of $F_{Norm}(\bar{r})$. This function can be found by least squares fitting or applying spline algorithms. We take a Tschebyscheff polynomial of degree up to 5.

The calibration factor functions of the gravity meters D-8 and D-9 are calculated independently of each other by utilizing the gravity differences $\Delta\tilde{g}$ mentioned at the beginning. They are also used to reinterpret the observations of the calibration lines (see also Fig. 5).

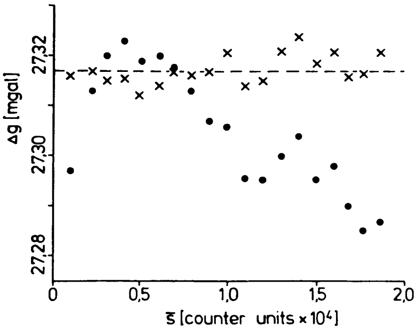

Fig. 4. Representation of measured gravity differences Δg as a function of the mean measuring screw position (D-8 meter) on the local line: ● calculated with constant calibration factor; × calculated with calibration factor function

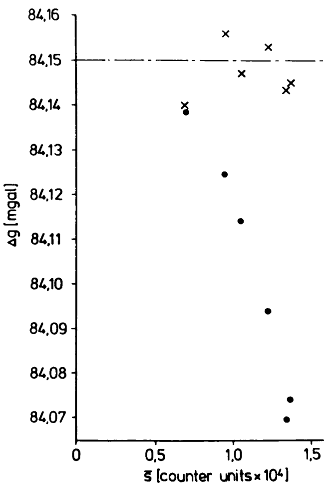

Fig. 5. Representation of measured gravity differences Δg related to the mean measuring screw position on the calibration line Torfhaus – Bad Harzburg (D-8 meter): ● calculated with constant calibration factor; × calculated with calibration factor function

Discussions

We are able to prove the quality of the calculated calibration factor functions of the last section by comparing the evaluations of those with a linear factor and those with a non-linear factor. In Figures 4 and 5 this comparison is presented with regard to the investigations of the D-8 gravity meter. First of all Fig. 4 shows calculation results with respect to various calibration factors on the local calibration line between Clausthal and Osterode. The observed differences of gravity are plotted as a function of the mean measuring screw position. It is evident that the reinterpretation with the function $Caf(r)$ provides gravity differences, which deviate statistically from the mean value. In contrast, the interpretation with a fixed calibration factor clearly depends on the superposition of the measured results by a trend-function. The mean of the local gravity difference on the calibration line is

$$\Delta g = 27.317 \pm 0.004 \text{ mgal}.$$

The calculation of gravity differences on the ECL-section Torfhaus – Bad Harzburg demonstrates a significant improvement of the expected gravity differences in the same way: no systematic relationship with the mean measuring screw position is observed any longer. Thus, the calculated calibration factor satisfies real conditions in the gravity meter (see Fig. 5).

We have to emphasize that the nonlinearity can be determined by the method described only for a small reset range. Therefore the question of whether the observed nonlinearities are caused by mechanical defects of the measuring screw or by faults in the spring is unresolved. This question can not be answered before the investigations are repeated on other calibration lines and in different reset ranges of the gravity meter. To check and possibly improve the calculated calibration factor functions of the two gravity-meters D-8 and D-9, more test measurements are planned on local calibration lines in Vienna and Clausthal.

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