Report of Activities of the IAG/ETC Working Group 4
« Calibration of the Gravimeters »

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Introduction:

During the meeting organized in Jena for the Working Group 7 [this issue of the BIM], G. Jentzsch has accepted to welcome our proposition to discuss about the problems concerning the calibration of gravimeters. It was an opportunity to analyse the present situation and we can formulate some general remarks. We are looking for methods which could achieve an accuracy better than 0.1% [Baker T.,1998].

Description of the problem:

We are concerned by the scale factor of gravimeters recording gravity variations, mainly tidal ones.

For the metrologist, any measurement aims to obtain the ratio between a quantity to scale and an another one selected like «standardized unit ».

For the tidal gravimeters, the situation is the same. A well known variation of gravity is induced and recorded by the instrument. The admittance between the signal and the modulation of gravity gives the scale factor as well as the phase characteristics of the instrument. It is sometimes interesting to determine the transfer function independently of the scale factor. When it is possible to modulate externally the restoring force of a gravimeter one can determine directly its transfer function by injecting a step function or sinusoidal signals[Richter & Wenzel, 1991; Wenzel H.-G., 1994; Van Camp & al., 1999].

What kind of processes could modify the acceleration felt by the gravimeter mass?
<1> The attraction of a moving mass is an obvious way to modify the gravitational field of the Earth and calibrate gravimeters. However it is a very weak action and a sufficient signal to noise ratio exists only for superconducting gravimeters.
<2> A second method consists to move the gravimeter in selected locations with different gravity values. This is the principle of the «Calibration lines ». Modulations of the gravity values can be very large and the signal to noise ratio does not limit of the accuracy.
<3> A third method consists to tilt the gravimeters to change the moment of force applied to the instrument. Systematic errors occur due to the changes of the gravimeter mechanical equilibrium and the 0.1% accuracy does not seem to be accessible through this technique[Kopaev A.,1998].
<4> A fourth method is based on the physical equivalence between the gravitational mass and the inertial mass. It is thus possible to calibrate a gravimeter by inertial forces e.g. those induced by sinusoidal motions.

The calibration processes <2>,<3> and <4> require to move the gravimeters. Additional mechanical systems are required for processes <1> and <4>.

The calibration process <2> is generally used to calibrate an intermediate standard of the field gravimeters the so called « micrometric screw ». The instruments using a feedback system can use calibration lines to calibrate directly the feedback force if the range of the first ones does not exceed the range of the second one.

It should be pointed out that the intercomparisons in one station of several gravimeters is not a « calibration » “senso strictu”.

The tidal gravimeters:

Nowadays the principal types of instruments able to record tidal gravity signals are :

- the superconducting gravimeters (SCG)
- the LaCoste-Romberg spring gravimeters (LCR)
- the Scintrex gravimeters (SCI)
- the Askania gravimeters (ASK)

Recently some authors used also

- the absolute gravimeters (ABS)

No calibration is required for absolute instruments(ABS) which are directly referenced to the wavelength of a laser beam and the time scale of an atomic clock. This type of gravimeter is the best one to measure the gravity values along a calibration line. Its use to record tides during a long time [Francis O., 1997] will remain marginal. It is generally used for intercomparisons with tidal instruments during a few days to calibrate them.

For spring gravimeters (LCR) & (ASK), a mechanical system modulates the elastic restoring force proportionnally to the rotation of a micrometer. After determination of its scale factor by intercomparisons on « calibration lines », the micrometer is used to determine the sensitivity of the gravimeters during tidal registration.

To record tides with (LCR) or other astaticized gravimeters it is necessary to use a restoring force working in the feedback mode in order to minimize the elastic after-effects inherent to the astatisation.

Some (ASK) are also equipped with a system allowing to put additional masses (balls) on the beam. The equivalent force was scaled against gravity by the maker. The precision of the method is poor as it is necessary to tilt the instrument in order to put and remove the ball.

For the (SCI), it is not possible to modulate the feedback force directly. However the scale factor seems to be very stable[Ducarme & al., 1997]. So the « maker calibration » checked on « calibration lines » can be used for tidal records.

For (SCG), it is not possible to move the instruments on « calibration lines » and no internal modulation of the restoring force is possible with the required accuracy. The so-called « electrostatic calibration » gives only apparent changes of sensitivity. Direct calibration is possible only through methods <1> and <2>.

Sources of errors:

The scale factor of an instrument has to be related to absolute units.

During the transfer process, two kinds of errors could exist which are systematic or random.

The first kind defined as systematic, is directly affecting the scale factor. This error is constant independantly of the number of calibrations.

The second kind which is defined like a random noise, is limiting the precision of the calibration. This kind of error decreases with the increase of the number of determinations.

We can have a very high repeatability of the results of calibration, meaning a low level of random noise, associated with very large systematic errors.

This risk is especially important for frequency dependent processes when the excitation periods are short like in process <4>. The slope of adjustment could be modified by an attenuation of amplitude due to low pass filtering of the mechanical or the parts of the system. As this effect is frequency dependent like the acceleration itself, the systematic errors have to be corrected by determinining the transfer function of the filters. It becomes thus possible to compensate the damping of the filters at different frequencies.

Systematic errors could exist in the process of transfer from the micrometer to the gravimeter itself of the scale factor (dead zone in the mechanichal transmission, long term drift, ...).
For process <1>, the gravimeters need sufficiently heavy mass to obtain significant signals. The risk exist of systematic errors induced by the mechanical effects due to the displacement of large masses.

Finally it is very important to know how the calibration process itself can modify the gravimeter records, altering its sensitivity and/or drift.

Selection of the methods:

It is clear that some methods are obsolete or will never reach the required accuracy. We shall try to summarize here some of the most promizing approaches.

Cryogenics instruments(SCG)
-Interesting results have been already obtained with mass calibration <1>,[Achilli & al., 1995; Casula & al.,1998]. However this experiment requires a special geometry for the instrument and is thus not applicable everywhere. It does not provide the transfer function as it is working at zero frequency.

-The most popular method has been so far the intercomparison with another relative instrument during a few months [Francis & al.,1997], or with an absolute gravimeter during a few days [Hinderer & al.,1998]. The precision is close to the required 0.1% one. The accuracy is equivalent to the precision when the primary standard is an absolute gravimeter. When using a relative instrument you should take into account the additional uncertainty on its calibration. Attention should be paid to the difference between the transfer functions of the instruments involved in the intercomparison.

-A special inertial device has been realised and tested [Richter B., 1991; Richter & al.,1995].Very high accuracy is claimed but no convincing results have been published so far.

Spring gravimeters
Much more calibration effort has been devoted recently to (LCR) than to (ASK) or (SCIN). We shall thus focus our attention on the first type of instrument.

-The signal to noise ratio is generally not sufficient to apply the mass calibration method <1> at the 0.1% accuracy level [Czapo, Szatmari,1995].

-The most popular method for (LCR) is the use of the micrometric screw which in turn has been calibrated using calibration lines. The calibration of the micrometer is better than 0.01%. The problem is to extrapolate results obtained in the several hundred milligal range to the tidal range. It is why special base lines of a few milligal range have been established in Germany and China[Wenzel H.G.,1995]. The second problem is to calibrate accurately the tidal records using the micrometric screw. Recent tests show that the apparent changes of sensitivity are accurately followed by the calibrations[van Ruymbeke M.,1998].

-Inertial platforms have been successfully tested[van Ruymbeke M.,1989], but much effort has still to be devoted to reach the required accuracy.

Conclusions:

The 0.1% of accuracy on a phenomenon which has a so small amplitude as the tides is at the limit of instrumentation and any method to improve calibration is useful to improve the gravimeters themselves.

We suggest to organize a meeting of people concerned by the determination of the scale factor of the gravimeters to overview the different approaches, including realistic evaluation of the accuracies. An intercomparison of results obtained by various ways is essential to eliminate the risk of systematic errors which are different in the various methods.

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