

# Absolute gravity measurements in Hamburg/Groß Flottbek at DESY (Deutsches Elektronen-Synchrotron) with the Hannover gravity meter FG5X-220 in October 2015

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## 1. Absolute gravimetry with the FG5X-220 free-fall absolute gravimeter

The upgraded absolute gravimeter FG5X-220 is deployed by IfE since summer 2012. Compared with the predecessor version FG5-220, the instrument has a different free-fall length (about 30 cm instead of 20 cm) and a different measuring segment along the vertical (from 138 cm to 108 cm above floor level instead of 128 cm to 108 cm). Additional information about the Hannover instruments can be found in *Timmen (2010)*. Descriptions of the FG5 and FG5X gravimeters are given in *Niebauer et al. (1995)* and *Niebauer et al. (2013)*.

## 2. Absolute accuracy

The expression “absolute” is based on the fact that the time and length standards (rubidium clock, iodine stabilized helium-neon laser) are incorporated as components of the gravimeter system. Thus, each absolute gravimeter allows an independent traceability to the SI units of time and length through the frequency calibrations of the laser and the rubidium clock. To validate the uncertainty of the whole gravimeter system, comparisons are performed between different absolute meters as well as reference measurements are carried out on well-known stations with an appropriate history.

Repeatability and accuracy of the FG5-220 or FG5X-220 system has routinely been controlled (especially before and after field projects) at the reference stations Hannover (gravimetric laboratory of IfE) and Clausthal (TU Clausthal, Geophysics, Harz Mountains). It has to be mentioned that the differences between single epochs contain also real gravity changes due to time-varying environmental effects like seasonal hydrological variations.

Since the 1980s, International Comparisons of Absolute Gravimeters (ICAG) were performed with a 4-years’ time interval at the Bureau International des Poids et Mesures (BIPM) in Sèvres until 2009. Since 2003, European comparison campaigns (ECAG) have been held at the European Centre of Geodynamics and Seismology (ECGS) in Walferdange, Luxembourg. After BIPM abandoned the international comparisons in Sèvres, the ICAG2013 was organized at ECGS. Such extensive comparison campaigns with a large number of absolute gravimeters may reveal biases not only between single instruments but also between different instrumental developments and technological realisations.

The first comparison at ECGS was held in November 2003 with 13 simultaneously observing instruments, assigned for research in geophysics (e.g. geodynamics) or for metrological purposes (definition of standards), cf. Table 1. The excellent agreement between the gravimeters was  $18 \text{ nm/s}^2$  (standard deviation). The recent international comparison ECAG) in Belval/Luxembourg was carried out in November 2015 and included the Hannover FG5X-220 instrument for the second time.

For us from the Hannover group it is obvious that our FG5 system is still in the measurement level of the international community. Within  $0.02 \text{ } \mu\text{m/s}^2$ , the Hannover instrument agrees with the internationally realized measuring level. Here, the international datum is defined by the physical standards (time and length) and, in addition, as the average result obtained from all qualified absolute gravimeters participating in the international comparison campaigns.

**Tab. 1:** Absolute gravimeter FG5-220 or FG5X-220 (after upgrade, 2012) are controlled by external (international) comparisons to ensure consistent long-term measurement accuracy and stability. Comparison reference values (CRVs) are defined by all participating qualified gravimeters

FG5-220 External Comparison	Remarks	Epoch	$\Delta g$ [ $\mu\text{m/s}^2$ ] (FG5(X)-220 – CRV)
ECAG2003, ECGS (Francis, van Dam 2006, Tab. 16)	13 abs. meters, 14 points, 52 determinations	Nov. 2003	<b>-0.019</b> s(single meter) = 0.018
ECAG2007, ECGS (Francis et al. 2010, Tab.5. 3)	19(17) abs. meters, 16 points, 73 determinations	Nov. 2007	<b>+0.024</b> s(single meter) = 0.020
ICAG2009, BIPM (Jiang et al. 2012) Tab. 11 and 13)	21 abs. meters, 5 points, 63 deter- minations	Oct. 2009	<b>+0.017</b> s(single meter) = 0.042
ECAG2011, ECGS (Francis et al. 2013, Tab. 5)	21 abs. meters, 15 points, 63 de- terminations	Nov. 2011	<b>+0.018</b> s(single meter) = 0.031
ICAG2013, ECGS (Francis et al. 2015, Annex B)	25 absolute meters, 15 points, 75 de- terminations	Nov. 2013	<b>+0.023</b> s(single meter) = 0.033
ECAG2015, Belval/Luxembourg (University)	17 abs. meters, 9 points	Nov. 2015	(waiting for results)

We may conclude that an overall accuracy (long-term stability and agreement within the group of internationally operating absolute gravimeters) of better than  $30 \text{ nm/s}^2$  is indicated for a single station determination with the Hannover absolute gravimeter.

### 3. Absolute gravimetric measurements in Hamburg/Groß Flottbek

The absolute gravimetric results are presented in Table 3. A statistical assessment is given in Fig. 1. The annex shows photographs about the absolute sites in the basement of the town hall. The gravimetric impact of air pressure variations on the absolute measurements were reduced by applying the factor  $-3.0 \text{ nm/s}^2$  per hPa. Table 4 compiles the applied Earth tide parameter for the tidal reduction. These parameter were derived from an Earth tides recording in Groß Flottbek in 2012 (84 days length). The vertical gravity gradient along the plump line was determined by relative gravimetry above the ground mark by the author of this report using the relative gravimeter Scintrex CG3M-4492. To avoid or minimize any deterioration of the absolute gravimetric result (g-value) caused by uncertainties of the vertical gradient, which is actually not a constant, the final absolute result is transferred to the sensor height  $h = 1.250 \text{ m}$  above floor level where the influence of the gradient becomes almost zero (“dead-gradient-point”). That ensures that the vertical gradient is only needed to transfer the g-value from the setup depending sensor height (corresponds to the effective measuring height of the FG5X-220, see Timmen 2003) to the reference height of  $1.250 \text{ m}$  over the small distance of less than  $2 \text{ cm}$  only. In this way, the station time series (history) of the gravimeter point can be used best to investigate a secular gravity change over years to decades. The reference height is useful to compare with other gravimeters and with older gravity determinations.

**Table 2:** Used coordinates of the absolute gravity site occupied by the Hannover meter FG5X-220 in Groß Flottbeck in June 2015

Station “DESY/DORIS”	$\varphi$ [deg]	$\lambda$ [deg]	H [m]	Description
Building 30a (Lager 048)	53.5776	9.8815	30	Perfect room conditions (temp. stability, low humidity, no windows, stable foundation) for abs. gravity measurements; no permanent ground mark; coordinates from Google Earth (internet).

**Table 3:** Absolute gravity values of the FG5X-220 measurements on the “DESY/DORIS” point. The gradient insensitive sensor height (“dead-gradient-point”) depends on the gravimeter setup and is around 1.25 m above floor level. Thus, the reference height  $h=1.250$  m (above floor point) is chosen for comparison reasons. The applied vertical gradient is assumed to be a constant and, because of the chosen reference height, the effect of its uncertainty of the absolute value can be neglected. The gradient  $\delta g/\delta h$  was measured with Scintrex CG3M-4492 between the sensor positions 26.5 cm and 145.2 cm above floor point ( $dh:118.7$ , std.dev.  $0.005 \mu\text{m/s}^2$ ). For relative gravimetry, the derived  $g$ -value at  $h=0.000$  m is also given.

Site <b>DESY/DORIS</b>	Measurement run (orientation)	Date in 2015	Drops	$\delta g/\delta h$ [ $\mu\text{m/s}^2$ / m]	$g_{h=1.250}$ [ $\mu\text{m/s}^2$ ]	$g_{h=0.000}$ [ $\mu\text{m/s}^2$ ]
Setup 1	20151012 (N)	12. / 13. Oct.	996	-2.826	9813689.778 $s=0.001$	
Setup 2	20151013 (S)	13. / 14. Oct.	998	-2.826	9813689.764 $s=0.001$	
<b>Average</b>		12. – 14. Oct.	1994	-2.826	<b>9813689.771</b>	<b>9813693.304</b>

**Tab. 4:** Applied Earth tide parameter for Hamburg/Groß Flottbek derived from an Earth tides recording in Groß Flottbek in 2012 (84 days length).

Frequency Start	Frequency End	Ampli- tude	Phase Lead[°]	Tidal Group
0.000000	0.000001	1.000000	0.0000	DC
0.000100	0.249951	1.18380	0.0081	Long
0.501370	0.911390	1.14671	-0.4522	Q1
0.911391	0.947991	1.14922	0.0785	O1
0.947992	0.981854	1.14876	0.9195	M1
0.981855	1.023622	1.13610	0.2796	K1P1
1.023623	1.057485	1.16975	0.0357	J1
1.057486	1.470243	1.16044	-0.0365	OO1
1.470244	1.880264	1.18298	3.7774	2N2
1.880265	1.914128	1.16704	2.6530	N2
1.914129	1.950419	1.17970	1.8218	M2
1.950420	1.984282	1.15396	0.7443	L2
1.984283	2.451943	1.18399	0.6593	S2K2
2.451944	3.500000	1.08330	2.1073	M3
3.500001	4.500000	8.39220	43.4278	M4

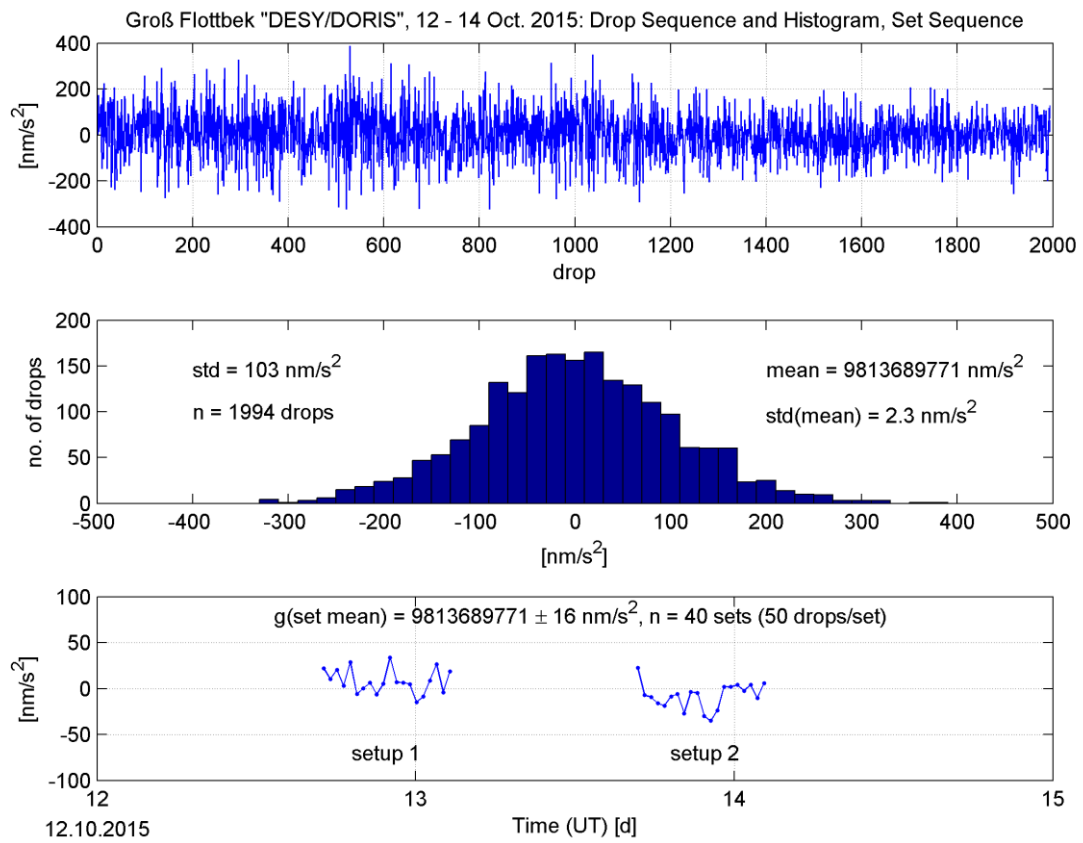


Fig.1: Statistical compilation of the station determination with the Hannover FG5X-220 absolute gravimeter at "DESY/DORIS" in Hamburg/Groß Flottbek, October 2015.

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**Annex:**

Absolute gravity site occupied with the Hannover absolute gravimeter FG5X-220 in June 2015: Hamburg/Groß Flottbek (“DESY/DORIS”). The site has been provided by the Geodesy group of DESY (MEA2 - Vermessung).

