Superconducting Gravimeter OSG-050 at the Station Pecný, Czech Republic

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Abstract

The Pecný station is equipped by first-rate instrumentations in the field of terrestrial gravimetry thanks to the absolute gravimeter (AG) FG5#215 and superconducting gravimeter (SG) OSG-050. Repeated AG observations at the Pecný station allowed to determine the two important parameters of the SG, its scale and drift. The repeatability of the FG5#215 has been also computed from combined time series.

One year of SG observations showed the sizeable improvement of earth tides observations respect to the existing observations with spring gravimeters and necessity to improve the method of air pressure effect correction by the single admittance. The noise of OSG-050 in the normal mode band is higher than it would be expected. Small improvement of the noise characteristic was achieved by careful setting of dewar pressure.

1. Introduction

Continuous tidal observations by spring gravimeters have been carried out at the station Pecný since early seventies of the last century (Broz et al. 2005). Different type of spring gravimeters (Askania Gs11, Gs15, L&R, ZLS) has been used for observations . Of course, during this long period, the gravimeters and registration was dramatically improved. Methods of calibration, digital registration, and feedback system development were milestones of observation improvements (Brož et al., 2002; Pálinkáš, 2006). These improvements allowed to increase the measurement accuracy more than 10 times during 30 years. The standard deviation of the observed hourly ordinate on the level of 0.1 μGal was achieved which is comparable with older type of SGs (Ducarme et al., 2002). Unfortunately this high accuracy is relevant only for the short-period tides due to the instrumental drift. The drift of spring gravimeters at Pecný can be considered as linear for the period below one week in spite of the temperature and humidity control at the station with precision of 0.1°C and 1%, respectively.

Fig. 1. The absolute gravimeter FG5#215 and the superconducting gravimeter OSG-050 at the Pecný station

The instrumentation of the tidal station has improved significantly thanks to the superconducting gravimeter (SG) OSG-050, installed in February 2007. The Pecný station as the core station of ECGN (European Combined Geodetic Network) is equipped with permanent GNSS station, absolute gravimeter (AG) FG5#215 and the superconducting gravimeter OSG-050. These high quality instrumentations in the field of gravimetry allow to monitor wide range of gravity variations of geophysical origin from Earth's free oscillations to secular gravity variations. Possibility of frequent simultaneous AG and SG observations at the station allow to solve main problems of both instruments: drift and calibration of the OSG-050 and the offset variations of the FG5#215.

2. Calibration and drift

The calibration factor and drift of the SG has been determined using simultaneous observations with the AG (Hinderer et al. 1998). Altogether 15, typically one-day absolute measurements with FG5#215 has been carried out from April 2007 to June 2008. For the purpose of SG calibration, five AG campaigns has been extended to three-days observations. These extended observations were carried out during tidal variations at least 230 μGal. The precision of all individual determination of scale factor was better than 0.07%. However, the final calibration factor and corresponding accuracy should be computed from results of repeated calibrations. The dispersion of individual results with corresponding error bars in Fig. 2 show necessity of such repeated measurements. The final calibration factor of the OSG-050 has been determined as average of all calibrations . From dispersion of individual result we can assume that accuracy of the final calibration factor is of about 0.06%.

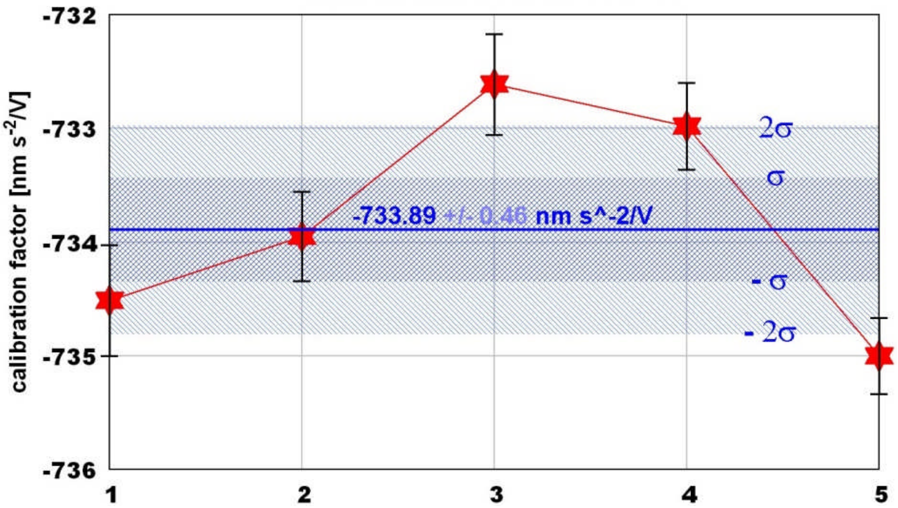

Fig. 2. Calibration factor of the OSG-050 determined from 5 simultaneous three-days observations with FG5#215. Error bars represents precision of individual calibrations.

The SG drift has been determined from the comparison between SG and AG observations (see, Fig. 3 and Fig. 4) and described by linear term 1.7 ± 0.4 μGal/year. We can assume, that after removing drift from SG time-series, the rest of differences between AG and SG is caused mainly by random and systematic errors of the AG. This approach can help to detect variations in AG offsets. In our case (see, Fig. 4) all differences are within expected error bars of the AG (1.1 μGal, Niebauer et al. 1995). Comparison of both techniques has been used for the evaluation of FG5#215 repeatability (precision) by such experimental way. The standard deviation of individual absolute gravity measurements of 0.6 μGal respect to the OSG-50 observations describe the precision of the FG5#215. It is necessary to say that the FG5#215 is not installed permanently at the Pecný station and the precision of 0.6 μGal includes error of instrumental set-up, meter alignments etc.

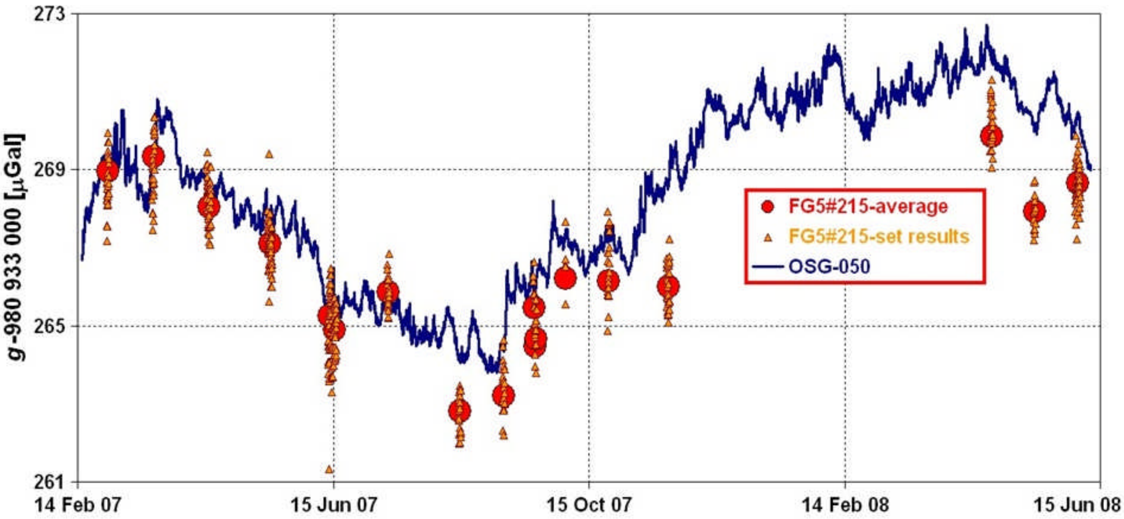

Fig. 3. Gravity series of the FG5#215 and OSG-050, corrected for earth tides, air pressure variations by single admittance and effect of polar motion.

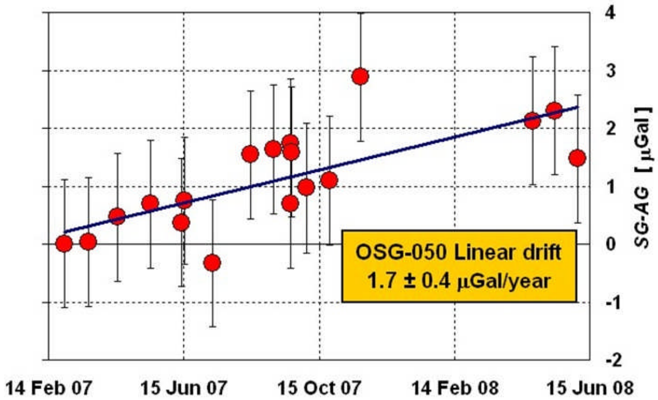

Fig. 4. Differences between gravity series for determination of SG drift and AG repeatability.

3. Time delay

The time delay of the OSG-050 in tidal frequency band was evaluated from the transfer function of the meter, experimentally determined by injection step voltage into the feedback (Van Camp et al. 2000). Altogether 34 injections have been carried out for three different size of steps (15V, 10V and 5V). For the processing the TSOFT (Vauterin and Van Camp, 2001) and ETSTEP (Wenzel, 1995) software were used. Both processing method and also three-different size of steps gave results within 0.03 sec (see, Tab. 1). Specially the results from ETSTEP software show high consistency and precision. Utilization of ETSTEP seems to be more efficient but it need careful and correct evaluation of initial and final step values. On the other hand the method using TSOFT is more user-friendly.

Table 1. Time delay of the OSG-050 for three different size of steps (15V, 10V and 5V) and computed with two different software (TSOFT and ETSTEP), θ - time delay, n - number of steps

	TSOFT	ETSTEP
	$\theta \pm \sigma_\theta$ *(n)* [sec]	$\theta \pm \sigma_\theta$ *(n)* [sec]
15 Volt	8.873 ± 0.012 (10)	8.856 ± 0.003 (4)
10 Volt	8.860 ± 0.010 (10)	8.853 ± 0.005 (4)
5 Volt	8.884 ± 0.019 (14)	8.853 ± 0.021 (4)
Average	**8.868 ± 0.009**	**8.855 ± 0.002**

4. Tidal analysis

The tidal analysis was carried out by the program ETERNA 3.4 (Wenzel, 1996) for the period April 2007 – June 2008. The tidal parameters of main tidal waves determined from the OSG-050 record show the agreement better than 0.05% in amplitude and 0.04 deg in phase with results of spring gravimeters during last 6 years. The very good agreement in amplitude demonstrates the accurate calibration of gravimeters by simultaneous measurements with FG5#215 (Pálinkás, 2006), when the spring meters and OSG-050 have been calibrated over 60 and 15 days, respectively.

Table 2. Comparison of the results of tidal measurements with Askania, LaCoste & Romberg and superconducting gravimeter at the station Pecný. The results were computed by ETERNA 3.4 (Wenzel, 1996), δ - amplitude factor, κ - phase lag [deg].

Gravimeter	**ASKANIA** Gs15 #228 electromag. feedback		**L&R G #137** MVR feedback		**OSG-050**	
Period Days	2000 04 – 2005 04 1568		2002 09 – 2004 04 522		**2007 04 – 2008 06 435**	
Wave	$\delta \pm \sigma_\delta$	$\kappa \pm \sigma_\kappa$	$\delta \pm \sigma_\delta$	$\kappa \pm \sigma_\kappa$	$\delta \pm \sigma_\delta$	$\kappa \pm \sigma_\kappa$
O_1	1.1503 1	0.122 0.004	1.1500 1	0.102 0.004	**1.1505 1**	**0.122 0.004**
K_1	1.1373 1	0.185 0.003	1.1370 1	0.155 0.003	**1.1374 1**	**0.196 0.003**
M_2	1.1851 1	1.229 0.003	1.1846 1	1.209 0.003	**1.1856 1**	**1.240 0.002**
S_2	1.1804 1	0.018 0.007	1.1820 1	0.104 0.006	**1.1826 1**	**0.156 0.005**
σ [nm·s^{-2}]	**1.61**		**0.63**		**0.59**	

The air pressure correction has been applied as component of the tidal analysis by ETERNA using regression coefficient with local air pressure. The regression coefficient of -3.3 nm s^{-2}/hPa as result of tidal analysis doesn't describe air pressure correction sufficiently due to frequency dependence of single admittance. This situation can be seen in Fig. 5 and confirm the necessity to improve the existing method of air pressure effect correction using single admittance. Implementation of corrections based on the 3D atmospheric models (Neumeyer et al., 2004) and local air pressure observations is necessary.

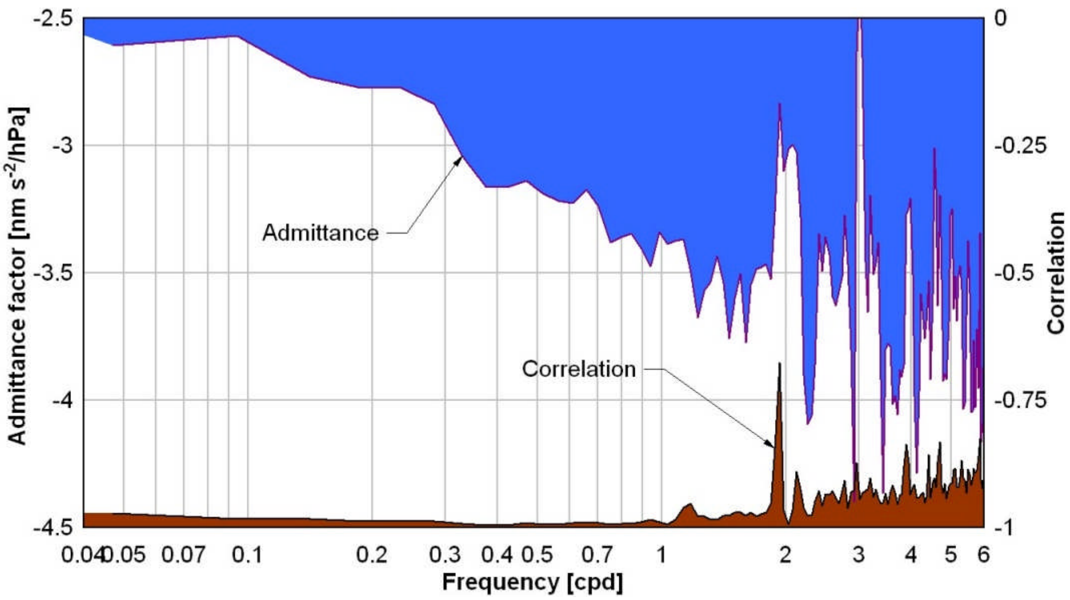

Fig. 5. Frequency dependence of the air pressure admittance

5. Noise in normal mode band

The Pecný station is located in a quiet place, far away from industrial noise and the SG pillar is founded on the quartzite bedrock. It should be expected, that noise in normal mode band (0.2 mHz – 10 mHz) will be low and thus the conditions for monitoring Earth's free oscillations excellent. Unfortunately, the comparison of power spectral densities with New Low Noise Model (NLNM, Peterson 1993) in Fig. 6 shows sizeable noise in this frequency band. The seismic noise magnitude(SNM, Banka and Crossley, 1999) of the OSG-050 is of about 1.4. To achieve best noise characteristic of the OSG-050, the influence of the dewar pressure setting has been experimentally studied by comparison of power spectrums under different pressure condition. Improvement less than 5 dB has been achieved by sensitive setting of the dewar pressure (see, Fig. 6).

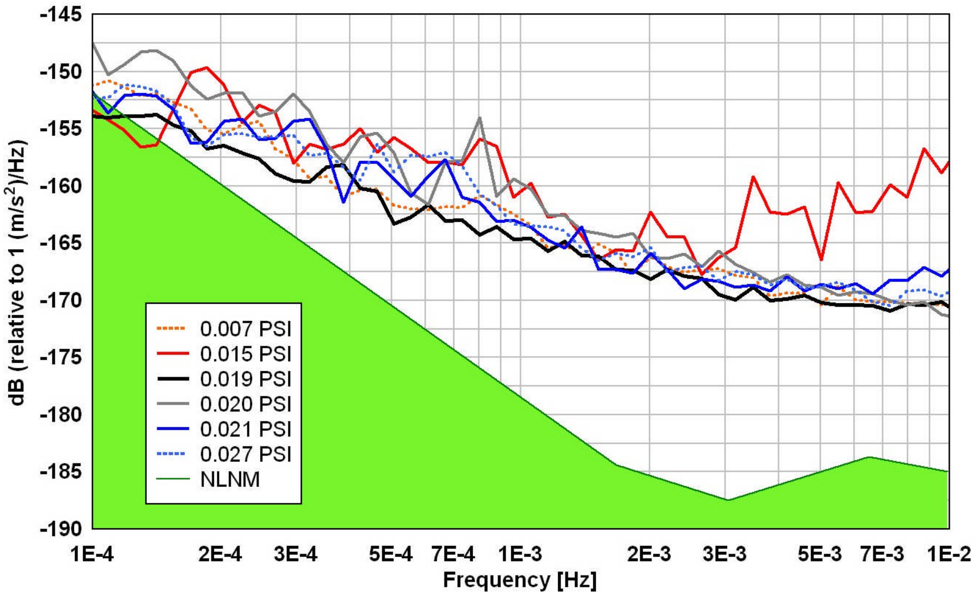

Fig. 6. Power spectral densities of the OSG-050 in normal mode band for different dewar pressures

6. Conclusions

During the first year of observation with the OSG-050 at Pecný the main parameters and characteristics of the meter has been determined. Calibration coefficient and the time delay were estimated with the accuracy of 0.06% and 0.01 sec, respectively. The comparison of SG and AG observations helped to determine the SG linear drift of 1.7 ± 0.4 μGal/year and the FG5#215 repeatability of 0.6 μGal. The analysis of recorded data showed the very good properties of the meter for monitoring gravity variations below 0.1 mHz (earth tides, hydrological effects etc.). On the other hand the observations in normal mode band (0.2 mHz – 10 mHz) are affected by sizeable noise of instrumental origin.

The superconducting gravimeter OSG-050 at the station Pecný represents dignified continuation of earth tide observation started in early seventies of the last century. Thanks to the good drift characteristics of the meter and regular repeated absolute gravity measurements, there is a good chance to determine valuable parameters of long-period tides and to monitor gravity variations of hydrologic and geodynamic origin. Moreover, the OSG-050 seems to be very important instrument for absolute gravimeter FG5#215 (national standard for acceleration due to gravity) to monitor variations of its systematic errors and consequently improve accuracy and credibility of our absolute measurements.

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