THE AUTOMATED BURRIS GRAVITY METER – A NEW INSTRUMENT USING AN OLD PRINCIPLE[1]

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Abstract

Key words: Burris gravimeter, zero-length spring principle, drift analysis, tidal record

The Burris Gravity Meter™ produced by ZLS Corporation, Austin/Texas, USA, is based on the invention of L. LaCoste and A. Romberg: The zero-length spring (ZLS). A digital feedback system (range of about 50 mGal) is used to null the beam. The feedback responds fast with high stability and accuracy. A metal alloy was used for the zero-length spring because of its low drift characteristics. The drifts observed are less then 1 mGal per month when new, and when mature, of less than 0.5 mGal. The nulling of the beam is controlled by the UltraGrav™ control system which incorporates an inherently linear pulse-width modulated (PWM) electrostatic feedback system. Calibrated ultra-miniature electronic levels are used for correction of horizontal misalignment to insure accurate and reliable operation of the gravimeter. The gravimeter can be operated in ambient temperature ranging from -15° to + 50°C. The gravimeter was tested in the Geodynamic Observatory Moxa for long-term behaviour. For this purpose we equipped the gravimeter with a recording system. Further, we have checked the calibration on the calibration line in Hanover, Germany, providing reliable results on the 1 to 3 µGal level.

Introduction to the Burris gravity meter

The Burris Gravity Meter™ is a product of the company ZLS Corporation, Austin/Texas, USA. It is based on the invention of L. LaCoste and A. Romberg (LaCoste, 1942): The zero length spring (ZLS). A digital feedback system is used to null the beam, taking full advantage of the latest development in digital technology. Thus, a large feedback range of about 50 mGal is achieved, responding fast with high stability and accuracy. A metal alloy was used for the zero-length spring because of its low drift characteristics. These metal springs are extremely stable providing drifts of less then 1 mGal per month when new, and when mature, of less than 0.5 mGal. The prototype even showed a drift rate of about 0.03 mGal per month. A metal micrometer screw was chosen to give the meter a 7,000-mGal range (ZLS, 2007).

The nulling of the beam is controlled by the UltraGrav™ control system which incorporates an inherently linear pulse-width modulated (PWM) electrostatic feedback system. This low power feedback system produces an electrostatic feedback voltage from the capacitive position indicator, which is then applied to the capacitor plates restoring the beam to the null position and keeping it there.

Ultra-miniature electronic levels insure accurate and reliable operation of the gravimeter. These levels consist of a vertical pendulum approximately 1.2 cm (0.5 in) in length, with a resonant frequency of approximately 5 Hz with a damping 0.707 critical, and have a resolution of one arc-second. They are orthogonally mounted on the lid of the sensor. Output of the levels can be monitored either on the galvanometers mounted in the gravity meter lid or on the screen of the host computer. Precise levelling of the meter is not required as real-time off level corrections are automatically calculated by the UltraGrav™ controller system.

The sensor, electronic levels, and critical electronics are all shielded from ambient temperature changes by a highly stable thermostated oven which allows the meter to be operated in ambient temperature ranging from -15° to + 50°C.

The zero-length-spring principle and feedback systems

This principle was developed to increase the resolution of the gravimeter by astatisation (Fig. 1; see also Torge, 1989). The patent was registered in 1942 by Lucien LaCoste (US Patent 2293437). The famous LaCoste & Romberg

[1] Compared to the printed version this paper is corrected with respect to the tidal analyses in tab. 4 concerning the phase differences.

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G- and D-Meters are based on this principle, as well as the L&R Earth Tide Meters (see e.g. Jentzsch, 1986; Jentzsch et al., 2000; LaCoste&Romberg, 2004). At first, the G- and D-meters were nulled manually, whereas the Earth Tide Meter had a complex mechanical feedback system to allow for continuous recording (LaCoste&Romberg, 1972). Later, these meters were equipped with an electrostatic feedback system of the SWR-type, constructed at the University of Hannover, and very many gravimeters were converted (Röder et al., 1988). Larson (1968) built such a feedback system for the Earth Tide Meter. The integration period of these systems is between 6 and 10 seconds, and the feedback ranges are about ± 10 Volts, corresponding to about ± 10 mGal for G- and D-meters. In the case of the Earth Tide Meter the total feedback range is about 7 mGal.

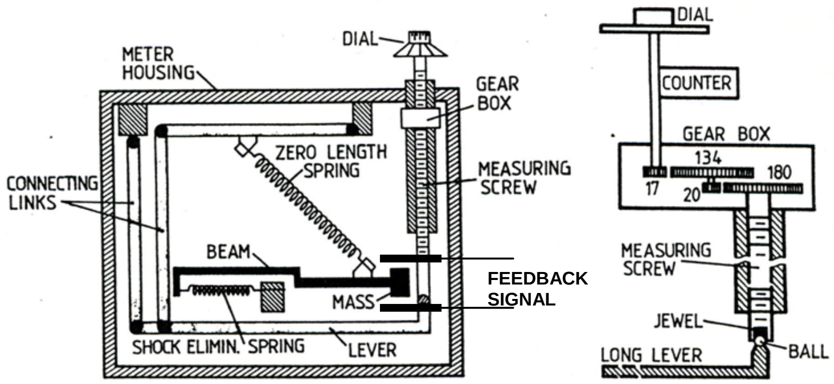

Figure 1. Zero Length Spring and lever system driven by a dial via a gear box: Note sketch of condenser plates to read out the position of the mass and to feed back the voltage necessary to null the beam. (modified after Torge, 1989)

The feedback system of the Burris meter is part of a fully digital microprocessor-based automatic reading and data logging system called UltraGrav™ which is installed on a PDA (Personal Digital Assistant) for flexibility in the field (optional wireless PDA module). The beam position is read out, and an inherently linear pulse-width modulated (PWM) electrostatic feedback control system automatically nulls the beam (Valliant et al., 1986). The feedback range is about ± 25 mGal.

If the feedback system cannot null the beam, the dial has to be adjusted manually. In the case of the Burris meter, it is possible to choose the option of a stepping motor to adjust the beam automatically. In that case, the beam is driven to a calibrated point of the dial (about every 50 mGal) such that circular errors are avoided over the whole 7,000-mGal range of the screw. During routine field tests standard deviations of ± 0.003 mGal or better were achieved.

The properties of the gravimeter are summarised in Tab. 1.

Calibration of B-025

The gravimeter tested has the production number B-025. After completion of the gravimeter a check of the calibration was carried out by the manufacturer at a baseline in New Mexico. In addition, we calibrated the feedback on the vertical baseline in Hanover / Germany. In the building of the Leibniz-University with 20 stories; we used floors 1, 9, and 17 with the station names 210, 290, 370.

In Tab. 2 gravity values and differences along this baseline are given in microgals[3]. Measurements were carried out in different loops between all points such that there were positive and negative feedback corrections. In all 43 differences in 3 blocks were observed, and at least 5 differences between all points could be analysed. All three blocks were adjusted using linear, quadratic and cubic terms. In Tab. 3 the results are summarized.

[3] 1 µGal ≡ 10 nm/s²

Table 1. Instrumental characteristics of the Burris Automated Gravity Meter with UltraGrav™ control system.

Sensor Type:	Metal Zero-Length Spring Hardened metal micrometer screw
Range:	7,000 mGal
Temperature range:	-15 to +50 C
Electronic Levels	
Type:	Single axis, vertical pendulum, air damped
Range:	+/- 5 arc-min (10 arc-min total)
Resolution:	1 arc-sec
Data Resolution	
Internal:	less than 0.001 mGal
Recorded:	single reading mode: 0.001 mGal
Data Repeatability	
Within 50 mGal:	0.001 - 0.003 mGal
Over 50 mGal:	less than 0.02 mGal
Precision of Calibration Points	
+/- 0.015 mGal	
Burris Gravity Meter™	
L x W x H:	7.5 in x 12in x 12 in (19.05 cm x 30.5 cm x 30.5 cm)
Weight:	12.75 +/-1.0 lb (5.18 +/- .45 kg) with Lithium battery
UltraGrav™ Control System	
Type:	Pulse width modulated electrostatic nulling system
Feedback range:	50 mGal
Input voltage:	10.5 to 14.0 volts DC
Auxiliary outputs:	analog: levels, beam and feedback; FM: Levels and beam; PWM: feedback
Host Computer Type:	Handheld Computer

Table 2. Vertical calibration line at TU Hannover: Given are the floors of the high building and the absolute gravity values as well as the gravity differences.

Floor / station	**absolute gravity [µGal]**	**gravity differences [µGal]**	**total difference [µGal]**
17 / 370	981245062.6		
		8,178.4	
9 / 290	981253241.0		**16,173.0**
		7,994.6	
1 / 210	981261235.6		

The results of the calibration along the vertical baseline in Hanover show a very good repeatability of the three measurement schemes, and they reveal a very good linearity of the feedback. The quadratic and cubic terms are very small and compared to the errors obtained negligible, especially in the cases of single block 1 and 2. The main result is: **The errors obtained are in the order of 10^{-4}.**

Table 3. Adjusted gravity differences: 43 differences in 3 blocks: Adjustments for linear, quadratic and cubic terms in different combinations. Note: One block covers the measuring scheme over the points mentioned; two blocks were measured at a dial value providing positive feedback values, the third block was measured with negative feedback values.

Adjustment of blocks	linear term	quadratic term in 1.D-6	cubic term in 1.D-12
all three	0.999939 +/- 0.000129	0.001534 +/- 0.000312	0.004302 +/- 0.003434
all three	1.000086 +/- 0.000054	0.001775 +/- 0.000247	---
single block 1	1.000313 +/- 0.000332	0.000763 +/- 0.001398	---
single block 2	1.000727 +/- 0.000311	-0.000749 +/- 0.001330	---
single block 3	0.998893 +/- 0.000225	-0.005205 +/- 0.001328	---
single block 1	1.000491 +/- 0.000067	---	---
single block 2	1.000555 +/- 0.000061	---	---

Digital Recording System

Our special interest was to use the Burris Gravity Meter for continuous recording of gravity changes. This requires a recording system which enables not only the gravity data acquisition, but also air pressure. For precise time keeping the computer time has to be adjusted to UT. There is the possibility to perform a record with the PDA, but the memory is limited and there is only quartz time. Since the PDA's usually do not have any additional ports, the connection to a PC as well as of a time signal receiver is impossible. Therefore, in the first step, we used a PC-version of the controlling program and installed it on a panel PC (under DOS operating system) with enough ports to connect a notebook computer for data treatment and storage (Adams et al., 2004).

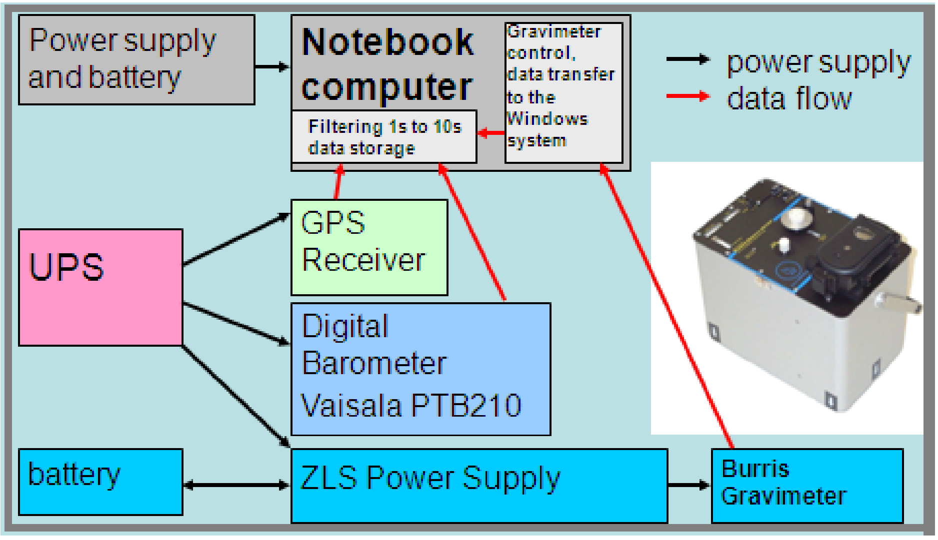

Figure 2. Layout of the recording system consisting of a dual-core notebook computer, the barometer and the GPS time receiver: The computer is used to control the gravimeter and to collect, filter and store the data.

Note: The PDA attached on top of the gravimeter is not used in our case.

To use the PC under WINDOWS to control the gravimeter was not a good solution, because the time stability as a prerequisite for the correct pulse width modulation is not guaranteed. Now, after a modification of the gravimeter which produces its constant pulses itself we could combine this PC for controlling the gravimeter with the notebook and run the control program in a DOS-window. Our recording program, developed by the Department for Applied Geophysics of the University of Jena comprises the reading of the second-samples coming from the DOS-box, the filtering to 10-sec samples as well as the storage of daily files. In addition, a Vaisala PTB210 air pressure sensor and a GPS time signal receiver are attached. The new configuration is given in Fig. 2. Further extensions like internet connection are possible.

Data and tidal analysis

For a longer recording period we installed the gravimeter in the Geodynamic Observatory Moxa, maintained by our department (Jahr et al., 2001). Fig. 3 shows the gravimeter B-025 together with B-028 on a pier. ZLS Corporation claims that drift rates of the spring are, when new, ~ 1.0 to 2.0 mGal per month. When mature the drift reduces, typically to less than 0.5 mGal per month. The prototype finally showed a drift of about 0.030 mGal per month. The gravimeter was delivered at the beginning of the year 2006: We recorded different intervals (the breaks were due to performed tests, especially in connection with the development of the recording system). The observed linear drifts of B-025 for four longer sections are:

- 1st interval: 04/24 to 06/23, 2006: ~ -0.87 µGal/h ≡ -0.62 mGal/month
- 2nd interval: 10/16 to 12/28, 2006: ~ -0.47 µGal/h ≡ -0.34 mGal/month
- 3rd interval: 01/02 to 03/08, 2007: ~ -0.32 µGal/h ≡ -0.23 mGal/month
- 4th interval: 03/11 to 04/22, 2007: ~ -0.90 µGal/h ≡ -0.65 mGal/month

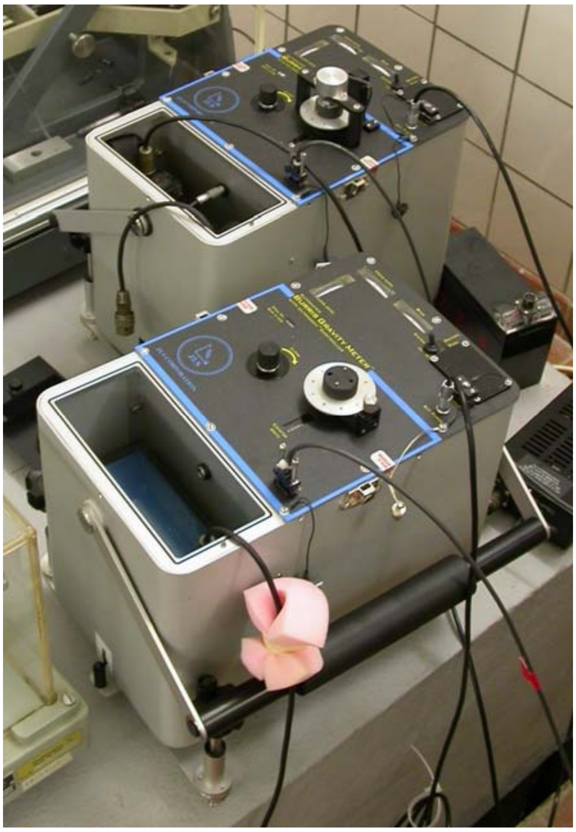

Figure 3. B-025 and B-028 in the Geodynamic Observatory Moxa being tested and equipped with a digital recording system.

Note: B-025 (upper meter) with dial motor.

The drift decreased considerably, but was higher again in the forth interval after a power fail in the observatory due to lightning. Part of the data of the first recording interval is shown in Fig. 4: The drift is nearly linear. The following Tab. 4 contains the results of the tidal analysis of B-025, from April 5, until June 23, 2006.

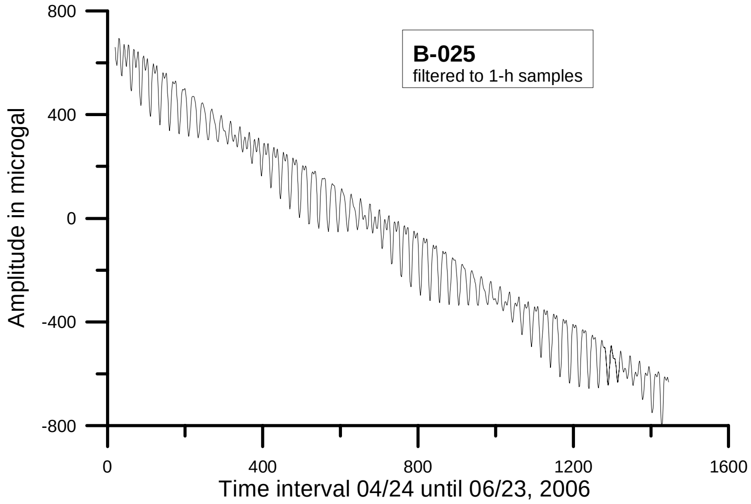

Figure 3. First long interval of the record in the Geodynamic Observatory Moxa from April 24 to June 23, 2006: Note nearly linear drift of about – 0.62 mGal per month. Data are filtered to 1-h samples.

Table 4. Results of the tidal analysis of an interval of nearly 77 days observed in the Geodynamic Observatory Moxa.

Summary of observation data:

20060405 20000...20060422110000 20060424140000...20060623 20000
Number of recorded days in total : 76.96
Hartmann+Wenzel (1995) tidal potential used with threshold 0.10E-06
WAHR-DEHANT-ZSCHAU inelastic Earth model used.
Inertial correction not applied
Spectral condition number of normal equations: 1.907
Estimation of noise by FOURIER-spectrum of residuals

0.1 cpd band	--- nm/s**2	1.0 cpd band	0.4830 nm/s**2
2.0 cpd band	0.2392 nm/s**2	3.0 cpd band	0.2159 nm/s**2
4.0 cpd band	0.2101 nm/s**2	white noise	0.2479 nm/s**2

adjusted tidal parameters:

from [cpd]	to [cpd]	wave	ampl. [nm/s**2]	ampl.fac.	stdv.	phase lag [deg]	stdv. [deg]
0.501370	0.911390	Q1	66.7735	1.14420	0.00489	- 0.112	0.245
0.911391	0.947991	O1	349.6408	1.14712	0.00080	0.166	0.040
0.947992	0.981854	M1	27.4979	1.14771	0.00839	- 0.423	0.417
0.981855	1.023622	K1	486.7218	1.13590	0.00054	0.344	0.027
1.023623	1.057485	J1	27.9823	1.16751	0.01216	0.996	0.598
1.057486	1.470243	OO1	15.1176	1.15322	0.01213	- 0.353	0.603
1.470244	1.880264	2N2	10.7858	1.16661	0.02092	0.422	1.026
1.880265	1.914128	N2	68.3776	1.18120	0.00297	1.815	0.144
1.914129	1.950419	M2	357.9534	1.18394	0.00048	1.579	0.023
1.950420	1.984282	L2	9.9843	1.16822	0.01688	0.536	0.826
1.984283	2.451943	S2	167.2546	1.18914	0.00107	1.040	0.052
2.451944	7.000000	M3	3.8431	1.01916	0.03320	2.689	1.866

Standard deviation of weight unit: 4.256
Degree of freedom: 1723
Standard deviation: 4.256 nm/s**2

Discussion

We have tested the Burris Automated Gravity Meter in our laboratory and equipped it with a digital recording system. Our results show that this gravimeter, based on the successful principle of the zero-length spring and combined with modern digital electronics provides a powerful tool for surveying and continuous recording. We were especially interested in the continuous mode, whereas others performed surveys or point measurements in the laboratory (Schulz, Kopaev, Lederer and Palinkas, all in this issue). During the calibration in Hanover it was possible to take a picture of these competing gravimeters (Fig. 5).

A comprehensive comparison of this gravimeter with the SCINTREX CG3/5 and the old L&R gravimeters is still pending, but some results are already available. These results obtained by Kopaev et al. and Lederer and Palinkas (both this issue) show the reliability of the Burris meter, and they reveal a slight advantage over the other two systems. Especially the strong drift of the CG5 is striking. Timmen and Gitlein (2004) gave a positive report about their CG3, but revealed a clearly non-linear drift, which could not be removed automatically.

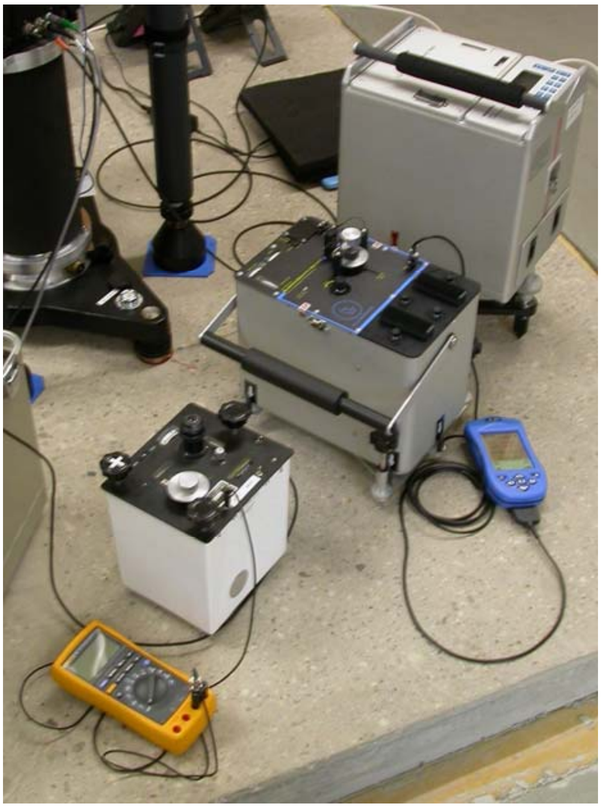

Figure 5. Picture taken during the calibration campaign in Hanover: We can make a visual comparison of the Burris meter with a Scintrex CG3 and a LaCoste & Romberg G-meter equipped with electrostatic feedback system SRW-Hannover.

Note:
The PDA used with the Burris Meter contains the controlling program and collects the data; the Burris meter and CG3 also contain the batteries, L&R not.

Acknowledgements

The Burris gravity meter was the property of Gravity Consult GmbH, situated in Jena, which cooperated with our institute in the tests of this gravimeter. The calibration in Hanover was supported by Dr. Ludger Timmen who provided the information about the gravity differences and helped to analyse the data using Wenzel's program system GRAV (1993). Based on former versions our technician Andreas Hoffmann wrote the up-to-date recording program for the recording station. Dr. Adelheid Weise carefully reviewed this paper and proposed considerable improvements. All this is gratefully acknowledged.

References

Adams, J., L. Burris, G. Jentzsch, A. Kopaev, and H. Valliant, 2004. The Automated Burris Gravity Meter - a New Instrument for Surveying and Continuous Operation. 15th Int. Symp. Earth Tides, Ottawa, August 2004, Abstract Book.

Jahr, T., Jentzsch, G., Kroner, C., 2001. The Geodynamic Observatory Moxa / Germany: Instrumentation and purposes. Proc. 14th International Symposium on Earth Tides, Special Issue of the Journal of the Geodetic Soc. of Japan, 47/1, 34 – 39.

Jentzsch, G., 1986. Auflastgezeiten in Fennoskandien. Habilitationsschrift, Berliner Geowiss. Abh., Reihe B, 13, Verlag von Dietrich Reimer, Berlin, 184 S.

Jentzsch, G., P. Knudsen, and M. Ramatschi, 2000. Ocean tidal loading affecting precise geodetic observations on Greenland: Error account of surface deformations by tidal gravity measurements. Phys. Chem Earth (A), Vol. 25, No. 4, 401 - 407.

Kopaev, A., V. Yushkin, G. Jentzsch, S. Merlet, and F. Pereira Dos Santos. Laboratory and field experiences with Sodin, ZLS Burris, and Scintrex CG5 gravimeters. Proc. Int. Symp. Terrestrial Gravimetry – Static and Mobile Measurements, St. Petersburg, 20-23 September 2007 (this issue).

LaCoste, 1942. US Patent 2293437. Cited after: Larson, J.V., 1968. A cross correlation study of the noise performance of electrostatically controlled LaCoste and Romberg gravimeters. Technical Report No. 752, University of Maryland, Dept. of Physics and Astronomy, College Park, Maryland.

LaCoste&Romberg, 1972. Manual of the Earth Tide Meter. 31 p.

LaCoste & Romberg, 2004. Instruction Manual Model G and D Gravity Meters. Austin, Texas, 127 p.

Larson, J.V., 1968. A cross correlation study of the noise performance of electrostatically controlled LaCoste and Romberg gravimeters. Technical Report no. 752, University of Maryland, Department of Physics and Astronomy, 138 p.

Lederer, M., and V. Palinkas. Thorough vertical gravity gradient determination at the Czech absolute stations. Proc. Int. Symp. Terrestrial Gravimetry – Static and Mobile Measurements, St. Petersburg, 20-23 September 2007 (this issue)

Röder, R.H., M. Schnüll, H.-G. Wenzel, 1988. SRW feedback for LaCoste-Romberg gravimeters with extended range. Bull. d'Inf. Bureau Gravim. Int. 62, p. 46-50.

Schulz, H.R. Improvement of the evaluation of micro-gravity data with the help of an integrated software solution with the focus on the improved terrain correction. Proc. Int. Symp. Terrestrial Gravimetry – Static and Mobile Measurements, St. Petersburg, 20-23 September 2007 (this issue)

Timmen, L., O. Gitlein, 2004. The capacity of the Scintrex Autograv CG-3M no. 4492 gravimeter for "absolute-scale" surveys. In: P. M. L. de Menezes (Ed.): Revista Brasileira de Cartografia (Brazilian Journal of Cartography) No. 56/02, 89-95, 2004.

Torge, W., 1989. Gravimetery. Walter de Gruyter, Berlin, New York, 465 p.

Valliant, H.D., C. Gagnon, and J.F. Halpenny, 1986. An inherently linear electrostatic feedback method for gravity meters. J. Geophys. Res., 91, No. B10, 10463 – 10469.

Weber, J., and J.V. Larson, 1966. Operations of LaCoste and Romberg gravimeter at sensitivity approaching the thermal fluctuation limits. J. Geophys. Res., 71, 6006 – 6009.

Wenzel, H.-G., 1993. Programmsystem GRAV, Version 1.5, Program Manual. Geodetical Institute University of Karlsruhe, March 1993.

ZLS Corporation, 2007. User Guide: Automated Burris Gravity Meter™ and UltraGrav™ Control System. 67 p.