Two Feedback Systems to the Gs 15 No. 228 Gravimeter

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Summary:

Two feedback systems were constructed for the tidal gravimeter Gs 15 No. 228. Both systems were based on the use of the gravimeter´s electro-magnetic record calibration device.

The first system was analog. It improved significantly accuracy of observations. The mean-square error (MSE) of an hourly ordinate from an analysis of observed data using the program ETERNA was 0.091 mGal. The results showed, however, that coils of the calibration device produced heat depending on magnitude of the compensation current. This heat can disturb the observations.

The second system was digital. In this case, an alternating current of 50 Hz was added to the compensation current. Its amplitude can be changed so that the total heat produced by the coils remained at the same level. This digital feedback system did not cause any time delay of the observed signal. According to performed observations, the MSE of the hourly ordinate was the same as in the case of the analog system. The reproduction of results had, however, significantly improved. Amplitude factors d of major tidal waves derived from monthly observation series are stable at 0.1% level.

1. Introduction

The gravimeter Gs 15 No. 228 has been used for tidal observations at the Geodetic Observatory Pecný since 1975. The analog recording system was replaced by the digital system in 1995. This operation improved the accuracy of observed data from 0.48 mGal to 0.15 mGal (based on the MSE of the hourly ordinate from the data analysis using the program ETERNA), (Brož et al., 1997).

Further improvement of the gravimeter Gs 15 was achieved by the feedback system that according to (Orejana and Vieira, 1984), (Chen Yi Hui et al., 1986) employed a device for the electro-magnetic calibration of gravimeter‘s record (Schulze 1965). In this approach, the compensation current in the coils of the calibration device, that is regulated to keep the beam in the zero position, is measured. This is contrary to the standard approach that is based on observations of beam‘s deviations from the zero position using a capacity sensor. The compensation current is directly proportional to the gravity variations, or better to changes of the vertical component of the tidal force. The capacity sensor (CPI) is used only as a balance indicator.

2. Analog feedback system

The analog feedback system for the gravimeter Gs 15 No. 228 was built in 1997. The diagram of the system is shown in Fig. 1. The feedback circuit consists of a differential amplifier and a proportional - integral regulator. The compensation current goes through a parallel adder into the coils of the electro-magnetic calibration device of the gravimeter. The parallel adder gives the possibility to feed the coils with both the compensation current and a step signal. Accurate determination of instrumental damping of the gravimeter is possible in this way (Wenzel, 1994). The current **I** from the **PI** regulation and that from the calibration unit are inverted into the voltage **U** and then recorded.

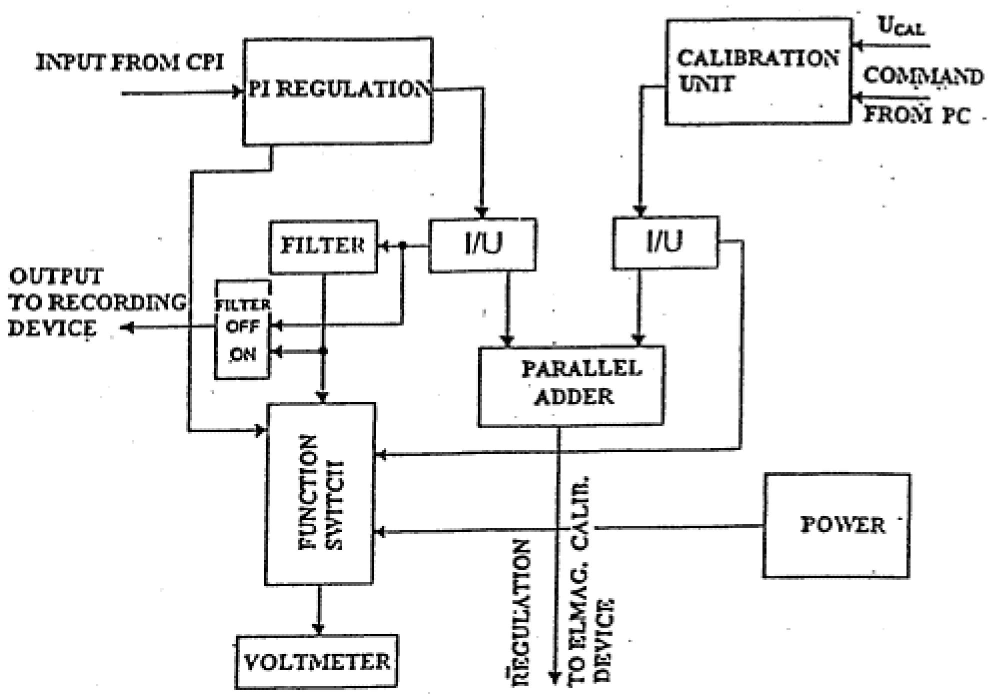


Fig. 1. Block diagram of the analog feedback device

The output voltage of the feedback system was filtered at the station by the Butterworth filter of the 2nd order with the time constant of 16 sec. The filter was in a series connection with an amplifier that increased the output voltage three times.

The registration (PC board AD 18P) recorded and digitalized data at a sampling rate of 1 sec. These data were later re-sampled to one-minute samples (Brož et al., 1997). The scale of the record was approximately 1.093 mGal / V that corresponds approximately to the current scale of 0.328 mGal / mA in the coils of the electro - magnetic calibration device. To avoid greater changes of the micrometer reading when calibrating the record using the measuring screw of the gravimeter, the range of the feedback system was set to ± 2.5 mGal. This corresponds to ± 2.29 V in the digital record or to ± 7.62 mA in the coils of the calibration system. It is preferred to calibrate the record in this range since the micrometer non-linearity causes large errors in the calibration results (Šimon and Brož, 1993).

A series of tests was performed using the tidal gravimeter with the analog feedback system. Special attention was paid to eventual noisy effect of the heat generated by the Helmholtz coils of the electro-magnetic calibration device. A series of record calibrations using the measuring screw of the gravimeter was completed. The measuring screw was reset in the following three ways:

A) Symmetrically by ± 50 micrometer divisions around the zero of the system (zero signal of the feedback system). The resulting scale of the record was **k** = 1.093 mGal / V.

B) Between zero and + 50 micrometer divisions (between the zero and negative signal of the feedback system), **k** = 1.132 mGal/V.

C) Between zero and -50 micrometer divisions (between the zero and positive signal of the feedback system), **k** = 1.055 mGal/V.

Large changes of the record scales in the cases B and C are due to the effect of the heat generated by the coils of the electro-magnetic calibration device. This heat is rather small when the measuring screw is set to signal magnitude close to zero. In the extreme settings of the measuring screw in the cases B and C, the same current is circulating in the coils but in opposite directions. The same amount of heat is generated. It is quite large since it increases with the current squared. Changes of the scale are also approximately the same in both cases but they have an opposite sign. This can be explained in the following way: the disturbing heat affects the elastic system of the gravimeter by a moment in direction of larger magnitude of gravity. Recorded voltage changes in the extreme settings of the measuring screw by about the same value in the positive direction. In the case B, a smaller difference of voltage is observed between the zero and extreme setting. As a consequence, the value of **k** is larger. The situation is reversed in the case C.

The linearity of the entire equipment was also checked as well as the possibility of its damping determination using step changes on the input of the gravimeter via the parallel adder.

Six short recordings were performed at last. The measuring screw was set to different settings so that the entire range ±2.5 mGal of the feedback was covered. The data of each recording were analysed by the program ETERNA with an unique record scale **k** = 1.094 mGal/V. This scale was obtained from several calibrations symmetric around the zero of the system.

Results of the analyses change significantly based on mean magnitude of the measured signal (distance from the zero of the system) in the particular recording. An apparent change of the record scale is shown in Fig.2. It was derived from changes of the amplitude factors d of the major tidal waves between individual recordings. Changes of the phase delay k of the wave M_2 only for the four recordings close to zero are shown in Fig. 3.

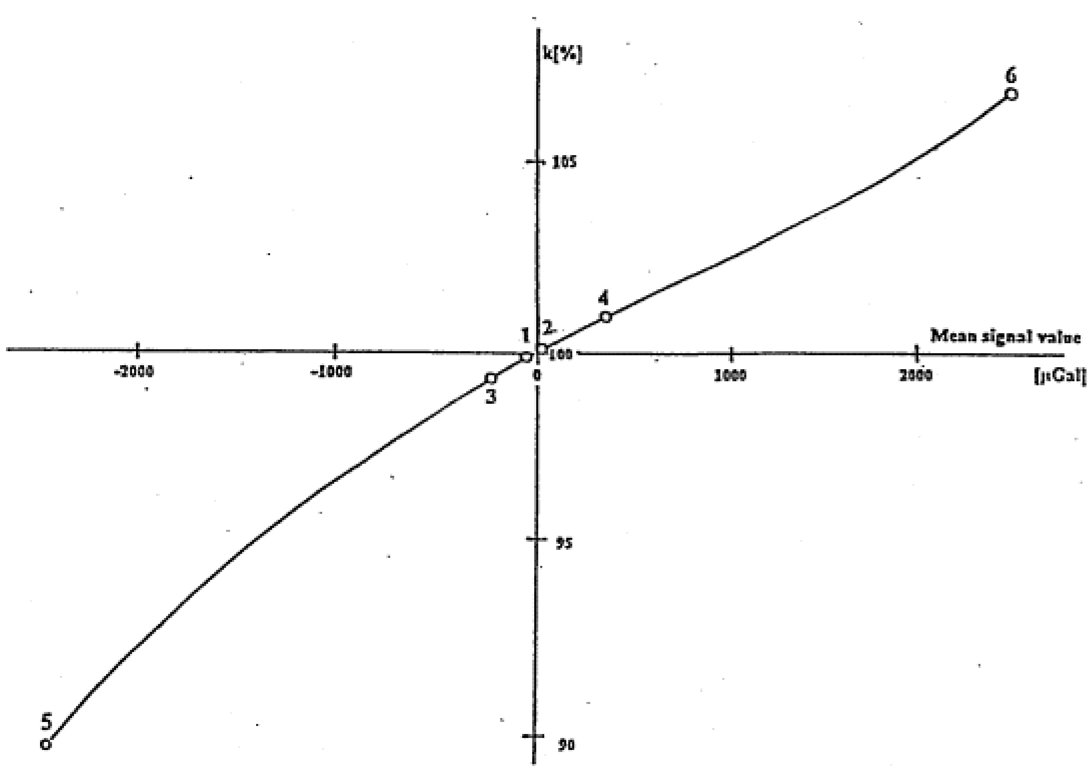


Fig. 2. Changes of the scale values *k* with distance of the record from zero (100% - prior measurement without feedback)

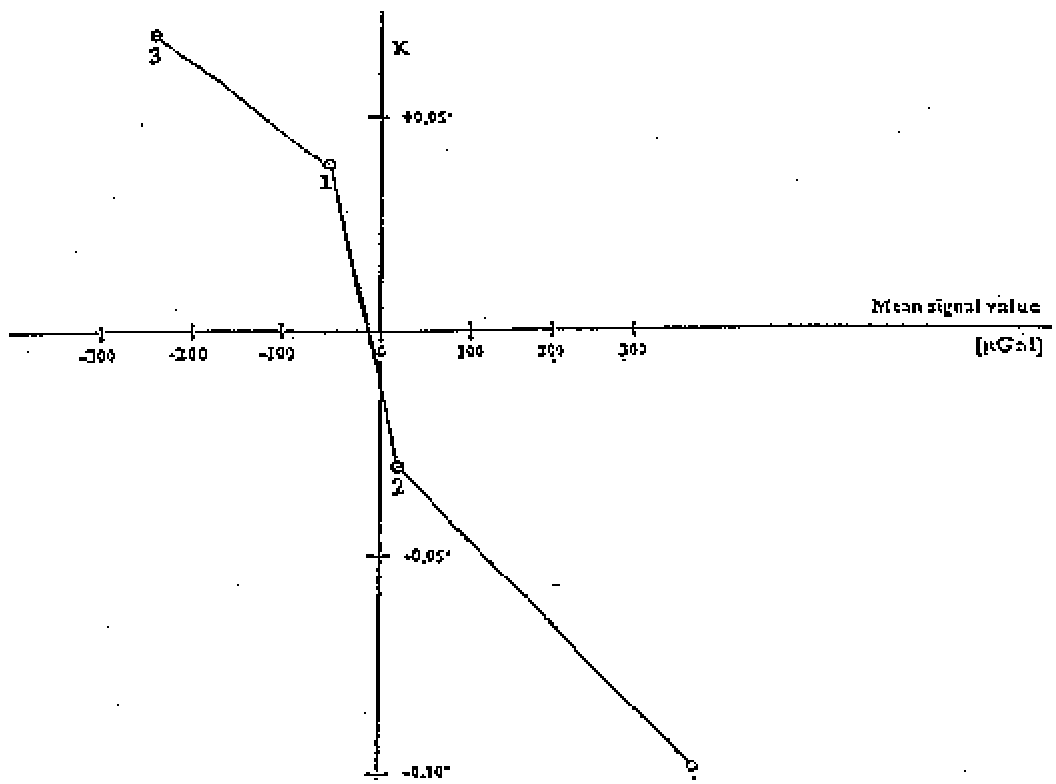


Fig. 3. Changes of the phase lags *k* of the M2 wave with distance of the record from zero (0° - prior measurement without feedback)

These results also indicate that the disturbing heat is generated in the coils of the electro-magnetic calibration device. This heat depends on magnitude of tides. Its disturbing effect is more pronounced with the larger distance of the record from the zero position. Each tidal wave is thus responsible for a disturbing heat wave that has the same frequency but certain phase delay. The amount of the generated heat increases with the square of the compensation current in the coils. The amplitude of the disturbing wave is thus proportional not only to the amplitude of the tidal wave but also to the average absolute magnitude of the feedback's signal. If the signal is positive (larger gravity than by the zero signal), the disturbing and tidal waves are added as two vectors. If the signal is negative (smaller gravity), the disturbing wave is subtracted. Parameters of the recorded wave change in this way.

One may conclude from all these performed tests that the tidal observations with the analog feedback system have reasonable quality only when the recording is done at the vicinity of the zero setting of the system. The record calibration must be performed symmetrically around the zero.

Tidal observations had been performed with the above described apparatus at the station Pecny since October 31, 1997 till January 3, 1999. The record was calibrated twice. The scale **k** was at the beginning equal to 1.0937 mGal/V and at the end to 1.0948 mGal/V. Corrections of the phase delay for damping of the system reached the value of 0.319° for the wave O1 and 0.663° for the wave M2. Results of the data analysis using the program ETERNA are in Table 1. The MSE of the hourly ordinate was estimated as 0.091mGal, i.e., the feedback system further improved the observation accuracy. Estimated values of the amplitude factors d and the phase delays k are in good agreement with previous results (Brož et al., 1997).

Due to the above described disturbing heat effect, analyses of monthly observation blocks were also performed. Deviations of the factors d from the values obtained in a complete analysis of all data for the waves O1, K1 and M2 are shown in Fig. 4 together with the mean values of the signal. The values are obviously correlated although the variations of the factors d are small. This dependency is not so significant in case of the values k.

Fig. 4. Variations of the amplitude factors d from one-month periods of measurement with the analog feedback device (zero - results of common analysis)

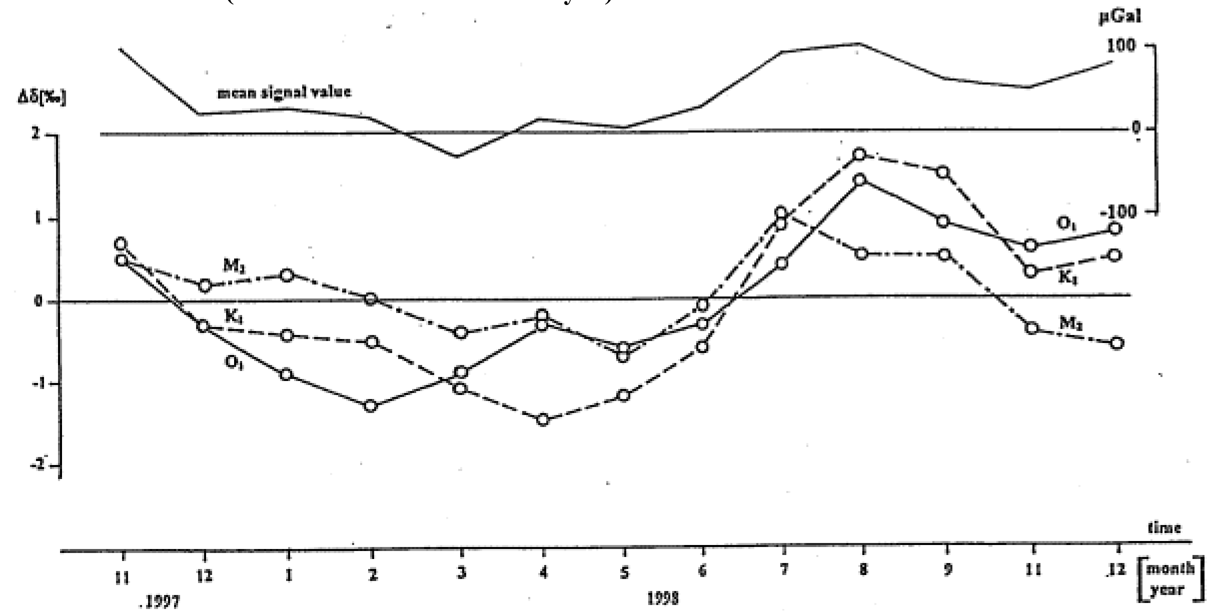


Table 1.

```
Program ETERNA, version 3.21 950117 Fortran 77,  file: 1998-sst.prn
######################################################################
# GRAVIMETRIC EARTH TIDE STATION  PECNY  NO.0930,  CZECH REPUBLIC    #
# RESEARCH INSTITUTE OF GEODESY,TOPOGRAPHY AND CARTOGRAPHY, ZDIBY    #
#  49.92 N  14.78 E  H 534 M  P 2 M D 400 KM  VERTICAL COMPONENT     #
# GRAVIMETER ASKANIA GS15 - NO.228  (TECHNICAL UNIVERSIITY PRAHA)    #
# CALIBRATION ELEKTROMAGNETIC; DIGITAL RECORD, ANALOG FEEDBACK       #
# 1997.10.31 - 1999.01.03        412 DAYS                            #
# INSTALLATION   Z.SIMON, J.BROZ; MAINTENANCE   J.BROZ               #
# CALIBRATED TO CZECH GRAVITY BASELINE                               #
# INSTRUMENTAL LAG CORRECTED FOR 0.32 DEG O1 AND 0.66 DEG M2         #
# WITHOUT INERTIAL CORRECTION                                        #
######################################################################

Latitude: 49.9200 deg, longitude: 14.7800 deg, azimuth:  0.000 deg.

Summary of observation data :
19971031140000...19980929160000  19981015 80000...19981126230000
19981128 80000...19990103160000
Initial epoch for tidal force     : 1997.10.31. 0
Number of recorded days in total :   412.17

TAMURA 1987   tidal potential used.
WAHR-DEHANT-ZSCHAU inelastic Earth model used.
UNITY window used for least squares adjustment.
Numerical filter is PERTZEV 1959 with  51 coefficients.

Estimation of noise by FOURIER-spectrum of residuals
0.1 cpd band99999.9990 nm/s**2       1.0 cpd band    0.0463 nm/s**2
2.0 cpd band     0.0344 nm/s**2      3.0 cpd band    0.0233 nm/s**2
4.0 cpd band     0.0203 nm/s**2      white  noise    0.0215 nm/s**2

adjusted tidal parameters :
```

from [cpd]	to [cpd]	wave	ampl. [nm/s**2]	ampl.fac.	stdv.	ph. lead [deg]	stdv. [deg]
0.721500	0.906315	Q1	67.125	1.14512	0.00058	-0.0567	0.0332
0.921941	0.940487	O1	351.768	1.14896	0.00011	0.0867	0.0064
0.958085	0.974188	M1	27.776	1.15354	0.00104	0.1602	0.0595
0.989049	0.998028	P1	163.983	1.15111	0.00020	0.1825	0.0113
0.999853	1.000147	S1	3.667	1.08852	0.01184	-4.3632	0.6780
1.001825	1.003651	K1	489.326	1.13643	0.00007	0.1464	0.0043
1.005329	1.005623	PSI1	4.252	1.26222	0.00858	3.7639	0.4906
1.007595	1.011099	PHI1	7.158	1.16743	0.00453	0.8187	0.2596
1.013689	1.044800	J1	27.776	1.15362	0.00135	0.0863	0.0776
1.064841	1.216397	OO1	15.267	1.15882	0.00331	-0.0699	0.1895
1.719381	1.872142	2N2	11.153	1.17080	0.00164	2.0695	0.0941
1.888387	1.906462	N2	70.363	1.17962	0.00033	1.6217	0.0190
1.923766	1.942754	M2	368.860	1.18397	0.00006	1.2030	0.0037
1.958233	1.976926	L2	10.378	1.17856	0.00255	0.0789	0.1463
1.991787	2.002885	S2	171.025	1.17991	0.00015	-0.0130	0.0085
2.003032	2.182843	K2	46.655	1.18404	0.00070	0.1518	0.0400
2.753244	3.081254	M3	4.153	1.05166	0.00320	-0.4170	0.1832
3.791964	3.937897	M4	0.004	0.09621	0.23271	143.8727	13.3332

```
Adjusted meteorological or hydrological parameters:
no. regr.coeff.        stdv.  parameter   unit
 1    -4.89812       0.01319  airpress.   nm/s**2 /hPa

Standard deviation of weight unit:       0.908
degree of freedom:                        9705
Standard deviation:                      0.908   nm/s**2
```

3. Digital feedback system

It was concluded in Section 2 that there is a small disturbing effect of the heat generated by the coils of the analog feedback system on the tidal observations. This effect remains despite all efforts to perform the recording as close to the zero of the system as possible. Should this effect completely be eliminated, the feedback device with the coils generating constant heat independent on magnitude of the compensation current would have to be constructed.

For this reason, the gravimeter Gs 15 No. 228 was equipped in 1999 by a new digital feedback system. The requirement for a stable heat output generated by the coils is satisfied using alternating current of higher frequency that is added to the compensation current $\mathbf{I_C}$. The amplitude **A** of this alternating current changes so that the total heating of both components has a stable mean value **P**, i.e.,

$$P = \frac{1}{T}\int_0^T R\left(I_C + A\sin 2\pi ft\right)^2 dt,$$

A stands for the amplitude of the alternating current, **T** for its period and **f** for its frequency. **R** is the effective resistance of the coils. The compensation current $\mathbf{I_C}$ can be assumed constant during one period of the alternating current. Then the amplitude **A** satisfies

$$A^2 = 2\left(I_0^2 - I_C^2\right),$$

where the constant $\mathbf{I_0}$ = P/R determines the range of heat compensation. For technical reasons, the value $\mathbf{I_0}$ = 7 mA was used. For the constant of the electro-magnetic device equal to 0.328 mGal/mA this range should be ±2.3 mGal.

The amplitude A depends only on $\mathbf{I_0}$ and $\mathbf{I_C}$. It reaches its maximum of 9.9 mA for $\mathbf{I_C}$ = 0, which corresponds to the amplitude of acceleration 3.25 mGal.

The frequency of the alternating current was chosen at level of 50 Hz. This current does not deflect the gravimeter's beam. It causes only slight vibration of the beam with this frequency. The mechanical measuring system of the gravimeter damps these vibrations by-70 dB, i.e., with a coefficient of $3.2 ´ 10^{-4}$.

The block diagram of the digital feedback system is depicted in Fig. 5. Its key component is the 16-bit processor ADSP-2181 made by Analog Devices. To measure the output voltage of the gravimeter, the sigma-delta converter AD7712 is used. The 16-bit DA converter is used to regulate the gravimeter. It is followed by the voltage - current converter. The output current, that is directly proportional to the gravity changes, is read by the resistor of 100 W and measured by another converter AD7712. The voltage output with a filter of 2nd order (to suppress the alternating component of the signal) can be used for eventual analog recording. The processor is connected to a PC via modules TTL/RS485 and UC485.

The regulation is solved in such a way that the transfer function of the gravimeter is preserved, i.e., the feedback system does not cause any time delay of the signal. Sampling frequency is 25 Hz. The used AD converter is equipped with the digital filter that suppresses any signal with frequency equal to multiplication of the frequency 25 Hz. The regulator computes 5 second averages of the compensation current.

Software consists of two programs. A service program is in the EPROM, a regulation program is in the FLASH memory.

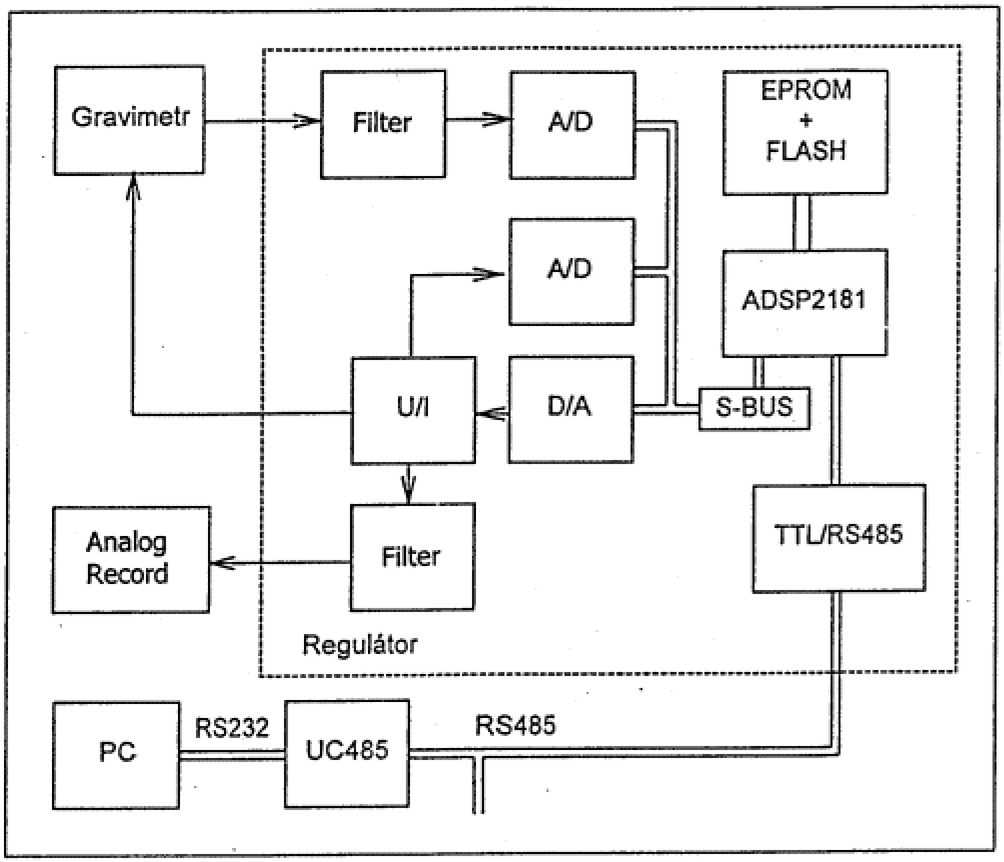


Fig. 5. Block diagram of the digital feedback device

The PC reads, after each 30th second UT, 13 five second averages of the compensation current $\mathbf{I}_C$ from the feedback. It estimates at the same time a correction of the regulator‘s clock. From these data, a value corresponding to each minute UT is computed by weighted averaging. The internal clock in the PC is controlled by DCF-77. The scale of the record is approximately 0.329 mGal / mA. Additional data are recorded together with the gravimetric data. The data are stored in the computer as the following four files:

The file rrrrmmdd.log contains five second averages of the tidal signal in mA .

The file rrrrmmdd.sut contains minute averages of the tidal signal and their MSE. This file is used for computation of the record calibration.

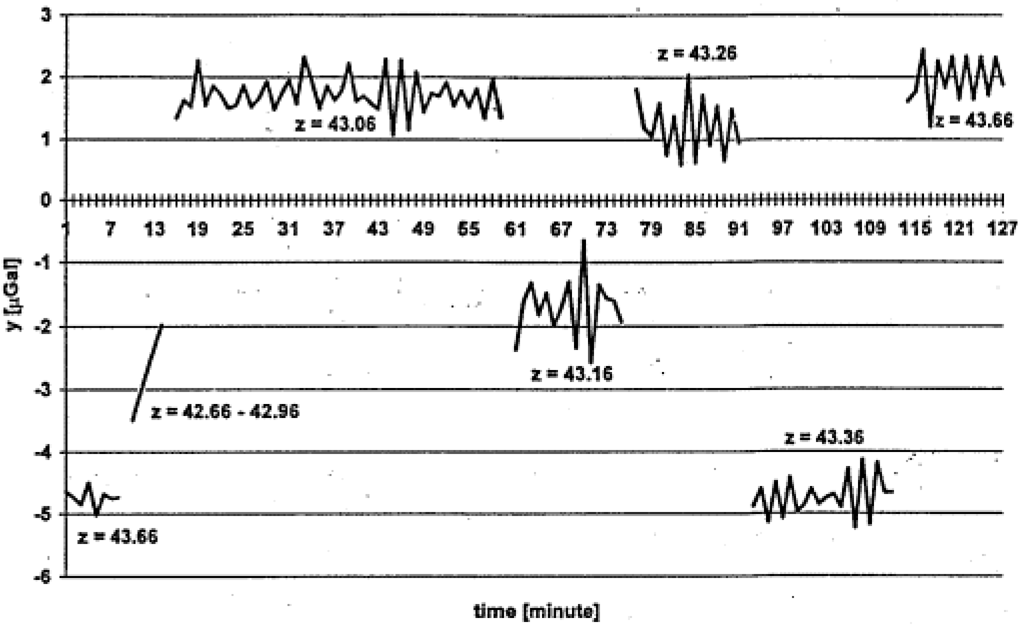
The file rrrrmmdd.sgt contains minute averages of the tidal signal in mA as well as minute samples of air pressure in hPa. These data are used after pre-processing in the tidal analysis.

The file rrrrmmdd.met contains hourly values of additional data such as the air pressure in hPa, air temperature in the chamber with the gravimeter and in the recording room in degree Celsius (°C), air humidity in the chamber in %, and the elevation of ground water level in m.

Tests of the digital feedback system showed that the actual range of heat compensation, i.e., the interval in mGal around the zero of the system with the constant heat power of the Helmholtz coils, is different from the expected range.

If the measuring screw is set to smaller values on its scale **z** (smaller than a value corresponding to the zero of the system), the recorded signal is positive. The heat compensation is effective for settings of the values **z** within the range of ± 0.6 scale division. No disturbances in the drift of the system can be observed, see Fig. 6. Note, that the settings from z = 42.66 to z = 42.96 indicated in Fig. 6 are too large, i.e. they are outside the sensing range of the system. The difference in **y** between the first and the last setting z = 43.66 is due to not exact setting of the screw.

Fig. 6. Output signal *y* with different settings of the measuring screw *z* in which the signal has positive values (tidal corrections introduced, reduced).



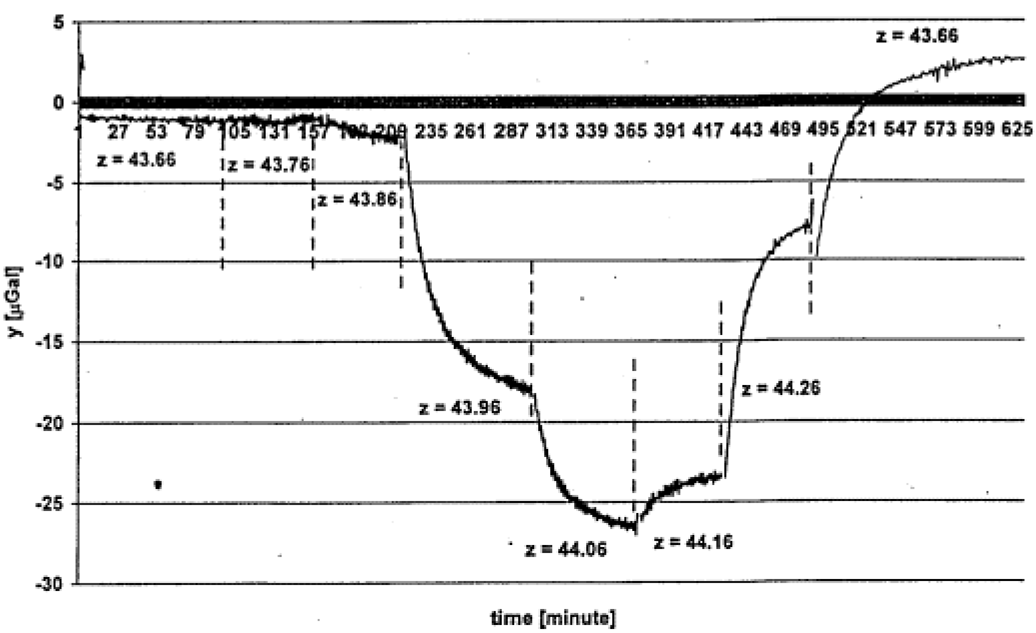


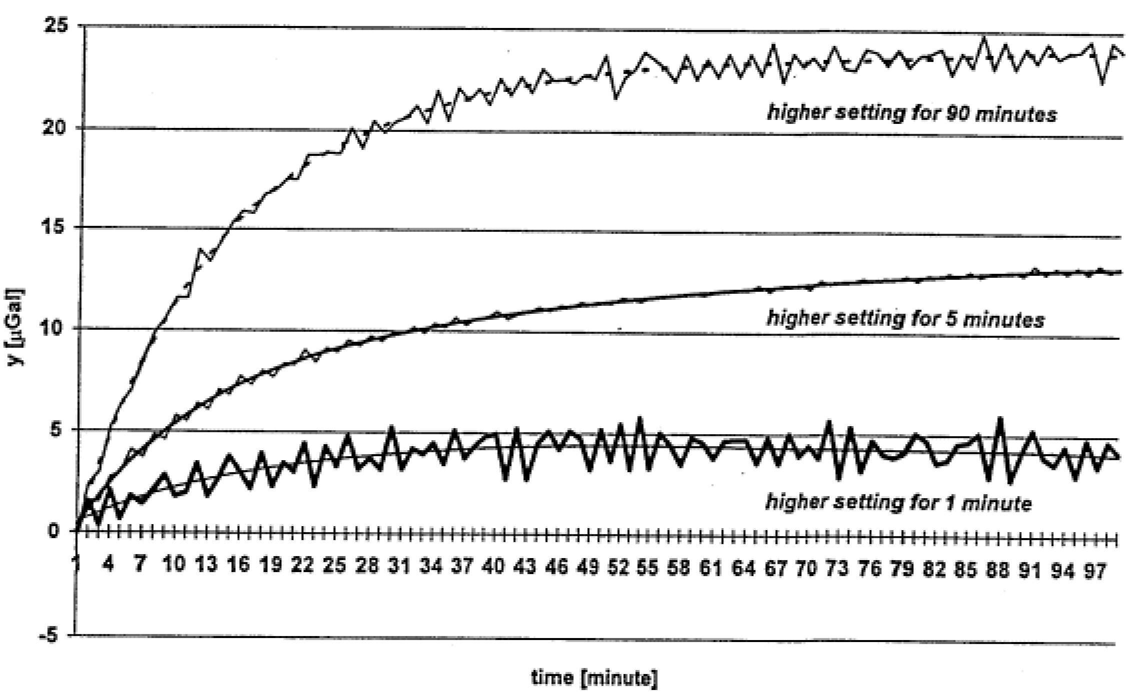
Fig. 7. Output signal *y* with different settings of the measuring screw *z* in which the signal has negative values (tidal corrections introduced, reduced)

From Fig. 6 it is obvious that all the records with different settings of the measuring screw between 43.66 and 43.06 are parallel i.e. heat compensation is effective.

If the measuring screw is set to larger values, i.e., the recorded signal is negative, the drift of the system is not disturbed for increasing of the value **z** only up by approximately 0.2 scale division. In the case of further increase of the value **z** up to approximately 0.4 scale division, transition effects in the direction of the further decrease of the signal can be observed. This corresponds to the loss of the heat produced by the coils, see Fig. 7. For values of z increased up to 0.6 scale division the transition effect is reversed. It corresponds to the repeated increase of the heating in the coils. The disturbances of the drift may reach values up to 25 mGal. The transition effects are stabilised approximately after 90 minutes. The damping of the system does not contribute anything since its time constant is negligibly small (see below) as is also obvious for example from Fig. 6.

Described behaviour of the feedback system has not been eliminated yet. The observation technique must thus be adjusted: registration of the tides must be performed within the range of complete heat compensation, i.e., using the positive signal of the device. Determination of the proper record scale is more difficult when the non-linearity of the micrometer should be eliminated by resetting the measuring screw during calibration by one scale division. Transition curves of the record for the measuring screw previously set to values larger by 0.5 scale division with respect to the zero with different time intervals can be found in Fig. 8.

Fig. 8. Output signal *y* with the measuring screw settings in which the signal is near zero. Each prior setting was for different period by 0.50 scale division higher.



It is obvious that the disturbance is significantly dependent on the time interval during which the larger values were set. If this interval is shorter than 2 minutes, the disturbance reaches approximately 5mGal and disappears completely after 40 minutes. If the measuring screw is reset during the record calibration by 5000 mGal, there will be an error in the record scale up to 0.1 %. If the reading **z** is increased during the calibration by 0.6 scale division and decreased by 0.4 scale division, the disturbance is smaller. It may reach only about 2 mGal because, as we can see from Fig. 7, the disturbance with the setting 44.26 is much smaller than that with the setting 44.16.

To establish a methodology for record calibration one has also to take into account that the used one-minute averages of the signal are derived from 13 five-second values distributed in the interval approximately -30 s, +30 s centred at the full minute. The record calibration then consists of the following steps:

1) A reading $\mathbf{z}_1$ is made on the scale of the measuring screw when the signal is close to zero. The record is left to balance for about 40 minutes. The last minute ordinate $\mathbf{y}_1$ is used for the calibration.
2) The measuring screw is set to a reading $\mathbf{z}_2$ smaller by 0.4 of the scale division 5 to 15 seconds after the full minute (the signal is positive). The following minute ordinate $\mathbf{y}_2$ is used for the calibration.
3) We return the measuring screw 40 to 55 seconds after this full minute back to a reading $\mathbf{z}_3$ for which the signal is again near to zero. The recording is performed for 5 minutes. The last minute ordinate $\mathbf{y}_3$ is used for the calibration.
4) The measuring screw is set to a reading $\mathbf{z}_4$ larger by 0.6 of the scale division 5 to 15 seconds after the full minute (the signal is negative). The following minute ordinate $\mathbf{y}_4$ is used for the calibration.
5) 40 to 55 seconds after this full minute, the measuring screw is set to a reading $\mathbf{z}_5$ for which the signal is close to zero. The record is left to balance for 40 minutes and the last ordinate $\mathbf{y}_5$ is used for the calibration.

Further calibrations follow that use the same procedure.

The reading scale **k** is determined twice from data obtained from the above five steps, i. e. from the pairs (z_1, y_1), (z_2, y_2), (z_3, y_3) and from the pairs (z_3, y_3), (z_4, y_4), (z_5, y_5).The ordinates **y** are corrected for the tidal effect using preliminary sooner estimated parameters of the tidal waves. The average value **k** computed from the two estimates is corrected for the non-linearity of the micrometer. The effect of incomplete heat compensation for the negative signal is practically eliminated. Since the steps of the calibration procedure do not proceed uniformly in time, the drift of the apparatus is not excluded from the results. However the drift may reach values at the level of 1 mGal/day and can be neglected.

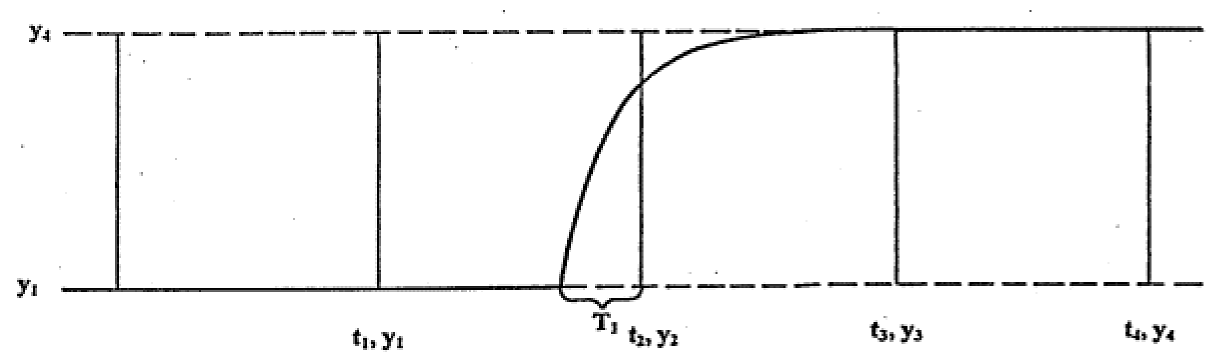
The damping of the apparatus is difficult to check because it is very small. Introducing a step change on the input using the measuring screw, the transition on the output vanishes in 5 seconds during which the feedback reads and averages the signal. Only seldom there is a transition between two 5 second intervals that allows one to determine approximately the time constant of the apparatus t.

The feedback systems outputs in the instants $\mathbf{t}_1$ to $\mathbf{t}_4$ average values of the signal from previous five seconds $\mathbf{y}_1$ to $\mathbf{y}_4$. The values $\mathbf{y}_1$ and $\mathbf{y}_4$ are stable but the values $\mathbf{y}_2$ a $\mathbf{y}_3$ are affected by the step, see Fig. 9. Assuming that the step response may be written as follows

$$y=(y_4-y_1)\left(1-e^{-\frac{T}{\tau}}\right),$$

differences (y_2 - y_1) and (y_4 - y_3) may be derived. **T** denotes an instant measured from the beginning of the step and $\mathbf{T}_1$ corresponds to an instant $\mathbf{t}_2$ .From the ratio of the differences (y_2 - y_1) and (y_4 - y_3) the time constant t can be determined. From many realised steps only 10 could be used. The estimated value of t is 0.64 ± 0.02 second.

Fig. 9. Supposed response of the signal after a step change on the input



The tidal variations had been recorded using the gravimeter with the feedback system since 20.4. 2000 to 18.9. 2001. Results of the data analysis using the program ETERNA can be found in Table 2. The MSE of the observed hourly ordinate is 0.096 mGal despite many interruptions of the recording caused by frequent tests of the apparatus as well as of the observation methodology. The record was calibrated three times and the analysis was performed with the constant record scale of 0.329316 mGal/mA. No corrections for the damping of the system were introduced. Final values of the amplitude factors d and the phase delays k of the tidal waves agree well with previous results at the station. The comparison of the results of all tidal observations at the station Pecný for the main waves is in Table 3. The values k from the analog recording system are burdened by systematic errors originating in visual reading of the ordinates.

The data were also divided in 17 one-month periods that were analysed individually. The comparison of resulting parameters d with the results from the analysis of the complete period can be found for the waves O1, K1, M2 and S2 in Fig. 10. No correlations are visible. While the gravimeter without any feedback system suffered from the systematic effect caused by the non-linearity of the capacity sensor of the beam's position and the gravimeter with the analog feedback system by the heat produced by the coils of the calibration system, there are no such effects in the case of the gravimeter with the digital feedback system.

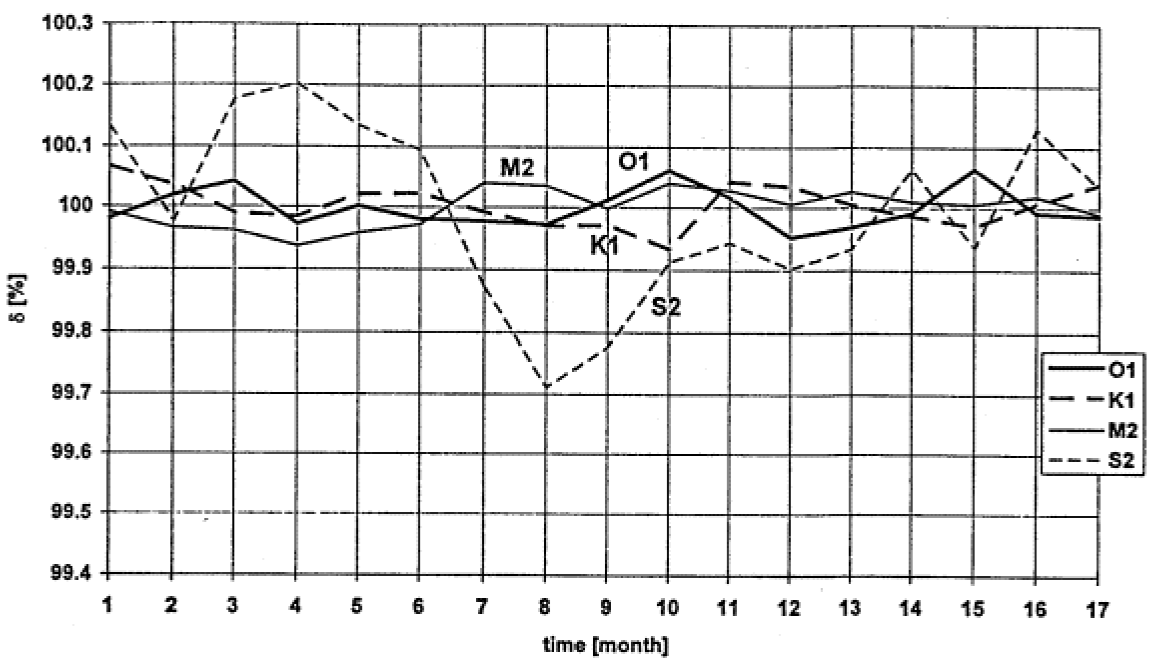


Fig. 10. Variations of the amplitude factors *d* from one-month periods of measurement with the digital feedback device **(100/% - result of the common analysis)**

Table 2.

```
Program ETERNA, version 3.21 950117 Fortran 77,    file: 41-00-09
####################################################################
# GRAVIMETRIC EARTH TIDE STATION  PECNY  NO.0930,   CZECH REPUBLIC #
# RESEARCH INSTITUTE OF GEODESY, TOPOGRAPHY AND CARTOGRAPHY,ZDIBY #
#  49.92 N  14.78 E  H 534 M  P 2 M  D 400 KM  VERTICAL COMPONENT #
# GRAVIMETER ASKANIA GS15 - NO.228   (TECHNICAL UNIVERSITY PRAHA) #
# DIGITAL FEEDBACK, DIGITAL RECORD                                 #
# CALIBRATION MEASURING SCREW, WITHOUT MICROMETER USE              #
# INSTRUMENTAL LAG CORRECTED FOR 0.00 DEG O1 AND 0.00 DEG M2       #
# 2000.4.20 - 2001.9.18      513 DAYS                              #
# INSTALLATION   Z.SIMON, J.BROZ,   MAINTENANCE   J.BROZ           #
# WITHOUT INERTIAL CORRECTION                                      #
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Latitude: 49.9200 deg, longitude:14.7800 deg, azimuth:  0.000 deg.

 Summary of observation data :
20000420 80000...20000825130000  20000828210000...20001031110000
 20001031120000...20010918160000

 Initial epoch for tidal force     : 2000. 4.20. 0
 Number of recorded days in total :    513.08
 TAMURA 1987  tidal potential used. WAHR-DEHANT-ZSCHAU inelastic
 Earth model used. UNITY window used for least squares adjustment.
 Numerical filter is PERTZEV 1959 with  51 coefficients.
 Estimation of noise by FOURIER-spectrum of residuals
 0.1 cpd band99999.9990 nm/s**2        1.0 cpd band      0.0367 nm/s**2
 2.0 cpd band     0.0298 nm/s**2       3.0 cpd band      0.0236 nm/s**2
 4.0 cpd band     0.0225 nm/s**2       white  noise      0.0222 nm/s**2

 adjusted tidal parameters :
 from       to       wave   ampl. ampl.fac.    stdv. ph. lead    stdv.
 [cpd]      [cpd]       [nm/s**2 ]                      [deg]     [deg]

 0.721500 0.906315 Q1     67.098   1.14466  0.00034  -0.1517   0.0195
 0.921941 0.940487 O1    351.560   1.14829  0.00007   0.1436   0.0040
 0.958085 0.974188 M1     27.637   1.14779  0.00119   0.3725   0.0680
 0.989049 0.998028 P1    163.818   1.14996  0.00015   0.1475   0.0085
 0.999853 1.000147 S1      3.763   1.11732  0.00886   0.8597   0.5074
 1.001825 1.003651 K1    488.673   1.13492  0.00005   0.1630   0.0029
 1.005329 1.005623 PSI1    4.129   1.22586  0.00629   0.0913   0.3608
 1.007595 1.011099 PHI1    7.205   1.17516  0.00341  -0.4287   0.1962
 1.013689 1.044800 J1     27.781   1.15382  0.00077   0.1267   0.0442
 1.064841 1.216397 OO1    15.139   1.14919  0.00186   0.1652   0.1064
 1.719381 1.872142 2N2    11.032   1.15810  0.00118   2.0204   0.0676
 1.888387 1.906462 N2     70.035   1.17413  0.00025   1.5910   0.0143
 1.923766 1.942754 M2    368.527   1.18289  0.00005   1.2314   0.0030
 1.958233 1.976926 L2     10.526   1.19530  0.00258   1.6073   0.1478
 1.991787 2.002885 S2    170.718   1.17779  0.00012   0.0806   0.0069
 2.003032 2.182843 K2     46.540   1.18115  0.00045   0.1380   0.0258
 2.753244 3.081254 M3      4.265   1.08019  0.00305   0.0300   0.1748
 3.791964 3.937897 M4      0.018   0.39053  0.24192 -35.1252  13.8605

 Adjusted meteorological or hydrological parameters:
 no. regr.coeff.       stdv.  parameter   unit
   1     -3.79874     0.01539  airpress.   nm/s**2 /hPa
 Standard deviation of weight unit:      0.958
 degree of freedom:                      12127
 Standard deviation:                     0.958  nm/s**2
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Table 3. Comparison of the results of tidal measurements at the Pecný station

Gravimetr	Gs 11 No.131		BN-26		Gs 15 No.228		Gs 15 No.228				Gs 15 No.228		Gs 15 No.228		LCR 137	
Record	analog		analog		analog		digital				analog feedback digital		digital feedback digital		analog feedback digital	
Period Days Analysis	70 09 - 80 02 1372 M 74		83 04 - 88 03 1326 M 74		76 04 - 95 03 4555 ETERNA 2.1		95 12 - 96 09 284 ETERNA 3.20		99 02 - 99 10 233 ETERNA 3.20		97 10 - 99 01 412 ETERNA 3.20		00 04 - 01 09 513 ETERNA 3.20		01 01 - 01 04 90 ETERNA 3.20	
vlna	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$	$\delta \pm m_\delta$	$\kappa \pm m_\kappa$
O_1	1.1490 11	0.15 0.06	1.1486 12	-0.02 0.06	1.1479 2	-0.01 0.01	1.1491 2	0.09 0.01	1.1489 2	0.11 0.01	1.1490 1	0.09 0.01	1.1483 1	0.14 0.00	1.1484 2	0.06 0.01
K_1	1.1362 7	0.42 0.04	1.1362 8	0.21 0.05	1.1348 2	0.06 0.01	1.1354 1	0.18 0.01	1.1365 1	0.19 0.01	1.1364 1	0.15 0.00	1.1349 1	0.16 0.00	1.1353 2	0.17 0.01
M_2	1.1847 6	1.28 0.03	1.1844 6	1.08 0.03	1.1849 2	1.03 0.01	1.1839 1	1.22 0.01	1.1836 1	1.21 0.01	1.1840 1	1.20 0.00	1.1829 1	1.23 0.00	1.1829 1	1.21 0.01
S_2	1.1805 13	0.88 0.07	1.1792 12	-0.04 0.07	1.1798 3	0.14 0.01	1.1807 2	-0.04 0.01	1.1784 2	0.09 0.01	1.1799 2	-0.01 0.01	1.1778 1	0.08 0.01	1.1806 3	0.07 0.02
m_o [µGal]					0.474		0.149		0.121		0.091		0.096		0.073	

References:

BROŽ, J. - ŠIMON, Z. - VANKA, P. - ZEMAN, A. (1997): High Accurate Tidal Data from a Gs 15 Gravimeter. B.I.M. No. 128, pp 9893 - 9905.

CHEN YI HUI - ZHU HAN YUN - GUO ZI QIANG - LEI YU TIAN (1986): Magnetic Feedback of GS 15 Gravimeter and Digital Record. Proceedings of the 10th Intern. Symp. Earth Tides, pp 21 - 26. Consejo Sup. de Invest. Cientific., Madrid.

OREJANA, M. - VIEIRA, R. (1984): Transforming an Askania Gs 15 Gravimeter into a Zero Gravimeter. Proceedings of the 9th Intern. Symp. Earth Tides, pp 311 - 313. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

SCHULZE, R. (1965): Eine neue Eicheinrichtung im Gezeitengravimeter. Askania - Warte, H.66.

ŠIMON, Z. - BROŽ, J. (1993) : Calibration of Askania Gravimeter Record. B.I.M.No˙ 115, pp. 8478 - 8483.

WENZEL, H.-G. (1994): Accurate Instrumental Phase Lag Determination for Feedback Gravimeters. B.I.M. No. 118, 8735-8752.