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Spectral Analysis for Gravitational Constant Measurements

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Abstract—Spectral analysis has been carried out for time series of gravitational constant measurements. Latent periodicities have been revealed, testifying to an influence of microseisms, non-equilibrium rarefied gas flows and temperature variations on the results of measurements.

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1. INTRODUCTION

In [1], time variations of the gravitational constant G have been detected. To improve the quality of measurements, it is desirable to reveal their nature. We have tried to affect the measurement results by external impacts. Thus, measurements of G were conducted under oscillations of the suspension point with a magnitude of 5 μm. We failed to obtain appreciable changes in G in this way. The topicality of analyzing non-equidistant series of G increased while storing the materials obtained.

2. GRAVITATIONAL CONSTANT MEASUREMENTS

Gravitational constant measurements were carried out using an evacuated torsion balance. A magnetic damper of swinging reduced the influence of microseisms. To reduce the effect of system parameter drifts, the measurements were carried out during two periods only. Spherically shaped masses were placed strictly along the balance equilibrium line. They were fixed in a few positions at different distances from the rotation axis.

Investigated were the measurement sets 860326.dat, 920225.dat, 010216.dat, and 020208.dat. The file name contains the year, month and day when the measurements began. The data sets 860326.dat and 020208.dat were obtained using a single-step scheme with one attracting mass, others using a two-step scheme with two masses.

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3. SPECTRAL ANALYSIS OF DATA SETS

The data set 860326.dat contains 5050 protocol lines with information about the line ordinal number, date and time when the measurement ended, the initial and final positions of the attracting mass, ten measured time intervals (five in each position), period and magnitude of the balance oscillations in the two positions, and the calculated value of G. An attracting ball of mass $M = 4287.347$ g was fixed in four positions, which led to six combinations G_{ij} of the gravitational constant. In the analysis, the combinations G_{12}, G_{13}, G_{14} were stored in the forward cycle, and the values G_{43}, G_{42}, G_{41} were used in the back cycle. As a result, 2526 protocol lines were stored. When twenty-four-hour measurements were singled out, there remained 906 lines. All three combinations of the forward and back cycles were clearly separated in time.

The results of the analysis, in the form of the function $A = f(T)$, where A is the magnitude of latent periods of duration T, are shown in Fig. 1. Of interest is the period of 1.133 h, equal to the mean measurement time in four positions. It is an average of almost equal periods reflecting the measurement times at each position. In the units of 10^{-15} Nm^2/kg^2, in which all further results are also presented, its magnitude is about 15. When only twenty-four-hour measurements are used, it increases up to 28. The second and third plots of Fig. 1 show a substantial difference in the results of the analysis when the 24-hour period is singled out. From the round-the-clock data, the magnitude is about 5.5. When all data are taken into account, the period becomes more pronounced, and the magnitude reaches 11. It is divided into two peaks

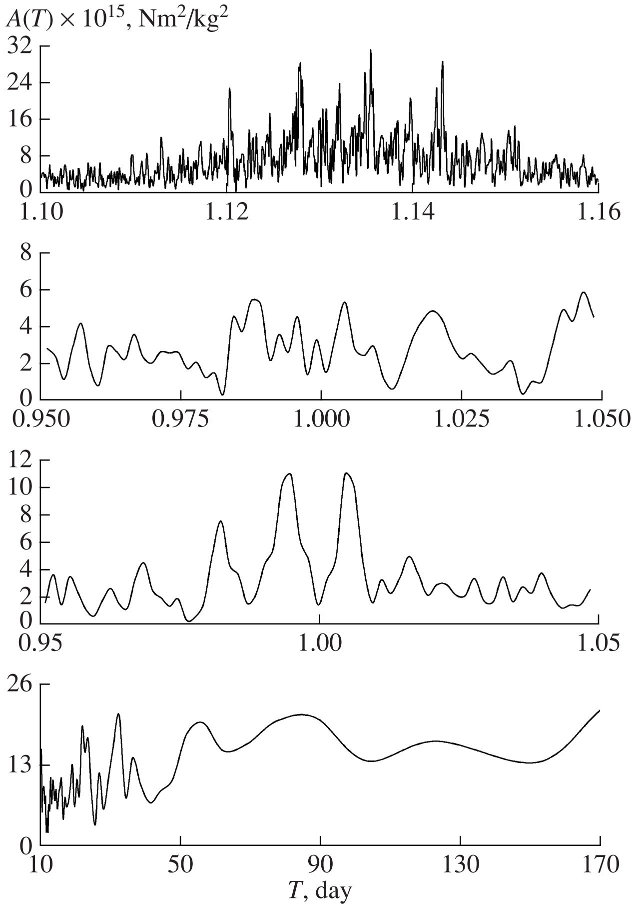

Fig. 1. Main periods of the data set 860326.dat.

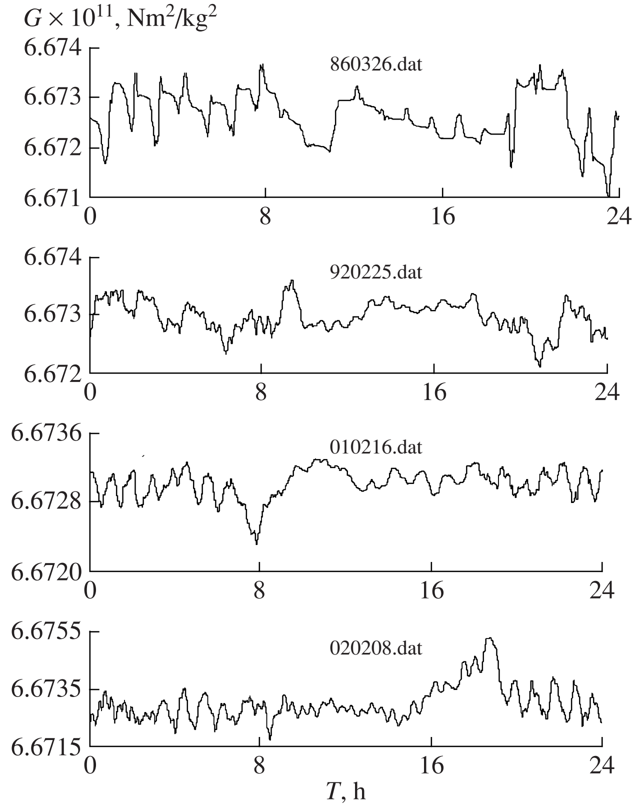

Fig. 2. 24-hour variations of G in data sets 860326, 920225, 010216, 020208.

by longer periods T. When round-the-clock measurements are used, a week period is clearly singled out. The last plot of Fig. 1 shows that, against the background of flicker noise, one can observe periods T of longer duration. Spectral analysis also makes it possible to single out a shorter period $T = 0.848$ h with a magnitude about 7, caused by measurements of five time intervals used in the calculations. They form 75 per cent of the full time needed to perform all operations at each position.

The data set 920225.dat contains 5918 protocol lines. Two steel balls of mass $M = 4457.457$ g were used, fixed only at two positions closest to the balance. In the analysis of round-the-clock measurements, 2206 lines are stored.

The most interesting period is $T = 0.712$ h, whose magnitude, in the same units 10^{-15} Nm^2/kg^2, has a value of the order 11. Its harmonics are easily singled out. A period equal to measurement times at the positions is absent. This indicates that, with small time intervals between measurements at adjacent positions, the microseisms are unable to substantially change their characteristics. For a shorter period of 0.712 h, the data repeat after time intervals four times as great as for the main period. For such an interval, the microseism characteristics substantially change, and they most likely make the largest contribution to the shorter period T. The 24-hour period is poorly singled out if one uses only round-the-clock measurements. It is, however, clearly pronounced in the analysis of all data.

The data set 010216.dat contains 8508 protocol lines. Attracting steel balls, 6 inches in diameter and of mass $M = 14083.566$ g, were fixed in three positions. All combinations were stored except G_{23} and G_{21}. Then 5669 lines remained, and for round-the-clock measurements, 2458 lines. The main period of $T = 0.922$ h has a magnitude of about 2.3. It has harmonics with a magnitude of the order 2. A 24-hour period is poorly seen at round-the-clock measurements. When all data are used, it is more clearly pronounced and has a magnitude of the order 1.

The data set 020208.dat contains 12 699 protocol lines. An attracting steel ball, 6 inches in diameter, of mass $M = 14011.590$ was fixed in three positions. All combinations except G_{23} and G_{21} were stored. In the analysis, 8462 lines were used, and for round-the-clock measurements 3780 were stored. The main period of $T = 0.938$ h has a magnitude of the order 30.

A 24-hour period for round-the-clock measurements has a magnitude about 3.5. When all data are analyzed, the magnitude of the 24-hour period appreciably grows, reaching a value about 20. One can clearly see splitting of the period into two peaks with longer periods. The shorter period of $T = 0.704$ h, with a magnitude about 8, is also reliably singled out.

4. 24-HOUR VARIATIONS OF THE GRAVITATIONAL CONSTANT

24-hour variations of G in all four data sets, obtained in the analysis of all data, are given in Fig. 2. In all results, one singles out a fractional part of the day, and multiplying it by a factor of 24, one translates it into hours. The data obtained are disposed in ascending order. In all data sets, sliding averaging has been performed. Also, the data were resampled down by division into groups.

5. DESTABILIZING FACTORS

All periods T, singled out in the four data sets, and 24-hour variations of values of the gravitational constant G are related to a number of destabilizing factors: action of microseisms on the balance suspension points, non-equilibrium rarefied gas flows, variations of temperature and its gradients. The first two factors lead to a drift of the balance equilibrium position and the oscillation period. The smaller is the magnitude of the latent periods, the higher is the quality of measurements.

Variations of the temperature and its gradients change both the contribution of non-equilibrium flows into the torsion system hardness and the position of the attracting mass. There are changes in the linear size of both the balance and the plate on which the mass-fixing construction is assembled. The temperature difference between the upper and lower surfaces of the plate due to its finite heat conduction leads to its bending deformation. The center of the attracting ball then significantly moves because the ball center is at a certain distance from the plate. Fluctuations in the attracting ball position lead to both 24-hour and longer periodic variations of the measured gravitational constant.

6. CONCLUSIONS

In all data sets, characteristic periods have been singled out. It turned out that the most informative of them is the period equal to the mean measurement time at all positions. It has a large number of harmonics. Of interest is also the period of 75 per cent of the measurement time at the positions. It is less pronounced. The 24-hour period is also very informative. When only round-the-clock measurements are taken into account, it is weakly pronounced, but when all data are used, it is quite clearly seen and splits into two peaks related to longer periods. In all data sets, revealed are periods of longer duration against the flicker noise background. Plots of 24-hour variations of the gravitational constant supplement the information obtained from spectral analysis. Destabilizing factors in gravitational constant measurements are rarefied gas flows and microseisms acting on the balance suspension point. The flows can change their influence on the balance due to changes in the ambient temperature as well as the feeding network voltage. Fluctuations of temperature and temperature gradients change the distances between the interacting masses, leading to gravitational constant variations with longer periods.

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