Gravity Experiment with a Physical Pendulum

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In recent decades, several methods significantly different from the classic method of the Cavendish torsion balance have been developed and used for measuring the gravitational constant G. Unfortunately, the new determinations of G have not reduced significantly its uncertainty. It seems that in recent times, the accuracy problem for the gravitational constant has not been the focus. This paper presents a private gravity experiment based on ten years research in Hungary. This experiment used a relatively big and heavy physical pendulum that was built, not for a newest measure of the gravitational constant, but for the study of *special gravitational effects* encountered accidentally. We have named a whole new group of gravitational phenomena *dynamic gravity*. Despite the simplicity of our gravity experiment, the observed extraordinary results could lead to an unexpected revolution in gravity science.

Keywords: experimental gravity, dynamic gravity, physical pendulum, quasi-resonance measuring method, extension of the Newtonian Law of Gravity.

1. Introduction

For a long time the main motivation for experimental gravity studies has been only the more and more precise determination of the gravitational constant G. Despite the long time and strong efforts, the gravitational constant is at present the least-well measured fundamental constant. [1,2] However, it seems that in recent times, the accuracy of the gravitational constant has not been the main focus of experimental gravity research.

Nowadays the main stream of experimental research has branched into state-funded and private spheres. The 'official' state researches concentrate primarily for the experimental proofs of the GRT consequences; *i.e.* for the reliable detection of gravitational waves, observation of black holes and newly re-examine the equivalence of inertial and gravitational mass of free falling bodies, including Bose-Einstein condensates (BEC) of gases [3]. Since 2004 until now there is going the '*Gravity Proba B*' space experiment what is also connected to the validity control of GRT [4].

In the private sphere, physicists now prefer to study the unknown features of gravitational interaction. Mainly, the different kinds of exotic antigravity experiments and theories have become very popular. The aim is not just to proceed to Newtonian gravity, but to overcome the GRT of Albert Einstein. A number of private experiments are planned and executed to demonstrate the possibility of gravitational shielding, or even of the gravitational repulsion (in other words, 'antigravity').

In our case, a blind chance helped us when we investigated a physical pendulum's sensitivity for gravity measurement.

In our experiment, the applied relatively big and heavy physical pendulum was built, not for a newest measure of the gravitational constant, but for the study of *special gravitational effects* encountered accidentally. We have named a whole new group of gravitation phenomena *dynamic gravity*. Despite the simplicity of our gravity experiment, the observed extraordinary results could lead to an unexpected revolution in gravity science.

2. Experimental Setup

Our new unconventional gravity measuring method is illustrated in Fig. 1.

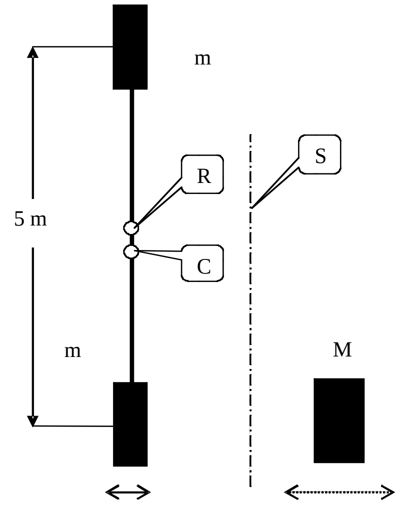


Figure 1. Setup for gravity measurement. (R: pivot point; C: mass-center; S: shielding; m: pendulum masses; M source mass)

Some of the technical features of the most successful physical pendulum are:

Pendulum arms: 2.5 + 2.5 meter (in vertical position)
Upper and lower masses: 24 - 24 kg (cubic lead)
Pendulum frame: made of aluminum
Total mass with frame: 54.7 kg
Support of pendulum: two 'in-line' wedges (steel)
High frequency filter: hydraulic damper
Applied pendulum period: 60 - 80 sec
Position detector: light-coupling without mechanical contact

Due to the relatively large dimensions, the adjustment of the pendulum period is very easy. The small pendulum amplitude results an acceptable low level of friction. The test masses used were made of lead cubes fabricated with standard geometry for the original purpose of radioprotection. During the control tests, we put an iron isolation plate into the gap between roundtable and pendulum to prevent magnetic and air-draft disturbances. This test demonstrated that the iron isolation plate has had no significance for the pendulum movement, because the supposed side effects were extremely weak. Reliable grounding of the apparatus is necessary for protecting it against the electrostatic disturbances.

The pendulum movement was recorded on-line by a personal computer, and was displayed in zoomed graphic form on the computer screen. For the recording of the pendulum movement, an optical measuring system was developed. The sampling period of pendulum position is adjustable between 0.2 and 2.0 sec; the resolution of the position detector is about 5 - 10 μm. Limitation of the pendulum amplitude was realized by using two soft mechanical breaks with adjustable distance in the range of 15-50 mm.

Our laboratory is situated at about 500 meters from the nearest road traffic, and in an environment of low gravitational and mechanical noise. The building of the laboratory is hermetically closed against the outer air draft. Nevertheless, in the fooundation of the laboratory continuous small mechanical vibrations could be observed, and the coupled vibration energy was transferred to the pendulum. An important part is not shown on Fig. 1: a plastic container filled with water, in which rides a light plastic damping sheet of about 500 cm^2 surface area connected to the lower arm of the pendulum. This works as a hydraulic damper that minimizes the high frequency disturbances. The remaining low frequency components of the background noise cause permanent swinging of the pendulum with amplitude about 3-5 mm. To avoid any gravitational noises, no persons should be present in or near the laboratory during measurements.

The application of the physical pendulum for the gravity measurement has two important advantages over the torsion balance method: firstly, the 'spring constant' of the physical pendulum is very stabile due to constant local gravity acceleration g, secondly, the dissipation factor of the physical pendulum is relatively smaller in comparison with the torsion balance method. The disadvantage of the physical pendulum is its small sensitivity; that is why gravity measure of such type has not occurred until this time (or we have no information about it).

Now here is a short calculation of the physical pendulum sensitivity. In the case of a small swing, the motion of the physical pendulum is a harmonic oscillation. The spring constant of the pendulum oscillator is:

$$k = m^* \omega^2 = 4\pi^2 m^* / T^2 . \tag{2.1}$$

where m^* is the *effective mass* of the pendulum, and T is the period of the pendulum. The typical value of T is about 60 s, the effective pendulum mass is about 50 kg. From these data the spring constant of our physical pendulum is:

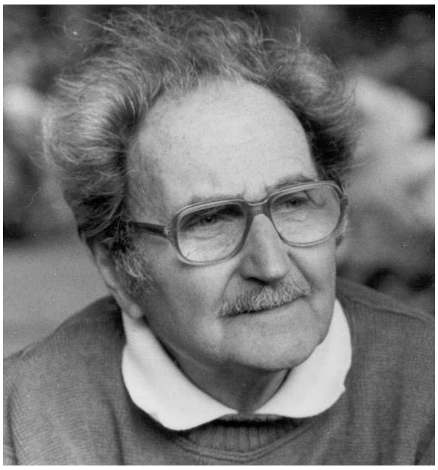
$$k = 0.087 \text{ N / m} . \tag{2.2}$$

In the case of a typical torsion balance measure the mass dipole is about 100 grams, the swing period is at least 1200 s which leads to the spring constant:

$$k = 4.36 \times 10^{-7} \text{ N / m} . \tag{2.3}$$

From this simple calculation one can conclude that the physical pendulum is not appropriate device for the measure of the gravity.

The following photos are of the Hungarian physicist Laszlo Bodonyi, and the gravity-measuring instrument that he devised:



Laszlo Bodonyi (1919-2001).

Bodonyi's instrument for the gravity measurement.

Mr. Bodonyi built his relatively large physical pendulum, intuitively supposing its capability for the gravity measurement, but he did not have enough knowledge to analyze the sensitivity of the physical pendulum. From the beginning it seemed that the physical pendulum 'really' measured the 'gravity'. Checking later into his experiment, we have concluded that the measured effect is neither an electromagnetic influence, nor a vibration side effect, but really a new physical interaction between the *neutral masses*. Firstly we have used the name '*strong gravity*', and later we called the new phenomenon by '*dynamic gravity*'.

Features of the Explored Dynamic Gravity

- The dynamic gravity effect occurs only between moving masses.
- The strong dynamic gravity effect appears when the source mass starts to move or stops.
- In contrast to the Newtonian (static) gravity approach, there is no static pendulum deflection. The pendulum deflection suddenly rises up only for a short duration, but with a remarkable magnitude.
- The dynamic gravity effect appears either in attractive or in repulsive forms. The repulsive force occurs in the case when the source is mass moving in the direction of the pendulum mass. Otherwise, an attractive force occurs.
- The dynamic gravity is significantly stronger comparing to the Newtonian (static) gravity.

Investigation of the Dynamic Gravity

The dynamic gravity effect appears only between moving masses. From the observed features of the new gravitational effect one can conclude that this new gravity effect may be due to the *extra acceleration* of the interactive masses causing by the *outer forces*. That is why, with its *quasi-static feature,* the traditional gravity measuring method with torsion balance *was not capable* to explore this new type of gravity.

The physical pendulum adjusted to its most reachable time period is a 'perpetual-motion machine' in consequence of the environment's noises. The highest components of these noises are reducible with appropriate dampers; we have applied the simple hydraulic damper. The successful measure of dynamic gravity requires a permanent motion of the source mass. It is clear that the source mass motion must be periodic in time.

3. The Quasi-Resonance Measure

For the purpose of detailed investigation of the dynamic gravity we have realized a quasi-resonance measure using the relatively big physical pendulum introduced above. The experimental setup of our measure is shown in Fig. 2:

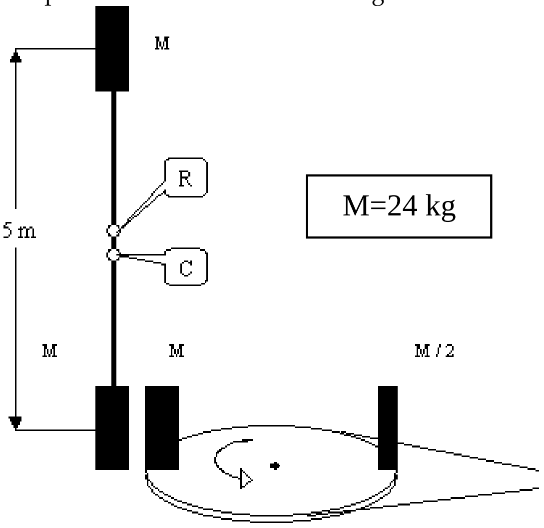


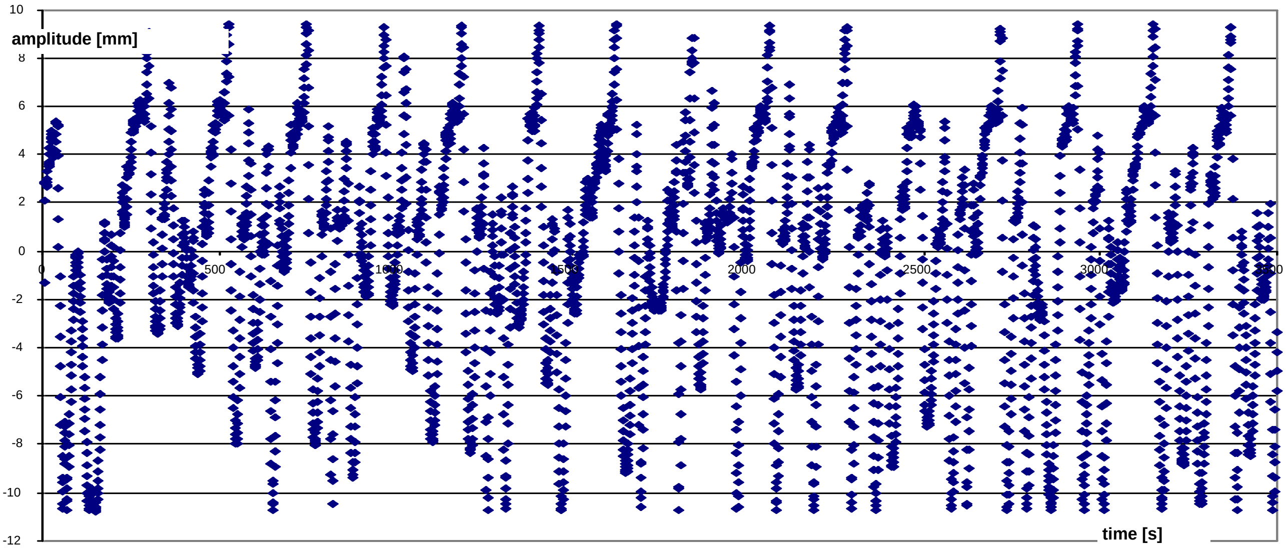
Figure 2. Setup for a resonance measurement of the dynamic gravity (R = pivot of pendulum; C = mass center of pendulum).

As is shown in Fig. 2, the current gravity measurement uses two source masses. The reliability of the gravitational experiment grows substantially with the simultaneous measuring of two masses. The additional advantage of this two source-mass method is better balancing of the roundtable. But if we measure the two masses separately in time, time-dependent drift errors might occur, for example from the motion of the Moon, or from the changes of the pendulum temperature. Nevertheless, it would have been better solution to operate a special air-conditioning system without any air draft in the laboratory.

Fig. 2 shows two moving source masses (M = 24 kg, M/2 = 12 kg,) placed diametrically on a rotating table driven by a small electro-motor through a narrow rubber belt. The rubber belt reduces the vibration noise of the motor-driver. The turntable is made of hard wood in our particular case, but generally any non-magnetic material could be used for this purpose. The turntable and its driver system are placed on the floor, while the hanging of the pendulum is fixed to the ceiling of the laboratory. This solution gives a good isolation against the coupled vibrations of the whole instrument. The fixation of the parts of the measuring system is realized with flexible materials (rubber and plastic spacers). The preliminary control tests proved that there was no measurable mechanical coupling between the turntable and the pendulum. It has also been shown that the automatic system for moving the source mass did not significantly affect the pendulum movement. The radius of the turntable is 0.5 meter; the minimum distance between the source masses and the pendulum lower mass is about 0.2 meter.

In the usual resonance method for gravity measurement, the pendulum frequency is adjusted to the frequency of the periodically rotating source mass. In the beginning of the test period, we tried this normal measuring procedure, but we were not able to reach the desired resonance. Fortunately, in time we succeeded in discovering the reason for this fault. The relatively quick-rotating source masses cause strong *amplitude modulation* to the pendulum movement, and simultaneously a *strong frequency modulation*. From our experience, we have learned that in the case of a relatively long-period pendulum, the period strongly depends on the amplitude of the pendulum. In our experiment the amplitude and period are approximately proportional to one another, showing the fact that the kinetic energy of the pendulum is almost constant. This situation occurs when the pendulum period is unusually big.

Because of the pendulum frequency instability, resonance conditions were not fulfilled. The solution was to reduce the turntable rotation frequency until gravitational resonance appeared. Away from resonance, pendulum amplitude is less than 3-5 mm, which we qualified as the basic noise of the pendulum. In our most successful measurements, the period of the pendulum was about 72 sec., and the rotation period of the turntable was slowly reduced, with resonance at period of about 4 x 72 = 288 sec. There the pendulum amplitude increased up to 10 mm. For this reason, our experimental measurement method could more precisely be called 'enforced resonance'. The rotating source masses produce modulation of the pendulum amplitude caused by the new gravitational effect. Graph 1 presents the dynamic gravity measure with resonance method in the case of arrangement of the experiment shown in Fig. 2.



Graph 1. Gravity measurement by quasi-resonance method: physical pendulum amplitude *vs.* time. Total duration of this measurement was 3500s.

4. Theoretical Investigation of Dynamic Gravity

A reliable theoretical analysis of the above-described gravitational experiment was not an easy task. It was only clear that in the experiment a continuous energy transport realized from the source masses into the physical pendulum. The quasi-resonance experiment was conducted at the end of 1999. Many years have been spent without an acceptable theoretical model describing our new 'dynamic' gravity. We have executed many calculations to check different erroneous ideas before reaching a physically comforting result. At last we have found the most simple successful math model for dynamic gravity force:

$$F_B = Ba\,m_1 m_2 / r^2 \quad . \tag{4.1}$$

Here B is the 'dynamic gravity' constant. The letter B was chosen to honor Laszlo Bodonyi, who was first to observe the dynamic gravity. The letter a signifies the acceleration between the gravitationally interactive masses caused by *non-gravitational forces*. If the extraneous forces vanish (*i.e.* in the cases of clean gravitational systems), the original Newtonian gravity law becomes valid:

$$F_N = Ba_0 m_1 m_2 / r^2 = Gm_1 m_2 / r^2 \quad . \tag{4.2}$$

The new, extended gravity law can be written into more general form, regarding to the both attractive and repulsive features of the experienced dynamic gravity:

$$\mathbf{F}_B = B(m_1 m_2 / r^4)(\mathbf{r}\cdot\dot{\mathbf{r}})\mathbf{r} \quad . \tag{4.3}$$

5. Simulation of Quasi-Resonance Experiment

The goal of the computer simulation was to prove the validity of (4.3) force law for the dynamic gravity. We have supposed that the free pendulum movement is nearly *harmonic*, considering the relatively small amplitude of its motion. The magnetic gravity effect acts on the pendulum as an *excitation force*. From the classical theory of the mechanics, the movement of the pendulum is determined mathematically with an inhomogeneous second order differential equation:

$$\ddot{x}(t) + 2\lambda\dot{x}(t) + \omega^2 x(t) = f(t) = F_B(t)/m^* \quad , \tag{5.1}$$

where m^* is the effective inertial mass of the pendulum. The damping factor of the pendulum is signified by λ. The ω is the natural frequency of the physical pendulum, which is approximately $2\pi/288\,\mathrm{s}$. In optimal circumstances, the pendulum has a sharp resonance-curve and the outer excitation force rigorously affects to the pendulum with the same pendulum frequency. In a real situation, these conditions are far from fulfilled. The pendulum behaves as a *broadband radio receiver* in a certain frequency domain. The two lead masses of the turntable radiate with different dynamic gravitational frequencies which both excite the pendulum. From the measured quasi-stationer pendulum movement (Fig. 3.) we can determinate the dominant pendulum frequencies and their intensities with *Fast Fourier Transformation* (FFT).

In a better simulation model we have replaced the simple equation (5.1) with multi-frequency equations:

$$\begin{aligned} &\ddot{x}_s(t) + 2\lambda\dot{x}_s(t) + \omega_s^2 x_s(t) = f(t) \quad , \\ &\text{for } \omega_s = s\omega_0 \quad , \quad \text{with } s = 1,\ 2,\ 3,\ldots \quad , \end{aligned} \tag{5.2}$$

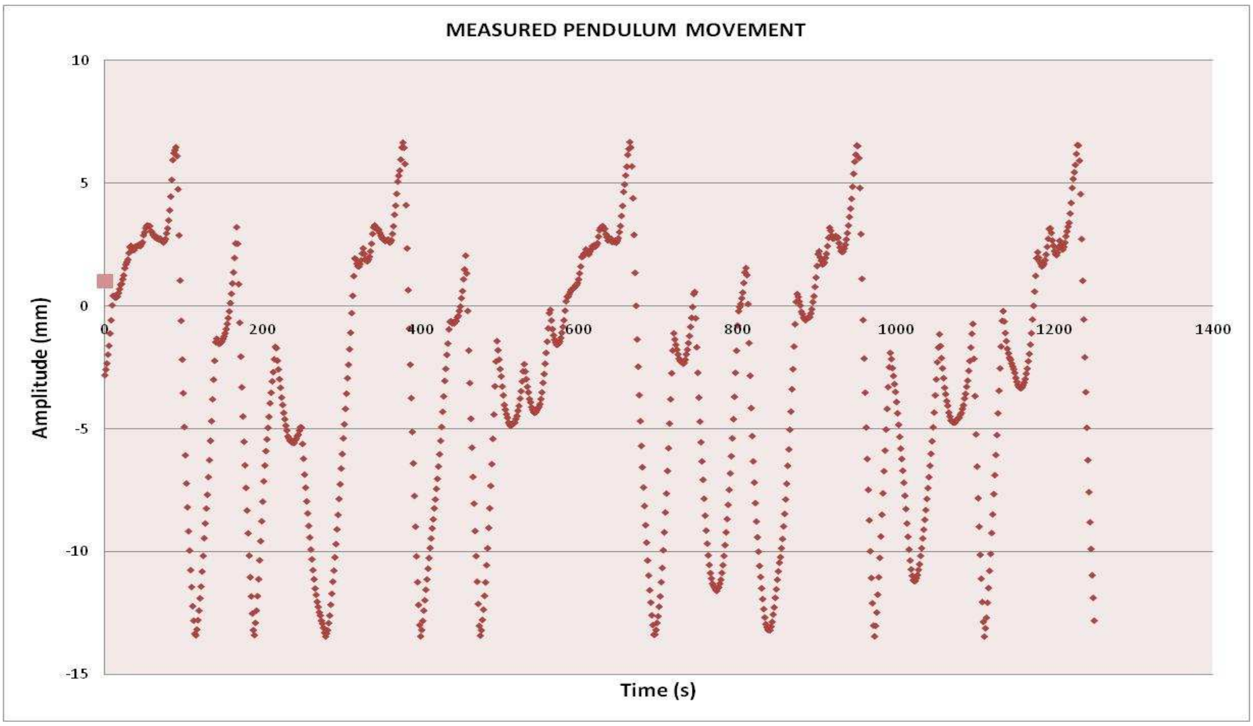
where ω_s are the dominant frequencies obtained from FFT. In the above expression the equations are independently resolvable for all measured frequencies. The observed pendulum movement can be approximated with a linear combination of the (5.2) solutions:

$$x(t) = \sum_s c_s x_s(t) \quad ; \quad \sum_s c_s = 1 \quad . \tag{5.3}$$

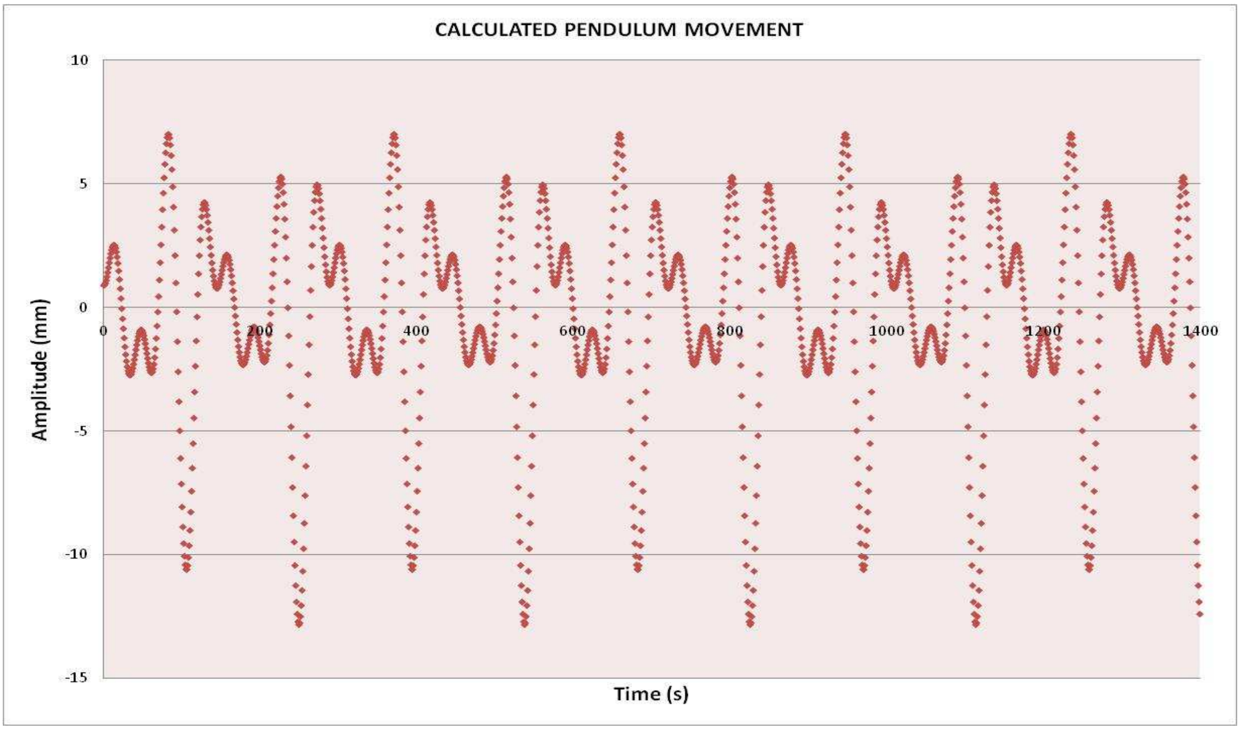
The simulation of the measured pendulum movement with the supposed (4.3) dynamic gravity force law needs the optimal determination of the weight factors c_S. From the math simulation of the quasi-resonance gravity measure based on (5.2) formulae was remarkably successful.

6. Results of Computer Simulation

In the simulation procedure we have investigated a part of the measured pendulum movement from Graph 1. The selection principle of this part was the best periodicity of the measured pendulum movement (Graph 2.):



Graph 2. A part of gravity measure with quasi-resonance method. The physical pendulum amplitude vs. time.



Graph 3. The mathematically simulated part of the gravity measure. The modeled physical pendulum amplitude vs. time.

The modeled pendulum movement based on the supposed force expression of the dynamic gravity (4.3) is given in the Graph 3. From the fitting procedure of the simulated pendulum movement we have found the important parameters featured in the dynamic gravity:

$$B \cong 6.7\ldots\times10^{-4}\ \mathrm{m}^2/\mathrm{kg}\ ;\ \lambda \cong 1/300\ \mathrm{s}\quad . \qquad (6.1)$$

Unfortunately, these two parameters depend on each other. The independent measure of the damping factor would give not a correct value because it depends on the pendulum amplitude.

Here are the main excitation frequencies and intensities representing of our quasi-resonance experiment (Table 1.):

Table 1. The dominant frequencies and intensities in the pendulum movement (simulation)

T(excitation)		Intensity c_s	c_{s+1}/c_s	
$T_4 = 72$ s	$\omega_4 = 4\omega_0$	0.143	1	$1/300\ \mathrm{s}^{-1}$
$T_6 = 48$ s	$\omega_6 = 6\omega_0$	0.286	2	$1/300\ \mathrm{s}^{-1}$
$T_8 = 36$ s	$\omega_8 = 8\omega_0$	0.572	4	$1/300\ \mathrm{s}^{-1}$

Despite all efforts, the experimental pendulum movement remained highly disturbed. That is why there was no sense to take into consideration in the model the highest frequency components.

7. Remarks and Conclusion

Our last quasi-resonance gravity experiment was conducted in 1999. In the absence of technical and financial backing, we could not continue the investigations related to 'dynamic gravity'. In the past years the most important goal was to find the correct theoretical interpretation of our main experiment described in this paper. As was mentioned earlier, numerous physical models were developed without a deep conviction about them. Our experiment was reported in a number of professional journals abroad and also at home, in Hungary. The most common feedback was that we have measured not the gravity but some other side effects (mainly unexplored vibration effects). Nevertheless, we have conducted some control experiment for the reliable exclusion of any side effects. Extreme attention was devoted for the exclusion of electrostatic disturbs with appropriate electrical grounding of the whole instrument. Unfortunately, working from different theoretical aspects, the physics community considers the results of our experiment to be not believable. So up to this time, nobody has tried to repeat this simple gravitational experiment.

First we have tried to interpret our experiment as a consequence of Newtonian gravity, and then as a *special gravitomagnetic effect*. Finally, the demonstrated very strong gravity constant B foiled these ideas. It seems not a good idea for the physical science community to accept a new hypothesis that the gravity has really two forms (weak and strong).

We hope that our final correct statement is that the dynamic gravity is a special behavior of Newtonian gravity. The Newtonian gravity law is valid (by everyday experience) for the closed gravitational systems, when the energy of system is constant and the systems are in an *equilibrium state* in certain sense. This equilibrium state is achieved after a certain time, and we can experience it, for example, especially in the *Cavendish torsion balance* experiment (having very slow movement of the torsion pendulum). There is a remarkable analog in the fact that the nucleons within the nuclei are loosely bound (a closed system, equilibrium state) in contrast to the *strong nuclear reactions*, where the energy of interactive nuclei are not constant.

In our quasi-resonance experiment a continuous energy exchange is realized between the interactive masses. In our relatively long-term experiment our measuring system could not reach the gravitational equilibrium because of the permanent exiting of the physical pendulum. The total energy of this gravitational system periodically changes. We supposed that this is the objective reason of our newly experienced gravitational phenomenon. The exact condition of this dynamic gravity effect is an outer, strong time-dependent force (from a motor-driven turntable) holding far the pendulum from the gravitational equilibrium. The planets of our Solar System constantly interact with each other, but the origin of these forces is only those gravity that caused by themselves. The Sun System is very like in gravitational equilibrium state: the *Kepler laws* are fulfilled for all of them determining their distances from the Sun and orbital periods. In addition, the *Titius-Bode rule* probably also shows a special unknown type of the equilibrium state of the whole system. If an outside force (for example a collision with a big asteroid) would act on any of them, probably a significantly stronger effect (dynamic gravity effect) would appear in our Solar System. Fortunately, we have no such experience of cosmic-scale dynamic gravity catastrophe, but our experiment could give important information about this extraordinary event in a small laboratory.

Acknowledgment

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