SULTAN IDRIS EDUCATION UNIVERSITY

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Team

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Project

Space Mass Balance

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Our video montage describing our participation in this program can be viewed here →

http://www.youtube.com/watch?v=zT-TCbI1ong

CONTENT

PART 1

EXPERIMENTAL REPORT

Motivation

Mass measurement is importance in scientific investigation. Common mass balance is useless in space since it exploits gravitational force to balance the mass being put on it. Therefore, we propose a simple space mass balance which is not only useful in the space, but the operation is independent of gravitational field. The mass balance employs two fixed-end springs being attached to the desired object being measured. The object is set into oscillation and its oscillation frequency reveals the mass value of the object. The oscillation frequency is detected by mean of the electromagnetic induction from a coil surrounding the oscillation path of the object. The relation between oscillation frequency and amplitude of the load and the mass of the load using the proposed mass balance is measured in hypergravity, normal gravity and microgravity conditions through parabolic flight. In this report, we describe two aspect of measurement

(i) *Observation on the oscillation frequency : Simple Design Of A Gravity-Independent Mass Balance*

In this section we describe the construction of our simple space mass balance. We found that the frequency oscillation is independent of gravitational conditions.

(ii) *Observation on the oscillation amplitude: Mechanical Efficiency Of A Mass-Spring System In Hypergravity, Normal Gravity And Microgravity*

In this section we observed the decay of oscillation amplitude for a given load is higher at higher gravitational condition. The effect can be related to the mechanical efficiency of simple machine where energy loss is larger in higher gravitational conditions.

(i) Observation on the oscillation frequency : Simple Design Of A Gravity-Independent Mass Balance

Abstract *The common mass balance has limited use in any gravitational condition. In this paper, we describe the simple design of a mass balance which is independent to the gravitational condition. Based on the Hooke's Law, the balance is constructed by attaching the object being measured in the middle of two-fixed end springs. The mass of the object is deducted from the frequency of the mechanical oscillation of the object. The performance of mass balance has been tested using seven different mass loads (ranging from 15.28 g to 27.50 g) in three different gravitational conditions (0G, 1G and 2G) during parabolic flight. Our field testing resulted in the independency of the oscillation frequency of the mass on the gravitational conditions.*

Introduction

On the earth, mass of an object is measured using a balance based on the Hooke's Law where the compression of an active element in the balance is directly related to the gravitational force acting on the object. However, recalibration of the balance is required when the gravitational value at the measurement position changes. In the space, where the gravity is approaching to zero, the balance becomes useless as no compression is detectable by the active element. Therefore, many methods have been proposed for mass measurement in the space where gravity is negligibly small. In general, mass measurement in weightless conditions can be categorized based on three measument of the following physical quantities: (i) natural frequency of mass vibration, (ii) centrifugal force, and (iii) impulse [1, 2]. The propose devices are usually very complicated and based on optical interferometry detection to sense the object motion. We try to simplify the mass balance by proposing the use of a conducting coil by which an oscillating mass though the coils induces an electromagnetic force (emf) signals indicating the oscillation frequency. Theoretically, the frequency $\boldsymbol{f}$ of the mass, $\boldsymbol{m}$-spring, $\boldsymbol{k}$ system can be generalized in the following expression

$$\boldsymbol{f = k/(4\pi^2 m)}$$

Materials and Methods

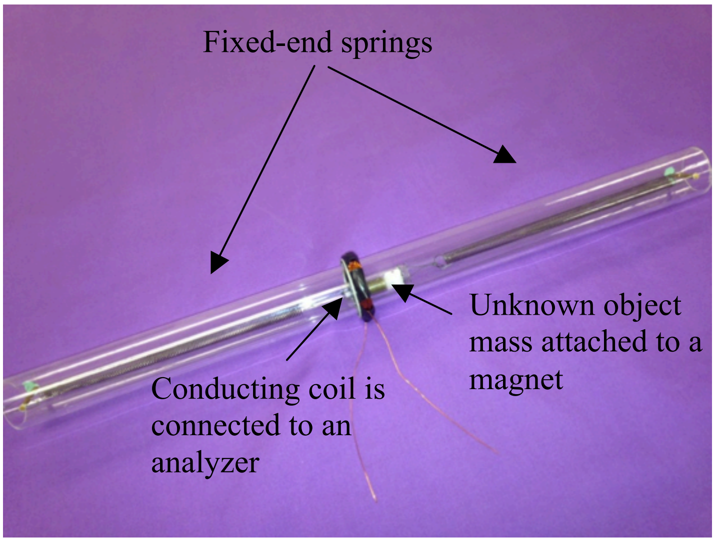


FIGURE 1 Simple mass balance

The simple mass balance that we developed is shown in Fig. 1 and its dimension is shown in Fg. 2. We prepared two set of four loads, each set for each parabolic flight. The masses in (as measured on the ground with A&D GF-300) set 1 are 9.77 g, 15.78 g, 18.92 g and 21.97 g and set 2 9.77 g, 12.358 g, 13.688 g and 15.048 g. The same load of 9.77 g are used in both set functioned as the measurement reference. The load is attached to two springs by using load cell. The load cell is made of strings, Perspex tube and magnet bar. The definition of the load is an object inserted into load cell. Loads are made from copper cylinder for set A and from bearing balls for set B. The loads mass are the number of parabolic flight cycle is tabulated in Table 1.

Table 1 Values of load mass and the cycle which the measurement in done.

Load Number	**1**	**2**	**3**	**4**
First day, Dec 26th Set A (g)	9.77	15.78	18.92	21.97
Cycle Number	1st , 2nd , 5th , 6th ,9th		3rd , 4th , 8th	
Second day, Dec 27th Set B (g)	9.77	12.36	13.69	15.05
Cycle Number	1st , 2nd , 5th ,7th ,9th, 12th		3rd , 4th , 6th ,8th ,10th, 11th	

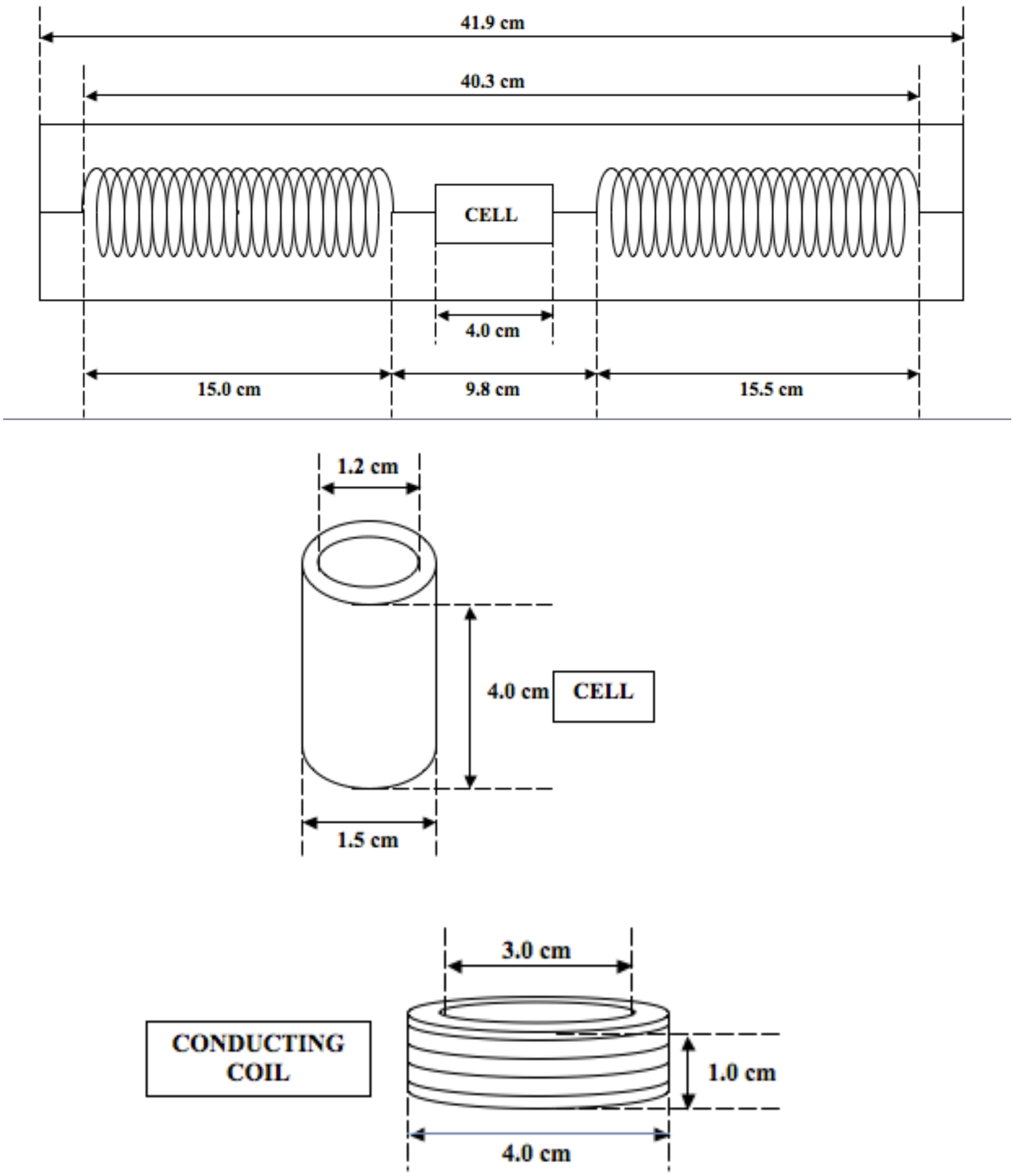


FIGURE 2 Drawing of the mass balance.

The other free ends of the springs as attached to fixed terminal. The identical springs have a spring constant of 6.912 N/m with unstreched length of 4.8 cm. The spring-load-spring combination system is stretched in 39 cm length. A 100-turns coil surrounds the load for the detection of induced emf. All experiment is fit into 60 cm x 50 cm x 50 cm aluminum cage. The experiment is done through parabolic flight which has been described elsewhere [1]. Two parabolic flights are performed for the purpose of this experiment where various gravitational conditions were established in cycle base, December 26th and 27th 2012. During each cycle of the gravitational change, the load is set into free oscillation motion by manually displacing the load. No measurement was made in 7^{th} cycle of the first day because our parabonaut has missed the cycle due to technical problem (her pen dropped at that time). Figure 1 shows our experimental cage which is fixed into the flight cabin.

The emf signal is recorder by data logger (GLXplorer Pasco). During the parabolic flight, the load is set into motion by displacing manually by pulling fishing string by about 3 cm.

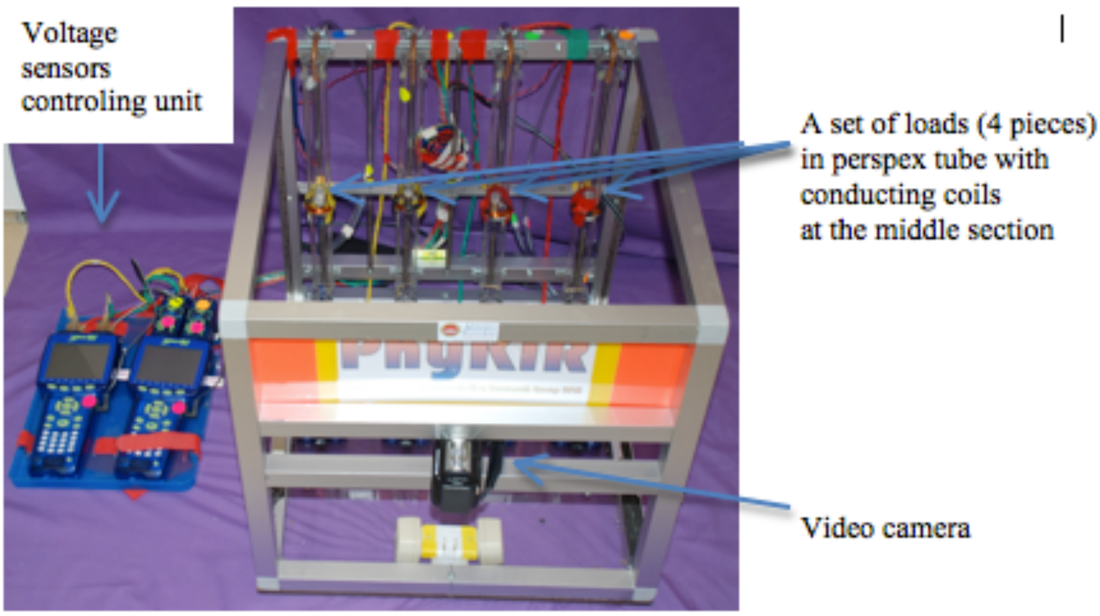


Figure 3 Experimental arrangement

Understanding signal

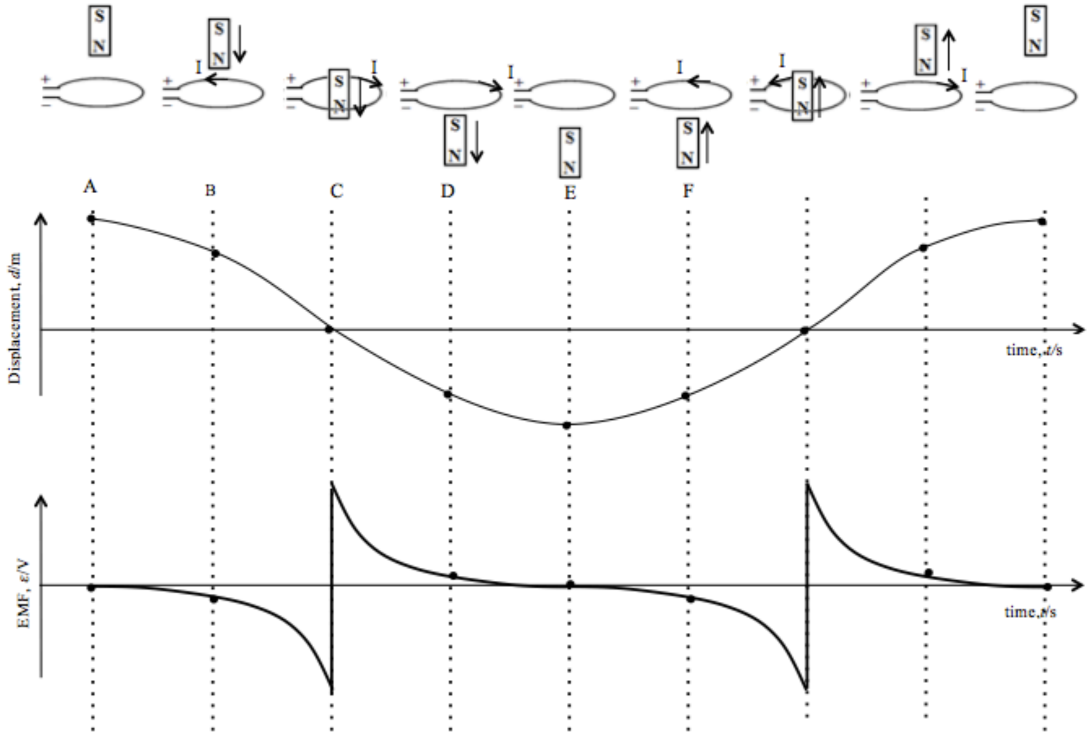


FIGURE 4 Corresponding induced emf and load motion in 1 G.

Faraday's Law describes the relation between the induced emf (ε) and the rate change of magnetic flux (Φ) as follows:

$$\boldsymbol{\varepsilon} \propto -\frac{d\boldsymbol{\Phi}}{dt}$$

Negative sign is described using Lenz's Law.

The magnetic flux is defines as

$$\boldsymbol{\Phi} = \boldsymbol{BA}$$

Since the coils area is fixed, the only changing parameter is the magnetic field strength at the coils plane.

$$\boldsymbol{\varepsilon} \propto -\boldsymbol{A}\frac{d\boldsymbol{B}}{dt}$$

A voltage probe is connected at the correct terminal shown (+) and (-) at the end of coils.

The motion of the load is illustrated by the upper graph.

The induced emf due to the load motion is illustrated by the lower graph.

At point **A**, the load is instantaneously stopped. The rate change of magnetic field is zero. Therefore, the induced emf is also zero.

At point **B**, north pole is speeding toward the coils. The rate change of magnetic filed is increasing. Therefore the induced emf is also increasing. By Lenz Law, the induced emf in the coils must have the magnetic flux which against the increasing flux from the load. Therefore, the induced emf is increasing in the negative value.

At point **C**, the polarity of the magnetic flux abruptly change because the north magnetic pole of the bar magnet left the coil. The sign of the emf flipped to +ve value.

At point **D**, the south pole is slowing down away from the coils. The rate change of the magnetic field is decreasing. Therfore the induced emf is also decreasing. By Lenz Law, the induced emf is decreasing in the positive value.

At point **E**, the load is instantaneously stopped before changing its motion toward the coils. The rate change of magnetic field is zero. Therefore, the induced emf is also zero.

At point **F**, the load continues to move at increasing velocity toward the coils. The rate change of magnetic field is increasing. Since the south pole is approaching, the induced emf have the magnetic field that against the south pole and have the negative values.

From the explanation, the induced emf is zero twice in one complete load oscillation. Therefore, the oscillation period is calculated from first to third periodic points (for example the first positive peak to the third positive peak or first minima to third minima)

Two considerations are made to make sure the induced emf detectable are

1) strong magnetic bar

- the magnet bar with the strength of more than 0.2 T.

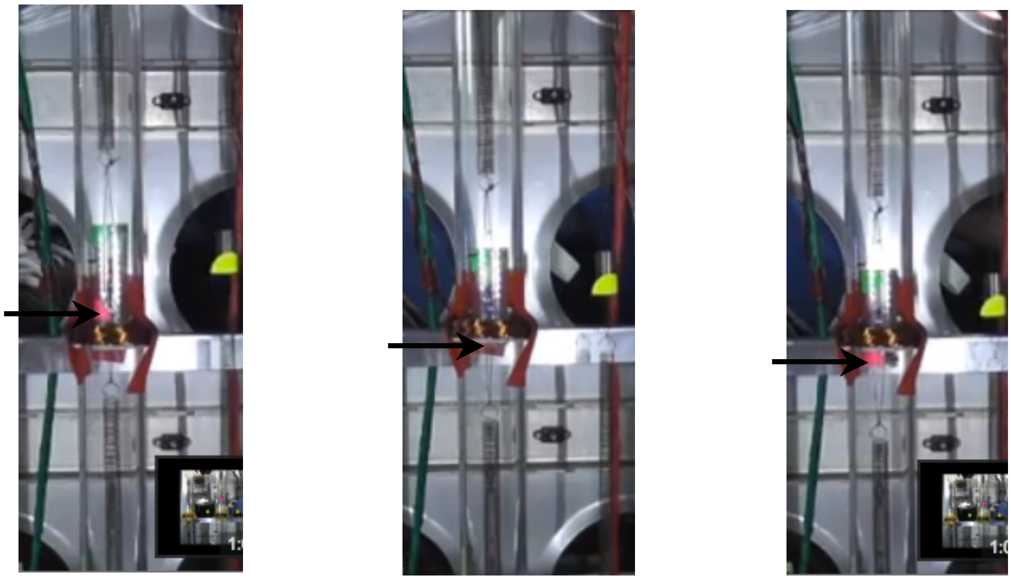
2) coils turn

   - 100 turns of coils with the diameter 3.0 cm was used

3) low resistance coils

   - we measured the resistance of the coils of 100 turns to be 0.2 Ω.

The above explanation is true at 1G where the magnet bar is fixed at the coils plane. At 2G, the magnet bar shifted downward. Therefore the equilibrium point shifted accordingly as shown in Fig. 5 below. At 0G, the magnet bar shifted upward. Therefore the equilibrium point shifted upward. Consequently, the pattern of the induced emf signal was a little bit change.



(a) 0G (b) 1G (c) 2G

Figure 5 The equilibrium position of a mass load in (a) 0G, (b) 1G and (c) 2G. The bottom of load is marked with pink label. Another cylindrical load is located at the right to the system is marked with yellow label for reference.

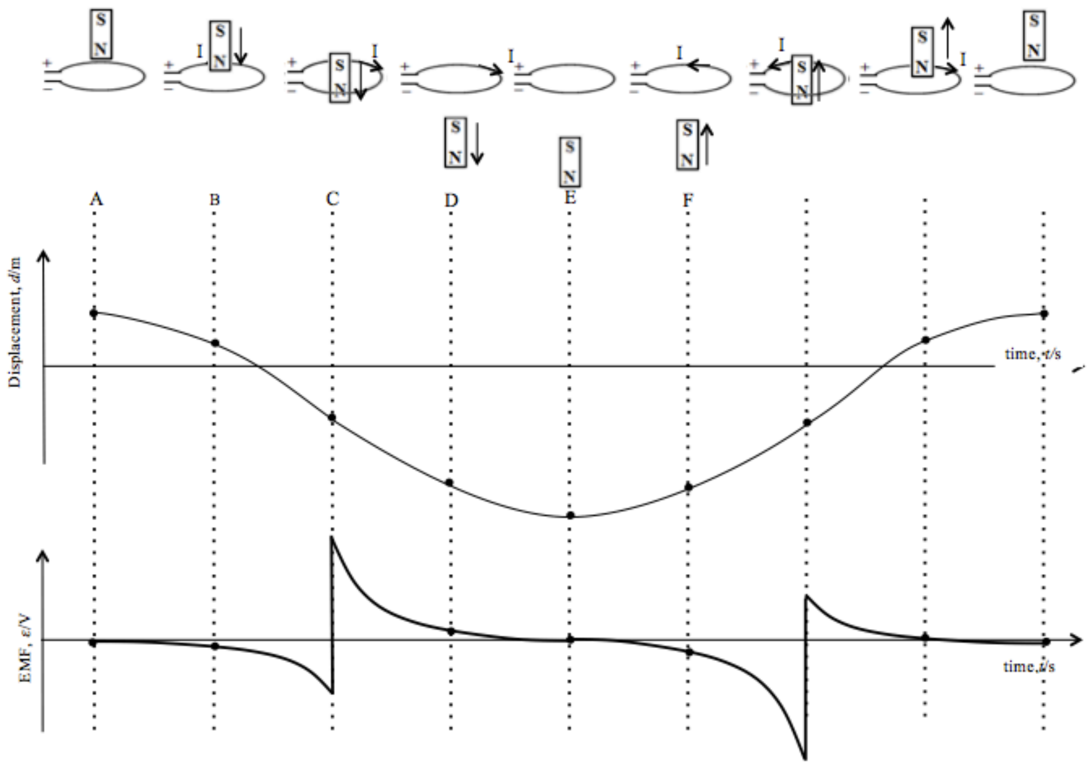


FIGURE 6 Corresponding induced emf and load motion in 2 G.

The induced emf in 2G can be understood with the help of Fig. 6. The equilibrium point is now shifted below the coils plane. Therefore, most of the time the magnet bar spends time on the lower part of the coils plane.

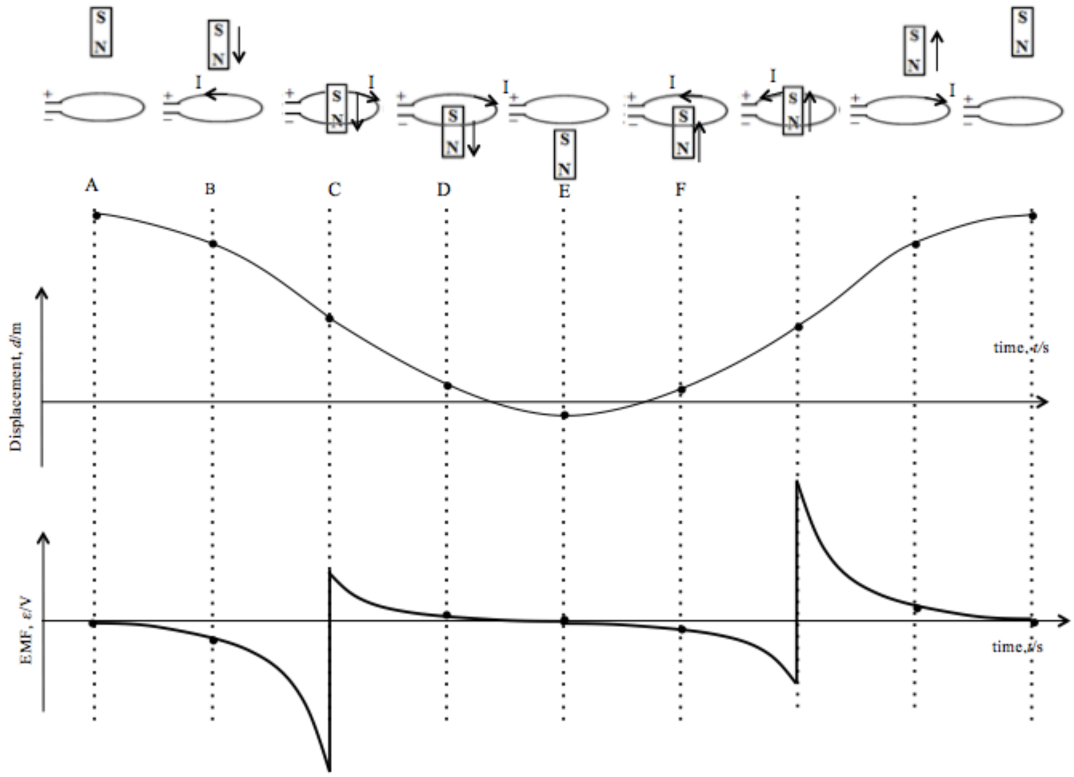


FIGURE 8 Corresponding induced emf and load motion in 0 G.

The induced emf in 0G can be understood with the help of Fig. 8. The equilibrium point is now shifted above the coils plane. Therefore, most of the time the magnet bar spends time on the upper part of the coils plane.

Result and Discussions

9 and 12 cycles of measurements were successfully done in the first and second day of the parabolic flight. **Fig.9 (a)** shows the example of signal obtained from the measurement of the induced emf from one of the load in one cycle. The first group and the second group of the signal correspond to the load oscillation in hypergravity and microgravity respectively. Both signal decays (in amplitude) due to what we believe coming from the spring internal friction and the friction of thread we used to set up the load motion. However, we can observe that the signal in hypergravity decays faster (about 10 second) compared to the signal in microgravity (more than 12 s). The same behaviour is observed for all loads. This would be an interesting effect which can be put into practical application for example in the development of long lasting simple electrical power generator in the space. The close up of the signal is shown in **Fig. 9(b).** The explanation why the signal has the distinct shape is described elsewhere for the magnet passing through a conducting coil and as explained in the previous subsection [3]. The frequency is calculated, for example from first-to-third peaks where one complete oscillation is achieved. For a given load, the frequency of oscillation is calculated by finding the oscillation period which is by measuring the time taken for the first 10 complete oscillations after being released, T_{10}. Therefore the frequency of oscillation is

$$f = \frac{10}{T_{10}}$$

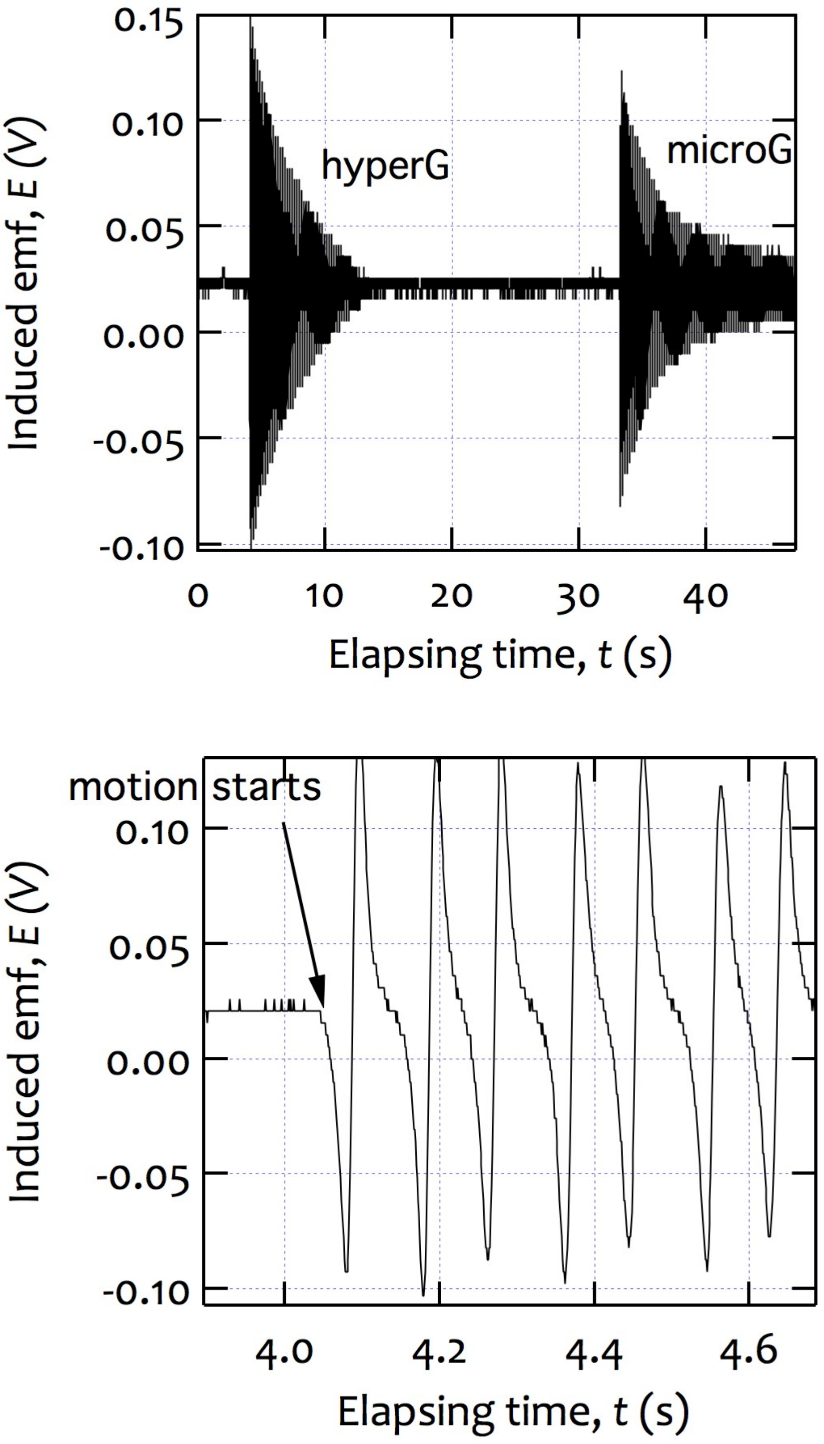


Figure 9 (a) The emf signal from load 9.77 g in the first cycle of the first day parabolic flight. (b) Signal close up obtained in the elapsing time range of 3.8 s to 4.7 s of (a).

Table 2 Frequency dependent load at 0G, 1G and 2G

	0G			1G			2G		
	Frequency (Hz)	STD (Hz)	STD (%)	Frequency (Hz)	STD (Hz)	STD (%)	Frequency (Hz)	STD (Hz)	STD (%)
A1	5.467	0.005	0.090	5.466	0.021	0.386	5.471	0.014	0.255
A2	4.430	0.005	0.105	4.429	0.006	0.130	4.437	0.008	0.182
A3	4.069	0.003	0.062	4.052	0.007	0.162	4.083	0.030	0.746
A4	3.798	0.007	0.175	3.792	0.004	0.100	3.819	0.019	0.488
B1	5.476	0.006	0.103	5.491	0.000	0.000	5.506	0.033	0.593
B2	4.892	0.011	0.220	4.877	0.005	0.103	4.894	0.017	0.347
B3	4.639	0.010	0.226	4.622	0.008	0.163	4.641	0.019	0.407
B4	4.497	0.052	1.155	4.474	0.000	0.000	4.503	0.047	1.043

Table 2 shows the average oscillation frequency at 0G, 1G and 2G for both set A and set B loads. The percentage of standard deviation for all values are less than 1.5%. A1 and B1 gives very close reading thus confirmed the similar experimental conditions for both the first and second day of parabolic flight. These values are plotted in Fig. 10.

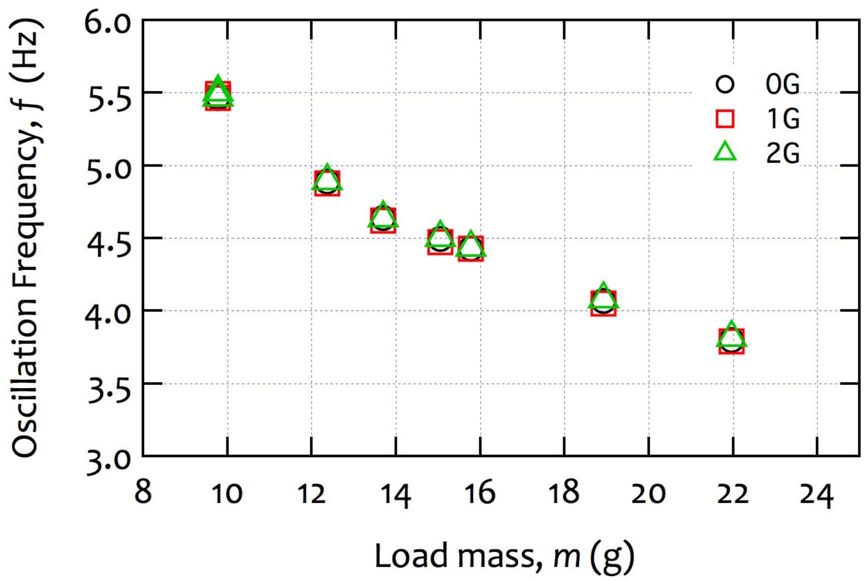


Figure 10 The oscillation frequency versus the load mass in three gravitational conditions: hypergravity, normal gravity and microgravity.

Figure 10 shows the relation between the measured oscillation frequency and the load mass in three onboard gravitational conditions; hypergravity, normal gravity (onboard) and microgravity. For a given load mass, there is **no frequency different observed** between the oscillation in the all three gravitational conditions within the experimental errors and the assumption that all four devices are identical. To the best of our knowledge, this is the first direct experimental evidence of the independency of mass-spring system on gravity.

Conclusion

We proposed a simple mass balance to measure the mass in various gravitational conditions. We found that oscillation frequency of a load is inversely proportional to the mass of an object. Within experimental setting and errors, the method is proved to be independent of gravitational field and therefore has proven experimentally that **gravity does not affect the oscillation frequency** of a mass-spring system.

(i) Observation on the oscillation amplitude: Mechanical Efficiency Of A Mass-Spring System In Hypergravity, Normal Gravity And Microgravity

Abstract. *The operation of a mechanical machine may behave differently in various gravitational conditions. We compare the mechanical efficiency of a mass-spring system in three different gravitational conditions, namely hypergravity (2G), normal gravity (1G) and microgravity (0G) through parabolic flight. The simple system consisted of a mass load (18.92 g and 21.97 g) attached between two springs 6.91 N/m which make overall length 410 mm. The mechanical efficiency is justified by the decay of the oscillation amplitude of the attached load. Our result shows that the mechanical efficiency for the simple mass-spring system is better in lower gravitational condition.*

Introduction

Gravity dominates our daily life routine to the way matter interacts on earth. Interesting phenomena is observable if gravity influence is much reduced for example the lost of fish swimming ability and the water motion under capillary action [1,2]. In this paper, we examine the oscillation of a mass spring system in various gravitational strength, namely hypergravity (2G), normal gravity (1G) and microgravity (0). Hypergravity is the gravitational condition where gravity is twice than on earth and microgravity is the gravitational condition is where gravity is reduced to 1/100000 than the earth gravity.

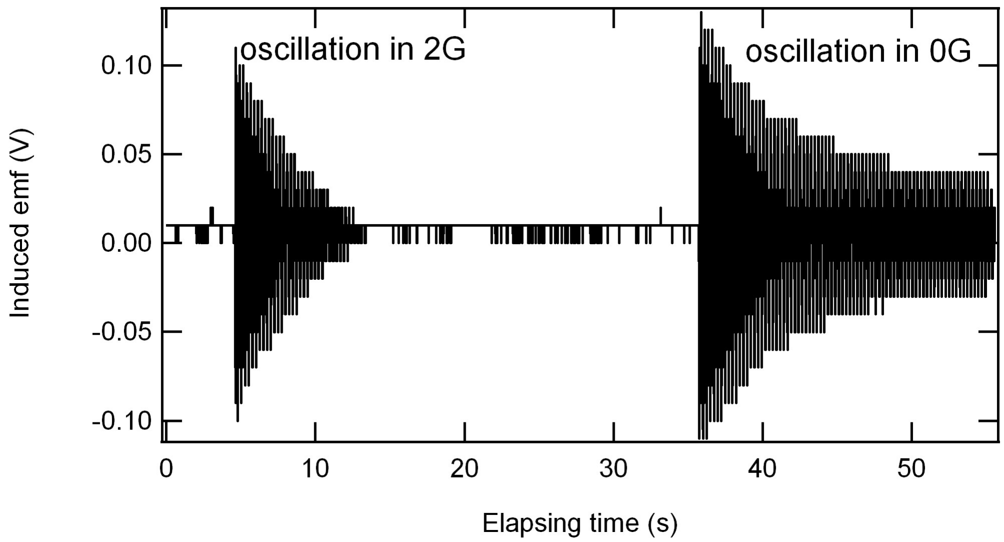
Mechanical machines or vehicles consist of at least several oscillation systems which are based on the mass-spring model. Understanding fundamental behavior of the model is crucial for future development in space exploration. Most systems perform harmonic oscillation when being disturbed from static equilibrium position for example, a mass suspended on a spring. If it is displaced and released, the mass will oscillate back-and-forth. In ideal case, the system oscillates forever. However, many factors may lead to energy dissipation in the system and decrease the mechanical efficiency of the system. We report the effect of the gravitational field strength on the mechanical efficiency of mass-spring system.

Materials and Methods

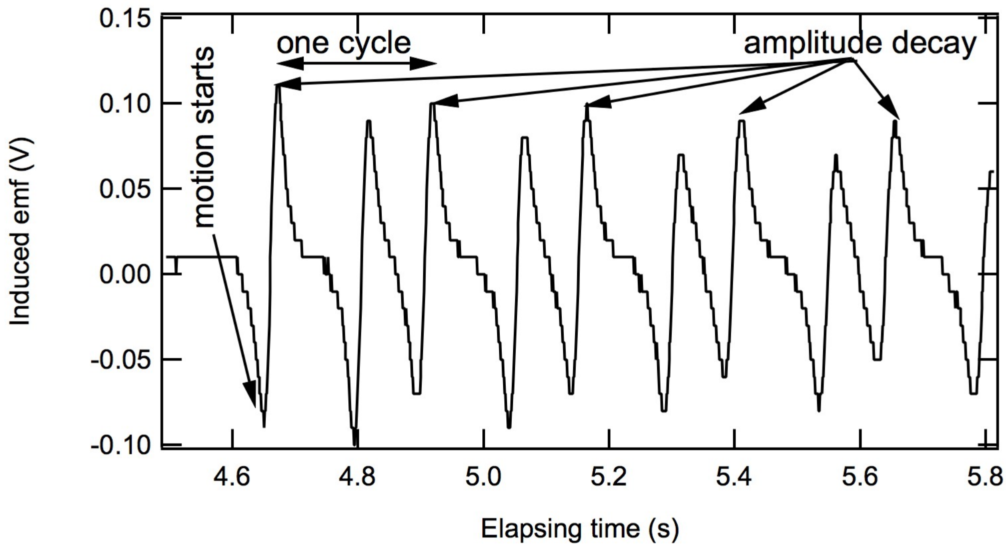
In order to conduct this experiment, oscillation of two loads A3=18.92 g, and A4=21.97 g were compared. These loads are selected for discussion here because both of them shows clear distinction eventhough all of load shows similar behavior. All other experimental conditions are explained in the previous sections.

Result and Discussion

Figure 11(a) shows the induced emf form the oscillation of m_1 in 2G and 0G. The close up view of the signal is shown in Fig. 2(b). The asymmetric nature of the emf signal has been explained elsewhere [4]. Qualitatively, the oscillation in 2G decays faster compared to oscillation in 0G. The similar decay behaviour was also observed for m_2.

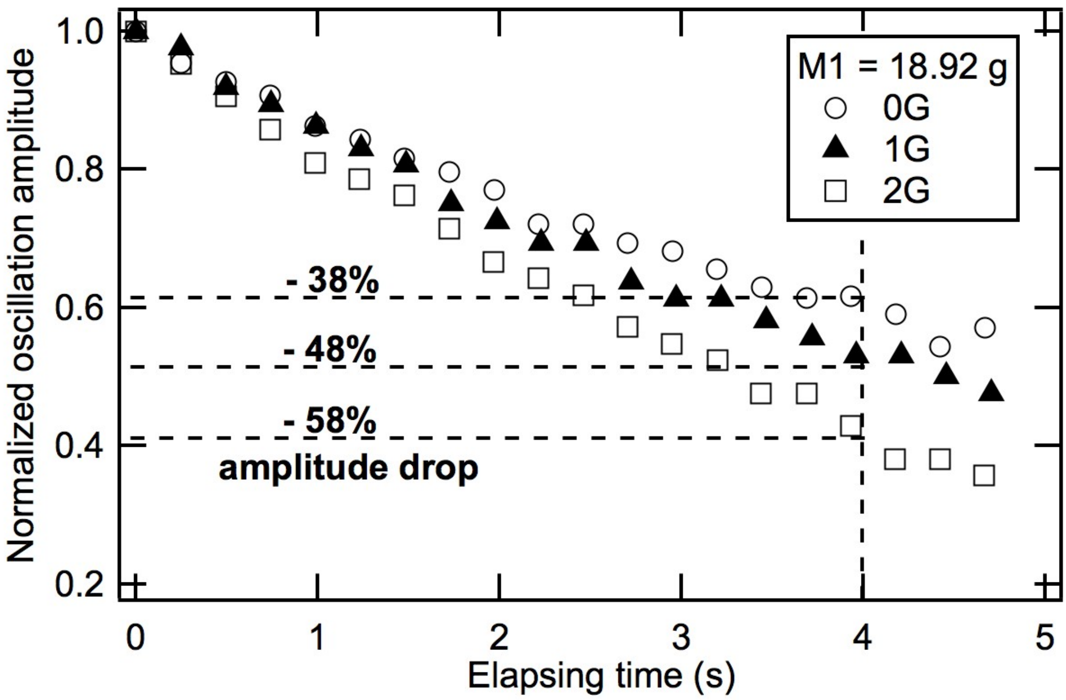


(a)

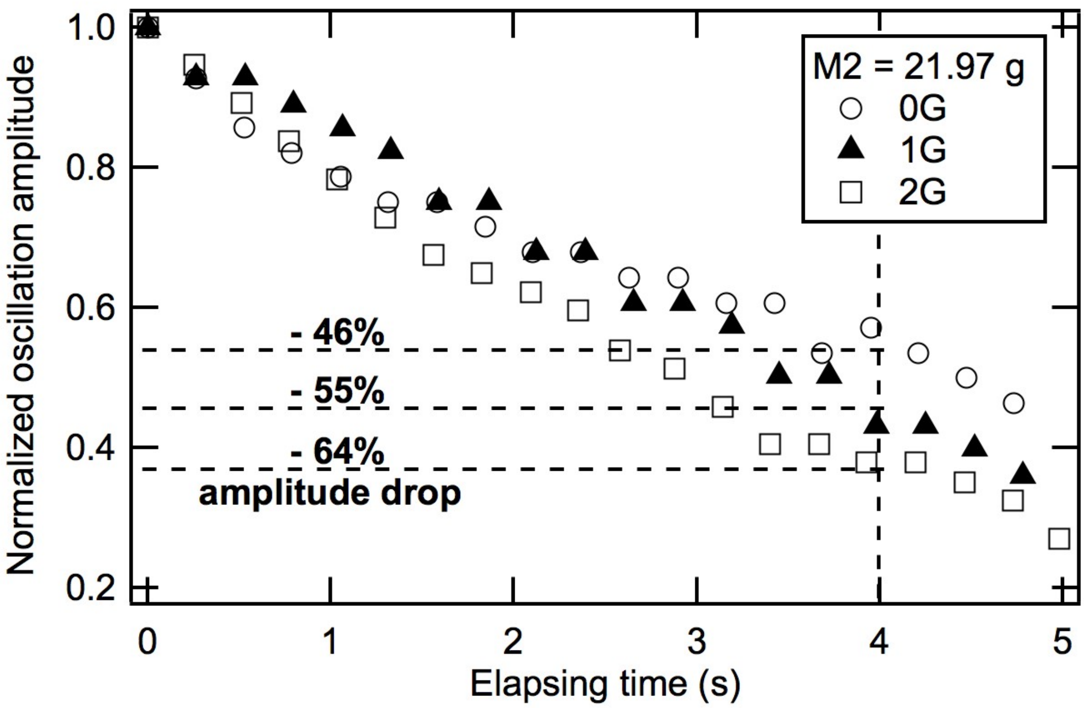


(b)

Figure 11 (a) Induced emf from the oscillation of A3 (a) in 2G and 0G. (b) Close up view of the signal (a) from 4.6 to 5.8 s.



(a)



(b)

Figure 12 The different of decays in hypergravity, normal gravity and microgravity from: (a) A3 and (b) A4.

We plot normalized amplitude of oscillations in 2G, 1G and 0G for m_1 and m_2 as shown in Fig. 12. The normalized amplitude is calculated from the positive peaks at each cycle as indicated in Fig. 11 (b). At time, $t = 0$ s, the first oscillation peak amplitude after load being released is taken as the initial oscillation point with normalized amplitude equal to 1. To simplify the analysis, the mechanical efficiency of the system is justified from the amplitude drop at $t = 0$ s to $t = 4$ s. Dashed straight lines are drawn in the figures as an eye guide.

The distinction between amplitude decay lines in 0G, 1G an 2G becomes clear at longer elapsing time. For m_1, the amplitude drops to 38%, 48% and 58% from its initial amplitude in 0G, 1G and 2G respectively. For m_2, the amplitude drops to 46%, 55% and 64% from its initial amplitude in 0G, 1G and 2G respectively. Therefore, more energy is loss in higher gravitational field thus reducing the mechanical efficiency of this simple system.

In general, energy loss in the mechanical is due to air resistance where energy losses by friction resulted from the relative motion of the load and the surrounding air. However, amplitude drops for m_1 (for instance) should be the same in any gravitational condition if only air resistance exist.

Another possible explanation for these variations in amplitude drop is the shift of equilibrium position of the load. Figure 4 shows the equilibrium position in 0G, 1G and 2G of a load in our experimental rack. At 0G, the load was equally stretched in both springs since no other gravitational pull is dominant on the load. While at 1G, gravitational pull acted on the load thus give weight in downward direction. Therefore, its equilibrium point shifted to the lower position. Consequently, the upper spring stretched longer and the stretched length of the lower spring shortened. When the load is set into motion, its oscillation is about this new equilibrium point. The unevenness in upper and lower stretch length of these springs introduces spring internal friction. At 2G, the equilibrium point shifted further downward and unevenness of the stretched length becomes more apparent. This unevenness may cause asymmetry in oscillation cycle and energy dissipation becomes larger [5].

However, further analytical investigation will be carried out to confirm the proposed and other possible factors.

Conclusion

We compare the oscillation of two mass loads (A3= 18.92 g and A4= 21.97 g) attached between two springs 6.91 N/m at fixed length, 410 mm in three (3) gravitational field strengths: hypergravity (2G), normal gravity on earth (1G) and microgravity (0G). We observed the oscillation amplitude decays at different pace in these gravitation conditions, which directly give a measure of its mechanical efficiency. For a given load, the mechanical efficiency decreases in higher gravitational conditions. For any of the three gravitational conditions, mechanical efficiency of m_2 is lower than m_1.

References

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