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Original Article

Reduced Gravity Devices Based on the YOYO Principle

[1]Ryojiro AKIBA, [2]Ikuo EGAMI, [3]Takemasa KOREKI, [4]Osamu FUJITA and [5]Masamichi YAMASHITA

[1]HASTIC/USEF, Sapporo/Tokyo, Japan, akiba@usef.or.jp
[2]HASTIC/Uchusen, Tokyo, Japan, i.egami@uchusen-net.com
[3]HASTIC/IA, Tomioka, Japan, takemasa-koreki@iac.ihi.co.jp
[4]Hokkaido University, Sapporo, Japan, ofujita@eng.hokudai.ac.jp
[5]JAXA, Sagamihara, Japan, yamashita@surc.isas.jaxa.jp

Abstract

The reduced gravity devices were developed based on the yoyo principle. Their performance was examined, and found useful to conduct experiments for scientific and educational purposes. The operation of this yoyo device was improved by governor mechanism attached to the pulley. The governor optimized the profile of momentum of inertia of the pulley assembly. Another option tested was the double-capsule configuration, which enabled to generate microgravity in the inner test section.

Nomenclature:
M : mass of the capsule
v : velocity of the capsule (downward positive)
t : time
F : tension of string that suspends capsule
I : moment of inertia of the pulley with the flywheel
r, θ : polar coordinates of the pulley groove
c : parameter of the logarithmic spiral pulley, Eq. (3)
ω : angular velocity of the pulley with flywheel
K : $=I/M$
C : constant of the energy integral
T : tension of the trampoline string
suffix 0: initial condition

1. Performance of Ez-Space and Educational Experiments on it

The authors developed a reduced gravity device applying the principle of yoyo, a popular toy from old days[1,2]. The original device is indicated in Fig. 1 that was named "Ez-Space". In this system, a capsule of test section is suspended by a string. The other end of this string is connected to the driving mechanism, which provides force for the motion of the capsule. Kinetic energy of the descending capsule is stored in the yoyo pulley of the driving mechanism and released force for ascending motion afterwards. A couple of spiral pulleys generate optimized torque of this yoyo motion, and create reduced gravity in the capsule.

The performance of Ez-Space was tested with an engineering model shown in **Fig.1**

Profile of gravity level in the test section is shown in **Fig. 2**. Partial g environment was repetitively obtained at a constant level during up and down motion of the capsule. The first period of reduced gravity for about a half second corresponds the initial fall from the top position, where the capsule was held. The successive phase with its g level higher than 2.5 g is defined as "repulsive phase". During this period, falling motion of the capsule is decelerated. Kinetic energy of the capsule is stored in the rotational energy of the pulley. Once the capsule reaches to the bottom, it is launched upward by converting the stored energy to the upward

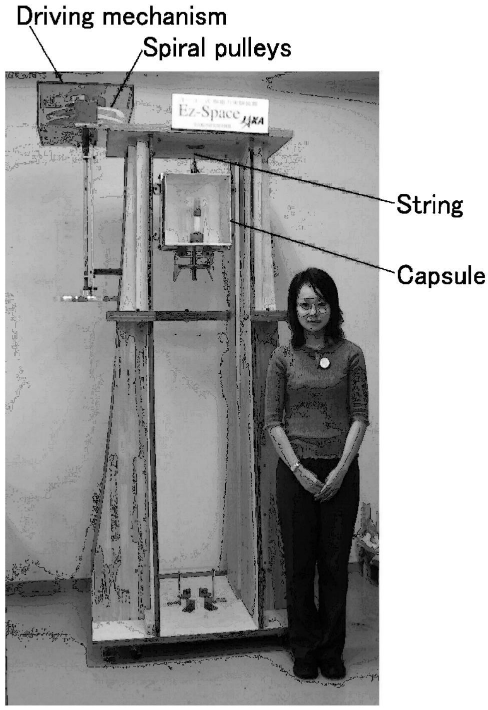


Fig.1 The original model of Ez-Space

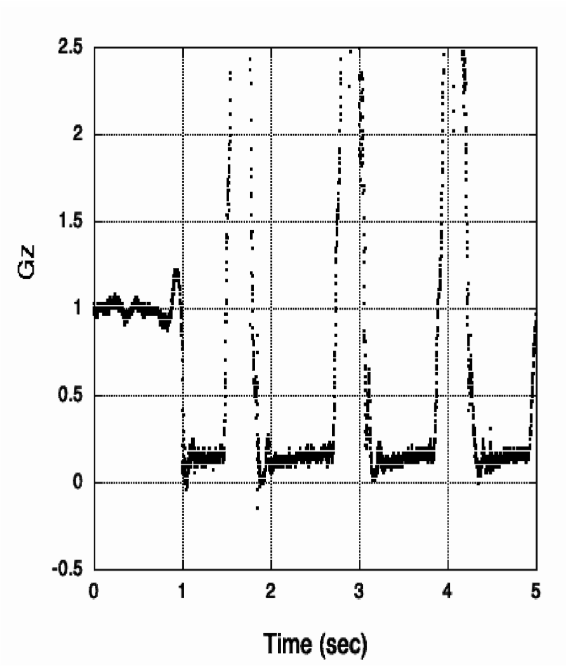
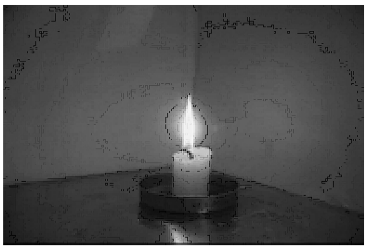


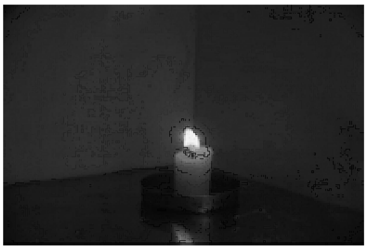
Fig. 2 Time profile of g level in Ez-Space

motion of the capsule. Duration of the second reduced gravity period and followings is almost twice of the first period, because both upward and downward path contribute to the reduced gravity period.

In order to prove usefulness of the device, several experimental set-ups were examined under 0.1 g. Experiment was selected to exhibit phenomena dominated by the action of gravity. A candle flame, shown in **Fig. 3**, was intended to demonstrate how gravity influences its aerial convection under normal 1 g and reduced gravity of 0.1 g.



(1)Under normal 1g



(2)under reduced gravity

Fig.3 Candle flames

Liquid meniscus in a capillary is also a good example to display the action of gravity.

In an experimental set-up, shown in **Fig. 4**, normal capillary effect of liquid (water with red ink) was shown under 1g condition. However, meniscus indicated puzzled behavior under the reduced g environment. It may be caused by a large deformation of free surface after the g transient. Viscosity of the fluid may increase time constant to reach the equilibrated meniscus longer than the duration of the reduced g period, in case the capillary diameter was smaller than 2 mm. The height of meniscus in capillary would be more sensitive against the contamination of the capillary wall under reduced g condition, or certain hysteresis in wetting phenomena might dominate this repetitive movement of the liquid. Carefully designed experiment may confirm which factor leads these unexpected results.

(a) (b)

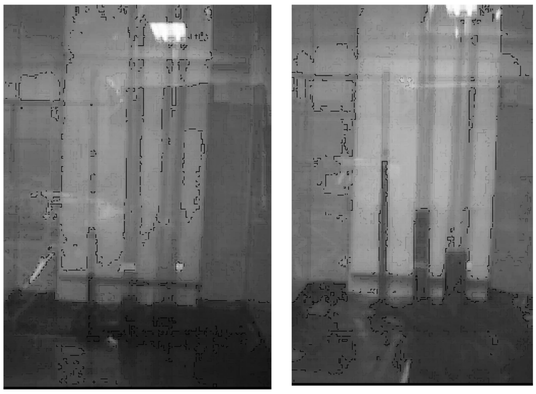


Fig.4 Experimental set-up of capillary phenomena
(a) under 1g (b) under approx.0.2g

Ez-Space is an appropriate device to answer questions such as:

- How is a fried egg cooked on the Moon under 1/6 g?
- Can an hourglass time-keep on Mars under 1/3 g?
- How is a candle flame shaped on the Moon?

2. Improvements of Ez-Space

Design guideline for the spiral pulley is somewhat self-contradictory. In order to realize a lower level of gravity, its moment of inertia should be reduced. On the contrary, it should be large at generating stronger force to pull the capsule up from the bottom. Thereupon, one must design the spiral pulley with a large diameter and a light weight structure to satisfy both above requirements. This design constraints is mitigated by attaching a governor, which provides additional moment of inertia exceptionally during a limited period of the repulsive phase. An example of a practical design of the governor is shown in **Fig.5**.

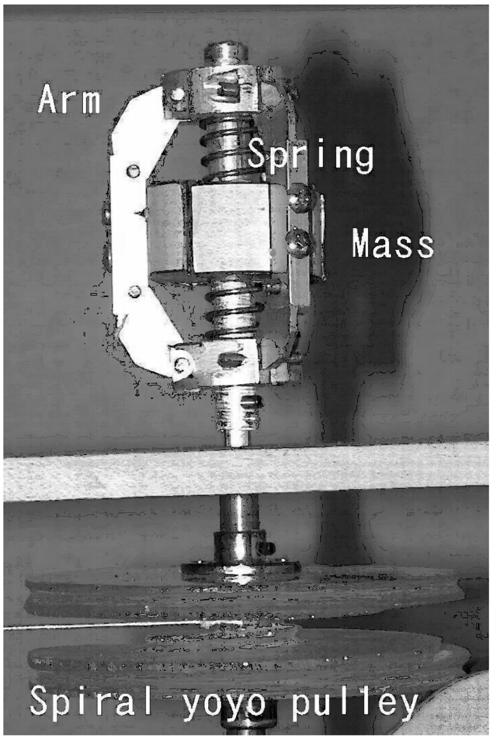


Fig.5 Governor mechanism

In general, such a governor has nonlinear characteristics against the centrifugal force. Fundamental equations of motion are,

$$M\frac{dv}{dt} = Mg - F \qquad (1)$$

for the capsule, and

$$\frac{dI\omega}{dt} = \frac{1}{\sqrt{1+c^2}}Fr \qquad (2)$$

for the spiral pulley and flywheel system including the governor with an assumption of a logarithmic shape for the groove of the pulley,

$$r = r_0 e^{-c\theta} \qquad (3)$$

A mathematical analysis leads the following expression to fill the condition of energy conservation:

$$r^2\omega^2 + \int K^2 d\omega^2 + 2\int K^{2'} \omega^2 d\omega^2 + \frac{2}{c\sqrt{1+c^2}}gr = C \qquad (4)$$

assuming that the moment of inertia of the governor depends solely on ω^2.

Floatation of an inner capsule inside an outer capsule is widely used to improve microgravity in free fall facilities. During the first drop period, the inner capsule is simply released from the top of the outer capsule. Since both rise and drop period after the first drop period in our system are utilized to generate reduced gravity, the inner capsule should be ejected from the bottom to start the reduced gravity. **Figure 6** shows this ejection mechanism designed and tested in this study.

Timing command of the ejection is issued electrically by detecting the end point of the acceleration.

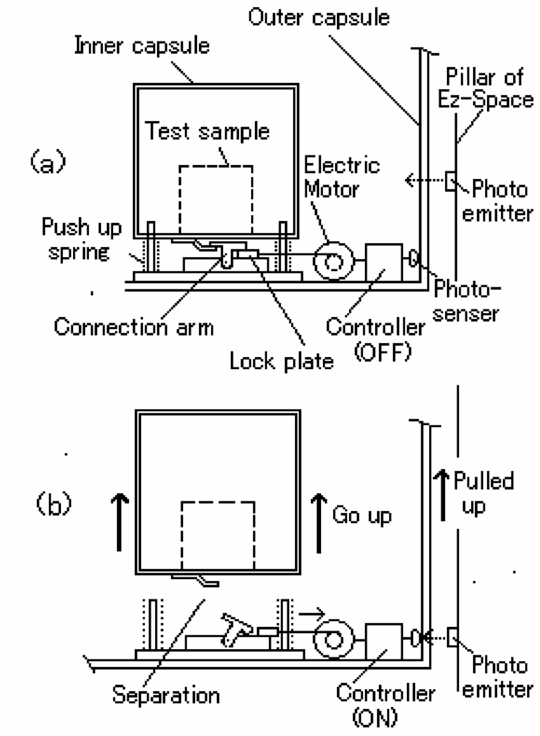


Fig.6 Ejection mechanism of the inner capsule
(a) before ejection (b) after ejection

Further improvement is in progress to control the motion of the yoyo pulley so as to change its rotational speed along the preprogrammed profile.

3. Conclusion

Performance of the original Ez-Space was demonstrated with several results of educational experiments. Prospective improvements have been made on the original Ez-Space to achieve its better performance, such as the wider range of reduced g.

Further improvements were reported in Ref.3.

References

1) Ito,H., Fujita,O., Akiba,R. and Ito,K, Construction Plan of Ground based Microgravity Experiment System and Diffusion Flame Synthesis of Carbon Nanotubes under Microgravity, *IAC2004* IAC-04-J.2.03 (2004).
2) Akiba, R., Egami, I., Koreki, T., Yamashita, M.,

Fujita, O.; Reduced gravity devices based on the yoyo principle, *Space Utiliz Res,* **21**, 1-4, (2005).
3) Akiba, R., Egami, I., Koreki, T., Fujita, O.; Yamashita, M., Reduced gravity devices based on the yoyo principle, IAC2005 IAC-05-A2.3.08(2005)

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