Making A Pendulum Clock Independent of Gravity Variations

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***Abstract-** Introduction most of the pendulum clocks work under the influence of gravity. The length of the pendulum and gravity are the two parameters that control the time of oscillation. It is given by the famous equation (1), discussed later in this paper. If the length is varied, then the time period also changes. The length variation is normally due to temperature variation. But if the gravitational force varies then also the time will vary. But an effort has been done to compensate the length variation in proportion to the variation of gravity. This paper gives theoretical design of a pendulum clock which is independent of the variation of gravity, even though it operates due to gravity itself.*

I. INTRODUCTION

The equation of pendulum for small amplitudes [1] ,[2],[3] is given by

$$T = 2\,\pi\sqrt{\frac{l}{g}} \quad (1)$$

Where "T" is the time period of oscillation in seconds,
"l" is the effective length of the pendulum in m, and
"g" is the acceleration due to gravity in m/sec^2.

Earth's gravity varies from place to place and the following are the popular maximum and minimum values of gravity.[4]

Mount Nevado Huascarán in Peru has the lowest gravitational acceleration, at 9.7639 m/s^2, while the highest is at the surface of the Arctic Ocean, at 9.8337 m/s^2. So, substituting these values in equation (1), we get

$$\frac{Tmount}{Tocean} = 1.003568$$

In a day of 24 hours, it is about 5.14 minutes. So, if two clocks are placed at these two places, the clock on the mount show 5.14 minutes less than that of the clock at ocean.

Suppose, we take the same pendulum clock to moon, where the acceleration due to gravity is 1.62 m/s^2, then

$$\frac{T_{Moon}}{T_{Earth}} = 2.438.$$

This is a huge difference. The time period for one oscillation on Moon surface is 2.438 times to that on the Earth. For every 2.438 seconds on Earth, same pendulum clock on moon shows only one second!

Suppose, we take the same pendulum clock to Jupiter, where the acceleration due to gravity is 24.79 m/s^2, then

$$\frac{T_{Jupiter}}{T_{Earth}} = 0.629.$$

This is also huge difference. For every second on earth, clock on Jupiter show only 0.629 second!

II. LOGIC OF MAKING TIME INDEPENDENT OF GRAVITY

Logic behind this particular design is based on the fact that if length of the pendulum is proportional to gravity, then the time shown by the pendulum clock will be constant, irrespective of the variation of the gravity.

It is shown by the equation below

Let length l = k * g, where "k" is a constant depending upon the material properties of the spring.

So Equation (1) becomes $T = 2 * \pi\sqrt{\frac{k*g}{g}}$ (2)

Hence we get $T = 2 * \pi\sqrt{k}$ (3)

So, the time of oscillation is constant for a given spring, irrespective of variations in the values of gravity. As we know a linear helical spring will deflect proportional to gravity for the same mass so keeping the mass constant the length of the pendulum is automatically proportional to gravity but the only problem is that there will be an initial length of the pendulum even at zero gravity in the normal arrangement. Therefore, a special mechanism has been done here to get zero length of the pendulum at zero gravity so that the length of the pendulum will be proportional to the magnitude of gravity. Therefore, the time will be constant, irrespective of the variations in gravity.

III. GRAVITY INDEPENDENT CONSTRUCTION

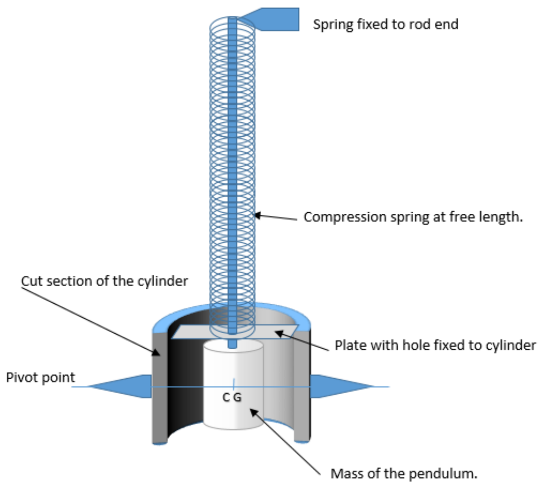

Figure 1.Constructional details.

The figure shows the complete constructional details this pendulum consist of a weightless spring mounted on a very light rod, supporting the mass of the pendulum at the other end. The movement of the pendulum due to deflection of the spring because of the gravitational force is restrained to only vertical axis by a plate with a hole. The plate is fixed to the outer ring. Outer ring is having knife edges shown as pivot points, which will facilitate the oscillation of the pendulum in the Y-direction as shown. All the parts are almost weightless compare to the 1 KG mass of the pendulum.

IV. ALLOWABLE RANGE OF VARIATION OF GRAVITY

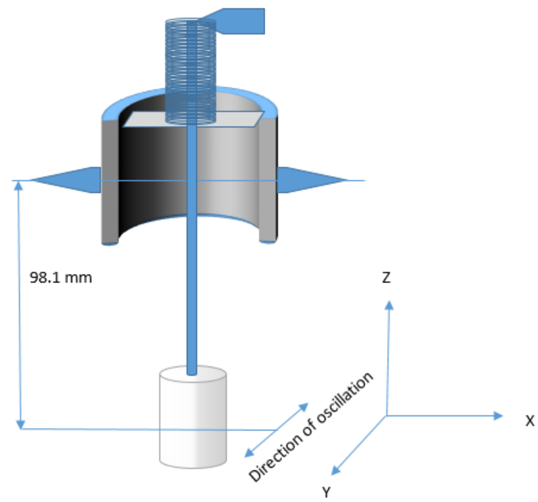

Figure 2.Deflection of the spring on the surface of the Earth.

Zero gravity depend on a mass centre of gravity coincides with the axis of the knife edge so that the equivalent length of the pendulum is zero which means it won’t translate at the time period is zero therefore the problem of initial free-length of the spring at zero gravity is compensated.

Spring selection.

The spring selected here is a compression spring with free length nearly equal to 50 cm. The stiffness of the spring is selected from the standard value which will be 10 cm per KG. At zero gravity, the spring will be in its free length of 50 cm and the mass is at zero length.

When it is subjected to the gravity of the Earth, then that 1 KG mass deflects the spring through 100mm but we actually want it to be deflected through 98.1 mm. Therefore initially we have to cut that 500 mm spring through approximately 10.5mm so that its equal length is 490.5 mm therefore in deflects 98.1 mm and its gravity ends it starts showing the exact time on Earth.

Depending upon the initial length of the spring and final length of the spring we can use this clock for a wide range of gravity.

For example:

- On moon the gravity is 1.6 m/s^2 and therefore the deflection will be only 16mm.
- Likewise, we can go up to nearly gravity equals 25 that is almost equal to Jupiter is gravity of 24.6 where the deflection will be 246mm.
- The range depends upon the spring and its properties and as the range increases, the size of the clock will increase.

This illustrates that this theoretical design will have a pendulum clock which works because of the gravitational force but it is independent of the variation in gravity.

V. SCOPE FOR FURTHER WORK

- Actual pendulum clock is fabricated according to the particulars discussed in this paper and experiments can be done at various values of gravity.
- Temperature compensation can also be done by using nitinol alloy for spring. [5]

CONCLUSION

1. This pendulum clock gives time independent of variation of gravity within the given range.
2. The design is simple and very easy to fabricate.
3. Temperature compensation can also be done by selecting suitable materials for the spring and the rod.
4. If the desired range of gravity is between 9.6 and 9.9, then the clock will be quite compact.

REFERENCES

[1] Avinash Puri[1] “Einstein versus the simple pendulum formula: does gravity slow all clocks?” Published 19 June 2015 • © 2015 IOP Publishing Ltd Physics Education, Volume 50, Number 4

[2] Wynn, Jared. (2013). “Motion of a Pendulum”. Undergraduate Journal of Mathematical Modeling: One + Two. 3. 10.5038/2326-3652.3.1.21.

[3] Peter F Hinrichsen “Review of approximate equations for the pendulum period” 2021 *Eur. J. Phys.* 42 015005.

[4] Hirt, Christian, Sten Claessens, Thomas Fecher, Michael Kuhn, Roland Pail, and Moritz Rexer. "New ultrahigh-resolution picture of Earth's gravity field." *Geophysical research letters* 40, no. 16 (2013): 4279-4283.

[5] Dieter Stoeckel Raychem Corp. Friedo Tinschert Mercedes-Benz AG “Temperature Compensation with Thermovariable Rate Springs in Automatic Transmissions” SAE Technical Paper Series, 1991.