Viscous Damping Constant Measurement System using Smartphone Sensor

Pradnya Vishal Sawant

Assistant Department of Physics, Sant Rawool Maharaj Mahavidyalaya, Kudal, Sindhudurg, India
Email: *sawantpradnya069[at]gmail.com*

Abstract: ***Viscous dampers are used in a variety of applications to control vibration and are essential for protecting the system. In this project, an accessible Smartphone-based viscous damping constant measurement system is presented. A Damped Spring Mass oscillator system is constructed using the vertical spring-mass apparatus. Damping is studied by recording acceleration using a built-in accelerometer in a smartphone using a sensor app such as the phyphox. The outcome of the study is represented by determining the viscous damping constant of the damped spring-mass system. The experimental method consists of the study of factors that affect damping such as liquids as a medium, weights, material, and geometrical structure. This experimental design provides a convenient, easy, affordable, and efficient way to study damping.***

Keywords: Damping, Spring-mass, Accelerometer, Smartphone

1. Introduction

A simple harmonic oscillator is a basic mechanical or physical system that exhibits a particular type of periodic motion known as simple harmonic motion (SHM). Damped oscillation occurs when a moving particle gradually loses its kinetic energy in interaction with resistive forces like air or friction. The displacement of a particle slowly reduces with time and ultimately reaches its state of rest. Viscous damping is a type of damping that occurs when an object moves through a fluid, such as air or water. Viscous damping is the dissipation of energy that occurs when a particle in a vibrating system is resisted by a force. Viscous damping is important for vibration-isolation systems and protecting systems by limiting vibrations. The viscous damping coefficient (VDC) is a theoretical parameter that explains the energy dissipation due to friction that slows motion. It's measured in N s/m.

The VDC is important for system modeling, control, and dynamic characteristic analysis. For example, the VDC of hydraulic actuators is important for behavior assessment, promotion of control performance, and efficiency. The Damping coefficient is a very important quantity because it measures the effectiveness of the damper to which it resists motion in practical applications. The damping Constant can be measured by different methods, like manual amplitude measurement followed by logarithmic decrement analysis, frequency response curve analysis, and Modal damping method where a finite element solver can reconstruct the modal damping ratios of an assembled structure. These and many similar methods have some shortcomings that give rise to less accurate results.

The damping constant is the most difficult dynamic property to predict at the design stage because the dynamic interaction of system components is complex and the presence of localized defects/imperfections to structural elements also the rate of sine sweep can be a major problem and most the method assumes a linear model of damping. In this project, we have introduced a novel method to measure the damping constant more precisely. The acceleration of the spring-mass damper is measured using a built-in accelerometer sensor in a smartphone. Smartphones have sensitive accelerometers to determine their movement and orientation, for gaming and fitness applications.

2. Theory

The system's equation of damped harmonic oscillator with mass m, spring constant k

$$\frac{d^2x}{dt^2} + c\frac{dx}{dt} + \omega_n{}^2 x = 0$$

Here, the Damping coefficient $c = 2\zeta\omega_n$

The damping coefficient is a measure of how effective a damper is at resisting an object's harmonic motion. The damping coefficient quantifies the rate at which oscillations decrease when the source is removed. The damping coefficient is given in units of newton-seconds per meter (Ns/m).

The natural frequency of the system is $\omega_n = \sqrt{\frac{K}{m}}$

The damping ratio is a measure describing how rapidly the oscillations decay from one bounce to the next. The damping ratio is a system parameter, denoted by ζ (zeta), that can vary from undamped ($\zeta = 0$), underdamped ($\zeta < 1$) through critically damped ($\zeta = 1$) to overdamped ($\zeta > 1$).

Damping ratio $\zeta = \frac{C}{C_c} = \frac{Actual\ damping\ coefficient}{Critical\ damping\ coefficient}$

Here, the Critical damping coefficient $C_c = 2m\omega_n = 2m\sqrt{\frac{K}{m}}$

Thus, Critical damping is a function of mass and stiffness only.

Here, We have considered underdamped motion, since the damping force is less than the critical damping force. This results in the oscillation decaying slowly. For underdamped oscillation, the damping is related to the logarithmic decrement δ

$$\zeta = \frac{\delta}{\sqrt{\delta^2 + (2\pi)^2}}$$

$$\delta = \frac{1}{n} ln\left(\frac{x_i}{x_{i+n}}\right)$$

$Here, x_i,\ x_{i+n}$ are amplitudes of i^{th} and $(i+n)^{th}$ peaks respectively, where n is number of cycles.

In the case of SHM, Amplitude a is

$$a = -{\omega_n}^2 x$$

This confirms, that measurements of the acceleration can be used to infer the displacement. $\delta = \frac{1}{n} ln\left(\frac{a_i}{a_{i+n}}\right)$

Thus, one can determine the damping constant by measuring acceleration over time of a damped harmonic system.

3. Experimental Setup

The experimental setup consists of a vertical spring mass oscillator system as shown in figure 1. The spring is suspended by the smartphone and is attached to a set of slotted weights system of variable masses. Damping is provided by inserting a set of slotted weights system inserted into various liquids (Water, oil) filled in a container. The acceleration changes sinusoidally with an amplitude that decreases in time and is recorded by an Accelerometer sensor integrated with a smartphone using the phyphox app.

Figure 1: Experimental Set up

4. Observations

4.1 Part 1:- Measurement of spring constant and accelerometer test

A smartphone can also be used as a swinging mass to record the oscillation of a spring pendulum. A measurement example, which was recorded with a smartphone with a mass m = 0.220 kg, is shown in Figure 1. The spring constant k can be determined by measurement of the period of oscillations of a vertical spring-mass oscillator using a smartphone as shown in figure 2. We found the spring constant to be 13.657 N m−1.

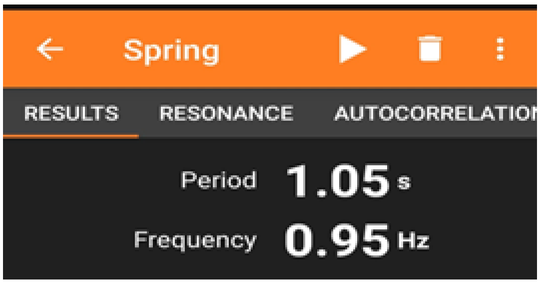

Figure 2: Period measured in phyphox

This measurement is in satisfactory agreement with another experimental value, 13.766 N m−1, obtained via the traditional static method. This measurement tests a built-in accelerometer in a smartphone before any new measurement.

4.2 Part 2: Damping constant measurement using a Smartphone sensor for different cases

In damped harmonic oscillations, the acceleration changes sinusoidally with an amplitude that decreases in time and is recorded by the accelerometer sensor integrated with a smartphone using the phyphox app. Figure 3 shows the acceleration (along y) measured in our oscillator. In this particular case, the phone was displaced (pulled down) by about 2 cm from its equilibrium position and was released from rest. The acceleration changes sinusoidally with an amplitude that decreases in time. Use the 'Pick data' function to directly measure the acceleration and time for each crest as shown in Figure 3. Measure at two successive crests. In our example, we measured an acceleration of 0.324071 m/s^2 at the fifth crest at 30.071 s.

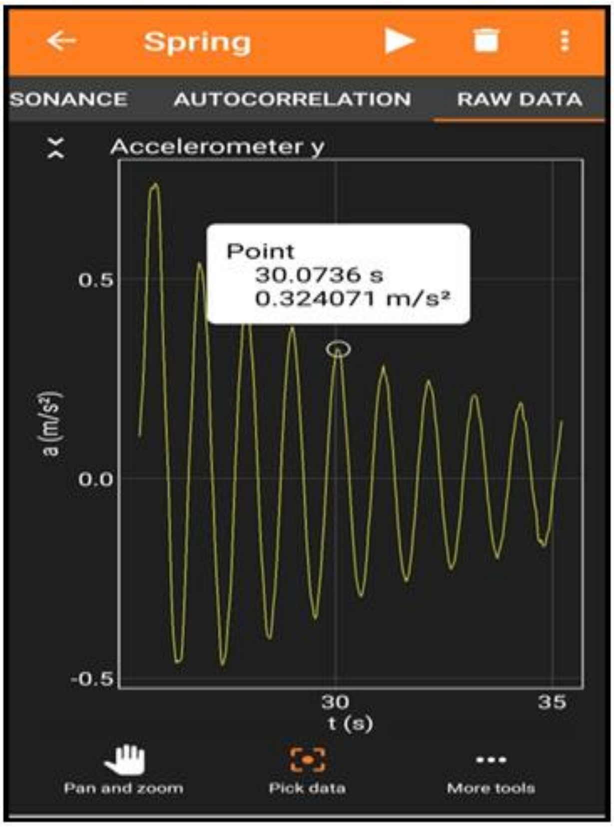

Figure 3: Acceleration of the phone versus time measured in phyphox

The experiment is carried out by taking different measurements to study the effect of parameters such as medium, masses, and geometrical structure. In each measurement, the acceleration is measured using an accelerometer sensor integrated with a smartphone using phyphox app. The Damping Constant is calculated by putting values of accelerations in the expression of logarithmic decrement δ. The various measurements of discussed below.

4.2.1 Measurement 1

Measurement 1 is performed by keeping a medium such as water constant, but with variable masses such as 100,150,200 and 250 grams. Figure 4.1 represents the variation of the damping constant with weights attached. It is found that the damping constant is directly proportional to the mass attached. This measurement shows that small changes in mass can be noticed by this experimental method.

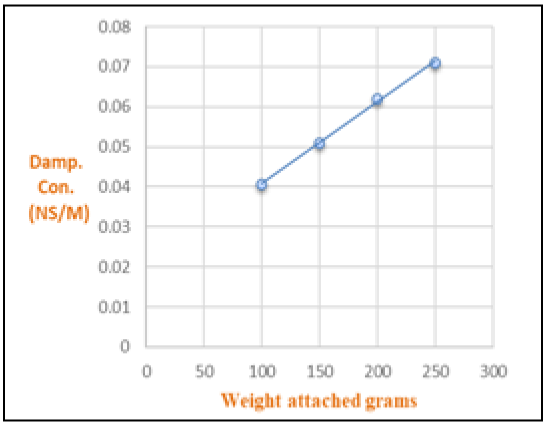

Figure 4.1

4.2.2 Measurement 2

Measurement 2 is carried out by keeping mass constant as 100 gm and by varying medium (Water, Coconut oil, Engine oil, burnt engine oil). Figure 4.2 represents a variation of the damping constant (NS/M) with variable medium. It can be seen that the damping constant is higher for medium having more density and viscosity. It is observed that changes in damping constant for engine oil and burnt engine oil can be detected by this method. Thus, This experimental technique is very sensitive to represent changes in the viscous properties of the medium.

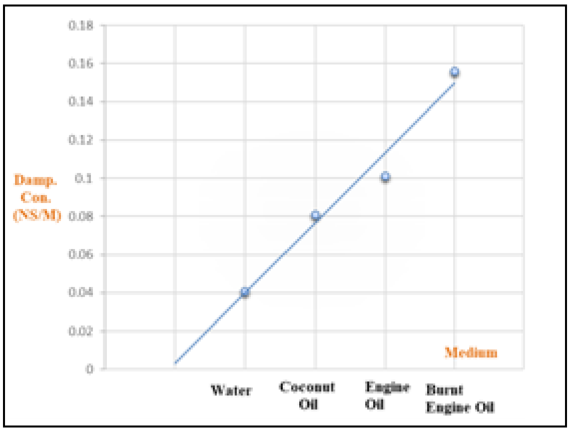

Figure 4.2

4.2.3 Measurement 3

The measurement 3 is carried out by keeping mass constant at 100 gm, constant medium (Water), and constant Material (Cement) by varying geometrical structure (Sphere, semi-sphere, Cube, Cone). Figure 4.3 shows different shapes like Spheres, semi-sphere, Cube, and Cone constructed by using cement material). Figure 4.4 represents changes in the damping constant (NS/M) due to different shapes. It is observed that the damping constant also changes with the geometrical shapes of the material. Thus, The experimental method is very responsive to note changes that occur in shape.

Figure 4.3: Geometrical Shapes

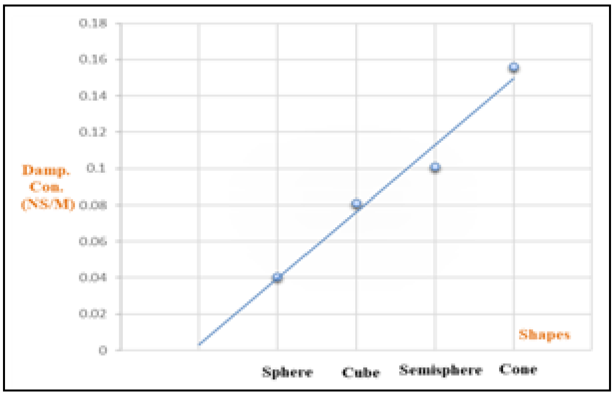

Figure 4.4

5. Advantages

The "Viscous Damping Constant Measurement System using Smartphone Sensor" experimental setup has an advantage over another setup used. The experimental setup is very simple to construct anywhere as apparatus like spring, mass, and smartphone are easily available and hence cost-effective. The experimental method is very easy to perform. In the measurement of amplitude smartphone sensor is used that provides atomization in measurement this improves the accuracy of the result. Measurements 1,2 & 3 show that the system is highly sensitive to mass attached, medium, material, and geometrical shapes of the material. The main advantage of this technique is that repeated measurements with variable factors are possible. Thus, by considering all these advantages, this experimental design can be used in different applications.

6. Applications

One widely used application of damped harmonic motion is in the suspension system of an automobile as a shock absorber attached to a main suspension spring of a car. The system helps to find a damping medium and material that improves engine efficiency.

It helps to know whether the system indicates undamped, under-damped, critically damped, or over-damped.

The experimental design provides a dynamic and effective teaching-learning model to study the properties of the damped pendulum in a course of mechanics for science and engineering students.

7. Conclusion

The presented "Viscous Damping Constant Measurement System using Smartphone Sensors" provides an appropriate, effective, and modest technique to determine the viscous damping constant of the damped spring-mass system. It provides a systematic study of damping and makes this experiment acceptable for practical application. The study of the effect of changing spring i.e.It is also possible to study the harmonic oscillator by giving a little extension and modification in this system spring constant),series and parallel combination of spring on damping constant can be easily done by slightly modifying the system. It is also possible to study the harmonic oscillator by giving a little extension and modification in this system. Thus, It can be concluded that the suggested design is successfully demonstrated and verified with its result.

References

[1] Kuhn, Jochen and Patrik Vogt. "Applications and examples of experiments with mobile phones and smartphones in physics lessons"
[2] Hammond, E C., and Assefa, M. "Cell Phones in the Classroom" The Physics Teacher 45 312, 2007.
[3] Kuhn, Jochen. "Relevant information about using a mobile phone acceleration sensor in physics experiments." Am. J. Phys. 81
[4] Kuhn, Jochen, and Vogt, Patrik. (Eds.). "iPhysicsLabs." Phys. Teach. 50ff. Column started on February 2012b
[5] https://phyphox.org/wiki/index.php/Experiment:_Spring
[6] https://en.wikipedia.org/wiki/Damping
[7] https://uclaphys5labs.weebly.com/uploads/1/1/0/7/110770949/ssa20_5bl_lab_4_manual.pdf