Exp 7: Vibration of a Single DOF System

In this experiment, you will analyse vibrations of a simple spring-mass system – a system with a single degree of freedom (DOF) – using micro electromechanical system (MEMS) based accelerometers, either available on a dedicated sensor chip or on your smartphone.

During the lab

You will be given a linear spring, a set of known masses, a ziplock bag, an accelerometer (MMA7361) and an Arduino for data acquisition. You will also need a smartphone with Phyphox installed and running on it during the experiment.

Find the stiffness of the spring (k) by connecting one end to a rigid support and attaching known masses to the other end, and measuring its elongation. Make sure you consider multiple data points on the load vs. elongation graph to draw the best-fit line to find the spring stiffness.

Place your smartphone in the ziplock bag, and hang it on the free end of the spring. Given that you can find the mass of the smartphone in its specification sheet, confirm that the spring is still in its linearly elastic region by measuring the steady-state elongation in the spring. Perturb this single DOF system axially, and find its natural frequency by manually noting the time taken for 10 to 20 oscillations. Compare this to the analytical frequency of the system calculated as follows:

$$\omega=\sqrt{\frac{k}{m}} \qquad [1]$$

Turn on Phyphox on the smartphone placed inside the ziplock bag. Connect the accelerometer to the Arduino board, and attach it to the ziplock bag using a double-sided tape, such that you are still able to operate Phyphox on the smartphone (Fig. 1). Ensure that the Arduino board is also attached in close proximity to the setup, albeit on the rigid frame, so that the connecting wires are not pulled during the oscillations. Perturb this single DOF system axially.

[1] Please refer to Chapter 2 of Rao et al. (1995, Mechanical vibrations, Vol 4) for the derivation of these equations

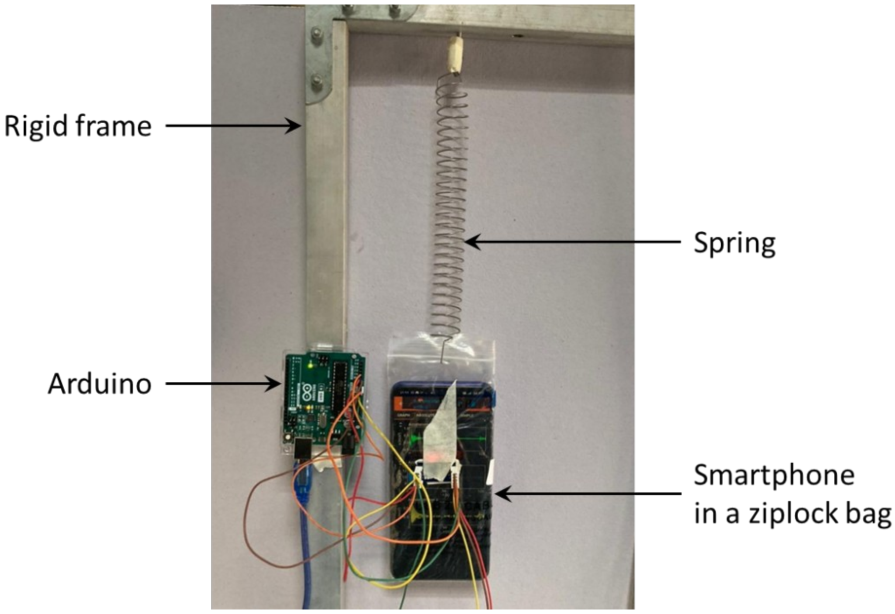

Fig. 1: Proposed experimental setup to quantify vibrations of a single DOF system

Ensure that the sampling frequency is set large enough to avoid aliasing. Precautions should be taken to avoid the contact of the pins of the Arduino board directly to the rigid metallic frame. Apply small perturbations to the smartphone as part of the experiment; larger displacements could result in spring jump-off causing damage to the smartphone.

Record the data from the dedicated accelerometer connected to the Arduino board using the script provided. Plot the captured data, and indicate if the sampling frequency was enough for the given experiment. Perform the fast Fourier transform (FFT) on the captured data, find the natural frequency of the system, and compare it to the analytical solution. Locate other peaks in the FFT, if any, and comment on the sources for the same. Analyse data along the secondary axes (in the plane perpendicular to the axis of movement), and comment on the importance of this data.

Perform the same analysis for the data obtained using Phyphox on the smartphone, and compare with results obtained from the dedicated accelerometer sensor.

Choose an appropriate damping model that fits the observed data plotted in the time domain (Appendix I). If a viscous damping model is considered, find the damping coefficient and damping ratio.

Please refer to Chapter 2 of Rao et al. (1995, Mechanical vibrations, Vol 4) for the derivation of these equations

Appendix I

Examples of the linear Coulomb damping (Fig. 2) and non-linear viscous damping (Fig. 3).

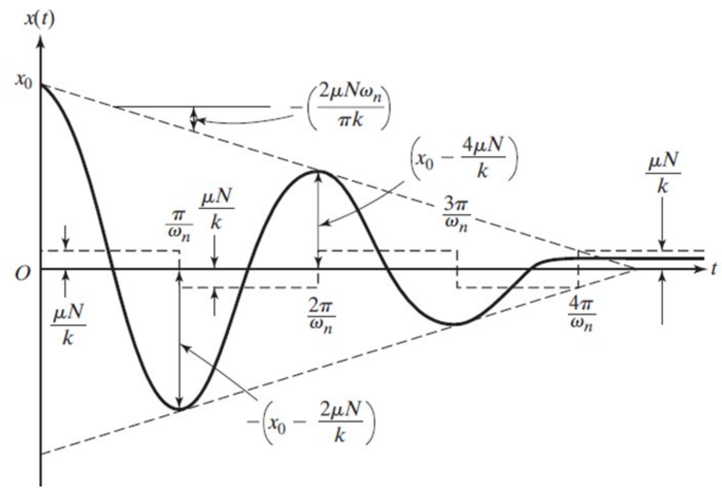

Fig. 2: Coulomb damping [Rao et al. (1995) Mechanical vibrations, Addison-Wesley]

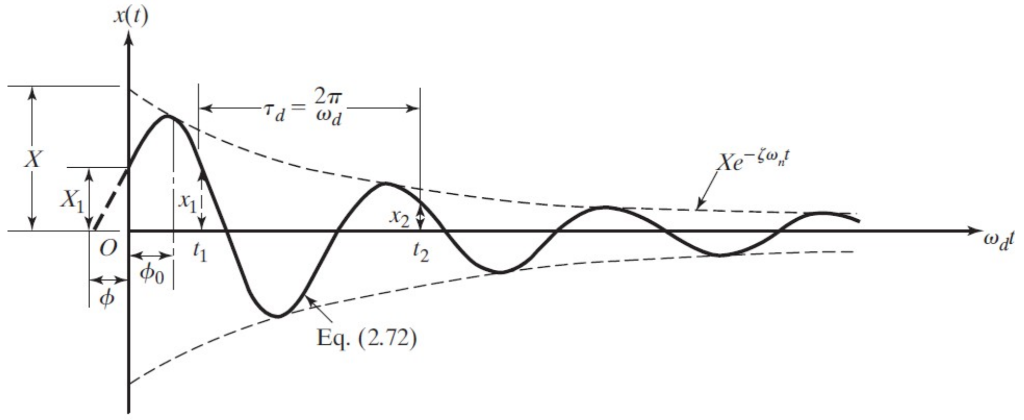

Fig. 3: Viscous damping [Rao et al. (1995) Mechanical vibrations, Addison-Wesley]

Logarithmic decrement (δ) can be defined as:

$$\delta = \frac{1}{m} \ln \left(\frac{x_1}{x_{m+1}} \right)$$

where x_i = amplitude of the i^{th} cycle

The damping ratio (ζ) can be defined in terms of (δ) as follows:

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

The damping coefficient (c) is defined in terms of the damping ratio (ζ) as follows:

Please refer to Chapter 2 of Rao et al. (1995, Mechanical vibrations, Vol 4) for the derivation of these equations

$$c = 2\zeta\sqrt{km}$$

Please refer to Chapter 2 of Rao et al. (1995, Mechanical vibrations, Vol 4) for the derivation of these equations