FIRST YEAR LABORATORY

FORCED OSCILLATIONS

1. Aims

1. To study the behaviour of a vibrating mechanical system as the driving frequency changes.
2. To study how the same system responds when the driving force is removed.

2. Objectives

1. To make measurements of the oscillation amplitude and phase as a function of the driving frequency, and hence determine the power absorption resonance curve.
2. To study the effects of damping on both forced and free oscillations of the system.
3. To measure the resonant frequency and quality factor of the system under various conditions.
4. To gain experience in using a digital sampling oscilloscope (DSO).

3. Theory of resonance

The theory and mathematics of resonance is described in King [1]. The displacement of a vibrating object as a function of time is given by the solution of the equation of motion, which in this case is a second-order differential equation. For this experiment you need only quote and use the solutions to the appropriate equations of motion, and the related definitions of amplitude, phase and Quality factor. These can be found in King [1] and Young & Freedman [2], and also in the pre-lab notes.

4. The Oscillator

The mechanical oscillator is a thin phosphor-bronze bar, rectangular in cross-section and clamped at one end.

The bar is driven by an electromechanical transducer through a coupling made with an elastic band. The driving oscillator consists of a loud speaker coil which drives a rod; the coil is powered by the amplified signal from a sine-wave generator (see Appendix A and the usernote on signal generators on Blackboard). The frequency of the sine-wave is variable in small steps.

Mounted on the horizontal bar is a rectangular coil consisting of 20 turns of insulated copper wire. As the bar oscillates, part of the coil moves between the poles of a fixed horseshoe magnet. The voltage generated by the coil is proportional to the **velocity** of the bar. The voltage is amplified for viewing on the oscilloscope (see Appendix A and the usernote on oscilloscopes on Blackboard.).

A vertical aluminium plate attached to the end of the phosphor-bronze bar, moves between the poles of an electromagnet as the bar oscillates. When the electromagnet is energised, eddy currents flow in the aluminium plate, providing additional damping. The damping force is proportional to the velocity of the bar.

5. Measurements

Resonance curves

Display the drive voltage (a sine-wave) and the amplified voltage from the coil (this may not be such a perfect sine-wave) on the oscilloscope. Measure the amplitude (or peak-to-peak) of the velocity waveform (in arbitrary units) of the oscillations of the bar, as a function of the driving frequency (at constant drive amplitude). Plot the resonance curve. Relate the velocity to the displacement and to the power (that is transferred by the elastic band). Plot the resonance curves for displacement and power. Determine the frequency, f_o, and the Q-factor of the resonance and estimate their uncertainties.

Note: Before measurements are made, make sure that, at the resonant frequency (typically in the range 12 to 20 Hz), the amplitude of oscillation is not too large. Think about how many data points you need to plot a useful resonance curve.

It is good practice to compare the frequency set in the signal generator with the value computed by the DSO.

Phase

Measure and plot the phase difference (in radians) between the driving sine-wave and the displacement (or the velocity) waveform, as a function of the driving frequency. Estimate the frequency of the resonance and the total phase change.

Free oscillations

Disconnect the drive and tap the bar to observe free oscillations. These slowly decay (air damping is always present). Display the decaying sine-wave on the DSO and measure the natural frequency of the oscillations and the decay constant, γ (see [1]), of the exponential decay. Determine the Q-factor of the resonance. Compare these values with the values obtained from the resonance plots.

Damping

Repeat the above investigations with the electromagnet energised to produce additional damping. Superposed plots of the amplitude and phase versus frequency for different amounts of damping might be instructive.

For two day experiment, you should complete the sections up to and including Free Oscillations, and also complete a repetition of one of your experiments to measure Q but with additional damping in your system. For the three day experiment, you should complete all parts of the experiment as detailed above.

Extension

Investigate the dependence of f_o and Q on the mechanical properties of the phosphor-bronze bar.

References

[1] G.C. King, 2009, Vibrations and Waves, Manchester Physics Series,Wiley, chapter3 (pp 49-64) and chapter 2 (pp 33-37 cd p43)

[2] Young and Freedman, 2016, University Physics, 14^{th} Ed., Addison-Wesley. Chapter 14, Periodic Motion.

Dr. F. K. Loebinger, January 1994, Revised May 1997.

Revised Dr Ian Duerdoth, March 2010

Revised Prof. F.K. Loebinger February 2011

Revised Dr M Lloyd July 2016

Appendix A Using the Function Generator and the Digital Storage Oscilloscope

There is an introductory video on Blackboard illustrating the basic use of a DSO. You should also read the User Notes for both the function generator and the oscilloscope you will be using for this experiment.

Forced Oscillations

Set your drive signal to be sinusoidal, on CH1 of the signal generator. The amplitude of the oscillation can be changed by altering the output voltage of the signal generator and/or the gain of the amplifier. The amplitude of the driving signal should not be set larger than 0.5 V. Use the separate amplifier box to amplify the signal if necessary. Note that this amplifier may behave non-linearly for signals larger than 0.5V. Before you start to take detailed measurements, vary the frequency of the drive signal from 10 to 20 Hz, and find the approximate resonance frequency of the system. Make sure that you are not over-driving the bar close to resonance. Adjust the amplification of the drive signal so that close to resonance, the response signal is as large as possible without becoming significantly non-sinusoidal. You should not be able to hear the bar tapping. Check your set-up with your demonstrator before you start to take detailed measurements.

Set up your oscilloscope so that you can see about two cycles of the driving waveform on the screen, and use the trigger if necessary to stabilise the displayed signal. Now make sure you can also see the response signal. It is helpful to set the drive signal from CH1 (yellow) of the function generator and to display this signal on CH1 (yellow) of the oscilloscope, and to display the response signal on CH2 (blue).

You can either measure the amplitude and phase of the velocity waveform using the oscilloscope's measure functions, or by using the cursors, as described in the Usernote. Be careful, especially when measuring phase, that your measurements are sensible, given the signals you can see; and that you know how the phase shift you record is related to the phase shift as defined in [1] and [2] between the driving force and the resultant displacement.

Decay of free oscillations

For this part of the experiment, disconnect the drive and trigger on the signal from the pick-up coil (CH2). Adjust the timebase setting on the DSO to display several cycles of the response velocity waveform so that you can see the waveform amplitude decaying. Use the RUNSTOP button to freeze the screen so that you can either download the response data or take measurements directly from the screen.

Steven Atkinson. 11th June 2002. Ian Duerdoth April 2010.

Myfanwy Lloyd. July 2016.