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Torsion Pendulum Phy 344

Introduction:

Resonance phenomena are ubiquitous in nature. A system with a mass and a restoring force can undergo oscillatory motion, with a characteristic resonance frequency determined by the system parameters. The presence of friction produces damping which will cause undriven oscillations to decay. If an oscillatory driving force is applied to the system, the response can range from small amplitude oscillations for drive frequencies far away from the characteristic resonance, to large swings as the resonance frequency is approached. In general, this behavior is described by the following equation:

$$\ddot{\theta} + 2\beta\dot{\theta} + \omega_0^2\theta = A\cos\omega t, \tag{1}$$

where θ is the angular position of the oscillator, ω_0 is the characteristic undamped resonance frequency, β describes the strength of the damping, A is related to the amplitude of the driving force, and ω is the drive frequency.

Objectives

- Study the solutions of Eq. 1 for different levels of damping and drive frequency.
- Observe the free oscillations of a torsion pendulum.
- Study the decay of the oscillations for varying levels of damping.
- Measure the amplitude and phase response of the pendulum for different driving frequencies.
- Map out the resonane curve for the pendulum response with different levels of damping.

Suggested Reading: Read a treatment of driven oscillations with damping. This problem is treated in any classical mechanics textbook, such as J. B. Marion and S. T. Thornton, *Classial Dynamics* (Harcourt Brace Jovanovich, 1988), pp. 106-120. Many introductory physics textbooks also discuss this problem, including H. D. Young and R. A. Freedman, *University Physics, Vol. 1* (Addison Wesley, 2004), currently used in Physics 211.

Suggested Apparatus:

1. Torsion pendulum apparatus from Leybold Didactic.
2. Power supply for driving motor.
3. Power supply for adjusting current through damping electromagnet.
4. Timer for measurements.
5. Multimeter for measuring drive voltage of motor.
6. Multimeter for measuring current through electromagnet.

Avoiding damage:

- Do not apply currents larger than 1 A to the electromagnet.

Instructions - Observing Free Oscillations

- Without turning on the drive motor or electromagnet power supply, displace the pendulum from its equilibrium position and observe the oscillations after releasing it.
- Using the timer, measure the frequency of these free oscillations. Consider techniques to minimize the error in your determination of the start and end times.
- Repeat the measurement of frequency for several different initial displacements of the pendulum.

Instructions - Damped oscillations

- Turn on the electromagnet current supply and increase the current to a moderate value, say 0.5 A and observe the influence on the undriven oscillations.
- Devise a technique for recording the decay of these damped oscillations, perhaps by sampling them at several points per oscillation cycle. Fit these data to an exponentially decaying sinusoid and extract a value for the damping parameter β.

$$\theta(t) = C \exp(-\beta t) \cos(\omega_1 t - \delta) \tag{2}$$

- Repeat this measurement procedure for three different nonzero current settings in the electromagnet to extract the dependence of β on the current in the magnet. Remember to keep the current below 1 A.

Instructions - Driven oscillations

- Turn on the drive motor and calibrate the variation of the drive frequency with the readout voltage from the motor as you vary the knob on the motor housing.
- With a low, but nonzero, current through the electromagnet, observe the oscillations of the pendulum for different drive frequencies. Notice the transient response which decays away after starting a new oscillation, leaving only the steady state response. Devise a technique for measuring the amplitude of the oscillations for a given drive frequency, as well as the approximate relative phase between the drive and the pendulum response.
- Map out the amplitude and relative phase as a function of drive frequency from frequencies well below to well above the characteristic resonance frequency determined from the free oscillation measurements.
- Perform this measurement sequence for the same three settings of current in the electromagnet as in the previous section.

Memoranda

- Can you fit your amplitude response curves to the expected functional form? How many fit parameters do you need to use?
- Does the variation of the relative phase follow the frequency dependence you would expect?
- Why would it be difficult to measure the amplitude response *vs.* drive frequency with no damping present?