Union College Fall 2008

Physics 110, Lab #3
Hooke's Law and Work Applied to Springs and a Wood Board

Part I: Springs

Springs provide an easy-to-study model of how structural forces respond to deformations. The expression for the restoring force of a spring is given by Hooke's Law, $F = -kx$. For this part of the lab, you will experimentally determine how well Hooke's Law describes the restoring force of a spring, obtain a representative plot of F vs. x of a spring force, and calculate work done. The results from this part of the lab will be useful for analyzing the restoring force of a piece of wood, which you will deform in the second part of this lab.

1. Open Excel to record (and later plot) all the following data.
2. Hang a spring from the horizontal rod next to the vertical meter stick. Measure the position of the end of a spring and record this in Excel as the spring's *relaxed position*. Estimate the uncertainty in this measurement and record in the neighboring box. Be sure to put labels and headers (with units) in your table.
3. Hang a small mass on the end of the spring, allow the mass to come to rest, and measure and record the new position of the end of the spring (*not the end of the mass*). Considering that the spring force is now exactly canceling the weight of the mass, calculate and record the magnitude of the force of the spring. Estimate and record the uncertainty (assume that the masses are well calibrated to the significant digits that are shown).
4. Hang a slightly larger mass on the spring, measure the new position of the end of the spring, and calculate the new force of the spring.
5. Repeat for a number of masses (use at least five masses, total).
6. For each spring position, calculate the displacement, x, from the relaxed position.
7. Plot the spring force, F, vs. displacement, x.
   Does your spring obey Hooke's Law? What aspects of your plot supports your claim? Hint: consider the expression for Hooke's law and whether your plot is a straight line?
8. Fit a straight line to your plot and use the fit to calculate the value of the spring constant. Use the regression analysis tool to obtain the uncertainties in the fit values.
9. Calculate the amount of work done against the spring by gravity with the largest weight. Using the "**Propagation of Uncertainties**" instructions at the end of this handout, determine the uncertainty in the work due to the uncertainties in k and x.
10. Repeat steps 1-9 above for a different spring using the same masses.
11. How do the results of the two springs differ? How does the plot of F vs x compare—what is similar and what is different? How does the value of k relate to the stiffness of the spring? Does the largest weight do more or less work against the stiffer spring?

Part II: Hooke's Law of Wood and Work Done in Breaking A Board

The internal forces of structural material are also often well represented by Hooke's Law; Hooke's Law is not just for springs. In this part of the lab, you will apply a known force to deform a standard wood board from its relaxed position. You should again see a Hooke's Law behavior. When you apply a large enough force, however, the deformity in the wood will be large enough that the bonds in the wood are broken and the whole board breaks. Using the same methods as in part I, you will calculate the amount of work involved in breaking a wood board.

1. In a new Excel table, starting on the second or third row, label the first column 'No. of bricks,' the second 'mass', the third 'total mass', the fourth 'dial reading (inches),' the fifth column 'deflection of the board (mm)', and the sixth 'total force (N)'.
2. Read the initial setting of the depth gauge (or dial). Record this number in a top row of your data table and label as the 'relaxed position (inches)'. Estimate and record the uncertainty as well.
3. Carefully hang the tray on the board. Input the mass of the tray in the "mass" column. Read the dial and input its value in the first line of the 'dial reading' column.
4. Enter the proper equations in the 'total mass' and 'total force' (in N) columns. Enter an equation in the 'deflection of board' column, to calculate the deflection, *in m*, using the dial reading and the relaxed position, following the professor's instructions about the depth gauge.
5. Measure the mass of a brick and carefully add it onto the tray (onto the spot labeled brick #1). Read the dial once the needle settles. Enter the mass of the brick and dial reading into your table (and make sure that all the calculations work).
6. Add anothe brick, after measuring its mass, and read the new dial setting, and enter the data.
7. Continue adding boards and entering the data ... until the board breaks. (Note: be careful to keep your feet away from the area below tray, in case the board breaks while you're there.)
8. Plot F vs. x.
   Judging from the shape of the plot, and considering your plots in part I, does the board's restoring force obey Hooke's Law? Discuss the similarities or differences between the wood's restoring force and that of the spring. Comment on the applicability of Hooke's Law to modeling structural forces.
9. Use the plot to determine the spring constant for the board? Use the regression analysis tool to calculate the uncertainty.
10. Calculate the total work (with uncertainty) required to break the board.
11. What is the force that did this work? The work did not change the board's kinetic energy, so considering conservation of energy arguments, where did this work, or energy, go?
12. Imagine breaking a board by dropping a hard object onto the board:
    a) Calculate the minimum height from which a 1-kg mass must be dropped in order to break this board.
    b) Estimate the mass of your fist and calculate the speed that it must move in order to break this board. Do you think you can accomplish that hand speed easily? (To avoid liability issues, though, you are not allowed to actually try this…your instructor will do it instead.)

Propagation of Uncertainties:

In this lab, you need to calculate the uncertainty in the work done by a Hooke's law force, i.e.

$$W = ½\, kx^2,$$

where k and x each have uncertainties themselves. The uncertainty in W is given by

$$\Delta W = \sqrt{(kx\Delta x)^2 + \left(\tfrac{1}{2} x^2 \Delta k\right)^2}$$

Put in your values of k and x for the largest mass hanging from the spring, the Δx from the uncertainty in reading the position of the end of the spring, and the Δk that you obtained from the regression analysis tool.

Similarly for the uncertainty in the work done in breaking the board, put in your values for k of the board, the largest x, the Δx from the uncertainty in reading the dial, and Δk that you obtained from the regression analysis in the F vs. x plot.