Lab experiment #13 [Based on PASCO lab manual 31 Hooke's Law and Elastic Potential Energy, written by Jon Hanks]

Hooke's Law and Elastic Potential Energy

Pre-lab questions

1. What is the goal of this experiment? What physics and general science concepts does this activity demonstrate to the student?
2. How does the spring force change with compressing the spring?
3. How can you tell if the spring force is conservative?

   The goal of this experiment is to investigate the validity of Hooke's law as a description for the force produced by a spring displace from its equilibrium length.

Introduction

When a spring is gently stretched or compressed to a displacement **x** from its equilibrium length, $\mathbf{x}_0$, it provides a force in opposition to the direction of this change that varies linearly with the amount of extension or compression, $\mathbf{F} = -k\,(\mathbf{x} - \mathbf{x}_0)$ where k is the spring constant of the specific spring. This force law, which is fairly accurate when the spring is not overly stretched or compressed, is known as **Hooke's Law**. (The same kind of relationship work for torsional springs that twist in angle rather than extend or compress – like a stretched wire.) Most of the time, we take the presence of the spring's equilibrium length as already applied and simply replace $(\mathbf{x} - \mathbf{x}_0)$ with **x** as representing the change in spring length. Then Hooke's law is simply written as $\mathbf{F} = -k\,\mathbf{x}$. Note, also, that the spring force is **conservative**. Work done by, or on, the spring follows the work-energy theorem.

As an object moves due to the spring force, work can be done and its energy can change. Its kinetic energy can change if the force acts on a mass without other restraints, or its potential energy can change if the motion is constrained regarding changes in velocity.

Assume that the spring is ideal, i.e., it has no mass and can be arbitrarily stretched or compressed while obeying Hooke's law. Stretching or compressing the spring requires an external force to act on the spring in opposition to the spring force, and this external force does work on the spring. If the overall state of motion of the spring does not change in this process, the work-energy theorem says that the work done on the spring is now potential energy stored in the spring. When it is calculated carefully, we find that the stored potential energy $U = ½\,k\,x^2$.

Equipment

Pasco Dynamics System, acoustic motion sensor, high resolution force sensor, (2) end stop, elastic bumper, spring cart launcher, (2) compact cart mass, balance scale.

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Experiment

The Force and Motion Sensors are used to measure the spring constant, and the amount of potential energy stored in the compressed spring. The cart is then launched, and its final kinetic energy is measured and compared to the stored energy in the spring.

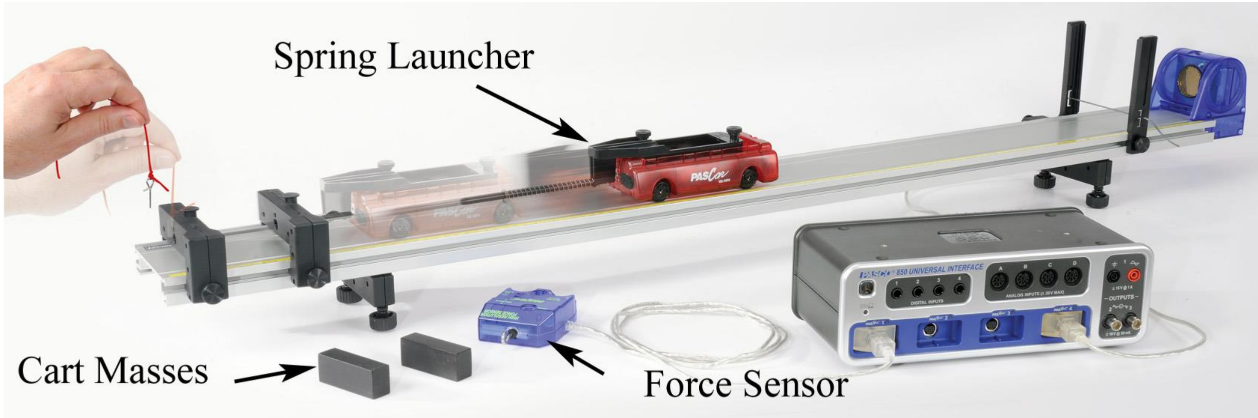

Figure 1: When the pin is pulled, the potential energy stored in the spring is released.

Setup

1. Attach the feet to the track, and then install the Elastic Bumper as shown in Figure 2. Attach the Motion Sensor and plug it into the interface. The range switch should be set on the "cart" icon. Later, if you have trouble getting good data from the Motion Sensor, try sliding the Elastic Bumper **closer** to the sensor.

Figure 2: Motion Sensor

2. Attach the Spring Launcher to the cart as shown in Figure 3. Use the strongest spring: It will have a small daub of black paint on one end. Note the orientation of the large end of the spring on the rod. Rotate the spring so that it catches and is attached to the support.

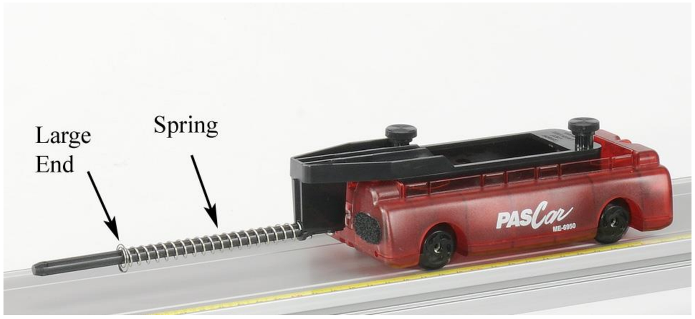

Figure 3a: Spring Cart Launcher

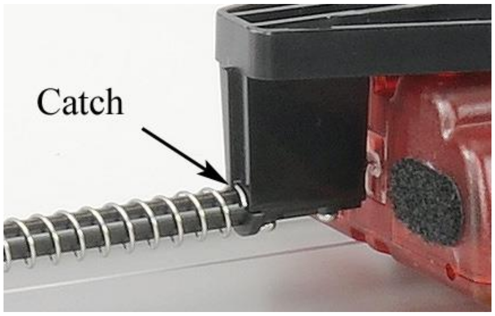

Figure 3b: Rotate the spring so that it catches and is attached to the support.

3. Figure 1 shows two endstops in use for later in the experiment. For now, you will only use one endstop as shown in Figure 4. Push the rod from the spring launcher through the hole in the endstop and tie a loop of string through the small hole in the end of the rod.

4. Plug the Force Sensor into the interface. With the sensor flat on the surface of the track, press the zero button to tare the sensor. Hook it onto the loop of string as shown in Figure 4.

5. In PASCO Capstone, set the common sample rate to 100 Hz. Create a graph of Force vs. Time. Add a plot area and put the Position on the vertical axis of the second plot area.

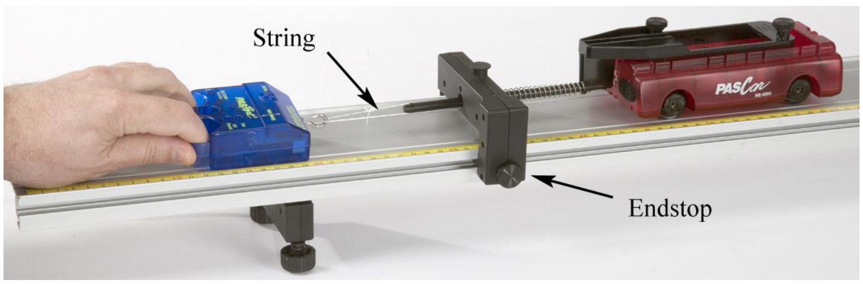

Figure 4: Finding the spring constant

Procedure – Force and Position Data

1. Pull on the Force Sensor so that the spring is just barely in contact with the endstop.

2. Click on Record, and then slowly increase the pull on the Force Sensor, compressing the spring. Note the original position of the PAScar and move it 7 cm as the spring compresses (the coils of the spring should not touch each other).

3. If you are not getting good position data from the Motion Sensor, try sliding the elastic bumper **closer** to the Motion Sensor.

4. If your force data is not positive you can open the Data Summary and click on the properties icon (gear) for the Force Sensor. Note the check box to change the sign.

5. Once you are getting good data, delete all the preliminary runs.

6. Now repeat step 2, except this time slowly compress the spring by 7 cm, then slowly allow the PAScar to return to its original position and then repeat the compression and decompression one more time for a total of two full cycles.

7. Click open Data Summary and label this run as "Force Curve".

Spring Constant:

8. Create a graph of Force vs. Position and select the Force Curve run. Examine the Force vs. Position curve and answer Questions 1 and 2 in the Conclusion.

9. Record the slow 7 cm compression (as in step 2 on previous page.) Hold the spring at the 7 cm compression for about 15 seconds before stopping the recording. Click open Data Summary and label this run as "loading 1". Repeat twice more labeling the runs as "loading 2" and "loading 3".

10. Then do three unloading curves by first holding the spring compressed by 7 cm for 15 seconds and then recording as the tension is slowly released. Label the runs "unloading 1", etc.

11. Repeat step 9 except this time allow your hand to move faster to release the tension more quickly. Label as "fast 1", etc.

12. Create a table with three columns. Create User-Entered data sets called "Loading", "Unloading", and "Fast Unload", all with units of N/m. Turn on the statistics with the mean and standard deviation.

13. Use a Linear curve fit on the force vs. position graph to find the slope of each of the nine lines. Use the Select tool to look at only linear areas of the graph, avoiding the beginning and ending of each run. Record your value in the table.

Spring Energy:

14. Create a graph of velocity vs. time.

15. Connect both endstops (about 9 cm apart) at the end of the track as shown in Figure 5.

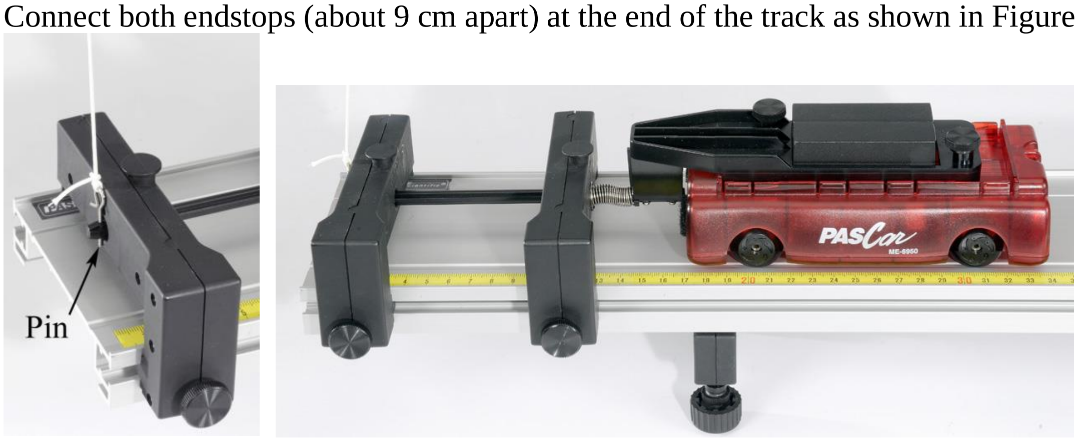

Figure 5: Compressed spring held with pin

16. Adjust the separation so that when the spring is almost compressed 7 cm, you can place the pin into the small hole at the end of the rod.

17. Place both of the black compact masses in the cart as shown, but you don't need the spring compressed at this time.

18. Adjust the "level" of the track using the adjustable feet. Place the cart on the track and give it a small push towards the Motion Sensor. Click on Record. Your data will stop automatically when the cart is within 20 cm of the sensor.

19. Using the screw feet, adjust the level of the track so that the cart travels at a constant speed when moving **towards** the sensor. By setting up the track so that it is slightly downhill, you will be eliminating the effects of unwanted frictional forces. Label your final run as "flat run".

Measuring Compression:

20. Create a graph of Position vs. Time.

21. Use a balance scale to measure the total mass of "cart + launcher + extra mass".

22. Move the cart towards the Endstop until the spring is very slightly compressed. You want the Motion Sensor to measure off the end of the cart, so keep your hand in the middle of the cart, not hanging over the end.

23. Click on Record, then compress the spring until you can insert the Pin. Let go of the cart with your hand, letting the Pin hold the cart in place. Click on Stop.

24. Use the Coordinates tool (with Delta tool) to measure x, the compression in the spring.

25. Using the spring potential energy equation and the mean spring constants you found earlier: calculate the energy stored in the spring using the loading data, and the energy recovered.

Kinetic Energy:

26. Looking at a graph of velocity vs. time, click on Record. Use the string to jerk the pin loose, and release the cart. You must pull upwards on the pin as quickly as you can. See Figure 1. There is a built-in stop condition that should automatically halt recording when the cart reaches the far end. Label the run "KE 1".

27. Repeat twice more.

28. Use the Coordinates tool to measure the max speed of the cart for each of the three runs and record below.

29. Calculate the mean speed.

30. Calculate the resulting kinetic energy of the cart using the mean speed.

Conclusions

1. Does the spring obey Hooke’s Law when it is compressed? Explain fully! Is this surprising?

2. Does Hooke’s Law appear to hold for any portion of the curve?

3. Can you explain the difference between the between the loading and unloading force curves in terms of friction in the system? Hint: consider the little "tail" on the loading force curves as the cart was held motionless for 15 seconds and the beginning tail on the unloading curves when the cart was released.

4. How well does the potential energy stored in the spring agree with the kinetic energy gained by the cart? Discuss fully!