Kinetic Energy, Potential Energy, Work, Power & Energy Storage

Prelab

1. Examine whatever elastic systems (hoop, extensible spring, or rubber band) are available to you. Apply varying force to the system and note the deformation.
2. Sketch a graph of the applied force *vs*. the change in length, based on what you felt.
3. When one force displaces an object twice the distance that a different force does, does it produce more work?
4. Do you think energy conservation applies only amongst similar types of energy, i.e. does it apply for instance to the kinetic energy of a system of two objects being the same before and after a process, or does it only apply to the total energy, which is the sum of all energy forms that appear in the process?
5. When two objects have the same velocity, do they possess the same kinetic energy? Why or why not?
6. When two objects have the same height above the ground, do they possess the same gravitational potential energy? Why or Why not?

Experiment

Purpose of Experiment

In the lab for Hooke's Law, you found that the energy stored in an elastic system was proportional to the square of the change in the length of the spring or rubber band deformed by the applied force. We called the energy stored in this way *elastic energy*.

This energy can be transferred to another object to produce a change—for example, when the spring is released, it can launch a toy dart. It seems reasonable that the more the spring is compressed, the greater the change in speed it can impart to the object. As the spring or band returns to its original shape, it transfers energy to the moving object. We say that the moving object stores energy in an account called *kinetic energy*. It seems reasonable that an object's kinetic energy is a function of its mass and velocity. It would be useful to determine a quantitative relationship between the kinetic energy and its velocity for a given mass.

Suppose that, instead of moving horizontally, the cart were to move up an incline. Gradually, the cart would come to a stop before it began to roll back down the incline. Let's examine for a moment the energy of the system when the object reaches its maximum height and its velocity is zero. While kinetic energy has diminished to zero, the energy of the system isn't "lost." It must be stored in some other account, which we call *gravitational energy*. This is the energy stored in the Earth-cart system as a function of its new height. Consider for a moment what system variables might affect the gravitational energy of the Earth-cart system.

While it is not a simple matter to measure this quantity directly, determining the *change* in the gravitational energy is straightforward. We can simplify this discussion if we arbitrarily assign a value of *zero* to both the gravitational energy of the system and the height of the object when it is as close to the Earth as it will get during the course of our investigation. Your goal is to determine a quantitative relationship between the gravitational energy and the height of an object above the zero-reference position.

Activity 1 ~ Personal Power Rating

General Procedure

Let's see how long it takes you or one of your lab partners to lift a heavy object a known height.

Procedure

1. Measure the mass of the object.
2. Set up the motion detector and software to measure the height and velocity of the object with time.
3. Begin collecting data, then lift the object vertically as quickly as possible.
4. Make sure your sensor tracked the object throughout the lift. Select a time when the object was at its starting position. Select a second time when the object has risen about 1 meter.
5. Record the height difference and the velocity of the object at the second time.

Analysis

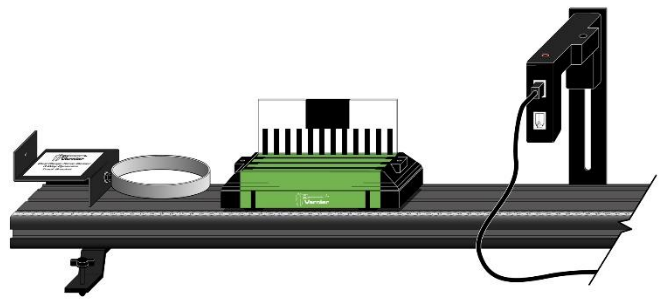
1. Determine your average power over the interval between the two times. This is the work you did over that time interval divided by the time it took. Your work is the force you exerted F times the height of the lift h. The net force on the object during the interval was the sum of the force you exerted and the opposing force of the objects weight: $ma = F_{net} = F - mg$. The force you exerted was $F = mg + ma$. The average acceleration of the object over the lift was $a = \frac{v_f^2 - v_i^2}{2h}$. Substitute this expression for a into the formula for your force F and simplify.
2. Multiply the formula you derived in 1 for force by the lift height h to obtain the formula for the work you did. Then divide the work done by the time interval Δt to find the formula for power.
3. Substitute the known values for m, h, vi, vf, and Δt into this formula to determine your personal power.

Activity 2 ~ Inelastic Collision

Procedure

1. Attach a hoop spring to the Dynamics Track Bracket, then mount the bracket on the end of a Track.
2. Obtain the value of the spring constant, *k*, for the hoop spring from your instructor.
3. In order to make the assumption that all the elastic energy stored in the hoop spring is transferred to the kinetic energy of the cart, one must minimize the energy "lost" due to frictional interactions. To accomplish this, the end of the track with the hoop spring should be raised enough so that the cart, given a gentle push, will travel to the far end of the track at nearly constant velocity. The leveling screws are sufficient for this task.

4. Attach the Cart Picket Fence to the dynamics cart. Set up a photogate near the dynamics cart so that the flag on the fence interrupts the sensor shortly after the cart leaves the spring, as shown in the Figure.



5. Determine the mass of your cart, fence, and any additional masses your instructor may have assigned you to use.
6. Start the data-collection program. Set up the photogate for Gate Timing. The length of the flag passing through the photogate is 0.05 m. The Gate State should read **Blocked** when the flag interrupts the sensor and **Unblocked** when it is moved beyond the sensor.
7. For this activity, you will first collect velocity data for varying changes in hoop spring compression, *x*, and record these manually in your lab notes. The change in length, *x*, is the distance that the hoop spring is compressed.
8. Start with a compression of 1.0 cm (hoop springs) and increment x by 0.5 cm. (don't compress beyond 50%)
9. Begin data collection. Perform several trials for each change in length, *x*. (How many trials should be run?) Be sure to stop data collection after each trial and then begin again before the next trial. When measuring *x*, it is important that you sight the scale from a position directly above the cart so as to avoid parallax error.

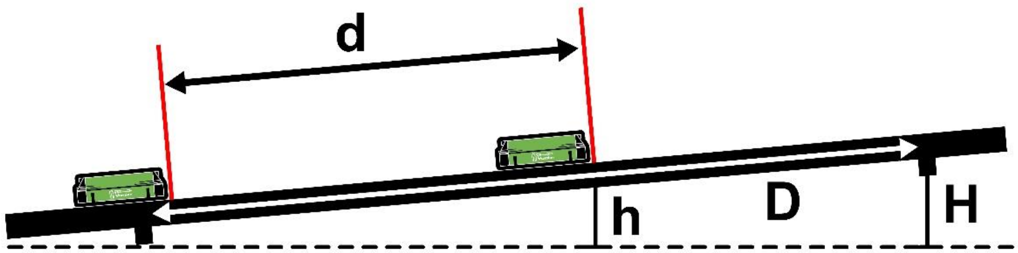
Analysis

1. Create a table for your data in Excel. Graph your data appropriately and add a trendline to your data. What does the slope of the line represent?
2. What relationship can you establish from your data. If you were to double the force, what relationships occur?
3. The area under a curve can also have physical significance. In this case, the area represents the work that was done on the spring as you applied a force parallel to the change in the spring's length. This work you did increased the *elastic energy* stored in the spring. Noting the shape of the area, write an equation relating the elastic energy to the applied force, *F*, and the change in length of the spring, *x.*
4. Determine the energy stored by the spring when it was compressed 0.020 m. Do this both algebraically, using the equation you derived in Step 3, and graphically, by finding the area under this portion of the curve. How do these values compare?
5. If you were to double the change in length of the spring, what effect would this have on the energy stored by the spring? Explain.

Activity 3 ~ Gravitational Energy

Procedure

1. Attach the same hoop spring to the Dynamics Track Bracket, then mount the bracket on the end of a Track.
2. In order to make the assumption that all the elastic energy stored in the hoop spring is transferred to the kinetic energy of the cart, one must minimize the energy “lost” due to frictional interactions. To accomplish this, the end of the track with the hoop spring should be raised enough so that the cart, given a gentle push, will travel to the far end of the track at nearly constant velocity. The leveling screws are sufficient for this task.
3. Let *D* represent the distance between the leveling feet and *H* the height you have elevated one end of the track. By measuring the distance, *d*, the cart moves up the track, you can use similar triangles to determine the cart’s height, *h*, above its zero position.



4. Position the cart so that it just touches the hoop spring without deforming it. It is helpful to adjust the position of the bracket so that one end of the cart falls on a “convenient” value on the scale. Note this value as the zero reference position, x_0, for the spring.

5. For this experiment, you will measure the distance, *d*, the cart travels before stopping as you vary the compression of the spring. This value, along with *H* and *D* will help you determine the height the cart reaches. You will create an Excel file to analyze the data you have collected.
6. Start with a compression of 1.0 cm (hoop springs) and increment x by 0.5 cm. (don’t compress beyond 50%)
7. Begin data collection. Perform several trials for each change in length, *x*. (How many trials should be run?) Be sure to stop data collection after each trial and then begin again before the next trial. When measuring *x*, it is important that you sight the scale from a position directly above the cart so as to avoid parallax error.

Analysis

1. Create a table for your data in Excel. Calculate values for the change in height of your cart, elastic energy and gravitational energy. Graph gravitational energy vs height and add a trendline to your data. What does the slope of the line represent?
2. Write a statement that describes the relationship between the gravitational energy and the height of the cart. Keep in mind any assumptions made in the design of the file for this experiment.
3. Examine the slope of the graph (units as well as numerical value). Recall that the SI unit of energy, joule, is defined as a N m. Simplify the units of the slope, then compare the value that you obtained with that obtained by other groups.
4. Now write the general equation describing the relationship between the gravitational energy and the height of an object (above the zero-reference position).

   Remember to complete and error analysis of your data!