Accelerometers

The use of accelerometers while at Silverwood adds to the experience and the enjoyment of your students in several ways. It gives the students a direct way to check any calculated values for accelerations and “g” forces that they have made as well as providing an opportunity for students with less sophisticated math backgrounds to quantitatively study the rides. It also provides a creative, hands-on activity for the classroom where students can design, construct and test the devices to be used at the amusement park. Trying to foresee and provide for all of the contingencies to be encountered at the park can lead to several days of class discussion and problem solving sessions.

There are basically two types of accelerometers, vertical and horizontal. Both directions are relative to the seat the rider sits in on the ride, with vertical taken as perpendicular to the seat. There are several good sources of information available describing the function and construction of accelerometers. Some of these references are listed at the end of this article. Here I have included the basic designs of two simple and common devices.

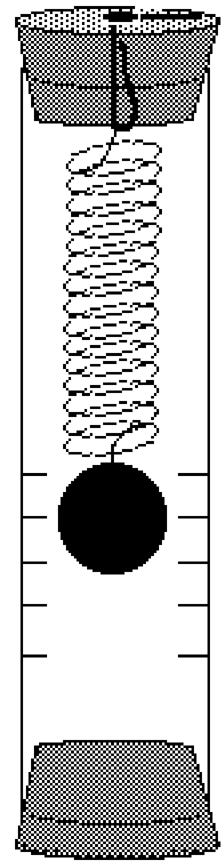
<u>Spring (vertical) Accelerometers</u>

Spring accelerometers are some of the simplest to build and understand. Basically they make use of Hooke’s law and consist of a mass hung from a spring. When the mass is hanging freely the extension, or stretch of the spring, is measured and gives an indication of the force being applied to the mass by gravity. When the device is at rest the stretch corresponds to the weight of the mass or an acceleration of 1g, or 9.8 m/s^2. If the spring is a good “Hooke’s law device” the force exerted on the mass by the spring is directly proportional to the extension of the spring, so doubling the stretch doubles the force, tripling the stretch triples the force, etc. The acceleration of the mass is given by Newtons second law, F=ma. Thus the extension of the spring give us a direct way of measuring the acceleration the device experiences, and the rider holding it. Spring accelerometers are useful in measuring vertical accelerations when held perpendicular to the floor and centripetal accelerations when held perpendicular to the axis of rotation. The construction of a simple spring accelerometer is described on the next page.

<u>Horizontal Accelerometers</u>

The horizontal accelerometer described later is simple to construct and use, once calibrated. It is also extremely useful on measuring angles of inclination for calculating heights of objects in the park. More on that later...

A Simple Spring Accelerometer



Materials

clear plastic tube, about 20-30 cm long
spring with hooked ends
small hanging mass or lead fishing weight
two rubber stoppers large enough to fit tube, one with a hole.
masking or duct tape
two <u>heavy</u> rubber bands
heavy paper clip

Procedure

1. Securely attach the hanging mass to one end of the spring, making sure it wont fly off during a ride.

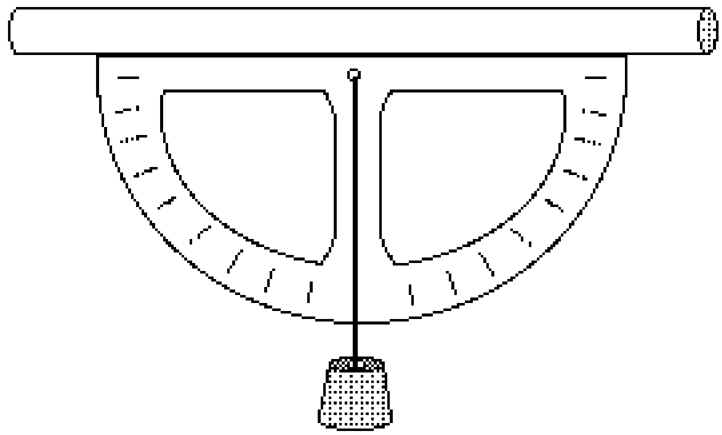
2. Bend the paper clip so that it has a loop in one end, as shown in the figure at right. Push the loop through the hole in the stopper from the top until it just pokes out the bottom of the stopper. Hook the free end of the spring to the loop and pull the loop back into the hole, drawing the spring tightly against the stopper. Bend the non-looped end of the paper clip over the top of the stopper to keep the spring held tightly in place. Place a small piece of tape over the end of the stopper to keep the paper clip in place.

3. Lower the mass/spring/stopper assembly into the plastic tube until the stopper is snugly in the end of the tube. Tape the edge to keep the stopper in place.

4. Calibrate the accelerometer. There are two ways of doing this: First, with the mass hanging freely, mark the position of the top or bottom of the mass on the plastic tube. This position corresponds to 1 g acceleration. Turn the accelerometer on its side and allow the spring to return to its unstretched length. Mark the position of the mass which now indicates a "zero g" acceleration. Be sure to use the same spot on the mass, top or bottom, that you used earlier. If your spring is a good "Hookes law device" (test it) the distance between the zero g and 1 g marks will be the same as the distance between 1 g and 2 g's, 2 g's and 3 g's, etc. Just measure them and mark them off on the tube. If your spring is not a good Hookes law device then hang another equal mass on the first and allow the spring to stretch. The position of the first mass will now represent an acceleration of 2 g's. Hang another mass on the other two and the first masses position represents 3 g's. Using either method mark off 4 g's worth of acceleration. None of the rides at Silverwood subject the rider to more than this. (Whew!)

5. Plug the open end of the tube with the remaining stopper and seal with tape. Form a wrist strap with the two rubber bands (so you won't lose it on a ride) by looping them through themselves and each other. (You'll just have to experiment, it can be done!) Secure it to the tube with another loop and some tape, and you're ready!

A Simple Horizontal Accelerometer



Materials

- 6 inch plastic protractor
- string
- small rubber stopper with hole
- large plastic drinking straw
- masking tape

Procedure

1. Attach the rubber stopper to one end of the string. Insert the other end of the string through the small hole in the protractor. Pull the string through the hole until the stopper hangs freely about 1 cm below the curved edge of the protractor. Knot or tie the string so that it stays in this position. (Note: if the protractor has a smooth side and a rough side, hang the string on the smooth side so that it can swing without getting hung up.)

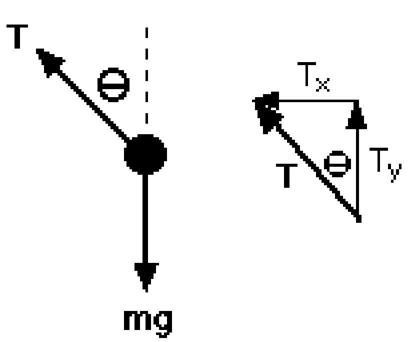
2. Tape the plastic drinking straw along the straight edge of the protractor.

3. Calibrate the accelerometer (see below).

Calibrating the horizontal accelerometer

When holding this device so that the straw is horizontal to the ground, there are two forces acting on the rubber stopper. Gravity and the string. Gravity pulls down with a force equal to the weight of the stopper, given by **mg**, where m is the mass of the stopper and g is the acceleration due to gravity. **T** is the tension in the string supporting the stopper. **T** can be resolved into its components T_x and T_y. The string supplies the force necessary to accelerate the stopper to the left (as shown in the figure) or to the right. T_x is the horizontal component of **T**, while T_y is the vertical component and cancels **mg** since the stopper is in equilibrium in the vertical direction. Since the stopper is accelerating in the horizontal direction (positive direction to the left) $T_x = ma_x$ by Newtons second Law.

As shown , the horizontal acceleration is given by g tan θ.



$$\Sigma F_x = T_x = ma_x \qquad T_x = T\sin\theta$$

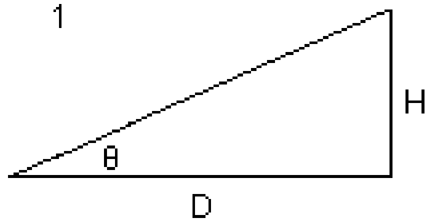
$$\Sigma F_y = T_y - mg = 0 \qquad mg = T_y = T\cos\theta$$

$$a_x = \frac{T_x}{m} = g\frac{T\sin\theta}{T\cos\theta} = g\tan\theta$$

Using the Horizontal Accelerometer to measure heights.

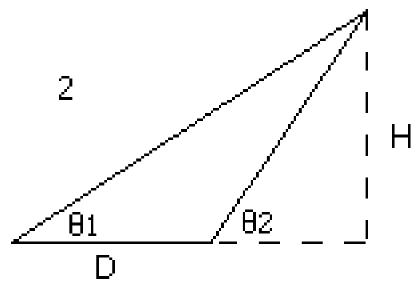
One of the nice features of the horizontal accelerometer is its double use as a clinometer. By sighting the top of the object through the drinking straw, the angle of inclination can be determined from the protractor by subtracting 90 from the angle indicated by the string. Depending on which base line D shown below the student is able to measure, the height of the object can be found by using the appropriate formula, given below, and a scientific calculator.

1



$$H = D \tan \theta$$

2



$$H = \frac{D(\sin\theta 1 \sin \theta 2)}{\sin(\theta 1 - \theta 2)}$$