10160 FORCE STICK

Purpose:

An accelerometer that can be used to determine peak values for horizontal or vertical accelerations.

Additional Materials Required:

Graph paper, triple beam balance

Description:

The force stick is a simple spring type accelerometer with a unique peak acceleration marker. It can be used to measure any acceleration, horizontal or vertical, in units of "g" (gravitational acceleration or gravitational field strength). A variety of experiments can be done to examine impulse and momentum, centripetal acceleration, linear accelerations, Hooke's law, simple harmonic motion, damping, and more.

Calibrating the Force Stick:

The mass on the Force Stick will move approximately 1.5 cm for every 1 "g" of acceleration. The stick portion of the Force Stick is intentionally left blank to allow the exercise of calibrating the device. This can be done by removing the mass from the spring and weighing it on a triple beam balance (approximately 14.4 grams), and then replacing the spring after recording its weight. Next, the weight of the entire device is measured and recorded, leaving the balance set up for the actual calibration process.

When the device is held vertically by the handle, the mass will hang in equilibrium. Mark the stick at the bottom of the hanging mass using a pencil. This is the position of the mass when the unit experiences 1 "g" of acceleration. If the unit is experiencing 2 "g" acceleration, the hanging mass will weight twice as much. To accomplish this calibration, set the balance to read the value of the assembled device plus the value of one more sliding mass. At this point, with the unit standing on the balance, push down gently on the sliding mass, stretching the spring, until the balance is in equilibrium. Again mark with a pencil to show the position of the bottom of the sliding mass on the stick. In this balanced condition, the sliding mass is where it would be if the device were experiencing an acceleration of 2 "g". By increasing the value set on the balance in increments of the sliding cylindrical mass, this procedure can be repeated to find marks for 2, 3, 4, 5, and so forth times the local acceleration due to gravity.

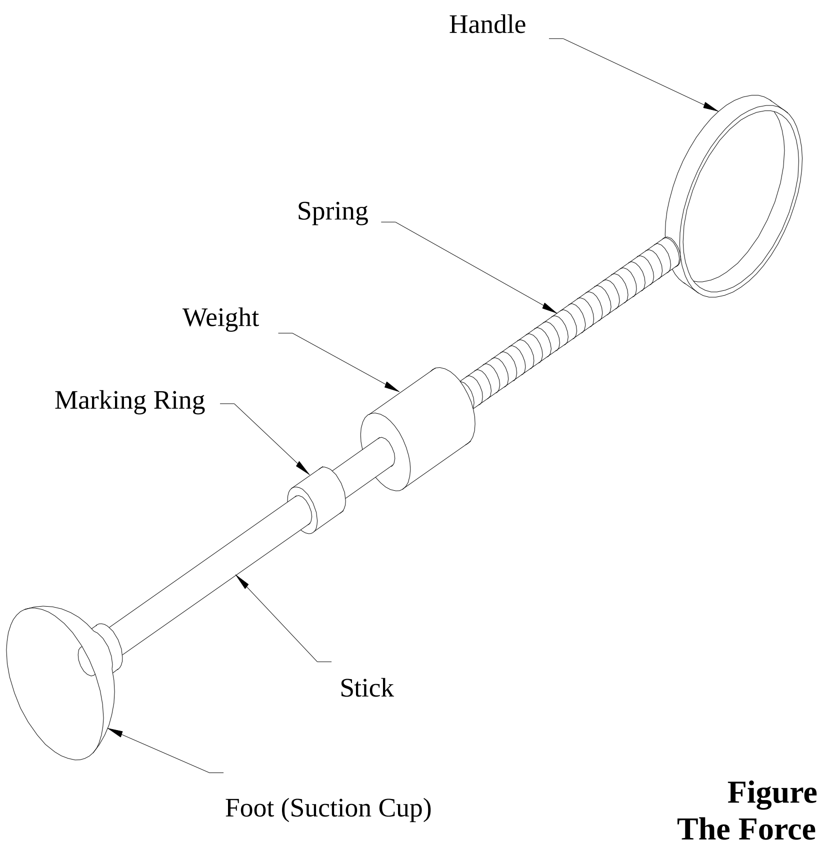

Figure 1
The Force Stick

Investigating Hooke's Law:

We can use the information gathered in the previous experiment to investigate Hooke's Law. Take a minute to look at the marks you have just made on the stick... I'll wait... Do all the marks have different spacings randomly distributed along the length of the stick? *Always* look for a pattern! In the great majority of cases, there will be a pattern in your collected data. So, with this in mind, are all of your data points equally spaced along the stick? Good! Now let's see if there is an equation to describe the stretched spring.

Take some graph paper and plot the spring force as a function of the displacement of the spring. Remember that the spring force is opposite in direction to the force you applied to the spring with your fingers, therefore, when you push down on the sliding mass, the spring is pulling up with an equal force.

The balance you used is calibrated to read in units of mass under the influence of gravity having a field strength of 9.8 newton per kilogram. To find the applied force, take the reading from the balance, express it in kilograms, then multiply this by 9.8, and add each entry to your table of values. Now plot the force required to stretch the spring as a function of the spring's displacement from equilibrium (its stretch).

After you have plotted these points on the graph paper, does it look like you can draw a straight line through these data points. If it does, draw the line. The general equation for a straight line is given by: $y = mx + b$, where:

y is the vertical coordinate of a point on the line
x is the horizontal coordinate of the same point on the line
m is the slope of the line (rise/run)
b is the intercept with the vertical axis

In our case, the y coordinate is the force applied to the spring, **F**. The x coordinate is the displacement of the spring from equilibrium (we'll still call this x), and m is the slope or proportionality constant relating the applied force to the spring displacement. This proportionality constant for the spring, usually called ***k,*** lets us write an equation which is valid for all simple springs: $F = -kx + b$ where the minus sign indicates that the spring's restoring force and the displacement are acting in opposite directions. The spring is always trying to return to the unstretched state. If the spring itself weighed nothing, and there were no friction in the system, we would expect the y intercept, b, to be zero.

Further Applications:

Estimating frictional forces:

Although the metal cylinder and the marking ring move freely, you may have noticed that they are not completely free of frictional forces. Friction will resist the motion of the metal cylinder and marking ring, making it seem as though the spring constant is slightly larger than it should be. This can be reduced by loosening the marking ring and smoothing the surface of the stick, but it cannot be eliminated completely. It is, therefore, helpful to estimate the size of the frictional force and use this estimate to determine the size of the error introduced into experiments done with the Force Stick.

Begin by locating the equilibrium position of the spring. This is done by holding the Force Stick upright and allowing the spring to stretch downward, making sure the marking ring is pushed all to the way to the foot, out of the way. After jiggling the stick, mark the stick at the bottom of the cylinder. Now tip the Force Stick upside down so the spring is compressed, jiggle it again, and once again mark the bottom (same as before) position on the stick. The equilibrium position is midway between these two marks, a position that can be found by measuring to each pencil mark from the same end of the device. Mark the equilibrium position of the spring on the Force Stick.

Next, hold the Force Stick horizontally and slide the marking ring up against the bottom of the metal cylinder, and continue to compress the spring. Gently let the spring push the metal cylinder and marking ring back towards the equilibrium position. Does the spring stop before reaching its equilibrium position? How far is the bottom of the cylinder from the equilibrium position? Because we know the spring constant, k, and the distance from equilibrium, it is a simple matter to calculate the force that is still compressing the spring. This force is due to friction between the weight and marking ring, and the stick.

Vertical Acceleration:

The Force Stick can be used in the laboratory or on field trips to measure both vertical and horizontal accelerations. The accelerometer will be most useful to you if you take the time to calibrate it first as already described. An approximate calibration may be achieved by marking 1 “g” intervals down the stick every 1.5 cm, starting at the equilibrium position and moving toward the foot of the stick.

To use the Force Stick as a vertical accelerometer, mount the suction cup on the foot of the stick by just pushing the post at the foot of the stick into the hole on the top of the suction cup. Firmly place the suction cup on the object whose acceleration you wish to measure. Hold the stick by the loop at the top and steady it so that it remains vertical throughout the experiment. For example, if you wish to measure the vertical acceleration encountered on a roller coaster, you would place the foot of the Force Stick on a convenient flat surface near you and within sight. While holding the top of the Force Stick, watch the movement of the metal cylinder as the ride progresses. As you experience different vertical acceleration, the weight will move up and down on the stick. If you have previously calibrated the force stick by one of the methods already described, you can monitor the acceleration as you go. To record the maximum acceleration, slide the marking ring up under the weight before beginning the ride, and as the weight moves, it will push the marking ring down the stick. The top of the marking ring will indicate the maximum acceleration for that trial.

Horizontal Acceleration:

Horizontal acceleration are determined in the same way as described above. Merely hold the Force Stick in a horizontal position with the suction cup foot firmly against the object whose acceleration you wish to measure. Again you can monitor the acceleration as you go, or use the marking ring to hold the maximum value for the particular trial.

Centripetal Acceleration:

We have described the determination of linear acceleration, but the device can be used also to determine the acceleration required for uniform circular motion. The Force stick can be spun in a horizontal circle by hand using the plastic ring at its top. Using a finger or a pencil, spin the device as smoothly as possible, moving your hand as little as possible. The sliding cylinder will give the centripetal acceleration of the mass for a particular rotational speed on the previously calibrated stick. Keeping the number of revolutions per second as constant as possible, the centripetal acceleration should be likewise a constant. After some practice, begin timing the revolutions. Centripetal acceleration is given by the expression: $a = \omega^2 r$

This is the acceleration toward the center of rotation. It is also equal to the restoring force per unit mass moving on the circular path. If you wish to check the acceleration indicated by the Force Stick, you can time some number of revolutions to calculate the rotational speed ω (radians/second). The radius r can be measured from the center of rotation to the position of the marking ring.

Vertical Circle:

Trying to spin the device in a vertical circle introduces other considerations since the local acceleration due to gravity goes from adding to subtracting from the centripetal force being exerted by the spring. The cylinder does not trace out a true circle, and the acceleration has minimum and maximum peaks. Near the top, the distance from the center of rotation is the smallest, and near the bottom, this distance is the greatest.

You can calculate the expected centripetal acceleration for a given angular speed by first looking at a force diagram for the Force Stick spinning in a vertical circle. At the top of the circle, all forces on the weight are downward. This includes the centripetal force, weight, and spring force. At the bottom of the circle, the centriptetal force and spring force are upward and the weight is still down. Pick the top of the circle as an example. At the instant the weight is at the top of the circle, the spring force and weight are both downward and are equal to the total centripetal acceleration. From the force diagram, this can be written: $-\omega^2 r = -mg -kx$

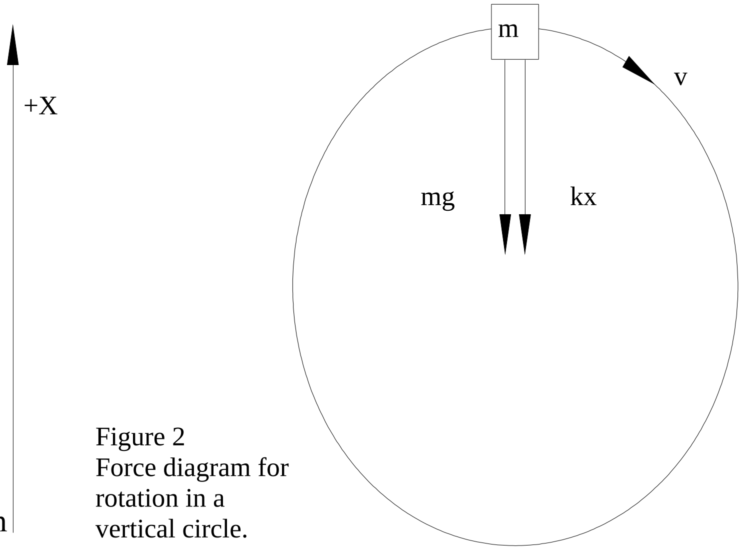

Figure 2
Force diagram for rotation in a vertical circle.

Remember that x is the distance from the spring's equilibrium position. Noting that the distance r from the center of rotation is just the equilibrium position of the spring, E, plus the spring's displacement, **x**. $m\omega^2(E+x = mg+ kx$ so that solving for the displacement, from equilibrium, gives us: $X = (\omega^2 E - g)/(k/m - \omega^2)$ Try calculating the spring displacement for the bottom of the circle and the sides. How do these values for the displacement, x, differ form that calculated for the top of the arc? Remember that the marking ring will only indicate the *maximum* displacement (and acceleration).

Elastic and Inelastic Collisions:

You can also use the Force Stick to investigate different types of collisions. By placing the suction cup on the foot of the stick, you can look at the effects of inelastic collisions. By replacing the suction cup with the rubber ball, the Force Stick will experience elastic collisions. These experiment are more qualitative, but are useful in demonstrating the relationship between impulse and change in momentum.

When you are ready to take measurements, begin with the inelastic collisions. Place the suction cup on the foot of the Force Stick. Hold the stick by its top ring a distance of one meter above the floor. After making sure it is not moving, release the device. As it strikes the floor, the metal cylinder will push the marking ring down the stick some distance. This records the maximum acceleration felt by the Force stick as it was stopped by the floor. Replace the suction cup at the foot of the Force Stick with the rubber ball and repeat the experiment described above, dropping the Force Stick from the same height of one meter. Measure and compare the maximum acceleration as before.

To get more useful readings from the Force Stick during collisions, it helps to attach the device to an object with a significantly larger mass than the Force Stick itself. For better elastic collisions, for instance, attach the suction cup foot of the Force Stick to a smooth inflated playground ball and examine the elastic collision between the ball and the floor.

Trouble Shooting:

Keep the length of the stick as smooth as possible. If the stick begins to get nicks and gouges on its sides due to rough handling, you can buff them out using very fine steel wool or very fine sandpaper. Pencil marks placed on the side of the stick can be removed with an ordinary eraser. Most other marks (such as felt markers) can be removed with alcohol on a soft cloth. The marker ring can be adjusted by removing the suction cup from the foot to allow the ring to be taken off. The split ring can be opened or closed slightly and then be replaced. The ring should offer some resistance on being pushed along the rod, but does not want to slide on its own without being pushed.

Time Allocation:

To prepare this product for an experimental trial should take less than two minutes. Actual experiments will vary with needs of students and the method of instruction, but are easily concluded within one class period.

Feedback:

If you have a question, a comment, or a suggestion that would improve this product, you may call our toll free number.