Statics

Equipment

<table>
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<tr>
<th>Quantity</th>
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<tr>
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<td>High Res Force Sensor</td>
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<td>Rotary Motion Sensor</td>
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<td>Dynamics Track System</td>
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<td>Cent. Force Pendulum</td>
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<td>Large Rod Base</td>
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<td>Table Clamp</td>
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<td>Multi-Clamp</td>
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<td>90 cm Rod</td>
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<td>Braided String</td>
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<td>1</td>
<td>Elastic Bumper</td>
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Introduction

This lab investigates the addition of vectors in a system that is in static equilibrium. The components of tension from the two parts of the string are compared to the Force Sensor pulling at the center of the string.

Figure 1: The movable Force Sensor (on the Base) applies a measured force to the center of the string, and the second Force Sensor (mounted on the Rotary Motion Sensor) measures the resulting Tension in the string. The string angle is measured directly using the Rotary Motion Sensor. By sliding the Endstop to the left or right, this angle can be easily varied.
Setup

1. Use the 90 cm Rod and Table Clamp (see Figure 2) to suspend the Rotary Motion Sensor.

![Figure 2: Rotating Force Sensor](image)

2. The Force Sensor fastens to the Rotary Motion Sensor as shown in Figure 3. Slide the aluminum cylinder (from the Centripetal Force Pendulum) onto the shaft, then drop the Force Sensor onto the cylinder.

![Figure 3: Connecting Force Sensor](image)
3. The brass screw and clip (from the Centripetal Force Pendulum) hold the Force Sensor cord at the rotation point, decreasing the unwanted torque of the cord. Slide the clip onto the cord (see Fig. 3) and use the brass screw to fasten it to the shaft of the Rotary Motion Sensor.

4. Tighten the black thumb screw on the Force Sensor to secure it to the aluminum cylinder.

5. Drape the Force Sensor cord over the Multi-Clamp (see Fig. 2). Keeping the cord vertical minimizes the torque of the cord.

6. Plug the mounted Force Sensor into Port P1 as shown in Figure 4. Plug a second Force Sensor into Port P4. Plug the Rotary Motion Sensor into Port P2.

![Image of Sensors](image)

Figure 4: Plugging in Sensors

7. The Force Sensor that applies the sideways force is supported by the 45 cm Rod and Base (see Fig. 5). Slide the Force Sensor all the way down on the Rod until it rests on the Base shoulder as shown in Figure 6.

8. Adjust the height of the Rotary Motion Sensor so that the hooks of the two Force Sensors are the same height. Make sure the axle on the Rotary Motion Sensor doesn't touch the Table Clamp.

9. The edge of the track rests up against the Rotary Motion Sensor. Use the Screw Feet to adjust the height of the track to match the edge of the Rotary Motion Sensor as shown in Figure 7.

11. Change the Sampling Mode to Fast Monitor Mode.

12. Create a table with five columns: Create a new User-Entered data set in the first column called String Angle (units of Degrees); create a User-Entered data set in the second column called String Tension (units of N); create a User-Entered data set in the third column called Side Force (units of N); create a calculation in the fourth column (units of N):

\[
\text{Calculated Side Force} = 2 \times \text{String Tension (N)} \times \sin(\text{String Angle (°)})
\]

and a calculation in the fifth column (units of %):

\[
\text{Percent Error} = \frac{\left| \text{Calculated Side Force (N)} - \text{Side Force (N)} \right|}{\text{Calculated Side Force (N)}} \times 100
\]

**String Center**

The Force Sensor pulls at the "center" of the string as shown in Figure 8. One end of the string is attached to the second Force Sensor and the other end connects to the Endstop. Since we measure the angle only on one side, we must make both angles the same. To accomplish this, follow the steps below:

1. Cut a piece of string about 1 meter long and tie a non-slip loop on each end. Place the loops over the Force Sensor hook and the Brass Screw used to fasten the Force Sensor in place as shown in Figure 9.

2. Loop the string around the Endstop Post, and adjust the Endstop position to tighten the string.

3. Hold the string as shown in Figure 10, and loosen the Endstop. Mark the "center" position at the end of the loop. Whenever you apply a force to the string, you must make sure that the Force Sensor hook is pulling at this location.
Figure 8: The length of the string on the right must equal the distance from the center Force Sensor out to the pivot point on the mounted Force Sensor. This makes the two angles equal.

Figure 9: Finding “center” of the String

Figure 10: Marking “center” of String

Theory

The Force Sensor (see Fig. 11) pulls on the center of the string with a force, F. Since the two lengths of string are the same, the angle, θ is the same for both sides (see Fig. 12), and thus the tension, T, is the same in both sides of the string. Breaking the two tensions into their components, one can show that for Static Equilibrium,

\[ F = 2T \sin \theta \]  

(1)

Percent Error

Often in lab you are measuring something that has a known or accepted value. To compare your measured result with the accepted value, it is useful to calculate the error in that measurement.

\[ \% \text{error} = \left( \frac{\text{Measured} - \text{Accepted}}{\text{Accepted}} \right) \times 100 \]  

(2)
Procedure

1. Remove the string and zero both Force Sensors. Replace the loop over the hook on the "String" Force Sensor: Don't get the ends switched!

2. Hold the other end of the string over the center of the post on the Endstop as shown in Figure 13. Have the Endstop as far from the Rotary Motion Sensor as possible. Click on Monitor in the Experiment Control Bar. The Rotary Motion Sensor will zero on start at this initial position. Note that the Angle and Forces are shown in the Digits display.

3. Use the "Movable" Force Sensor (mounted on the movable Rod Base) to pull sideways on the string as show in Figure 14. Adjust the position of the Endstop for an angle between 10° and 15°. By gently moving the Rod Base, adjust the Side Force to be about 5 N. Check that the "String" Force Sensor is free to rotate and reads the correct angle.

4. Make sure the Movable Force Sensor hook is at the "center" of the string, and is square to the track: The string must pull straight out on the hook. It helps to loosen the thumb screw (see Fig. 14) and then re-tighten.

5. Recheck that the Side Force is about 5 N.

6. Click on Stop.
Changing Angle

7. Record your values in row 1 of Table I.

8. Using the angle and the measured tension in the string, use Eqn. (1) to calculate the expected Side Force, and enter in column 4 of the Table.

9. Compare this Calculated Force to your measured value using Eqn. (2) and enter this error in column 5 of the Table.

10. Move the Endstop about halfway towards the Rotary Motion Sensor. Hold the end of the string over the center of the post on the Endstop as before to set the zero. Click on Monitor.

11. Adjust the position of the Endstop for an angle between 45° and 50°.

12. By gently moving the Rod Base, adjust the Side Force to be about 5 N as before.

13. Check all measurements as before, then click on Stop.

14. Record all values in row 2.

15. Repeat for an angle between 70° and 75°. If the track tends to move, have someone hold it in place when pulling on the string.

16. Record all values in row 3.

Analysis

1. How do your calculated values for the Side Force compare to your actual measured values?

2. What might account for the discrepancies? Which angle was the most accurate? Why?

3. At your largest angle, which is bigger, the Tension in the string or the Side Force?

4. In the limit that \( \theta \rightarrow 90° \), what is the Tension in the string compared to the Side Force?

5. What is the physical arrangement of the string?

6. At your smallest angle, which is bigger, the Tension in the string or the Side Force?

7. In the limit that \( \theta \rightarrow \) zero, what is the Tension in the string?
Setup - Elastic

You will now replace the String with Elastic Cord (from the ME-8998 Elastic Bumper). This allows you to take continuous data as the cord is stretched (see Fig. 15) and the angle is changed.

1. Cut a piece of Elastic Cord about 0.8 m long and tie a non-slip loop on each end.

2. Stretch the Elastic Cord between the Force Sensor and the Endstop. Move the Endstop back to about 1m, to create a large enough force to turn the Force Sensor on the Rotary Motion Sensor. Don't pull sideways on the cord with the Force Sensor on the Base yet!

Figure 15: Using Elastic Cord

Figure 16: Notice how the Base slides under the Track. This allows the Force Sensor to reach clear to the middle of the Track.
Elastic Data

3. Create a table with three columns: Angle in the first column, Force Ch. P4 (side force) in the second column, and Force Ch. P1 (tension) in the third column.

4. Change the Sampling Mode to Keep Mode.

5. With the Cord stretched straight along the Track, click on Preview in the Experiment Control Bar below. The program is in "Preview" mode and will not record the data until you press "Keep Sample". Note that the current values for the two forces and the angle are displayed in Table II on row 1.

6. Tap the Force Sensor (on the Rotary Motion Sensor) to make it oscillate slightly: This breaks loose the friction and allows it to settle down to its true equilibrium position. If the Angle doesn't read zero, stop and restart recording.

7. Use the "Movable" Force Sensor to pull sideways on the cord (as before). Pulling at the center of the cord, adjust the force to achieve an angle of about 1°. Note that the Base slides under the track as shown in Figure 16. Tap the Force Sensor to make it oscillate to break loose the friction.

8. Click on "Keep Sample" to store the values. Do NOT press stop!

9. Increase the sideways pull to achieve an angle of about 2°. Click on "Keep Sample" to store the values.


11. Click on Stop

Normalized Tension

Since both forces were changing each time you made a measurement, it is difficult to see the trend.

Create a table with four columns: In the first column, create a calculation (with units of degrees)

\[|\text{Angle}|=\text{abs}(|\text{Angle (°)}|)\]

In the second column, select the Force Ch. P4; In the third column, select the Force Ch. P1; and in the fourth column, create a calculation (with units of N)

Normalized Tension=[\text{Measured String Tension, Ch P1 (N)}]/[\text{Measured Side Force, Ch P4 (N)}]

The "normalized" Tension ratio shows you at a glance how much bigger (or smaller) the Tension in the string is.
Another way to view this calculated value is to say that if you had always made the Side Force be 1 N, then this value would be the actual Tension Force in Newtons.

1. Take the ratio of a few of the values to make sure the calculation is correct.

2. In general, what happens to the Tension in the string as the angle, $\theta$, gets smaller?

3. Create a calculation:

$$\text{sine (}|\theta|\rangle=\text{sin}(\text{abs}([\text{Angle (°)]}))$$

4. Make a graph of Normalized Tension vs. sine (|$\theta$|).

5. Is this graph linear? Should it be?

6. Try an Inverse Fit from the Curve Fit Tool. How does it fit?

7. What is the relationship between the tension, $T$, and the sine of the angle?