LAB 9: TORQUE AND COUNTERTORQUES(TPL1)

Goals:

- Calculate and measure the torque on a horizontal bar with vertical or angled cables

Introduction The force probe provides a very convenient way to measure forces that are applied to an object. If we set up a horizontal bar with weights hanging at different intervals, the force probe can be used to measure the torques on the bar, as applied to different points.

Preliminary activities

1. Prepare equipment. Connect the force probe through USBLink and then to the laptop. It would be very helpful to look at the online help page for this lab. Start the DataStudio software.

2. Load the experiment file. Download the DataStudio file **`Lab09_Torque.ds`** from the lab schedule webpage.

3. Preparing force probe. There are two vertical poles we will be using, one in the middle of the table, and the other clamped near the end. The force probe should be clamped to the pole on the end of the table, pointing downward.

4. Zeroing force probe. Press the ZERO button on the side of the probe (this is a "mechanical" tare for the probe). We can't "zero" the probe in DataStudio, so occasionally we might need to keep track of a zero "offset" and account for it.

Part 1 Simple Torques on Horizontal Bar (Hanging Sign problem)

One of the classic problems in equilibrium physics is the "hanging sign" problem. You want to hang a horizontal bar out from a building and be able to hang a sign vertically down from it. In this section, we will start with a "cable" that lifts vertically, and in the next section we can deal with a cable at an angle.

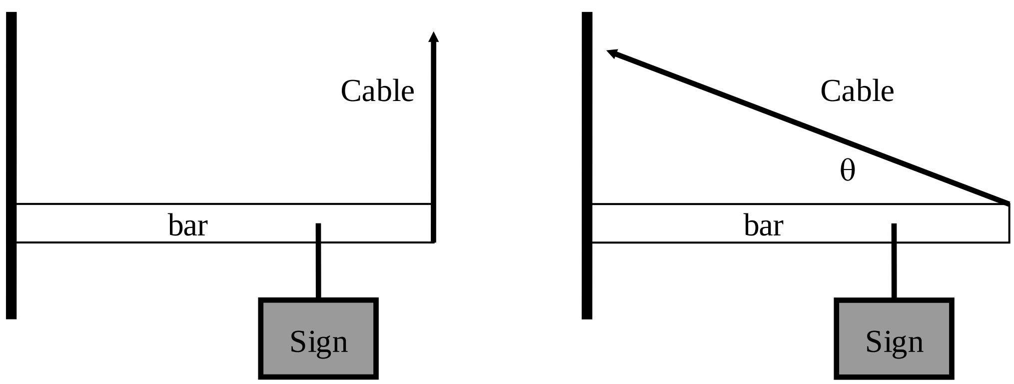
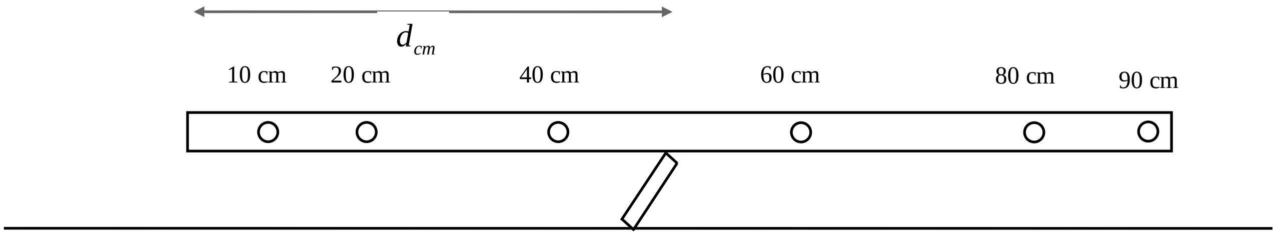


Figure 1 - Conceptual view of hanging sign problem (vertical and angled cable).

1. Determining the mass of the meter stick. We will need to know the meter stick's mass for some of the later calculations. Record the mass (measured from the scale) below:

Mass of meter stick = ________ kg

We also need to know exactly where the center of mass is (since the holes may not be symmetrical) ... to do this, you could balance the meter stick on an edge of the small piece of wood as illustrated below, or on your finger:



Location of CM of the meter stick = d_{cm} = ________ m

<u>2. Preparing equipment.</u> For the pole that is placed in the middle of the table, there is a short wooden rod that should be clamped horizontally to the interior pole. This will be the "pivot pin" for the meter stick that represents the bar. Slip the hole at the 10 cm mark on the meter stick over the pivot pin. At the 90 cm hole, there should be a string that will rise vertically to the force probe. Adjust the position of the force probe (or the pivot pin) so that the meter stick is horizontal with the table. See the diagram below:

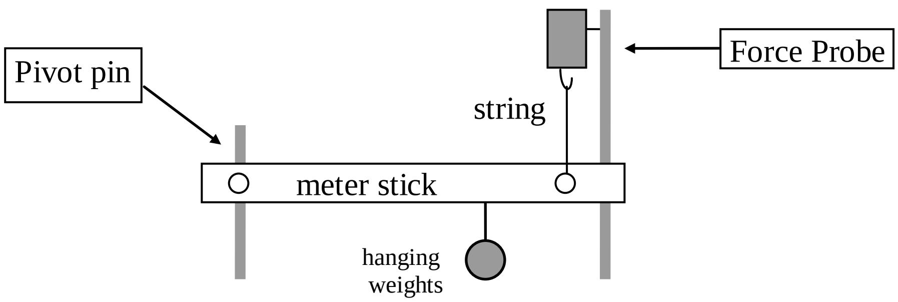
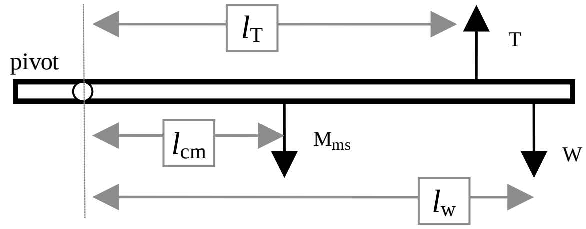


Figure 2 - Vertically supported horizontal bar.

<u>3. Torque calculations.</u> There will be forces acting on the bar that will try to rotate the bar in one direction or another around the pivot point. If a weight is hung from the bar somewhere to the right of the pivot in the picture above, the bar will try to rotate clockwise. The string will support the bar (with a force that will try to rotate the bar counter-clockwise) and we can read the tension in that string with the force probe. If the bar is not moving, then it is in a state of equilibrium. In this situation, that means that all the forces and all the torques sum to zero in a vector sense. Taking into account a hanging weight (w=mg) at a distance (l_w) from the pivot, and the weight of the meter stick ($m_{ms}g$) acting at the "middle" (center of mass = center of gravity) of the meter stick (l_{CM}) and the tension in the string T acting at the distance where the string touches (l_T), the torque equation becomes:

$$\text{Torque}_{ccw} = \text{Torque}_{cw}$$
$$T(l_T) = m_{ms}g(l_{cm}) + w(l_w)$$
$$T = \frac{m_{ms}g(l_{cm}) + w(l_w)}{l_T}$$



Remember - all values are measured relative to the Pivot point!! (l_{cm} = d_{cm} – 10 ... in this case)

4. Bar without any hanging weights. Without any hanging masses on the meter stick, click START to record the force needed to support just the meter stick. Record the force in the Data/Question sheet data table, calculate the expected tension (based the relationship above), and calculate the % difference between the two values. (This may be very "rough" since there is not much weight on the force probe.) Record this information on the Data/Question sheet.

Question Answer on Data/Question sheet.
If you hung masses from different locations along the bar, what would the effect be on the tension measured at the far end? Explain.

5. Masses hung from center of bar. Test the relationship developed in Section 1.4 by hanging a 300 gram mass, and separately, a 600 gram mass from the center of the meter stick, and then directly under where the string is attached. Measure the tensions for each of these four cases, calculate the expected tensions, and compare them. Don't forget to take into account the torque of the meter stick's own weight on the pivot.

REMEMBER TO ZERO THE FORCE PROBE BEFORE EACH TRIAL

Express your results in the charts on the Data/Question sheets.

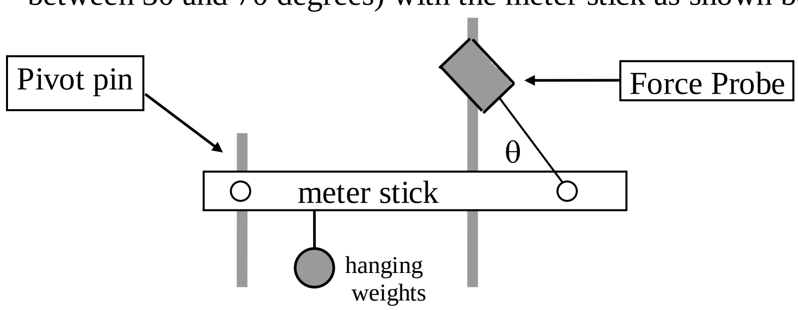
Prediction Answer on Data/Question sheet
Suppose you hung the 300-gram mass at a point closer to the pivot than the center, or a point farther away compared to the center. What would the effect be on the tension measured by the force probe for those two cases?

6. Masses hung from non-standard locations along bar. Hang a 300-gram mass from the distance values in the chart below (the distances are relative to the pivot). Measure the tensions for each of these two cases, calculate the expected tensions, and compare them. Don't forget to take into account the torque of the meter stick's own weight on the pivot. Express your results in the chart on the Data/Question sheet.

Question Answer on Data/Question sheet.
Do the results in the chart above match your prediction above? Explain any significant differences.

Part 2 Angled Cable Support on Horizontal Bar

1. Setting up equipment. Adjust the equipment so that the support string makes an angle (something between 30 and 70 degrees) with the meter stick as shown below:



*Note: Each time you make a measurement, make sure the string is **parallel** to the axis of the force probe (comes straight out from the end!)*

Figure 3 - Angle-supported horizontal bar.

Angle of string with respect to horizontal bar = _________ degrees

2. Torque calculations for angled support cable. We can modify the relationship above by substituting the vertical component of the string force in place of the total tension. (The horizontal component of the tension is balanced by a horizontal force acting at the pivot pin.) The torque equation becomes:

$$T \sin\theta (l_T) = m_{ms} g(l_{CM}) + w(l_w)$$

$$T = \frac{m_{ms} g(l_{CM}) + w(l_w)}{l_T \sin\theta}$$

3. Bar without any hanging weights. Without any hanging masses on the meter stick, click START to record the force needed to support just the meter stick. Record the force below, calculate the expected tension (based the relationship above), and calculate the % difference between the two values. Record on Data/Question sheet.

Force probe tension = _______ N Tension calculated = _______ N

$$\% \text{ difference} = \frac{|T_{calc} - T_{meas}|}{\left(\frac{T_{calc} + T_{meas}}{2}\right)} \times 100 = \_\_\_\_\_\_\_\_ \%$$

Prediction Answer on Data/Question sheet
If you hung masses from different locations along the bar, how would the effect on the tension in this case compare with the previous case (vertical support cable)? Explain.

4. Masses hung from different lengths along bar. Test the relationship developed in Section 2.2 by hanging a 300-gram mass from the different positions along the meter stick as shown in the chart below. Measure the tensions for each of these three cases, calculate the expected tensions, and compare them. Don't forget to take into account the torque of the meter stick's own weight on the pivot. Put data in the chart on the Data/Question sheet.

Question Answer on the Data/Question sheet.
Do the results in the chart above match your prediction above? Explain any significant differences.

DATA/QUESTION SHEET - LAB 10: TORQUE AND COUNTER TORQUES

Part 1 Simple Torques on Horizontal Bar (Hanging Sign problem)

4. Bar without any hanging weights.

Force probe tension = _______ N Tension calculated = _______ N

$$\% \text{ difference} = \frac{|T_{calc} - T_{meas}|}{\left(\frac{T_{calc} + T_{meas}}{2}\right)} \times 100\% = \_\_\_\_\_\_\_\_ \%$$

Question If you hung masses from different locations along the bar, what would the effect be on the tension measured at the far end? Explain. ___________________________________

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5. Masses hung from center of bar.

Mass hung from the center point

Mass (kg)	Weight = mg	T (calc) N	T (meas) N	% difference
0.3 kg				
0.6 kg				

Figure 4 - Chart for hanging masses at center of bar.

Mass hung from point where string is attached

Mass (kg)	Weight = mg	T (calc) N	T (meas) N	% difference
0.3 kg				
0.6 kg				

Figure 5 - Chart for hanging masses at end of bar.

Prediction Suppose you hung the 300-gram mass at a point closer to the pivot than the center, or a point farther away compared to the center. What would the effect be on the tension measured by the force probe for those two cases? ____

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6. Masses hung from non-standard locations along bar.

Distance from pivot (cm)	T (calc) N	T (meas) N	% difference
20 cm			
60 cm			

Figure 6 - Chart for hanging masses at non-standard positions

Question Do the results in the chart above match your prediction above? Explain any significant differences. ____
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Part 2 Angled Cable Support on Horizontal Bar

1. Setting up equipment.

Angle of string with respect to horizontal bar = _________ degrees

3. Bar without any hanging weights.

Force probe tension = _______ N Tension calculated = _______ N

$$\% \text{ difference} = \frac{|T_{calc} - T_{meas}|}{\left(\frac{T_{calc} + T_{meas}}{2}\right)} \times 100\% = \_\_\_\_\_\_\_\_ \%$$

Prediction If you hung masses from different locations along the bar, how would the effect on the tension in this case compare with the previous case (vertical support cable)? Explain.
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4. Masses hung from different lengths along bar.

Distance from pivot (cm)	T (calc) N	T (meas) N	% difference
20 cm			
55 cm			
80 cm			

Figure 7 - Chart for hanging masses at different distances from the pivot point.

Question Do the results in the chart above match your prediction above? Explain any significant differences. ____
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Questions/Suggestions → James Nolta - Nolta@LTU.EDU