Experiment 6: Coefficients of Friction

Figure 6.1: Inclined Plane

EQUIPMENT

Inclined Plane
Wood Block
Triple-Beam Balance
Digital Balance
Lab Pro and Connections
Dual-Range Force Sensor
Masses
Mass Hanger
10 cm length of string

Advance Reading

Text: Newton's Laws, maximum static friction, kinetic friction, coefficients of friction.

Lab Manual: Appendix B (*Logger Pro*)

Objective

To measure and analyze the coefficients of friction μ_s and μ_k between a wood block and wood plane.

Theory

Friction is the force that resists the relative motion of one surface in contact with another surface. We consider two types of friction: static and kinetic. Usually, kinetic friction is less than the maximum value of static friction.

The maximum static friction is given by:

$$F_{f_{max}} = \mu_s F_N \tag{6.1}$$

and the kinetic friction is given by:

$$F_{f_k} = \mu_k F_N \tag{6.2}$$

where μ_s is the coefficient of static friction, μ_k is the coefficient of kinetic friction, and F_N is the normal force.

The *angle of repose* is defined as the maximum angle at which an object on an inclined plane will retain its position without tending to slide. It can be shown that the tangent of this angle equals μ_s:

$$\tan\theta = \mu_s \tag{6.3}$$

Similarly, it can also be shown that when an object slides down an incline at constant velocity:

$$\tan\theta = \mu_k \tag{6.4}$$

In this experiment, the frictional force between a wooden block and the wooden surface of a horizontal and inclined plane will be derived and measured. By graphing these data, coefficients of static and kinetic friction will be obtained.

As you perform this experiment, theoretical quantities will be determined prior to measuring for *Part 2* through *Part 5.* These calculations will require the free-body diagram solution method (refer to Page 28).

When $a = 0.0\ \mathrm{m/s^2}$, the force probe measures the force necessary to counteract friction and thus is equal to F_f.

If the block is pulled at constant velocity, starting from rest, there is a "bump" at the beginning of the graph, and the remaining graph is, on average, horizontal.

The bump at the beginning of the graph is a result of overcoming the maximum static friction, $F_{f_{max}}$, which is usually greater than kinetic friction, F_{f_k}. The maximum value of this bump allows us to determine μ_s. The horizontal portion of the graph, $F_{f_{avg}}$, allows us to determine μ_k. A sketch of how your graph should look is shown in Fig. 6.2. Note that the force begins at zero newtons, which will require you to leave slack in the string until data is being collected.

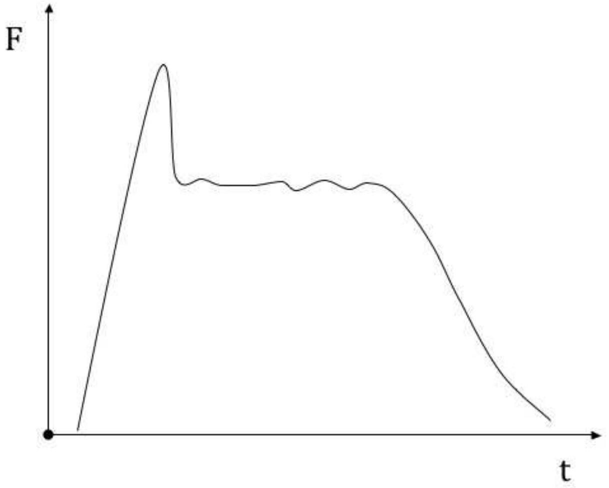

Figure 6.2: Sample *Force vs. Time* graph

Prelab 6: Coefficients of Friction

Name: ____

1. Define the angle of repose. (20 pts)

2. Using the free-body diagram solution method (Page 28), derive the equation for T for a block of mass m being pulled horizontally ($\theta = 0°$) at a constant velocity. (Draw the forces to scale and include friction.) *Note*: It is unlikely that you will be able to finish the experiment if you are not able to solve force problems in a timely manner; refer to *Prelab Questions 2, 3, and 4.* (30 pts)

3. Using the free-body diagram solution method, derive the equation for T for a block of mass m being pulled up an incline ($\theta > 0°$) at a constant velocity (tension parallel to the plane). Set the coordinate system such that the *x-axis* is parallel to the incline. (Draw the forces to scale and include friction.) (30 pts)

4. Using the free-body diagram solution method, calculate T for a block of mass $m = 150$ g being pulled up a 15° incline at constant velocity. The coefficient of kinetic friction, μ_k, is 0.3. (20 pts)

PROCEDURE

PART 1: Preparation

1. For all calculations involving forces, always use the free-body diagram solution method provided on Page 28.
2. Consider a wood block being pulled horizontally at a constant velocity. Derive the equation of force, T, in terms of the following quantities: m, g, μ, θ.
3. Ask your TA to check your equation before proceeding.
4. Refer to *Appendix B* for *Logger Pro* information. Open "12a Static Kinetic Frict.cmbl." A window will open as a *F vs. t* graph.
5. Calibrate the force sensor: *Experiment* ⇒ *Calibrate* ⇒ *Lab Pro*. The window has four tabs at the top. Choose *Calibrate*. Click on "Calibrate Now."

Reading 1:

6. Calculate and enter the force due to 0.00 kg. Hold the sensor steady, supported vertically against the table edge. Select *Keep*.

Reading 2:

7. Measure, then suspend 0.55 kg from the sensor.
8. Calculate and enter the force due to 0.55 kg. Hold the sensor steady. Select *Keep*, then *OK*.
9. Test the calibration: Click *Collect* while suspending 0.55 kg from the force probe. The graph should plot the correct amount of force. If it does not, then there is a problem. First, re-calibrate. If that isn't sufficient, refer to *Appendix B*.

PART 2: Block on a Horizontal Plane: $\theta = 0°$

10. You will need to understand *Step 11* through *Step 14* before collecting data.
11. Always leave slack in the string until the collection of data begins.
12. Technique will be important for this experiment. You will want to use the same part of the inclined plane for all parts of the experiment; keep the string parallel to the surface of the inclined plane while pulling the block, and pull the block at a constant velocity.
13. A few trials using small and large diameter masses prior to collecting data will yield more accurate results.
14. You will need to determine for each trial f_{max}, f_k, and F_N (details follow):
    - To determine the graph value of f_{max}, use the *Examine* button, then position the cursor at the highest peak.
    - To determine f_k, click-and-drag the mouse to select the constant force section of the graph, then use the *Stats* button.
    - To determine F_N, refer to your free-body diagram solutions.
15. Measure all masses!
16. Define $g = (9.80 \pm 0.01)$ m/s^2
17. Measure the mass m = (block + 0.5 kg).
18. Attach the string from the block to the force sensor. Click *Collect*. Pull m (block + 0.5 kg) across the plane at a constant velocity.
19. Determine f_{max}, f_k, and F_N.
20. Increase m for each trial, in increments of 0.5 kg, until a total of 2.5 kg has been added.

PART 3: Block on an Inclined Plane: $\theta = 30°$

21. Derive T (algebraically) for an object of mass m being pulled up an inclined (angle θ) at constant velocity (quantities as before).
22. Use the force probe to measure T for this situation ($\theta = 30°$, m = (block + 0.5) kg)

PART 4: Coefficient of Static Friction

23. Measure the angle of repose by slowly raising the inclined plane until the (block + 0.5 kg) just begins to slide.
24. Calculate μ_s from the measured angle (Eq. 6.3).

PART 5: Coefficient of Kinetic Friction

25. Measure the angle that the (block + 0.5 kg), when tapped, slides *without acceleration*.

26. It can be shown that when an object slides without acceleration after being tapped, then $\tan\theta = \mu_k$. Calculate μ_k from the measured angle.

PART 6: Graphing

27. Plot f_{max} *vs.* F_N and f_k *vs.* F_N on the same graph.
28. What do the slopes represent?

PART 7: Analysis

29. Derive the angle of repose equation for an object of mass m (Eq. 6.3).
30. It can be shown that when an object is lightly tapped, then slides *without acceleration*, $\mu_k = \tan\theta$. Derive this equation.
31. Calculate T from *Part 3* using your graph value of μ_k.
32. Compare μ_s values obtained from *Part 4* and *Part 6*.
33. Compare μ_k values obtained from *Part 5* and *Part 6*.

QUESTIONS

1. Show that $\mu_s = \tan\theta$ for the angle of repose. Refer to Page 28.
2. If the mass of the block is tripled, does the angle of repose change?
3. Why was it necessary to tap the block to get it started in *Part 5*?
4. Why can anti-lock brakes stop a car in a shorter distance than regular brakes? (Comment on the difference between static and kinetic friction.)
5. Compare the graph and experimental values for the coefficients of friction. Is $\mu_s > \mu_k$ for each method?