Lab 3. Friction

Goals

- To determine whether the simple model for the frictional force presented in the text, where friction is proportional to the product of a constant coefficient of friction, μ_K, and the magnitude of the normal force between the surfaces, n, applies to the cases of sliding aluminum-wood and aluminum-felt surfaces.
- If appropriate, to determine the kinetic coefficients of friction between wood and aluminum and between felt and aluminum.
- To determine whether the "constant" coefficients of friction are independent of the speed that one surface slides over the other for the two cases previously characterized. This is accomplished by letting the wooden block accelerate on the surface of the aluminum track.

Introduction

From a fundamental point of view one can say that all friction is due in one way or another to electromagnetic forces. Inter-atomic forces (also known as chemical bonds) are electromagnetic forces that act through distances that are on the order of the spacing between atoms, that is 10^{-10}–10^{-9} m. Most surfaces that appear smooth are rough when viewed microscopically. When viewed using visible light (with wavelengths between 400 and 700 nm), the surface will appear smooth and shiny if the roughness is smaller than the wavelengths of the light. Consequently the actual surface roughness can be as large as 10^{-7} m, equivalent to a hundred or more atomic spacings, before the roughness becomes apparent to the eye.

What we call friction arises from adhesion (atomic attraction) between the atoms of two surfaces in close proximity, even when roughness limits physical contact to the "peaks" on each surface. In some instances pieces of material can be torn off in the process of sliding across another surface, thus breaking some of the chemical bonds. For example, material is removed from a skidding rubber tire or a piece of wood as it is smoothed with sandpaper. Because chemical forces are ultimately electromagnetic in nature, friction can be attributed to electromagnetic forces.

The details are not yet well enough understood to make meaningful calculations and predictions. This is unfortunate, since about one-third of the world's energy resources are ultimately consumed by friction in one form or another.[1] The alternative is to characterize friction empirically, in other

[1] Bharat Bhushan, *Principles and Applications of Tribology* (John Wiley, New York, 1999).

words by experiment. Since static friction (the friction between two surfaces which do not move with respect to one another) is even more difficult to reproduce consistently, we will limit our study to kinetic friction, when two surfaces slide with respect to each other. Your textbook has made some simple claims for kinetic friction, namely that (1) the frictional force for a particular interface is directly proportional to the normal force exerted by one surface on the other, and (2) the frictional force is independent of the speed with which the surfaces are sliding with respect to each other.

Both of these claims are tested in this experiment, so you can begin to "get a feel" for the concept of friction. We will be studying the friction of a wooden block on a smooth aluminum surface and the friction of a felt covering on the block relative to the same aluminum surface.

Equipment set up

A 1.2 m long aluminum track acts as the supporting surface as a wooden block is dragged over it. To supply a constant force to the system in the direction of motion, a hanging mass is suspended by a string passing over a pulley at the end of the track and attached to the wooden block. By equipping the pulley with a photogate, the rotation rate of the pulley can measured. From this, Capstone computes the speed of the sliding block. This will allow you to keep the speed relatively constant as we do the measurements. Naturally, it will be impossible to keep the speed exactly constant.

Friction between wood and aluminum

Constant velocity measurements

If the wooden block and the hanging mass are moving at constant velocity, then we know that the net force acting on the system of the block and the mass must be zero (since the acceleration of the system is zero). Draw a free-body diagram of this system and show that the magnitude of the frictional force is equal to the weight of the hanging mass if the acceleration is zero. Your task is to test the hypothesis that $f_K = \mu_K n$, where f_K is the frictional force between the wooden block and the aluminum track, n is the normal force at the block-track interface, and μ_K is the constant coefficient of kinetic friction between the block and the aluminum track. Remember that μ_K is a dimensionless quantity; it has no units.

It is easier to achieve constant velocity at higher normal forces. Starting with the highest normal force and working down is less frustrating than starting with a low normal force and working up. Start with all four 100 g masses on top of the block for a total of 400 g of added mass. then remove one 100 g mass at a time. For each value of normal force, find the weight of the hanging mass which will keep the velocity of the system constant at a value between 0.2 and 0.3 m/s. You must give the system an initial push at the desired final velocity, since the acceleration after you quit pushing should be essentially zero when the weight of the hanging mass and the friction force are equal. From your text, you know that the force of friction on objects at rest can exceed that for objects in motion. Therefore the force of friction must change at some low velocity. It is important

to make sure that the velocity is approximately constant and within the correct range. Keeping the variation in speed small is better, but don't spend too much time on it.

Make an appropriate graph to determine whether the frictional force is directly proportional to the normal force in this case. If it is directly proportional, then determine the value for the coefficient of kinetic friction from your graph.

Checking for velocity effects

If we make the wooden block accelerate from rest rather than moving at a constant velocity, we can check whether the frictional force is really constant over a range of velocities from zero to the final velocity of the block at the end of the track. This is easily achieved by adding mass to the hanger. To evaluate the results, you will need to derive a relation between the acceleration of the wooden block, the hanging mass, and the frictional force. Include the details of this derivation in your report.

Draw free body force diagrams for both the hanging mass and the wooden block. For each of these objects the net force is equal to the mass times the acceleration according to Newton's second law of motion. (Assume that the pulley has no mass and has frictionless bearings.) The tension of the string connecting the two objects together should appear in the equations for both objects. You should have two equations with two unknowns, namely, the string tension, T, and the acceleration, a. Eliminate T and solve for a in terms of various known quantities, including the μ_K value you found above. If the frictional force is indeed a constant, you should observe that the acceleration depends only on quantities with constant values. (The mass values can be varied, of course, but they are constant during a given run; in the equation, therefore, they are constants.) The acceleration during a given run should be constant if the frictional force is constant for a given combination of mass values.

Place 300 g of mass on top of the block and add enough mass to the hanger (start with 120 g) so that the final velocity of the block when the hanger hits the floor is 1.0–1.2 m/s. A significant range of velocities is necessary if we are to test the hypothesis that the frictional coefficient is a constant, independent of velocity. Release the block from rest and let it accelerate down the track. Avoid looking at an acceleration graph directly because it is quite noisy; averages of noisy data are not so precise. If the acceleration is constant, the velocity-time graph should be linear. If so, use the curve-fitting capability of the Capstone software to get the numerical values for the slope and its standard deviation. (If you need help from your TA to do this, ask.) Taking three or more runs with same mass values gives a more reliable average acceleration value than simply a single run. You can also see how consistent the acceleration values are from run to run.

Using the equation that you derived earlier for acceleration versus mass, predict the magnitude of the acceleration for the block using the numerical value of μ_K determined from your constant velocity measurements. Compare this prediction with the actual acceleration obtained from the slope of the velocity plot in this exercise. (If the velocity-time graph is significantly curved, compare your predicted acceleration with the slope of the graph over the velocity range employed for the constant velocity measurements.) Use the standard error of the slope in this region as the uncertainty estimate for acceleration.

Based on your data, does the frictional force between the wood and aluminum surfaces depend on the relative velocity of the two surfaces? If so, does the frictional force increase or decrease as the relative velocity at the interface increases?

Friction between felt and aluminum

Constant velocity measurements

Turn the wooden block over so the larger felt side slides along the aluminum track. Use the same procedure you used for constant velocity measurements of μ_K on the wood-aluminum interface, keeping the velocity in the range 0.2–0.3 m/s. Make an appropriate graph to determine whether the frictional force is directly proportional to the normal force in this case. If it is directly proportional, then determine the value for the coefficient of kinetic friction from your graph.

Checking for velocity effects

Examine the effect of velocity on friction at the felt-aluminum interface using the same procedure you used to study the wood-aluminum interface. Place 200 g on top of the wooden block and about 100 grams on the mass hanger. Use enough mass to achieve a maximum velocity of 1.0–1.2 m/s. Do several runs, checking for consistency and for constancy of the acceleration. Predict the acceleration, using your value of μ_K from the constant velocity measurements (valid for velocities in the 0.2–0.3 m/s range, at least) and the equation you derived above. Compare this predicted value with the average acceleration over the same velocity range you used to determine μ_K. Again take three or more runs with the computer to get a better average and a meaningful uncertainty.

Based on your data, is the frictional force between the felt and aluminum surfaces independent of the relative velocity of the two surfaces? Does the frictional force increase, decrease, or remain constant as the relative velocity at the interface increases?

Summary

Summarize your findings clearly and concisely. Do your results support the hypothesis that friction can always be described by the simple equation given in your textbook? Cite numerical values from elsewhere in your report as you address this question.

Before you leave the lab please:
- Quit the Capstone software.
- Straighten up your lab station.
- Report any problems or suggest improvements to your TA.