EXPERIMENT 5

DETERMINATION OF FRICTION COEFFICIENT

**Purpose:** Determine $\mu_s$, the kinetic coefficient of friction and $\mu_k$, the static friction coefficient by sliding block down that acts as an inclined plane. $\mu_s$ and $\mu_k$ will be determined by the board with a pulley mounted on it in a horizontal position and applying known forces to the block.

**Apparatus:** Smooth wooden block with pulley attached to one end, string, mass holder, slotted massed, an inclined plane and hook.

**Theory:** We encounter friction at almost all times during the day. Friction between our foot and the floor helps us walk. In spite of its importance, friction is still not well understood. However, empirical laws describe the friction between two surfaces. Friction is a resisting force that acts along the tangent to two surfaces in contact when one body slides or attempts to slide across another.

Normal force is the force that each body exerts on the other body, and it acts perpendicular to each surface. The friction forces is directly proportional to the normal force. Static friction occurs when two surfaces are still at rest with respect to each other, but an attempt is being made to cause one of them to slide over the other one. The static friction force $f_s$ is given by

$$f_s \leq \mu_s N$$  \hspace{1cm} (Eq.1)

Where $N$ is the normal forces between the two surfaces and $\mu_s$ is a constant called the coefficient of static friction. Eq.1 tells us that the static friction forces varies in response to applied forces from zero up to a maximum value. If the applied force is less than the maximum, then there is no motion. The object will begin to move and no longer friction force is available.

When two surfaces are moving with respect to each other then, kinetic friction occurs, thus the friction is characterized by $\mu_k$ called the coefficient of kinetic friction. The kinetic friction force $f_k$ is given by
\[ f_k = \mu N \]  

(Eq.2)

Where \( N \) again stands for the normal force. Kinetic friction does not vary with speed and both friction coefficients are independent of the apparent area of contact between two surfaces.

If the block is placed on an inclined plane, after at some angle \( \theta \), the block will slip down. The block is in equilibrium for motion perpendicular to the plane, and these forces are equal and given by,

\[ N = mg \cos \theta_s \]  

(Eq.3)

Where \( \theta_s \) is the angle where the block just begins to slip on the inclined plane. The free body diagram is given by Fig.1 and shows the forces acts on a block on the inclined plane. Generally, \( \mu_s > \mu_k \) therefore a push is needed to get started to slip the block.

![Fig. 1](image)

Fig. 1 shows the forces acting on a block on an inclined plane.

\[ f_s = \mu_s N = mg \sin \theta_s \]  

(Eq.4)

From Equations 3 and 4 we get,

\[ \mu_s = \frac{mg \sin \theta_s}{N} = \frac{mg \sin \theta_s}{mg \cos \theta_s} = \tan \theta_s \]  

(Eq.5)
When the block is slipping down the plane at a constant velocity, it is in equilibrium with the vector sum of forces on the block equal to zero.

\[ N = mg \cos \theta \quad \text{and} \quad f_k = mg \sin \theta \]  

(Eq.6)

Combining these two equations,

\[ \mu_k = \frac{mg \sin \theta_k}{N} = \frac{mg \sin \theta_k}{mg \cos \theta_k} = \tan \theta_k \]  

(Eq.7)

Equation 7. is used to determine the kinetic friction coefficient at which the block moves down the inclined plane at constant velocity.

At horizontal position of the board a force needs to be applied to the block for sliding down by means of a string running over a pulley and down to mass shown in Fig.2. For a given block mass \( M_1 \) it is possible to slowly add mass to \( M_2 \) until \( M_1 \) begin to move. When the system is in equilibrium, static friction is acting, thus the following conditions are met:

\[ T = f_s = M_2 g = \mu_s N = \mu_s M_1 g \]  

(Eq.8)

Where \( T \) is the tension of the string. Combining these four equations,

\[ f_s = M_2 g = \mu_s N = \mu_s M_1 g \]  

(Eq.9)

from Eq.9, we get,

\[ M_2 = \mu_s M_1 \]  

(Eq.10)

The same procedure can be applied to generate the coefficient of kinetic friction. Namely, when the system is moving at a constant velocity, we say the system is in equilibrium, and thus the following expressions can be obtain:

\[ T = f_k = M_2 g = \mu_k N \]  

(Eq.11)
Fig. 2 Shows force applied to a block on horizontal plane.

Combining these equations we get,

$$M_2 = \mu_k M_1 $$  \hspace{1cm} (Eq.12)

Eq.12 is useful to measure $\mu_k$ by finding the value of $M_2$.

**EXPERIMENT**

**The Inclined Plane**

1. On the block, there are three different A, B, and C surfaces. A and B surfaces were made of wood but their surface area is different. A and C surfaces were made of different material but their surface area is the same one another.

2. Place the block with the hook attached with its large surface down so that the block begins to slide on board. Record the value of height of the block as Y. Measure the angle with a goniometer and record the value of the angle.

3. Static friction can no longer hold the block when it begins to slide down. Record the data of X, the distance from the pivot line of the board to the block as shown in Fig.3.

4. Repeat step 3 three more times for a total of four trials with only the block itself on top of the board. Record the values of X associated with each of these trails (0 mass will be added).
5. Repeat step 4 using a light type, attach 0.2 kg mass to the top of the block and record X values.

6. Repeat step 5 using different masses (0.4 and 0.6 kg) on the block and record X values. Determine the static friction coefficient $\mu_s = \tan \theta_s = \frac{Y}{X}$.

**Fig.3** Shows X and Y positions, we need to measure.

**Horizontal Plane with Pulley**

1. Place the board in horizontal position on the table with the pulley beyond the edge.

2. Attach a piece of a string to the hook in the block. Place it over the pulley and attach the mass holder to the other end of the string. Add mass to the mass holder to find the minimum mass needed to just cause the block to move. Record the value as $M_2$. Include 0.05 kg mass of the holder in the total for $M_2$.

3. Repeat Step 2 by adding 0.02 kg to the top of the block. Determine the minimum mass needed to just begin to move. Try it for 3 times and record each as $M_2$.

4. Repeat Step 3 for 0.04 and 0.06 kg.
CALCULATIONS

For inclined plane

1. Calculate the mean value of $\bar{X}$ for the static friction for the four trials at each value of $M_1$. Calculate the value of $\mu_s$ as $tan\theta_s = Y/\bar{X}$ and then calculate $\mu_s$.

2. Calculate the mean value of $\bar{X}$ for the kinetic friction for the four trials of $X$ at each value of $M_1$. For each of the values of $\bar{X}$, calculate the value of $\mu_k$ as $tan\theta_k = Y/X$. Calculate $\mu_k$.

For horizontal plane

1. Calculate the mean $\bar{M}_2$ for the three trials of $M_2$ for each of the values $M_1$ for both static and kinetic cases and record them.

2. Calculate standard deviation for the force act on $M_2$ mass for three trial $M_2$ masses.

$$\Delta F = \mp \sqrt{\frac{\sum(F_{act})^2}{n}}$$

GRAPHES

1. For horizontal plane case, graph the static friction data with $\bar{M}_2$ as vertical axis and $M_1$ as horizontal axis. Show the straight line obtained from the fit.

2. Repeat Step 1 for the kinetic friction coefficient.