Oscillating Screw

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ABSTRACT

This research is about the behavior of a screw when placed on its side on a ramp and released. It may experience growing oscillations and travels down the ramp. To Investigate how the motion of the screw, as well as the growth of these oscillations depend on the relevant parameters some different experiments have been done. As it is observed, the screw has two different types of motions. One of these motions is related to the rolling of the screw; and the other to its slipping, sliding and oscillations .The angle of releasing , different sizes and other parameters of the screw are studied to solve this problem.

Keywords : *: Screw, Oscillation, Motion, Slipping, Sliding, Angle*

1. Introduction

To illustrate a phenomenon different experiments are performed to help in finding suitable analysis. The conducted study represents a scientific investigation aimed at solving a complex problem in IYPT2023. The focal point of this research revolves around a fundamental inquiry, stated as follows:

When placed on its side on a ramp and released, a screw may experience growing oscillations it travels down the ramp. Investigate how the motion of the screw, as well as the growth of these oscillations depend on the relevant parameters.

As it is observed, the screw has two different types of motions. One of these motions is related to the rolling of the screw; and the other to the slipping, sliding and oscillations of it.

2. Observation and Theory

Applied forces on the screw are shown in (Fig. 1). As it is observed, the screw has two different types of motions. One of these motions is related to the rolling of the screw; and the other to its slipping, sliding and oscillations. The growing oscillation happens in y axis and there is an acceleration in x axis.

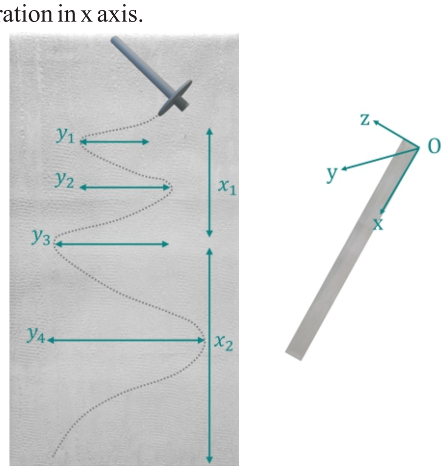


Fig. 1: Motion of the screw

The force analysis has been shown here; there is a gravity force that has been divided into two parts. Parallel force to ramp and perpendicular weight force to ramp in origin system in point A and A'. There are also incline forces and friction forces for both of the points in y and x axes (Fig. 2).

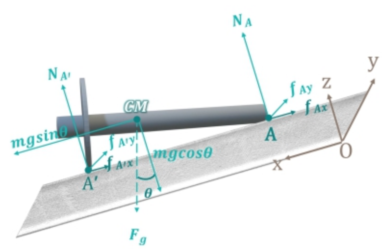


Fig. 2: Applied forces on screw

where;

- F_g = Gravity force
- $mgsin\theta$ = Parallel force to ramp
- $mgcos\theta$ = Perpendicular weight force to ramp
- $N_{A'}$ = Normal force of incline of point A'
- N_A = Normal force of incline of point A
- $f_{A'x}$ = x-axis friction of point A'
- f_{Ax} = x-axis friction of point A
- $f_{A'y}$ = y-axis friction of point A'
- f_{Ay} = y-axis friction of point A

These are some of the data that have been extracted for the further equations. The data has been divided into two individual parts for the head and the body of the screw. An important consideration is that there are three centers of mass. First the body's center of mass, second the head's and third, the whole screw's center of mass.

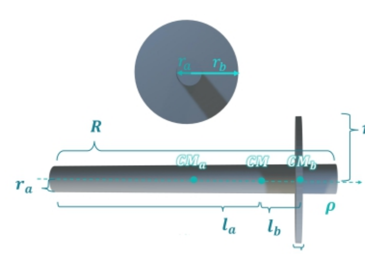


Fig. 3: Different parts divisions in screw

where;

- CM_a =The center of the body mass
- CM =The center of mass
- CM_b =The center of the head mass
- r_a =Body radius
- R =Body length
- r_b =Head radius
- d =Head thickness
- ρ =Density
- l_b = Distance between the and the CM and the head of the screw
- l_a =Distance between the CM and the bottom of the screw

For the friction magnitude of A and A' calculation, the following formula can be used (Eqs. 1, 2) (Fig. 4).

$$(N_{A'}\mu_K)^2 = f_{A'x}{}^2 + f_{A'y}{}^2 \quad (1)$$
$$(N_A\mu_K)^2 = f_{Ax}{}^2 + f_{Ay}{}^2 \quad (2)$$

where;

- $N_{A',A}$ = Normal forces
- μ_K = Coefficient of kinetic friction
- $f_{A',Ax}$ = x-axis frictions
- $f_{A',Ay}$ = y-axis frictions

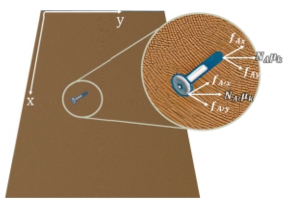


Fig. 4: Frictions applied on X-Y axes

In a perfect rolling when the screw rotates, the distance between the center of the circle that has been created from the screw's rotation and the end of the screw is constant in the whole rotation time. We call this distance x. In this phenomenon, there is a motion close to perfect rolling (Fig. 5).

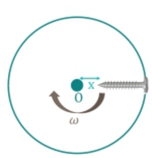


Fig. 5: Perfect rolling

The data are collected and some of the forces acting on the screw on the horizontal plane are shown in (Fig. 6).

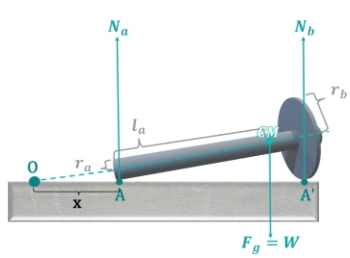


Fig. 6: Screw on horizontal plane

By placing the screw on a horizontal surface, if we continue the symmetry axis until it meets the horizontal surface, a cone is created.

Now, the screw is placed on a ramp with Theta angle. As the screw moves down and slides, a torque applies to it, which equals to the weight of the screw multiplied by the angle that the symmetry axis makes with the surface of the ramp. Actually, x is a way to reach the torque (Fig. 7).

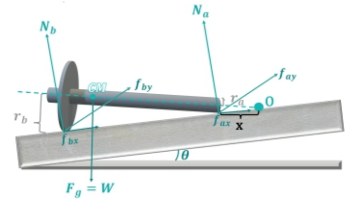


Fig. 7: Screw on a plane with Theta angle

For calculation it is simplified as a cone (Fig. 8).

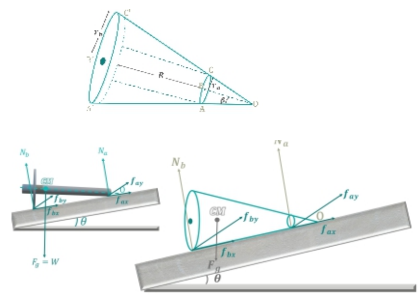


Fig. 8: Screw is considered as a cone

Frictional forces apply on 2 points on our cone. If the screw rolls on two wheels AC and A'C without slipping, the screw rotates around the point O (Fig. 9).

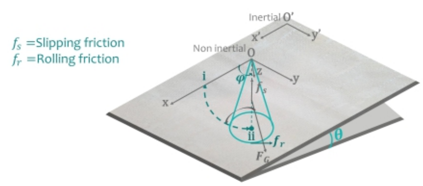


Fig. 9: Frictional forces

One time it is considered the as rolling without slipping and another time rolling with slipping. So the torque is used for the first situation and the dynamic system is studied for the second part.

The cone is of polar system type that centered around O. Because we want to investigate the situation of the symmetry axis toward the x axis, the screw has been considered in a non-inertial origin system so it can be studied as O sliding as a particle in the x' direction from O'(Figs. 10, 11)(Eq.3) .

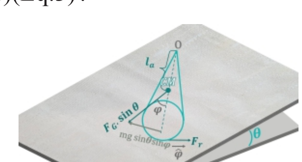


Fig. 10: Torque in the first situation

$$\begin{cases} \tau_\varphi = -F_G \sin\theta \sin\varphi\, l_a + f_r R \\ \tau_\varphi = I_\circ \ddot{\varphi} \end{cases} \Rightarrow -F_G \sin\theta \sin\varphi\, l_a + f_2 R = I_\circ \ddot{\varphi} \quad (3)$$

In rolling with sliding (Eqs. 4-6).

When the sliding is perpendicular to the x axis and k isn't constant by the rotational motion based on rolling friction and torque", coefficient of friction as a function of tangential velocity is calculated and If the φ in differential equation becomes small enough the Equations (4-8) are given (Fig. 11).

$$\vec{f_r} = kN_r\hat{\varphi} \qquad (4)$$

$$k \simeq k_o + k_1 \upsilon \quad \upsilon = \text{Tangential velocity} \Rightarrow \quad \upsilon = l\dot{\varphi}$$

$$-F_G \sin\theta \sin\varphi \, l_a + f_2 R = I_\circ \ddot{\varphi} \qquad (5)$$

$$\ddot{\varphi} = -A\sin\varphi + B\dot{\varphi} + C \qquad (6)$$

$$-F_G \sin\theta \sin\varphi \, l_a + k_o R + k_1 R l \dot{\varphi} = I_\circ \ddot{\varphi} \qquad (7)$$

$$\ddot{\varphi} \approx -A\varphi + B\dot{\varphi} + C$$
$$\Longrightarrow \varphi \approx C_1 e^{at} \sin t + C_2 \qquad (8)$$

In this formula C1 and C2 are the constants and according to the screw's specific characteristics for a small angle of φ, the chart is given in Figure (11) and it happens when the oscillation angle around the x axis is between 12 and 90 degrees.

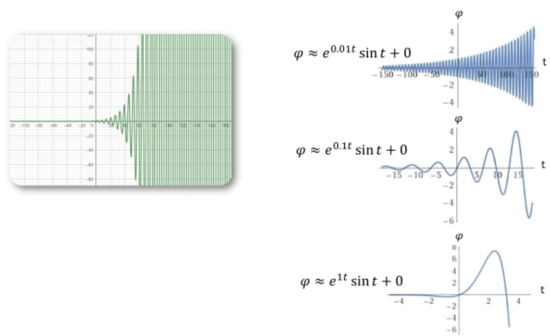


Fig. 11: the diagram of oscillation If the φ in differential equation becomes small enough

These are a part of the charts that have been obtained from the theory. This is for a case where the screw deviates to the left and right, and then when the screw becomes horizontal, it moves like an axle with two unequal wheels.

The related parameters include the friction coefficient of the ramp, the angle of the ramp(α), The angle at which we release the screw(β), The body's length(d), The mass of the head of the screw and the Radius of the washer (r).

If the φ gets bigger (Eq. 9):

$$\sin\varphi \not\approx \varphi$$
$$\ddot{\varphi} = -A\sin\varphi + B\dot{\varphi} + C \qquad (9)$$
$$12° < \varphi < 90°$$

3. Experiments

Different size of the screws, the washers with different radiuses, and the holes with different sizes are the main parts of the experimental setup (Fig. 12).

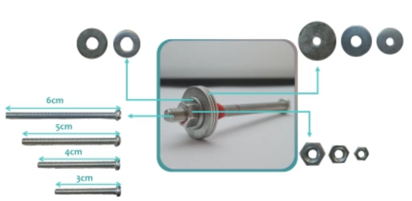
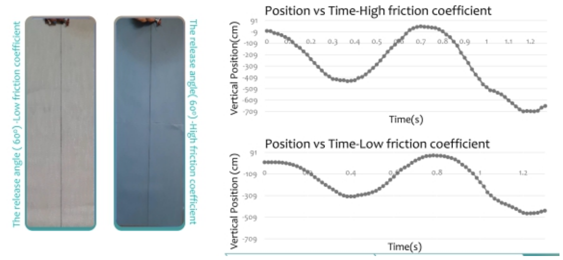


Fig. 12: Experimental setup

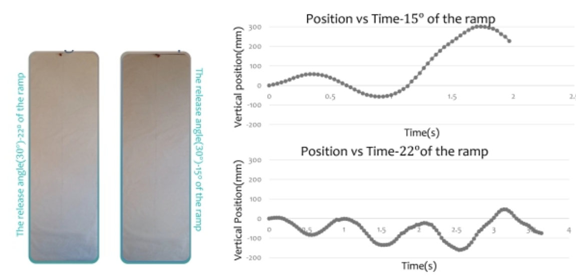
By increasing the friction coefficient of the ramp while the number of oscillations increases, the oscillations amplitude decreases.

When the angle of the ramp decreases, the number of oscillations increases, but the oscillations amplitude decreases.

The angle of releasing the screw is one of the other parameters. By increasing this angle, it has been observed that the number of oscillations decreases, but the oscillations amplitude increases (Figs. 13a and b).



(a)



(b)

Fig. 13: a) the role of friction , b) the angle of ramp

The angle of releasing the screw is one of the other parameters. By increasing this angle, it has been observed that the number of oscillations decreases, but the oscillations amplitude increases (Fig. 14).

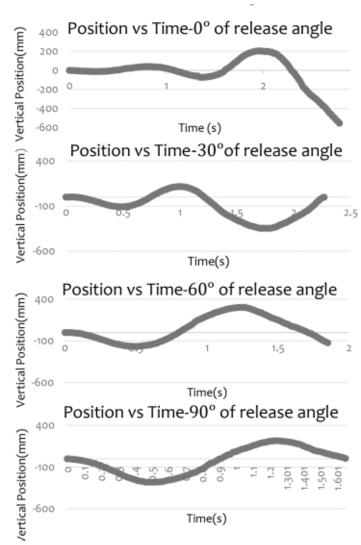


Fig. 14: The angle of releasing the screw

Changes in the screw's body's length have been investigated as well. By decreasing the body's length, the number of oscillations increases (Fig. 15).

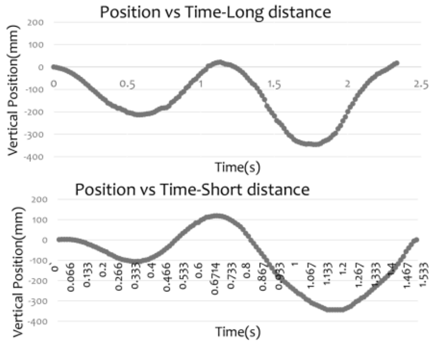


Fig. 15: The effect of body length

We've done experiments with different sizes of radius. As it can be observed , the oscillation amplitude in the screw with a smaller radius is higher than the oscillation amplitude in the screw with a bigger radius (Fig. 16).

Also by changing the mass of the head of the screw, the number of oscillations decreases, but the oscillations amplitude increases (Fig. 17).

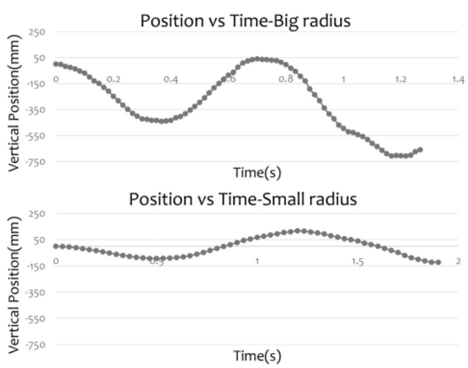


Fig. 16: Different radiuses of the washers

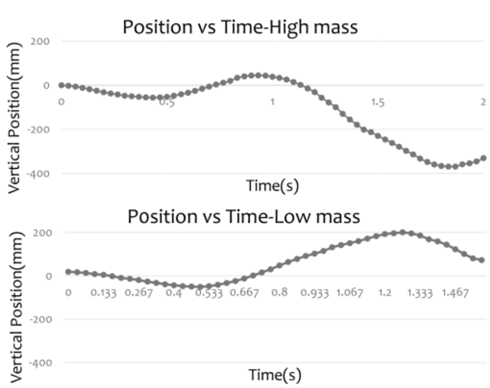


Fig. 17: Different masses of the head

4. Results

By comparing the charts obtained from the experiment and theory, it can be seen that they fit well together. If some part of it doesn't fit the chart obtained from the theory means various reasons may cause errors, including surface friction that occurs due to the non-uniformity of the surface.

Different parameters have been investigated in our theory and experiment to find the main reason of the screw oscillation in a plane in different angles.

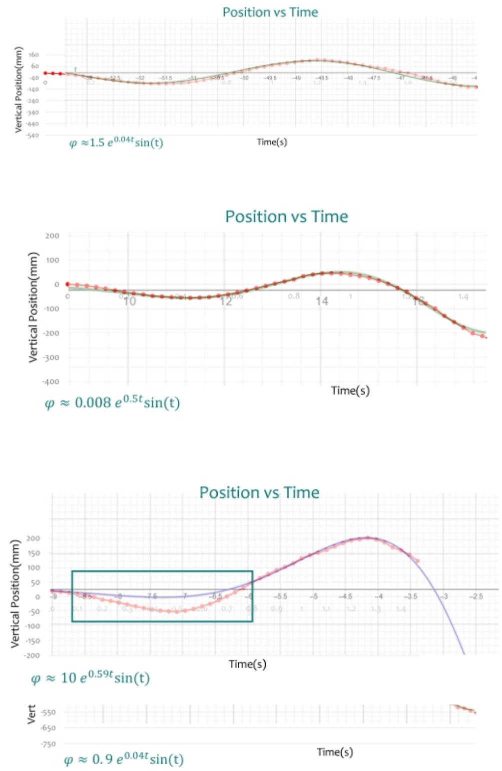


Fig. 18: Comparison between Theory and Experiments

5. Conclusions

1. By decreasing the friction coefficient of the ramp while the number of oscillations decreases, the oscillation amplitude increases.
2. By increasing the angle of the ramp, the number of oscillations decreases, but the oscillations amplitude increases.
3. By decreasing the release angle, the number of oscillations increases, but the oscillations amplitude decreases.
4. By increasing the body's length, the number of oscillations decreases, but the oscillations amplitude increases.
5. By decreasing the mass of the head, the oscillation amplitude decreases.
6. By increasing the radius of washer, the oscillation amplitude increases.

References

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[2] https://physics.stackexchange.com/questions/753918/back-and-forth-oscillation-of-a-screw