SPINNING OR SLIDING OF A WASHER ON A VERTICAL ROD

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ABSTRACT

The motion of the washer on a vertical steel rod is investigated which may start spinning instead of simply sliding down. Terminal velocity of this movement and other affective parameters are considered by different experiments. It is possible to observe the washer will start to rotate on the rod by an initial velocity and rotate till it reaches a maximum angle and a steady state for the washer's rotation and finally reaching to the point that we can perceive a free fall motion for the washer's movements .

Keywords : *Terminal Velocity, Washer, Kinetic Energy*

1. Introduction

The problem states that a washer on a vertical steel rod may start spinning instead of simply sliding down. To study the motion of the washer and what determines the terminal velocity with the most parameters that would affect on it, several experiments are designed .

To find the optimum conditions different rods and washers are studied.

2. Theories and Methods

Starting with initial observation and introduction of the phenomenon, the main purpose of the statement is to investigate the terminal velocity and the parameters that would affect the terminal velocity of the washer, it is possible to observe that the washer will start to rotate on the rod by an initial velocity and it will rotate till it reaches a maximum angle and a steady state for the washer's rotation and finally reaching to the point that we can perceive a free fall motion for the washer's movements.

To start the basic theory and to have a better intuitive view of the phenomenon, amplitude of the sound that is possible to hear by the washer's movements on the rod is recorded (Fig. 1).

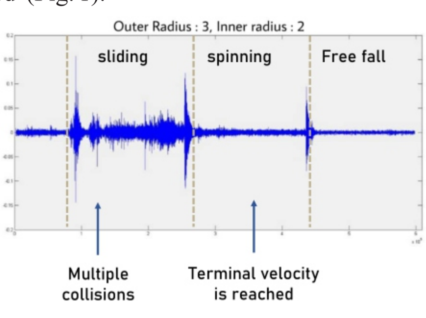


Fig. 1: Recorded sound of washer movement on the rod

The basic transition between the motion of the washer will be sliding motion which involves acceleration and tilting of the washer around the rod. It is expected to be a free fall motion but will turn into a spinning motion which is possible to observe different types of angular velocity in different conditions.

Terminal velocity of the system leads us to a maximum tilt angle . By tracker the change of the angle per time and the maximum tilt angle are measured. Having a schematic observation of the contact points, 3D printed washer designed to see that there are two contact points.

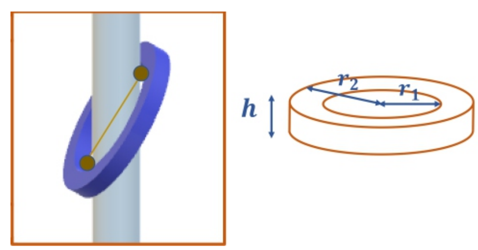


Fig. 2: Washer's dimensions and its contact points on the rod

The main motion of the washer will be rotating around the rod that we can divide this motion to two different motions one in z direction and the other one in "x,y" which makes the phenomenon more clear.

A theory based on energy determines the velocity of the system but this theory will be in the steady state condition that the angular velocity of the system is stable . Each term of the equation is investigated and we will start with the air resistance which by estimation is negligible.

Now to divide each kinetic energy that affects on the washer's movements, there are two kinetic energies. One of them is based on the angular velocity in different directions z and x, y. The other kinetic energy is based on terminal velocity of the washer, but because the rotational energy , this formula represents the equation for inertia in z and x, y components (Eqs.1-5).

$$k_1 + k_2 + \frac{1}{2}mv_z^2 - mg(v_z t) + \mu N(r\omega_{xy}t) + W_{air} = \text{cte} \quad (1)$$

$$E = k_1 + k_2 + \frac{1}{2}mv_z^2 - mg(v_z t) + \mu N(r\omega_{xy}t) \quad (2)$$

$$E = \frac{1}{2}I_{xy}\omega_{xy}^2 + \frac{1}{2}I_z\omega_z^2 + \frac{1}{2}mv_z^2 - mg(v_z t) + \mu N(r\omega_{xy}t) \quad (3)$$

$$I_{xy} = \frac{1}{12}m(3(r_2^2 - r_1^2) + h^2) \quad (4)$$

$$I_z = \frac{1}{2}m(r_2^2 - r_1^2) \quad (5)$$

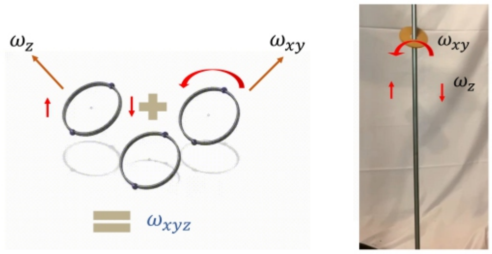


Fig. 3: The angular velocity of the washer in different directions

The equation for energy of the system involves the terminal velocity in z component due to the change of velocity based on change of washer's, and we obtain the terminal velocity in z component by this equation. By observing the motion in steady state from the experiment we can get a better intuitive view of the condition that the energy stays constant and why the equation from the qualitative theory is based on the fact that the motion is stable in the steady state (Eqs. 6-8).

$$v_z = \frac{D_{rod}}{2\pi}.(\omega_{xy}+\omega_z) \quad (6)$$

D_{rod}= 1cm

$$\frac{D_{rod}}{2\pi}.(\omega_{xyz}+\omega_{xyz}) - \mu N r \omega_{xy} = 0 \quad (7)$$

$$E = k_1 + k_2 + \frac{1}{2}mv_z^2 - mg(v_z t) + \mu N(r\omega_{xy}t) \quad (8)$$

0.8 (μ); $mgcos\alpha$ (N); rotation time in α_{max} condition (t)

3. Experiment

In our experimental setup 64 different sizes for washers are used.

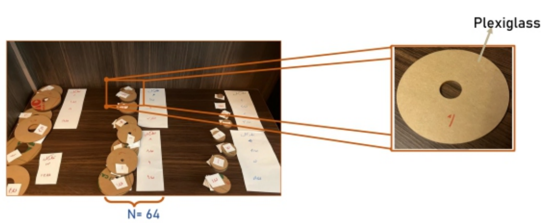
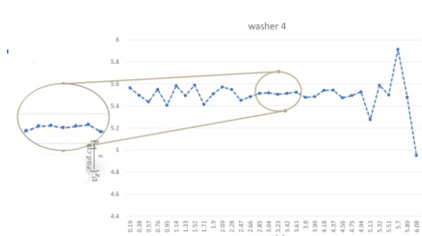
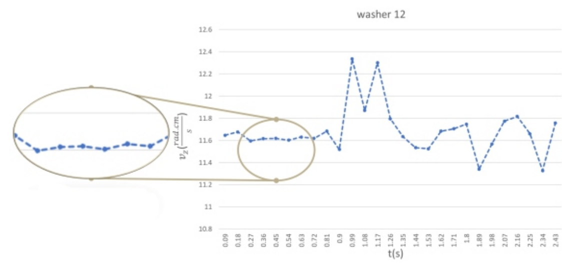


Fig. 4: Plexiglass washers in 3 mm thickness

The energy and terminal velocity in steady state for different washers and the time range of movement are calculated according to the theory for 25 different plexiglass washers that the longest time for the washer rotation belongs to washer number 9 (Diameter 6 cm and hole diameter 3 cm) (Figs. 5-7).



(a)



(b)

Fig. 5: Terminal velocity of washers in two samples a) washer No 4 , b) washer No12

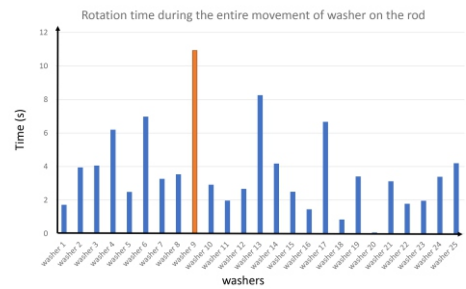


Fig. 6: Rotation time of different washers

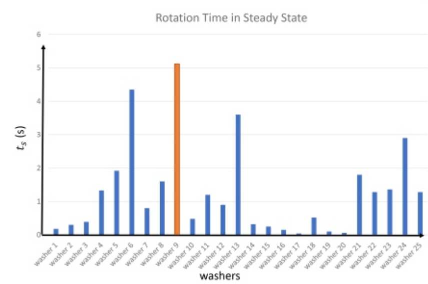


Fig. 7: Rotation time of different washers in steady state

The same experiment goes for the velocity of each washer in z component, and by the result of the experiment, the most displacement in z direction belongs to washer No17, but as the main investigation in steady state, as much as the terminal velocity in z axis decreases for instance the washer No3, the time that the washer stays in steady state increases (Fig. 8).

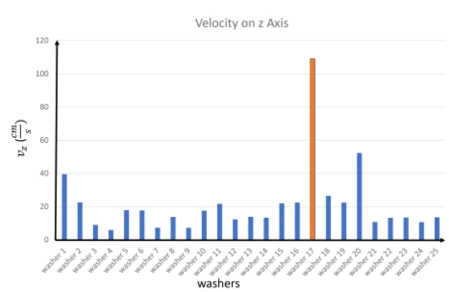


Fig. 8: Velocity of different washers on Axis Z

4. Conclusions

In this research we found several parameters regarding different washers movement on the rod including time range in steady state, which clarifies the time of start of the state till the end of it.

To start the basic of the theory and to have a better intuitive view of the phenomenon, we used amplitude of the sound that is possible to hear by the washer's movements on the rod and a basic transition between the motion of the washer will be sliding motion which involves acceleration, tilting of the washer around the rod and it will turn into a spinning motion and after that we expect a free fall motion and it is possible to observe different types of angular velocity in different conditions. Tracker and 3D printed washer is used to measure the change of the angle per time and the maximum tilt angle. To determine the velocity of the system theory based on energy is used . But this theory is in the steady state condition that the angular velocity of the system is stable for different washers. The comparison between theory and the experiment shows a good agreement.

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