Investigating a Falling Tower by Building a Robot

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A B S T R A C T

Identical discs are stacked one on top of another to form a freestanding tower. The bottom disc can be removed by applying a sudden horizontal force such that the rest of the tower will drop down onto the surface and the tower remains standing. This phenomenon has been investigated and the conditions and the most important parameters which allow the tower to remain standing are found. By using free body diagram the identical forces are explained and in MATLAB more comparative and accurate measurements related to various angular accelerations are measured.

Key Words :*discs, forces, measurements, angular acceleration*

1 Introduction

Towers as tall structures are specifically distinguished from buildings in that they are built not to be habitable but to serve other functions using the height of the tower.In this research we are going to study the movement and balance of a tower which is built by different discs stacked on top of each other .

2 Theory and Methods

In this experiment there are different conditions as follows:

a) When the force is applied quickly to the bottom disc, without friction most probably you can see the rest of the tower will drop down on to the surface and the tower remains standing (Fig. 1).

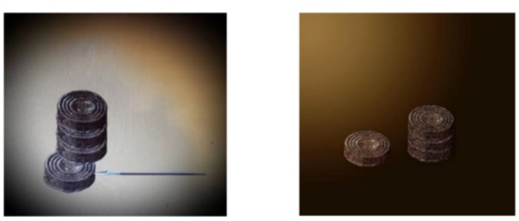


Fig. 1: Standing tower when the force is applied quickly to the bottom disc

b) When the force is applied slowly to the bottom disc most probably the rest of the tower will drop down on to the surface and the tower does not remain standing (Fig. 2).

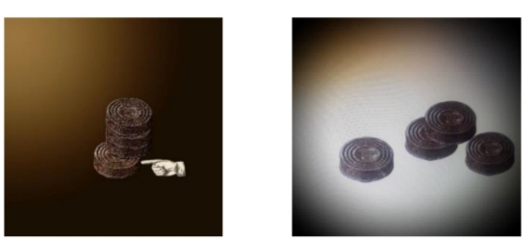


Fig. 2: Disturbing the balance of the tower when the force is applied slowly to the bottom disc (without friction)

c) When the force is applied quickly, with friction the rest of the tower will drop down on to the surface and the tower remains standing but with displacement in the discs (Fig. 3).

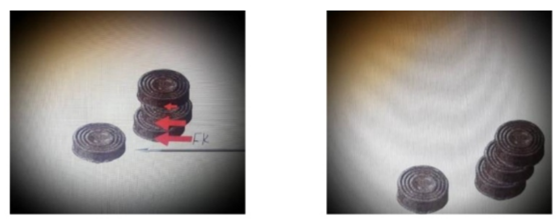


Fig. 3: Displacement in the discs by considering the friction

2 Basic Theory

All the applied forces are shown by using free body diagram (Fig. 4).

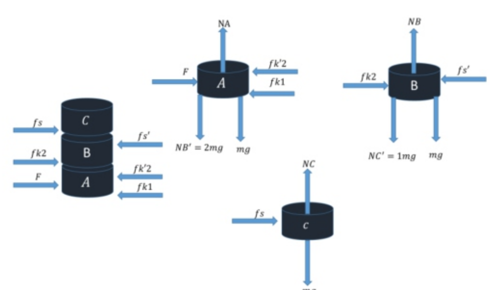
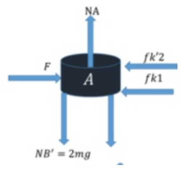


Fig. 4: Free body diagram and forces on the discs

First, we exert the force F to disc A, without gravity, the lower box moves in the same direction of the force and the upper disc stands unmoving. The friction force between the earth and disc A is f_k . But with gravity force, the upper box will accompany the lower box to some distance. It means that the force will push this box forward in the same direction of the exerted force. This force is called f_{k2} and is exerted on disc B. Similarly, the opposite force on disc A is called f_{k2} . These forces are the same for the disc above disc B (disc C) and all are calculated as follows (Eqs. 1-3) .

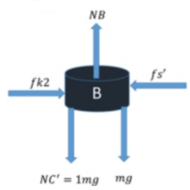
$$\sum fx = F - fk1 - fk2' = F - (\mu k.3mg + \mu k.2mg) \quad (1)$$

$$= F - 5\mu k.mg = ma\,, a = \frac{F}{m} - 5\mu k.g$$

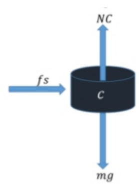


$$\sum fx = fk2 - fs' = \mu k.2mg - ma \qquad (2)$$

$$= ma\,, \mu k.2mg = 2ma\,, a = \mu k.g \qquad fs = fs' = ma$$



$$\sum fx = fs = ma\,, fs \le (\mu s) \times NC\,, \sum fx = ma \le (\mu s) \times mg\,, a \le (\mu s)g \qquad (3)$$



Rotational speed $\varpi = \frac{\Delta\theta}{\Delta t}$ and angular acceleration α in this phenomenon are the main parameters should be calculated and measured accurately (Eqs. 4-7).

$$D = z = x - \frac{\omega}{2}\,, \tau = f.D = mg \times \left(x - \frac{\omega}{2}\right) = mgx - mg\frac{\omega}{2} \qquad (4)$$

$$I = Icom + md^2 = \frac{1}{12} m\,(\omega^2 + h^2) + m\,((x - \frac{\omega}{2})^2 + (\frac{h}{2})^2\,) \qquad (5)$$

$$\sum M = I\alpha,\ \tau = I\alpha\ \,, mgx - mg\frac{\omega}{2} = \qquad (6)$$

$$(\frac{1}{12} m\,(\omega^2 + h^2) + m\,((x - \frac{\omega}{2})^2 + (\frac{h}{2})^2) \times \alpha$$

$$\alpha = \frac{mgx - mg\frac{\omega}{2}}{\frac{1}{12} m(\omega^2 + h^2) + m((x - \frac{\omega}{2})^2 + (\frac{h}{2})^2)} \qquad (7)$$

By MATLAB program more comparative and accurate measurements are done. By coding various angular accelerations and changing the displacement (x), different accelerations are measured. As demonstrated here, a linear diagram was obtained from this relation (Fig. 5).

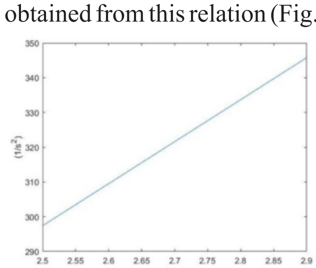


Fig. 5: Angular acceleration versus displacement

3 Experimental Setup

To reduce errors a robot was built (Fig. 6).

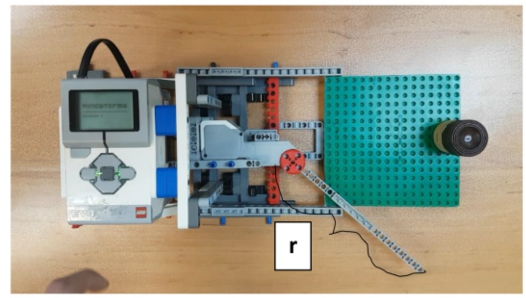


Fig. 6: Experimental setup

Angular velocity (ω) and v are calculated according to $\varpi = \frac{\Delta\theta}{\Delta t}$ and $v = r\omega$ then the probability of falling the discs is investigated (Fig. 7).

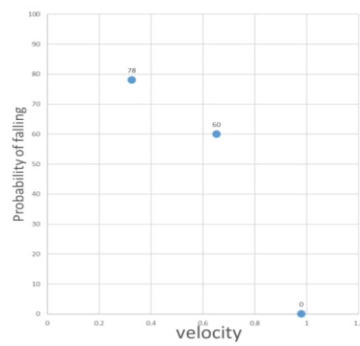


Fig. 7: Probability of falling versus velocity

It is clear by decreasing the velocity, the probability of falling increases. On the other hand, as the number of the discs increases, the probability of falling increases too (Fig. 8).

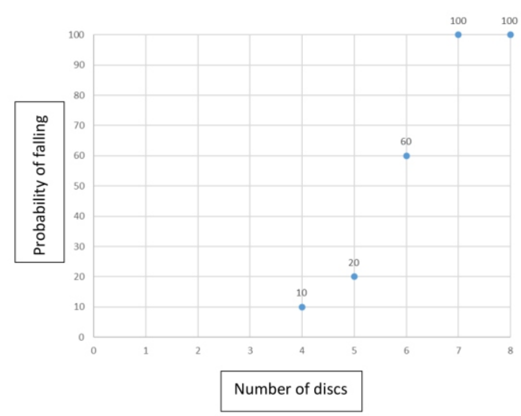


Fig. 8: Probability of falling versus the number of discs

By increasing the height of the discs in different experiments the possibility of falling was zero on the first two experiments. When the height of the discs are tripled, the possibility of falling was increased up to 50%. Finally, When the height of the disc was quadruplicated the possibility of falling raised to 100% (Fig. 9).

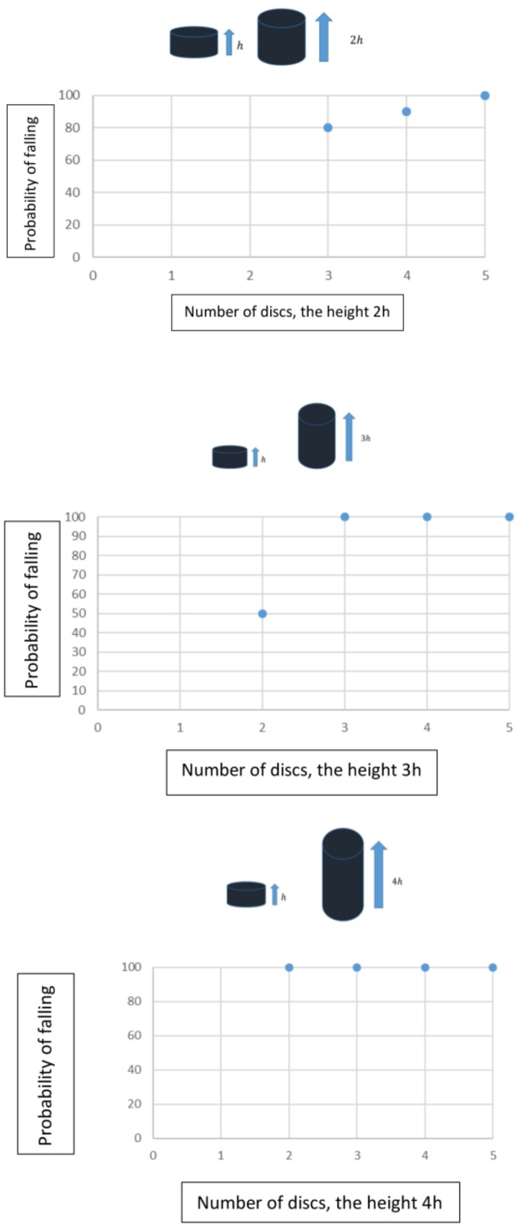


Fig. 9: Probability of falling versus the number of discs in different heights

4 Results and Conclusion

As shown, by increasing the height of the discs in various experiments, the possibility of falling is more. It is also needed to point out that the diameter of all discs is 3cm. Accordingly, when the height of the discs increased over 3cm, the possibility of falling raised to 100%. By increasing the height, the angular acceleration also increases. In conclusion the probability of falling is more when the altitude is higher so the angular acceleration is faster.

References

[1] D.Halliday , R.Resnick ,J.Walker (1923). Fundamentals of Physics. John Wiley & Sons.