How Does a Magnetic Field Affect the Oscillation of a Suspended Sphere

Sogand Radka , Iran Alghadir School , Tehran / Iran, s.radka8506@gmail.com

ARTICLE INFO

Silver medalist in ISAC Olympiad 2023 and

Bronze medalist in IGO 2023 UK

Awarded by Ariaian Young Innovative

Minds Institute , AYIMI

http://www.ayimi.org ,info@ayimi.org

ABSTRACT

To understand the dynamics of moving objects through the Earth's magnetic field, a light sphere with a conducting surface is suspended from a thin wire which is rotating about its vertical axis in a magnetic field. This work is studying the oscillation of either hollow or solid sphere with a conducting surface when is rotated about its vertical axis (thereby twisting the wire) and then released in the presence of a magnetic field. To investigate how the presence of a magnetic field affects the motion the most detailed and analysis was carried out and the produced drag torque felt by the sphere as a result of the charge redistributions and currents was studied.

Keywords : *: Magnetic Field, Oscillation, Light Sphere, Torque*

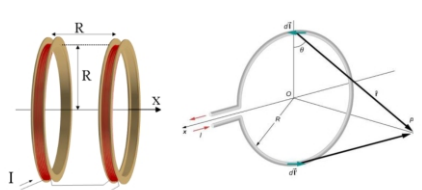
1. Introduction

The interaction of a constant magnetic field with a moving extended conductor is an important area of study with applications to linear induction motors, eddy current braking, and levitation. The interaction of a constant magnetic field with a moving conductor sphere makes forces which are exerted on the electrons in the sphere. These electrons generate a non-uniform charge density and electric fields with eddy currents. To find the currents, rotating of a hollow sphere about a perpendicular axis with an applied uniform magnetic field, is studied. By moving the sphere through the magnetic field or when the magnetic field surrounding a stationary conductor is varying, it results in the conductor experiencing a change in the intensity of a magnetic field which produce eddy currents.

2. Materials and Theory

Both solid and hollow sphere will have a radius given by (R) , total mass (M), moment of inertia (I) and angular frequency around the z-axi (ω). The rotation of the sphere in a magnetic field which is produced by Helmholtz coil, makes current around the axis of rotation. The total magnetic field of Helmholtz Coil (Fig.1) is given by (Eq.1).

$$B_t = \frac{\mu_0 N I R^2}{2}\left\{\frac{1}{\left[R^2+\left(z-\frac{R}{2}\right)^2\right]^{3/2}}+\frac{1}{\left[R^2+\left(z+\frac{R}{2}\right)^2\right]^{3/2}}\right\} \quad (1)$$



a) b)

Fig. 1: a) Helmholtz Coil, b) Magnetic field of a loop

Since the sphere is rotating through a magnetic field according to the Lorentz law, it generates forces on the charges in the sphere which is conductive and neutral, the electrons can move and this can result in charge redistribution and possible currents.

The total velocity of the electrons, *Vt,* due to the velocity of sphere, $\acute{V}$, is given by (Eqs. 2, 3).

$$\mathcal{V}_t = \mathcal{V}\, sin(\theta_1.\theta_2) \quad (2)$$

$$\mathcal{V}_t = \frac{L\, sin(\theta_1.\theta_2)\, \acute{\mathcal{V}}}{R} \quad (3)$$

The sphere is a 3D object so we will put it in a spherical coordinate system (Fig. 2), where each of the electrons will have a distance from the source point as L:

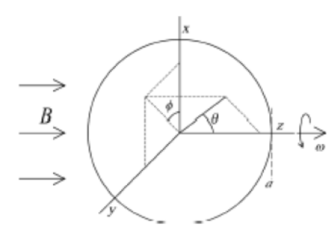


Fig. 2: Modeling of the rotating hollow sphere when the rotation axis is parallel with the uniform magnetic field

$\vec{L}$={$L \sin\theta_1 . \cos\theta_2, L \sin\theta_1 . \sin\theta_2, L\cos\theta_1$}

Then the velocity of any point is (Eq. 4).

$$v = \vec{\omega} \times \vec{L} \quad (4)$$

Another parameter is the magnetic force which is applied to the sphere from a uniform field parallel to rotation (Eq. 5).

$$F_m = \omega\overrightarrow{LB} = \frac{\acute{V}L\, sin(\theta_1.\theta_2)\mu_0 N I R^2}{2Rl(z^2+R^2)^{3/2}} \quad (5)$$

The eddy current is generated by the applied magnetic field interacting with the rotating conducting sphere, but it is not the total current. This eddy current generates a magnetic field within the sphere that, yields a second eddy current. Then, the second eddy current generates another magnetic field that yields a third eddy current, and, this third eddy current is of the same form as the first eddy current but of opposite sign. So, the third eddy current acts to cancel the eddy current, yielding a negative feedback loop.

The interaction between the current that generated the applied field and the currents inside of the sphere yields equal and opposite forces, but one acts on the sphere and the other on the coil or the magnet that generated the applied field.

The torque by hanging a hollow conducting sphere by a thin wire and measuring the decay in the amplitude of its torsional oscillations yields (Eq.6).

$$\tau = I\dot{\omega} = -K\theta \qquad (6)$$

where $\dot{\omega}$ is the time derivative of the angular velocity, K is the torsion constant of the wire, and θ is the rotation angle of the sphere. There are two resistances, one due to the frictional loss and the other one is magnetic drag, which make the angular velocity of the sphere to be equal as analyses (7).

$$\ddot{\omega} = -\left(\frac{1}{\alpha}+\frac{1}{\gamma}\right)\dot{\omega} - \frac{K}{I}\omega \qquad (7)$$

which

α: *Magnetic damping*

γ: *frictional damping*

I: *moment of inertia*

$\dot{\omega}$: *Time derivative of the angular velocity*

K: *Torsion constant of the thread/wire*

ω: *Angular frequency*

While our frictional and magnetic losses are small, equation of sphere oscillation will be (Eqs. 8-9).

$$T = 2\pi\sqrt{I/K} \qquad (8)$$

$$exp\left[-\frac{t}{2}\left(\frac{1}{\alpha}+\frac{1}{\gamma}\right)\right] = exp\left(-\frac{t}{\delta}\right) \qquad (9)$$

where

δ: *Total decay time*

The total decay time can be found by measuring the decay in the oscillation of hanging hollow sphere without a magnetic field, which gives the frictional damping term γ and then by the magnetic field, δ is found.

3. Experiments

We provided two coils with 600 turns per coil and 8.5 Ω and 1200 turns per coil and 35 Ω, power supply, hollow and solid spheres and wire as in Fig. 3. The current through the coils generates a magnetic field measured by a Gauss-meter.We hung hollow and solid aluminum sphere in the center of the coils by a steel wire with a length of about 0.5 m.

Fig. 3: Experimental setup

In our experiments different spheres, hollow and slid, with different mass have been investigated to get relevant parameters by comparing the frequency of their rotations and oscillations. The spheres hang at different distances from the coils and the results are compared with each other.

To track the oscillation of the spheres we used tracker and the plots are recorded in different positions (Figs. 4- 6).

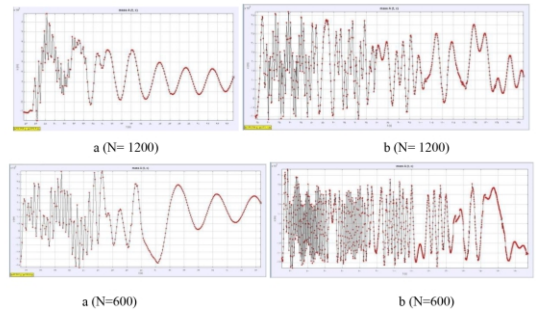


Fig. 4: 9 centimeters distance between the coils, a) hollow sphere, b) solid sphere

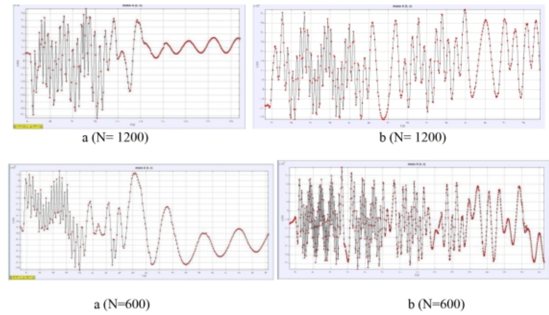


Fig. 5: 13 centimeters distance between the coils, a) hollow sphere; b) solid sphere

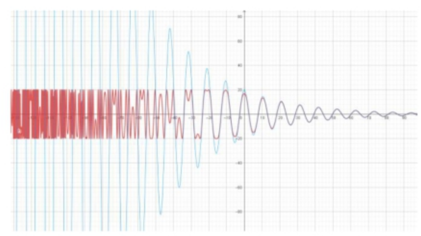


Fig. 6: Comparing the results of solid and hollow spheres

4. Conclusions

Our experiments were performed to examine the forces, torques, and magnetic field interactions with hollow and solid sphere when it starts to slowly oscillate in an applied magnetic field. Finally, the results show in hollow sphere and less distance between coils with more magnetic field and more elasticity of wire the speed of oscillation is more and it stops earlier.

References

[1] Robert C. Youngquist, Mark A. Nurge, and Stanley O. StarrFrederick A. LeveMason Peck. (2016), "A slowly rotating hollow sphere in a magnetic field: First steps to de-spin a space object", Citation: Am. J. Phys. 84, doi: 10.1119/1.4936633

[2] Mark A. Nurge, Robert C. Youngquist, and Stanley O. Starr, (2018), " Drag and lift forces between a rotating conductive sphere and a cylindrical magnet",Citation: American Journal of Physics 86, 443 doi: 10.1119/1.5024220

[3] http://ntrs.nasa.gov/archive/nasa /casi.ntrs.nasa.gov/19630002720.pdf

[4] http://adsabs.harvard.edu/full/1977IrAJ...13....1W