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Circular Electromagnetic Accelerator: A Novel Approach for High-Velocity Propulsion

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Abstract: ***Historically, linear electromagnetic acceleration models have been used to accelerate feasible objects; they faced the limitation of large area requirements and a limited amount of momentum being generated. As a result, electromagnetic propulsion is avoided in accelerating objects with high mass, as a large area is required to accelerate them to the limiting velocity of the model. To counter these problems, inspiration has been taken from the coil gun mechanism and the LHC has been taken. The following model has been proposed through research into different accelerator models and their mechanisms. In this paper, a circular electromagnetic accelerator model has been proposed. Since it is circular, limited area is required, and because the object loops repeatedly, objects with higher masses can be accelerated to significant velocities. In this model, all resistive forces have been dealt with, resulting in seamless looping of the object. Due to this, the model solves the problem of accelerating high-mass objects via electromagnets to the limiting velocity of the model in a confined space.***

Keywords: circular electromagnetic accelerator, high-mass object propulsion, coil gun mechanism, confined space acceleration, resistive force elimination

1. Introduction

Electromagnetic acceleration has long been a cornerstone of advanced propulsion technologies, with linear systems such as rail guns and coil guns leading the way (Marshall, 1985). Every electromagnetic acceleration model has a limiting velocity. After achieving this velocity, there is no major increase in the velocity as the projectile's initial velocity increases as it goes through the acceleration units.

Lower-mass objects reach this limiting velocity after passing through minimal acceleration units, but for higher-mass objects, they need to be passed through way more acceleration units, which is not feasible considering the amount of area and resources it takes. As a result, electromagnetic acceleration has not been able to make a huge pivot in accelerating higher-mass projectiles.

However, despite their success, linear acceleration systems face critical limitations, including energy inefficiency, mechanical strain on components, and challenges in achieving sustained high velocities over long distances (Fowler, 1978).

For the sake of accelerating higher-mass objects to the limiting velocity of the electromagnetic system, a way higher amount of momentum can be produced, helping in further improving our accelerator systems. For this purpose, a circular accelerator model is being proposed, as the object can pass through same set of acceleration units repeatedly via looping around the track, without requiring a large area, reaching the limiting velocity of the electromagnetic system.

This paper dives into a theoretical circular accelerator model which can be used for the purpose of accelerating higher-mass objects to the limiting velocity of the electromagnetic system. It also explores various factors of the model and provides an insight into contactless centripetal force. It also tells us about its applications. is this good it's my final version

2. Electromagnetic Acceleration Principle

When a magnet is placed in a magnetic field of magnitude B and has a magnetic pole strength m, it experiences an attractive force $F = mB$ in the direction of the field, where m is the pole strength (Griffiths, 2013). By leveraging this principle, a contactless method of accelerating the magnet, known as electro- magnetic acceleration, can be implemented. In this process, a magnet is introduced into the magnetic field generated by a solenoid, oriented such that the solenoid is perpendicular to the plane of the magnet. The magnet is naturally attracted toward the center of the solenoid due to the alignment of magnetic forces. At the precise moment the magnet reaches the solenoid's center, the current through the solenoid is abruptly turned off. This sudden disruption of the magnetic field results in a forward jerk.

This phenomenon propels the magnet forward without any physical contact, demonstrating a practical application of electromagnetic forces for acceleration. This mechanism can serve as the basis for developing innovative propulsion systems, enabling frictionless and efficient motion.

3. Methodology

This experimental setup is designed to explore the interaction between electromagnetic fields and superconductivity to achieve efficient electromagnetic acceleration. The system consists of 8 primary components arranged in a circular configuration, with specific angular differences to optimize the interaction between the components. Below is the breakdown of the setup and the methodology:

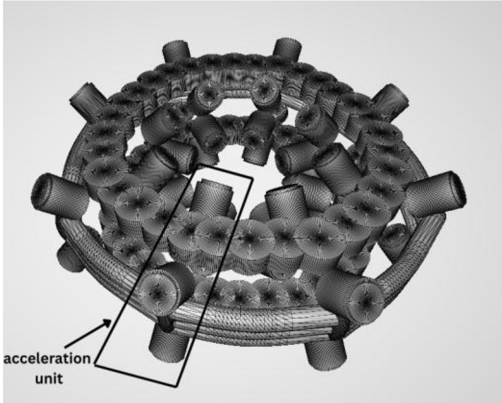

Figure 1: Complete accelerator model

3.1 Setup Overview

The experimental system consists of 4 forward acceleration coils, 1 centripetal acceleration coil, a vacuum unit, and a superconductor, all arranged in a circular formation. The components are strategically positioned to achieve the desired electromagnetic effects, with precise angular placements to facilitate efficient operation and cooling. The object referred to throughout the paper, which is being accelerated, is a magnet.

3.2 Component Placement and Configuration

- **Acceleration Coils:** There are 4 acceleration coils, each placed at a 90- degree angular separation from the adjacent coil. The axes of these coils intersect at the center of the circle, which forms the central focal point for the electromagnetic acceleration process. The coils are energized to create a magnetic field that accelerates the magnet
- **Centripetal Coils:** One centripetal coil. The coil work to maintain the centripetal force required for the object to stay on the intended path, providing the necessary magnetic field to counteract the object's radial motion and keep it within the circle by attracting the projectile towards itself

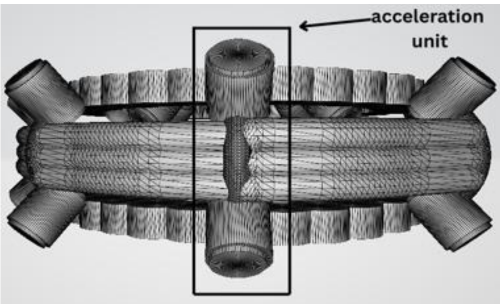

Figure 2: Complete accelerator model- side view

- **Vacuum Unit:** A vacuum unit is placed at an angular difference of 180 degrees from the superconductor and is designed to reduce air resistance, creating an ideal environment for the electromagnetic acceleration. The vacuum ensures that the object moves with minimal friction, improving the overall efficiency of the system.
- **Superconductor and Cooling Tube:** The superconductor, positioned 180 degrees opposite the vacuum unit, is essential for the levitation of the magnet. The superconductor is used to generate Meissner effect which results into levitation of the magnet. Attached to the superconductor is a cooling tube, which is placed beneath it. The cooling tube ensures that the superconductor maintains an optimal low temperature to preserve its superconducting properties such as Meissner effect.

3.3 Levitation Unit

All 7 components (4 forward acceleration coils, 1 centripetal acceleration coil, 1 vacuum unit, 1 superconductor with cooling tube) are arranged around the circle at a precise angular difference of 45 degrees. This configuration ensures a balanced and symmetrical setup, allowing for even distribution of electromagnetic forces across the system. To achieve efficient and consistent acceleration in the proposed circular electromagnetic accelerator model, friction must be minimized. Friction not only generates heat, which can cause energy loss and retardation, but it can also compromise the stability and performance of the system.

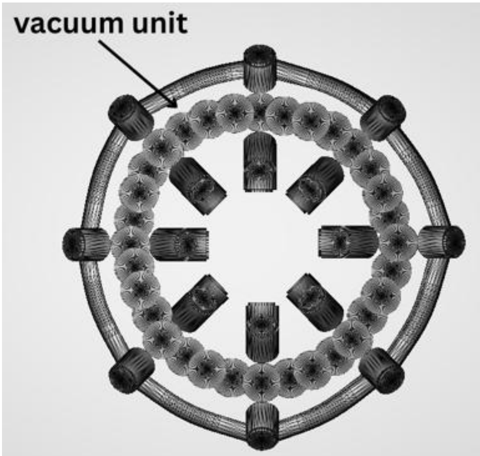

Figure 3: Complete accelerator model- top view

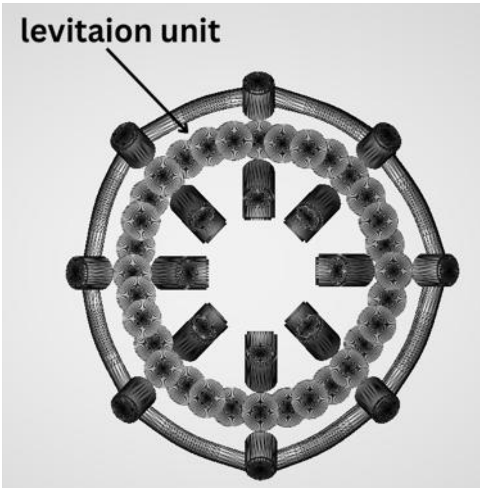

Figure 4: Complete accelerator model- bottom view

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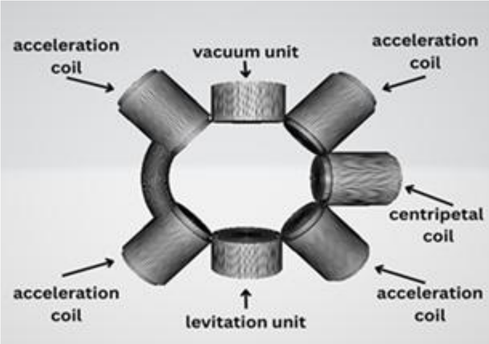

Figure 5: Magnetic field and the positioning of the magnets

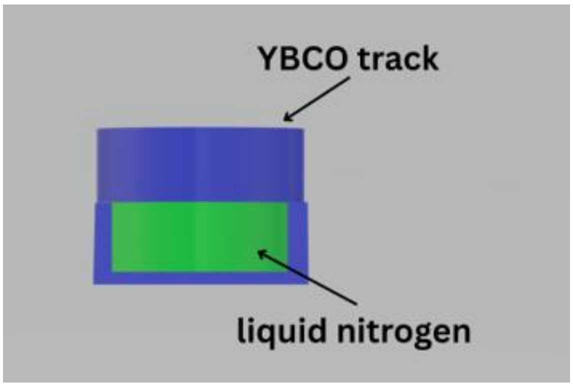

Figure 6: Vacuum unit

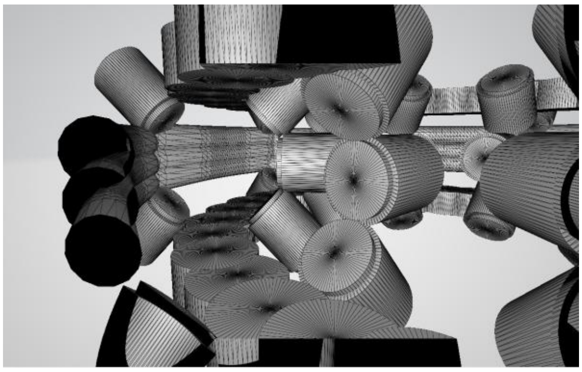

Figure 7: Accelerated projectile point of view

To eliminate friction, the track is constructed using yttrium barium copper oxide (YBCO), a high-temperature superconductor (Norton, 2004). YBCO exhibits superconducting properties when cooled below its critical temperature of 90K. This cooling is achieved through a dedicated cooling tube containing liquid nitrogen, which remains in direct contact with the YBCO track. The liquid nitrogen ensures that the YBCO is maintained at a temperature below 90K, enabling it to act as a superconductor.

Under these conditions, the Meissner effect comes into play, allowing the magnet to levitate above the cooled YBCO track (Meissner and Ochsenfeld, 1933). This levitation eliminates physical contact between the magnet and the track, effectively eradicating friction and enabling smooth, efficient acceleration. The circular design of the accelerator, combined with the levitating magnet, addresses several challenges faced by linear synchronous acceleration systems. By eliminating the constraints of friction and heat generation, the model pro- vides a stable platform for acceleration. However, the centripetal force required to maintain the magnet's circular trajectory remains a critical factor, demanding precise control and synchronization of the magnetic fields.

4. Working of the Acceleration Unit

The acceleration unit operates by attracting the magnet with a force $F = mB$, where B represents the magnetic field provided by the unit, and m is the magnetic pole strength of the magnet. The magnetic field generated by each elec- tromagnet on its axis is given by the expression:

$$B = \frac{1}{2}\mu_0 n I \mu_r$$

where μ_0 is the permeability of free space, μ_r is relative permeability of the core n is the number of turns per unit length in the coil, and I is the current through the coil (Griffiths, 2013).

In the proposed setup, four electromagnets are strategically arranged for the purpose of accelerating the magnet. To achieve consistent acceleration, the total magnetic field provided by the acceleration unit is the combined field from the active electromagnets. When four electromagnets contribute to the magnetic field, their combined effect results in:

$$B = 2\mu_0 n I \mu_r$$

As the magnet moves toward the accelerating unit, it is pulled with increasing force until it reaches the axis intersection of the electromagnets. At this exact moment, the current through the electromagnets is abruptly cut off. This timing is critical to ensuring that the magnet receives a forward jerk, propelling it further along its trajectory without unnecessary deceleration.

Thus, the magnet is propelled by a force:

$$F = m \cdot B = m \cdot 2\mu_0 n I \mu_r$$

This demonstrates that the magnet is accelerated contactlessly by the electromagnetic field, with precise timing and synchronization of the magnetic fields ensuring maximum efficiency.

By cutting off the current at the precise moment the magnet reaches the axis intersection, the system avoids backward pull from the magnetic field, allowing for efficient and contactless acceleration. This mechanism leverages the synchronized operation of the electromagnets to provide a smooth, consistent force, crucial for maintaining high efficiency and minimizing energy losses.

5. Resolution of the Propelling Force

After the magnet is propelled by the force $F = m \cdot 2\mu_0 nI$, this force can be resolved into two components based on its orientation relative to the circular track:

5.1 Perpendicular Component $F_{\perp}$

The component of the force that is perpendicular to the tangent of the track is given by:

$F_{\perp} = F \sin\theta$

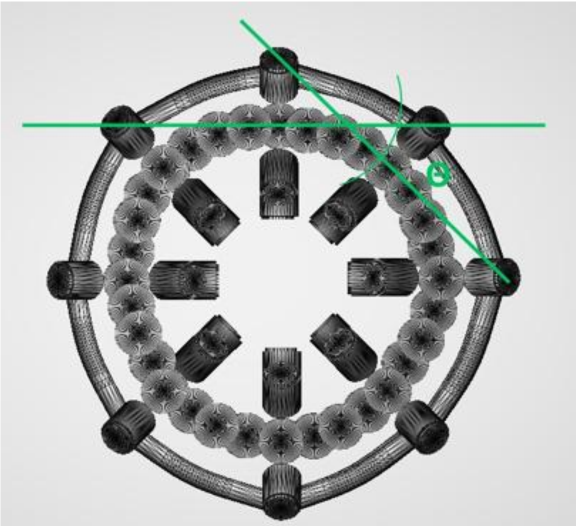

Figure 8: Resolution Angle

This component acts as the centrifugal force and needs to be balanced with the necessary centripetal force to maintain the motion of the magnet along the circular path.

5.2 Tangential Component $F_{||}$

The component of the force that is parallel to the tangent of the track is given by:

$$F_{||} = F \cos\theta$$

This tangential component contributes to the forward motion of the magnet along the circular track. It is responsible for increasing the velocity of the magnet as it progresses around the system.

Here, θ is the angle between the force vector and the tangent of the circular track.

6. Balancing Centrifugal Force with Centripetal Force

In the system, the centrifugal force acting on the magnet due to its motion can be counteracted by applying a centripetal magnetic force of equal magnitude but opposite direction (Powell and Danby, 1966). This centripetal force is provided by the centripetal coil, ensuring the magnet remains on the circular trajectory without being pushed outward. The current through centripetal coil is flowing until the object reaches the center at that exact point the current through the centripetal coil is turned off, which ensures that the magnet is not attracted back to the centripetal coil after moving forwards.

6.1 Centrifugal Force $F_{\text{centrifugal}}$

The centrifugal force due to the motion of the magnet is given by:

$F_{\text{centrifugal}} = 2\mu_0 nIm\mu_r \sin\theta$

where:
- μ_0 is the permeability of free space,
- n is the number of turns in the coil per unit length,
- I is the current in the acceleration unit,
- m is the magnetic pole strength of the magnet,
- θ is the angle between the force vector and the tangent.
- μ_r is the relative permeability of the core.

6.2 Centripetal Force $F_{\text{centripetal}}$

The centripetal magnetic force provided by the centripetal coils is given by:

$$F_{\text{centripetal}} = mB$$

where B is the magnetic field of the centripetal coils.

6.3 Balancing the Forces

For the system to remain stable, the centripetal force must equal the centrifugal force in magnitude but act in the opposite direction:

$$F_{\text{centripetal}} = F_{\text{centrifugal}}$$

Substituting the expressions:

$$mB = 2\mu_0\mu_r nIm \sin\theta$$

6.4 Expression for the Magnetic Field B

$$B = 2\mu_0\mu_r nI \sin\theta$$

6.5 Implementation of the Centripetal Magnetic Field

The magnetic field generated by the centripetal coils should vary as a function of $\sin\theta$, given by:

$$B = 2\mu_0\mu_r nI \sin\theta$$

This ensures that the centripetal magnetic force precisely cancels out the centrifugal force at every point along the circular path, stabilizing the magnet's trajectory. The variation of the centripetal coil's magnetic field as a function of $\sin\theta$ is achieved by dynamically controlling the current through the centripetal coils.

7. Deriving the Current Through the Centripetal Coils

The centripetal force required to counteract the centrifugal force is provided by the magnetic field from the centripetal coils. This magnetic field is generated by electromagnet whose fields is attractive. The magnetic field can be varied by adjusting the current passing through the centripetal coils $I_{\text{centripetal}}$. The current through the coil is flowing until it reaches the center of the coil, after which it is cut off to counteract the pull back effect of the attractive coil.

7.1 Expression for Magnetic Field B of the Centripetal Coil

The magnetic field produced by the centripetal coils is:

$$B = \frac{1}{2}\mu_0 n\mu_r I_{\text{centripetal}}$$

where:
- μ_0 is the permeability of free space,
- n is the number of turns in the coil per unit length,
- $I_{\text{centripetal}}$ is the current through the centripetal coils.

7.2 Balance Between Centrifugal and Centripetal Forces

From the previous derivation, the required centripetal magnetic field is:

$$B = 2\mu_0\mu_r n I_{\text{acceleration}} \sin\theta$$

where $I_{\text{acceleration}}$ is the current through the accelerating coils.

7.3 Equating the Two Expressions for B

Substituting for B from both equations:

$$\frac{1}{2}\ \mu_0 n \mu_r I_{\text{centripetal}} = 2\mu_0\mu_r n I_{\text{acceleration}} \sin\theta$$

7.4 Solving for $I_{\text{centripetal}}$

$I_{\text{centripetal}} = 4\sin\theta I_{\text{acceleration}}$

7.5 Final Expression for the Centripetal Current

The current through the centripetal coils is:
$I_{\text{centripetal}} = 4\sin\theta I_{\text{acceleration}}$

7.6 Practical Implementation

a) The centripetal current $I_{\text{centripetal}}$ varies dynamically as a function of the angular position θ of the magnet.
b) This ensures the magnetic field produced by the centripetal coils cancels out the centrifugal force at all points along the circular path.
c) The synchronization of $I_{\text{centripetal}}$ with $I_{\text{acceleration}}$ and the position θ is crucial for maintaining a stable trajectory of the magnet.

This approach enables the system to achieve a contactless, frictionless, and dynamically stable circular acceleration.

8. Derivation of Final Velocity After the First Acceleration Unit

1) The forward force acting on the magnet is given by: 2) From Newton's second law: 3) where m_0 is the mass of the magnet and a is the acceleration. Equating the two: 4) Using the kinematic equation $v = u + at$ and taking the initial velocity $u = 0$:

1) $F = m \cdot 2\mu_0\mu_r ni\cos\theta$
2) $F = m_0 a$
3) $a = \dfrac{m \cdot 2\mu_0\mu_r ni\cos\theta}{m_0}$
4) $v_1 = \dfrac{m \cdot 2\mu_0\mu_r ni\cos\theta \cdot t}{m_0}$

9. Final Velocity for the Second Acceleration Unit

Using the equation of motion:

$$v_2^2 = v_1^2 + 2as$$

where $s = r\phi$, half the arc length of the accelerating unit. Substituting v_1 and a from the first derivation:

$$v_2^2 = \frac{m \cdot 2\mu_0\mu_r ni\cos\theta \cdot t^2}{m_0} + 2\,\frac{m \cdot 2\mu_0\mu_r ni\cos\theta}{m_0} \cdot r\phi$$

$$v_2^2 = \frac{m^2 \cdot 4\mu_0^2\mu_r^2 n^2 i^2\cos^2\theta \cdot t^2}{m_0^2} + \frac{4m\mu_0\mu_r ni\cos\theta \cdot r\phi}{m_0}$$

10. Derivation of Final Velocity After the Third Acceleration Unit

For the third acceleration unit, the initial velocity is v_2^2. Using the same kinematic equation, Substituting v^2 from the second derivation:

$$v_3^2 = v_2^2 + 2as$$

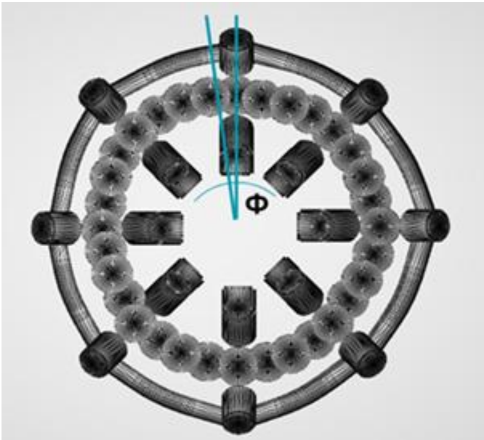

Figure 9: Resolution angle

$$v_3^2 = \frac{m^2 \cdot 4\mu_0^2\mu_r^2 n^2 i^2\cos^2\theta \cdot t^2}{m_0^2} + \frac{4m\mu_0\mu_r ni\cos\theta \cdot r\phi}{m_0} + \frac{4m\mu_0\mu_r ni\cos\theta \cdot r\phi}{m_0}$$

$$v_3^2 - \frac{m^2 \cdot 4\mu_0^2\mu_r^2 n^2 i^2\cos^2\theta \cdot t^2}{m_0^2} + \frac{4m\mu_0\mu_r ni\cos\theta}{m_0}(r\varphi + r\varphi)$$

$$v_3^2 = \frac{4m\mu_0\mu_r ni\cos\theta}{m_0} \quad \frac{m\mu_0\mu_r ni\cos\theta \cdot t^2}{m_0} + 2r\phi$$

11. General Expression for Velocity After Passing the q-th Accelerating Unit

For the q-th acceleration unit, the velocity v_q can be expressed as:

$$v_q = \frac{s}{\frac{4m\mu_0\mu_r ni\cos\theta}{m_0} \quad \frac{m\mu_0\mu_r ni\cos\theta \cdot t^2}{m_0} + (q-1)\, r\phi}$$

Where:

- m: Magnetic pole strength of the magnet.
- μ_0: Permeability of free space.
- n: Number of turns per unit length in the solenoid.
- i: Current through the accelerating coil.
- $\cos\theta$: Angle factor for force direction relative to the tangent.
- m_0: Mass of the magnet.
- t: Time duration of acceleration in each unit.
- r: Radius of the circular track.
- q: q-th accelerating unit
- ϕ: Half of the angle covered by each accelerating unit (in radians).

12. Advantages

12.1 No dragging force or frictional force

Due to the use of a levitation unit and vacuum environment, there are no resistive forces acting on the object, which makes the acceleration seamless.

12.2 Limited area is required to reach greater velocities

In linear models, reaching the same velocities may require a much larger amount of area.

12.3 Fewer acceleration units are used due to looping

In total, fewer coils will be used due to the circular structure of the track.

12.4 Larger momentum can be generated

As the object can loop, its mass can be heavier, resulting in greater momentum.

13. Potential Uses

13.1 Spacecraft Propulsion

The circular accelerator could be adapted to provide high-efficiency propulsion for spacecraft (Jahn, 2006). it can be used to project space crafts or satellites in the atmosphere as mass is not a concern and area required is confined too

13.2 Electromagnetic Guns

It can be used to fire heavy ammunition, as the ammunition can loop around, reach a certain velocity, and then be fired. This will also extend the system's lifespan, as there is no wear and tear as well as no chemicals.

14. Limitations

The absence of simulations is one of the major limitations of the study. As no simulations were used, there is limited quantified data available in the paper. Future research should reconfirm these findings by conducting simulation-based studies and providing more quantified and practical data. Additionally, the melting point of the object was not considered during the research; after being exposed to a magnetic field, the object may heat up and potentially melt.

15. Conclusion

This research was conducted to develop a more suitable electromagnetic accelerator model for accelerating objects with higher mass based on a theoretical framework. This challenge was addressed by a circular accelerator model design. It showcased how it could be more effective. However, in some cases, the linear model would still be superior, such as in projecting objects with lighter mass. This research should be further improved by making a simulation, providing more quantitative data, and by developing a prototype model. This research provides deep insight into electromagnetic acceleration and different types of models, mainly a theoretical circular model and its applications.

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