ISSN: 0976-3031

Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 8, Issue, 10, pp. 21043-21047, October, 2017

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

CHARACTERISTIC ANALYSIS OF MULTI STAGE ELECTRO MAGNETIC ACCELERATORS

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DOI: http://dx.doi.org/10.24327/ijrsr.2017.0810.1004

ARTICLE INFO

Article History:

Received 20th July, 2017
Received in revised form 29th August, 2017
Accepted 30th September, 2017
Published online 28th October, 2017

Key Words:

Electromagnetic Coil accelerator
Design Coil paramters
Muzzle Velocity Trajectory

ABSTRACT

Electromagnetic coil accelerator is used to apply linear forces to ferromagnetic objects. A development of a theoretical model allows for the estimation of optimized accelerator design. This article mainly concentrates on comprehensive design, implementation and validation of an electromagnetic coil accelerator. Mathematical models of a single stage and multistage coil accelerator are developed and analyzed. The performance curves of single stage and three stage accelerator models are presented for analysis. The inductance formula was developed based on various position of the moving object inside the coil.

INTRODUCTION

Electromagnetic accelerators (EMA) are a class of linear machines that can be used to accelerate ferromagnetic objects with lower drive currents than other induction machines [1]. In an EMA, a current pulse is applied to an accelerating coil that generates a transient magnetic field. This field induces a force on a positioned ferromagnetic object [2]. Thus, these accelerators have an easy control on the launch velocity of the moving object by controlling the accelerating coil currents.

An Electromagnetic accelerator consists of either a single or series of coils wound on a cylindrical hollow metallic tube. A single-stage Electromagnetic accelerator consists of one stator coil, known as a drive coil, configured coaxially with a ferromagnetic projecting object so that applying a current pulse to the coil accelerates the object towards its center due to the induced magnetic field. This paper presents the design and interpretations of the electromagnetic coil accelerator with a Canister which provides higher force density with a simple structure. A canister is a hollow ferromagnetic cylindrical structure which can accelerate the projecting object out of the accelerator, when drive coils are energized. A schematic of such a system is shown in Fig1. The canister is initially positioned at a displacement ‘x’ away from the center of the drive coil. When the drive coil is energized, the created transient magnetic field applies a force on the canister, drawing it to the center of the coil.

The inductance offered by the drive coil will change, as the canister moves into the coil. The inductance maximum when the center of the canister coincides with the center of the drive coil. Once the canister moves past the point of maximum inductance, the net restoring force acts to return the canister back. This effect is named as `suck-back' action. This action is undesirable as it is opposing the desired direction of motion of the canister and it reduces the resultant muzzle velocity of the projecting object from the accelerator system. Consistently, it is important to terminate the magnetic field once the canister reaches the point of maximum inductance. The magnetic flux distributions in the accelerator are shown in fig.2&3.

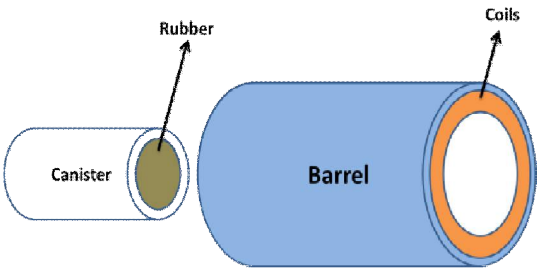

Figure 1 Schematic diagram of Single stage Launcher.

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The design and analysis of electromagnetic accelerators in general is quite complex approach. There are several design tools available for commercial and research applications but most of them are confined to a particular design [3-7].

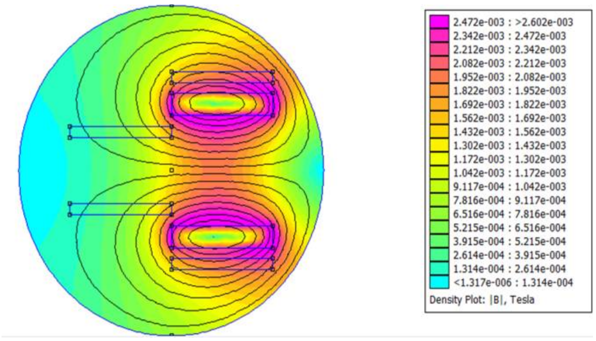


Figure 2 Magnetic Flux Density when the projecting object is outside the coil using FEMM

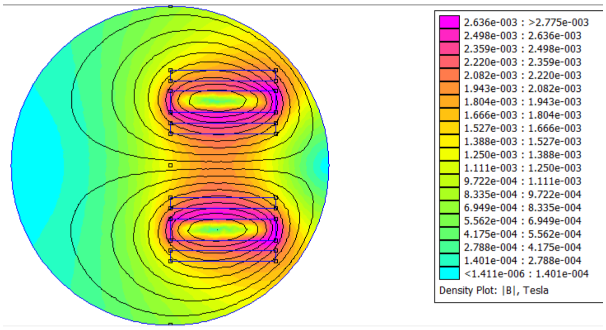


Figure 3 Magnetic Flux Density when the projecting object is completely inside the coil using FEMM

This article presents the characteristic analysis of the electromagnetic accelerator (EMA) with a canister based mechanism to accelerate an object. The inductance calculation is developed considering the position of the canister in the coil. As the magnetic flux plays an important role in generating the thrust in an electromagnetic accelerating system, each and every flux region is taken into account. This article mainly highlights the inductance profile equation derived from the flux distribution including entry and exit leakages.

The above mentioned limitations from the past literature are restrained. A novel control switching circuit is used to switch the coil in the sequence based on the displacement of the projecting object inside the coil. When compared with previous studies, the proposed coil driven system can provide a much better output performance and control with a low cost. Symmetrical Sleeve type Canister is considered as shown in fig 1.

System Parameters

The total design of the electromagnetic accelerator is based the inner diameter (D_i) and outer diameters (D_o) of the drive coil.

$$D_i = f(D_p, g)\text{.................}(1)$$

$$D_o = D_i + f(D_w, A_w, layers)\text{.................}(2)$$

Where 'A_w' is area of cross section of conducting wire, *'layers'* indicate the number of layers wound on the drive coil, 'D_i' inner diameter of the drive coil, 'D_o' outer diameter of the drive coil, 'D_w' diameter of wire.

To analyze the accelerating forces and exit velocities, the inductance gradient at every displacement position is to be calculated. Firstly the electrical parameters of the accelerating system are derived from [8-9]

$$R_{coil} = f(l_w, A_w, \rho_w)\text{...........}(4)$$

$$l_w = f(l_c, d_i, d_o, N)\text{...........}(5)$$

$$[L(x)^-, L(x)^+] = f(l_c, l_p, N, x, \mu_r)\text{...........}(6)$$

Where R coil is the coil resistance, L(x)-& L(x)+ are the minimum and maximum inductances, *x* is the displacement of the object, *lp* is the length of canister.

The accelerating force and exit velocity are estimated from the following equations:

$$F = f(I, \frac{dL(x)}{dx})\text{...........}(7)$$

$$a = f(F, M_p)\text{...........}(8)$$

$$v = f(a, t)\text{...........}(9)$$

Analysis and performance Plots

Electromagnetic accelerators are available in single stage and multi stage, designed by the required size and firing range. A single stage accelerator is executed with a single drive coil where as multistage with series of coils connected to a power supply bank, control unit to switch off the supply at every stage relative to the position of the canister.

For improving efficiency of the system, multi stage accelerators are adopted as they exhibit high exit velocities from the resultant magnetic forces of sequential coils. The user-defined parameters are presented in Table 1.

Table 1 User-defined Parameters (Input)

Variables	Values	Units
Voltage ,V	100	volts
Number of turns ,N	500	-
Coil length , lc	0.06	m
Air gap Length	0.003	m
Thickness of the Metallic Sheath in Canister	0.006	m
Thickness of the Metallic Sheath in Barrel	0.006	m
Diameter of the Conducting Wire	0.61	mm
Permeability of Canister	5000	
Radius of the Metallic Sheet	0.0535	m
Diameter of Canister	0.1	m

With the equations derived from section II, single stage and multi stage (3 stages) models are built to analyze and compare their performances. Figures 4,5&6 presents the single stage EMA model and its characteristics.

Three Stage Model

A three stage electromagnetic accelerator model is shown in fig 7. Initially all the coils are in OFF state. Each coil is switched ON and switched OFF depending on the position of the canister. The Switching Sequence is followed in such a way that the first coil is switched OFF when the canister completely fills the coil. The next coil is ON when it is just leaving the previous coil.

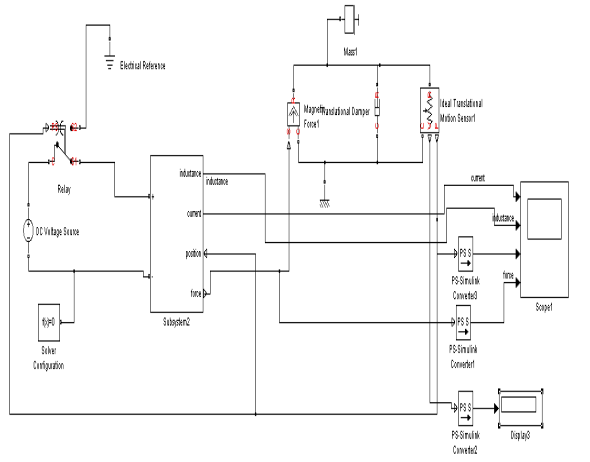


Figure 4 Building block of single stage electromagnetic accelerator

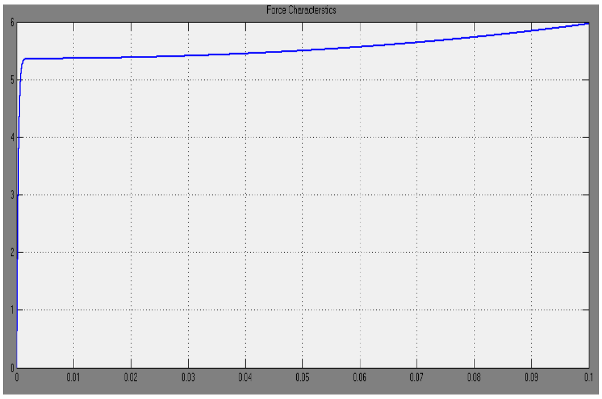


Figure 5 Force characteristics of electromagnetic accelerator

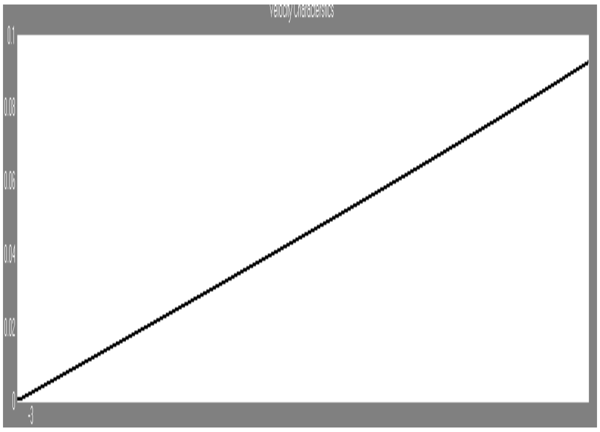


Figure 6 Velocity curve of a single stage accelerator

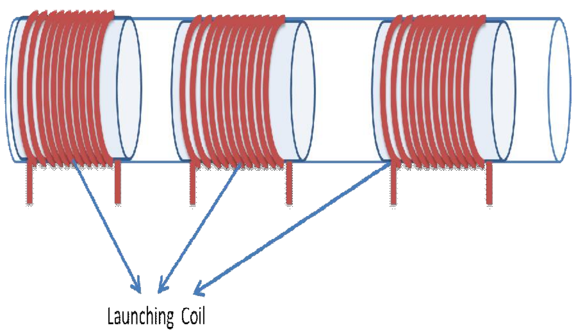


Figure 7 Three stage electromagnetic accelerator

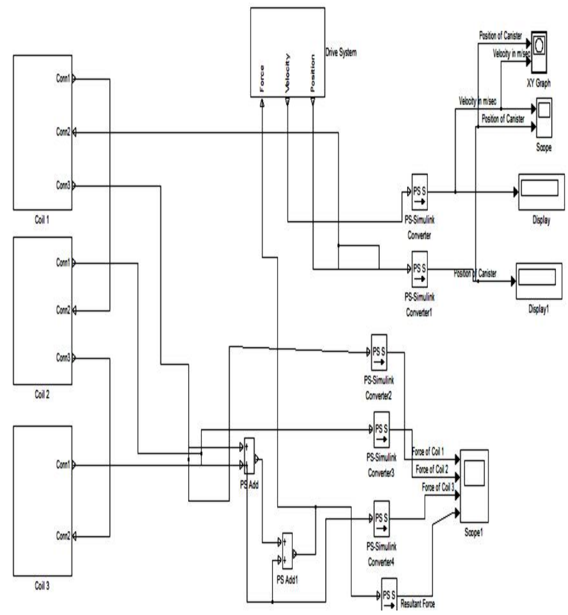


Figure 8 Three Stage Electromagnetic Accelerator

Figure 8 is the simulation mode and fig 9[a-d] are curves presenting the individual forces applied by each coil on the canister according to the sequence switching of the coils. From fig 10 it is observed that the exit velocity is much enhanced as the three forces acting on the canister are adding up each other and pushing the projecting object out with more velocity.

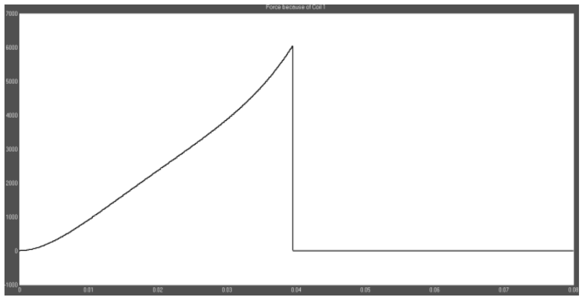


Figure 9 a Force by First Coil

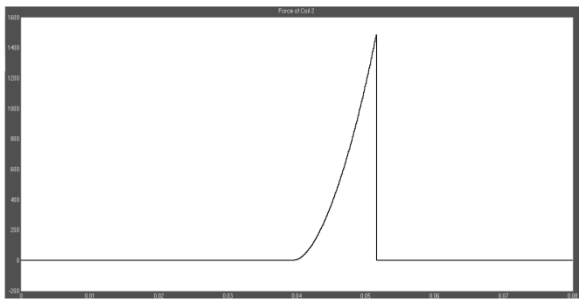


Figure 9 b Force by Second Coil

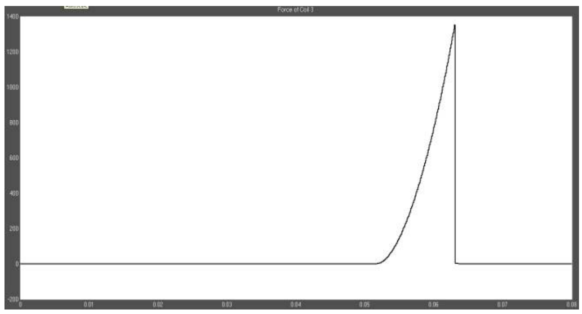


Figure 9 c Force by Third Coil

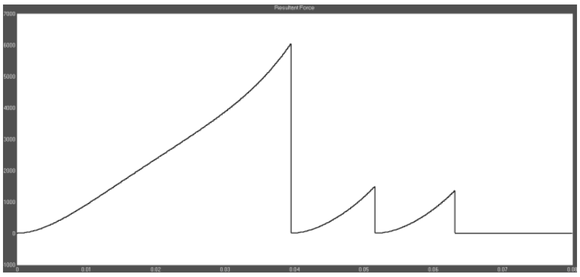


Figure 9 d Resultant Force in 3 stage Accelerator

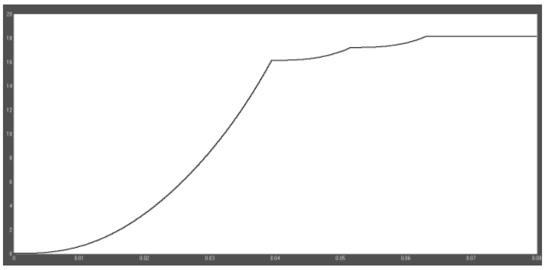


Figure 10 Resultant exit velocity of a 3-stage accelerator

The position of the canister is very much essential for the sequential switching of coils. Fig11 indicates the position of the canister inside the drive coil and its velocity at that particular position.

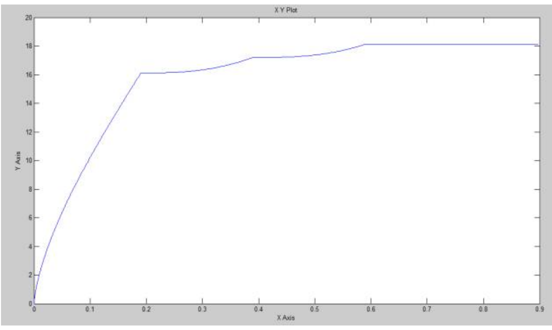


Figure 11 Velocity (y-axis) Vs Position (x-axis) Plot

The exit velocity of the propelling object depends on the magnetic field produced in the drive coil i.e. indirectly on the supply given to it. Hence two different voltages are injected to check the velocity of the system. The characteristic in fig 12 clearly indicate that increase in applied voltage will enhance the resultant velocity of the accelerator.

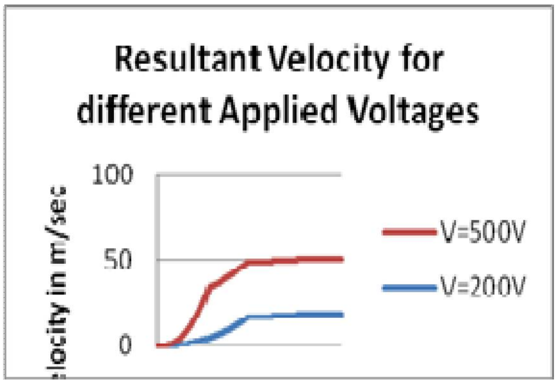


Figure 12 Resultant Velocity with different applied voltages

Similarly, the effect of change in number of turns of the drive coil and mass of the canister are varied to observe their impact on the exit velocity and force. The curves in fig 13&14 clearly show that with decrease in number of drive coil turns, the resultant velocity increases. Increase in coil turns raises the coil resistance, reduces the current drawn by the coil causing less resultant force and velocity in the accelerating system.

The drag force of any object depends on the inertia and mass, objects with less weight will experience the higher force impacts. Therefore the as the mass of the object is increasing, the resultant exit velocity of the accelerating object is dropping. The light weight objects are propelled with higher velocities as shown in fig 15.

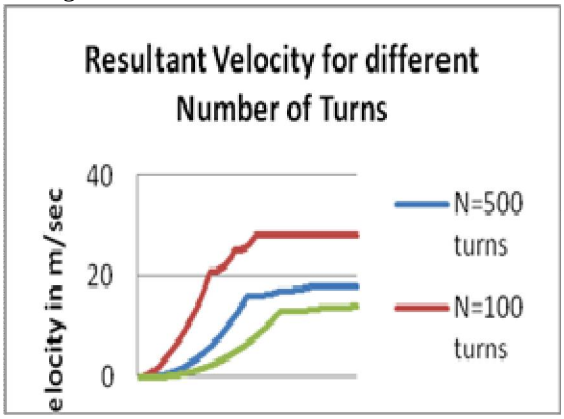


Figure 13 Resultant Velocity with change in Drive coil turns

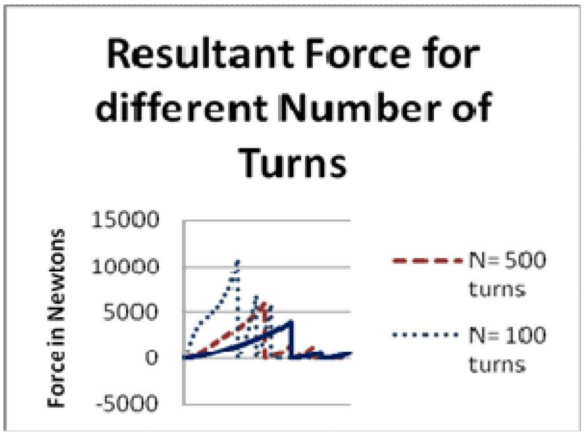
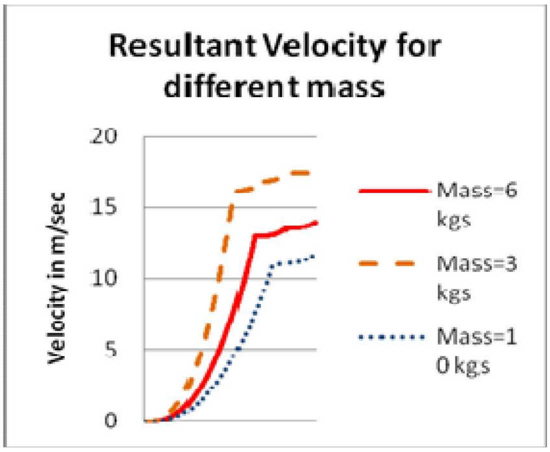


Figure 14 Resultant Force based on different Drive coil turns



Time (sec)

Figure 15 Resultant Velocity for different canister weights

A trajectory can be described mathematically either by the geometry of the path, or as the position of the projecting object over time. The trajectory of the projecting object is shown in fig 16.The launch barrel is set to correct angle before it's actually fired so as to hit the target. The angle is set in horizontal plane between 0^o to 90^o as the muzzle speed will vary slightly with angle. The launching angle of 50^o is adjusted to hit the target placed at a distance of 32m with a velocity of 18m/sec. From the graph, the time taken to reach the target is 2.25 sec.

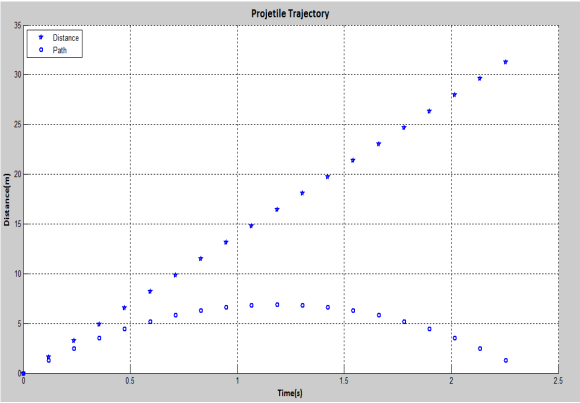


Figure 16 Trajectory of the object when the launching Angle is 50 deg

CONCLUSION

In this article, multi stage accelerating system is modeled to develop the desired velocities. It is observed that the performance of the launching systems can be improved using multistage accelerator by 15-20 times more than with a single stage accelerator. It is notice that for launching an object of weight 6kg to a distance of 32m, the electromagnetic accelerator requires 2.2 sec of time. The obtained exit velocity of the launcher is 18m/sec. Simulation analysis and comparison with different parameters shows that proposed multistage system is much more effective and suitable for different speed and high thrust applications.

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How to cite this article:

Sandhya T and MallikarjunaRao P.2017, Characteristic Analysis of Multi Stage Electro Magnetic Accelerators. *Int J Recent Sci Res.* 8(10), pp. 21043-21047. DOI: http://dx.doi.org/10.24327/ijrsr.2017.0810.1004

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