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Microarticle

A novel type coil-multipole field hybrid electromagnetic launching system

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ABSTRACT

This paper describes the concept of a Coil-Multipole Field Hybrid Electromagnetic Launcher. The electrical and magnetic equivalent circuits of coil gun and multipole field electromagnetic launch system (MFELS) are discussed. An attempt is made to analyze the combination of coil gun and MFELS. Simulation and finite element analysis are used to study the Coil-Multipole Field Hybrid Electromagnetic Launcher. A comparative study is carried out on the performance of coil gun, MFELS and coil-multipole hybrid launcher. Results shows that the speed of the proposed hybrid launcher is greater than that of a single coil gun and MFELS. Lastly, the advantages of the proposed hybrid electromagnetic launcher are discussed.

Introduction

Electromagnetic launching system is one of the new brands in the family of weapon launchers. There is an imperative need for a new generation of electromagnetic launching system with superior performance and supplement for hydraulic and chemical systems with especially low maintenance. One of the existing launch systems is the Coil gun launching which has higher projectile velocity and good accuracy. The projectiles rely on kinetic energy at the target for their devastating effects and the coil gun device obviously needs no explosive propellants [1–7]. Multipole Field Electromagnetic Launch System (MFELS) is one of the effective alternatives in the field of launching systems with additional advantages of controlled switching and less amperage requirement [8–12]. For selected projectile weights, difference in propulsion force, launch mechanism, design and projectile velocity, coil gun is good for medium weighted projectiles and high initial velocities, whereas MFELS is good for light weighted projectiles and high force applications. The basic geometrical configuration of a coil gun and MFELS are shown in Fig. 1(a and b). (For more details about the literature review of coil gun and MFELS please refer to the supplement article).

The main objective of this paper is to develop a novel type coil-multipole field hybrid electromagnetic launching system with a combination of coil gun and MFELS, where coil gun is used to provide initial velocity and MFELS is used for guiding the projectile for higher velocities. The electrical and magnetic equivalent circuits of coil gun and MFELS are developed. The performance of coil gun, MFELS and coil-multipole hybrid launcher system are compared to highlight the advantages of hybrid system.

Permeance network method

The electrical equivalent circuit of MFELS is shown in the schematic diagram of Fig. 2(a), whereas the equivalent of coil gun is represented with a simple RL circuit excited by a voltage source. The inductance of the coils in both the launch systems will change accordingly with the movement of the projectile inside the coil due to flux deviations. Therefore, the magnetic flux line flows in the launch systems are realized using FEMM software as shown in Fig. 2(b and c). Permeance network method is adopted to calculate the reluctance offered by each flux path [13,14]. The magnetic equivalent circuits of coil gun and MFELS are developed as shown in Fig. 2(d and e), to calculate the equivalent reluctance values. Further, the coil inductances are finalized based on the projectile positions [7,13,14]. The dynamic inductance ($L(x)$) of the accelerating coil of MFELS is calculated using the equation given below, where L_m is the average of difference between maximum

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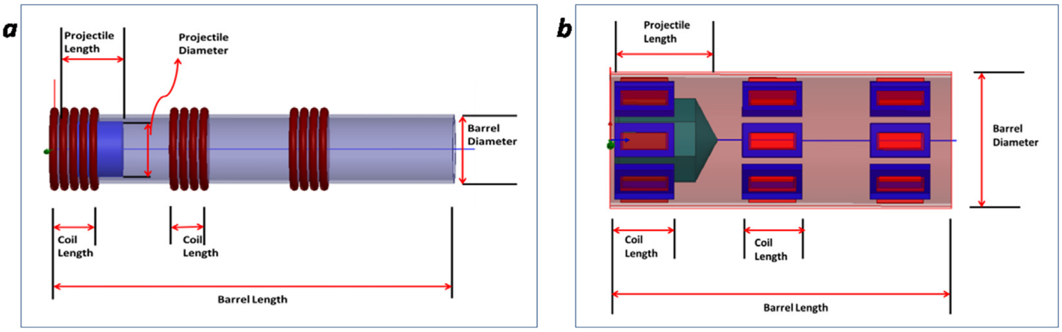

Fig. 1. a). Geometric Configuration of Coil gun; b). Geometric Configuration of MFELS.

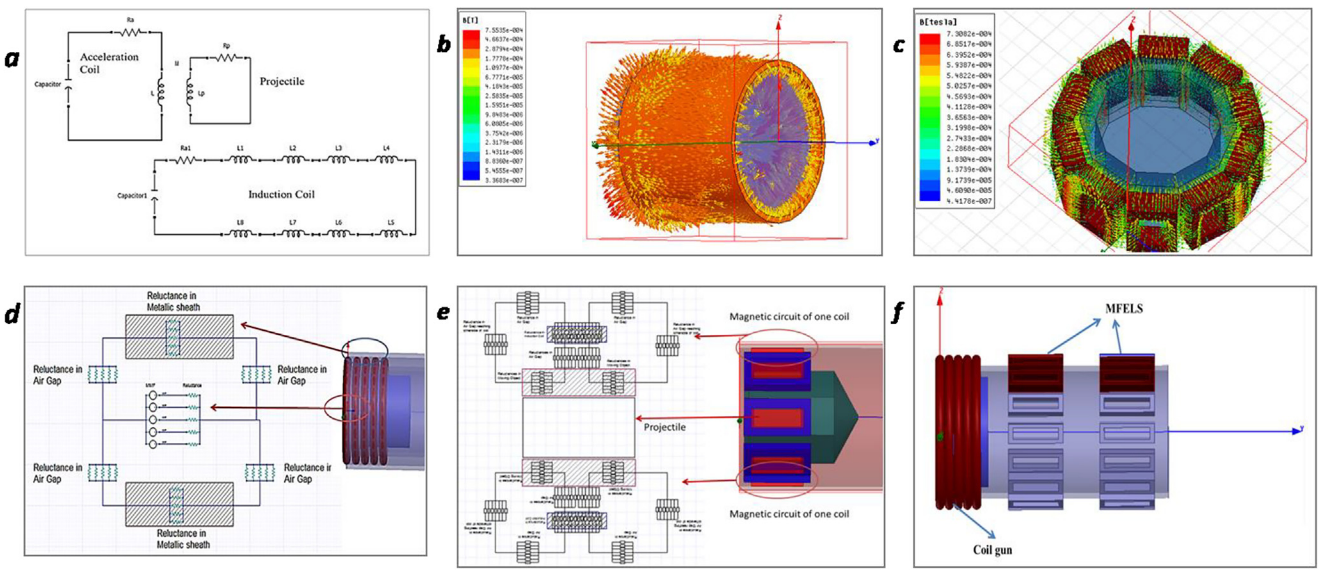

Fig. 2. a). Electrical Equivalent circuit of single stage MFELS; b). FEM model of single stage coil gun model when projectile inside the coil; c). FEM model of MFELS; d). Magnetic circuit of single stage CG; e) Magnetic equivalent circuit of MFELS; f). Coil gun – MFELS Hybrid Electromagnetic Launcher.

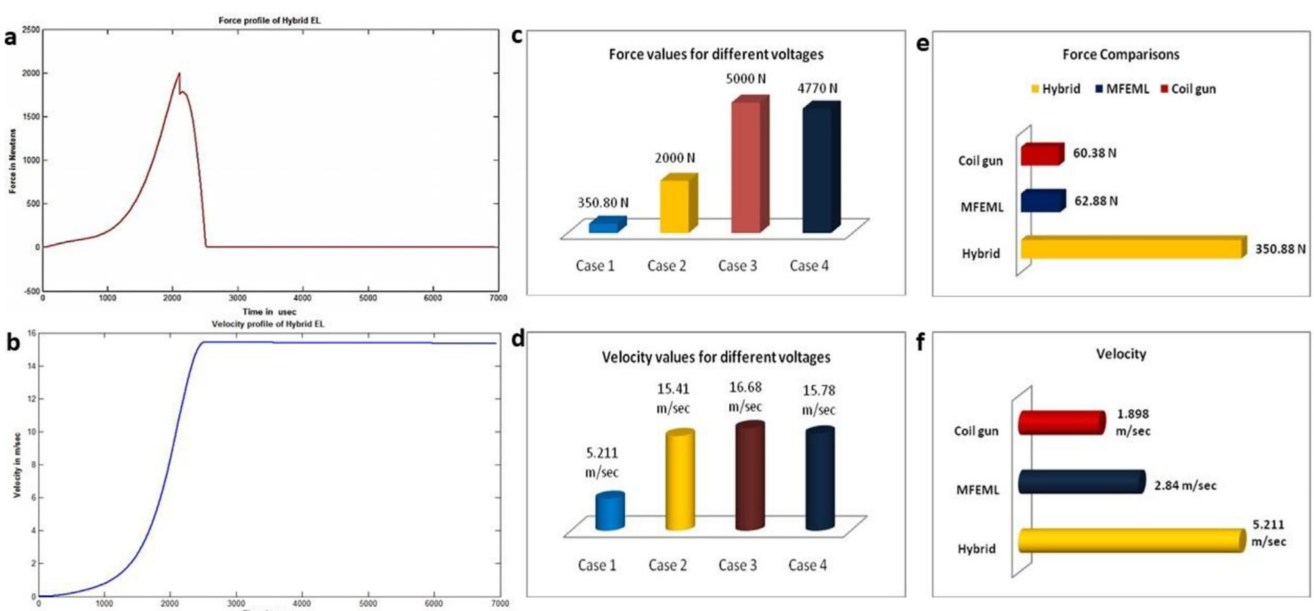

Fig. 3. a). Force of Coil-Multipole Field Hybrid Electromagnetic Launcher; b). Velocity of Coil-Multipole Field Hybrid Electromagnetic Launcher; c). Force obtained for various voltages of Coil-Multipole Field Hybrid Electromagnetic Launcher; d). Velocities obtained for various voltages of Coil-Multipole Field Hybrid Electromagnetic Launcher; e). Force comparisons between CG, MFELS and Hybrid Electromagnetic Launcher; f). Velocity comparisons between CG, MFELS & Hybrid Electromagnetic Launcher (for 1 kg projectile).

Table 1
Performance Parameters of Hybrid EL for different input voltages.

	Case 1	Case 2	Case 3	Case 4
	V_{CG} = 220 V, V_{MFEL} = 220 V	V_{CG} = 220 V, V_{MFEL} = 1 kV	V_{CG} = 1 kV, V_{MFEL} = 1 kV	V_{CG} = 1 kV, V_{MFEL} = 220 V
Force	350.88 N	2 kN	5.04 kN	4.77 kN
Velocity	5.211 m/s	15.41 m/s	16.68 m/s	15.78 m/s

inductance (L_{max}) and minimum insuctance (L_{min}).

$$L(x) = L_m\left[1 + \sin\left(\frac{\pi}{l_c}x\right)\right] + L_{min} \quad (1)$$

The Fig. 2(f) shows the new developed coil- multipole field hybrid electromagnetic launch model with an arrangement of coil gun at the forefront of the launch barrel followed by an assembly of multipole field coils. Based on the mathematical models developed on coil gun and MFELS, a simulation model is executed for coil-multipole field hybrid electromagnetic launch model. The hybrid launch system uses coil gun to accelerate the projectile from stationary state and inject it into the launching bore. The switching of the MFELS is accomplished to enable high power pulsed supply discharge to the accelerating coils of MFELS to exert the high electromagnetic thrust. Thus, the total thrust exerted on the projectile is the sum of the thrusts generated by coil gun and MFELS.

Results and discussions

The single stage model of a Coil-Multipole Field Hybrid Electromagnetic Launcher is simulated using the input specifications of projectile length = 0.1 m, projectile diameter = 0.03 m, projectile mass = 1 kg, wire diameter = 0.45 mm, air–gap length = 0.1 mm, coil turns = 1300, coil length = 0.02 m, layers in coil = 21, mechanical translational viscous coefficient = 0.1 N/(m/s), coils used in MFELS = 8, permeability of projectile material (iron) = 5000, Input voltage = 220 V. Sensors are used to detect the projectile position for triggering the circuit switches. The performance curves of the force and velocity acted on the projectile of the hybrid launch system are shown in Fig. 3(a and b). From the characteristics, it is observed that the coil gun is providing the initial thrust to the projectile till 2 μs. After 2 μs, the projectile has entered into the region of MFELS. At 2 μs, the accelerating coils of MFELS are energized. The final velocity attained is 15.36 m/s and the output force is 2 kN. Based on the results, it is observed that the combination of Coil gun and MFELS can provide high output velocities. From Table 1, it is observed that the initial velocity will play a vital role in the launch mechanism of electromagnetic launchers. When coil gun is energized with high voltage the resultant final thrust value has increased. MFEL system will guide the projectile to move in the barrel without any decay in the velocity. Fig. 3(c and d) has presented the graphical comparison of force and velocity for different combinations of input voltages.

In Fig. 3(e), the force values are compared, and it is observed that the coil gun is generating a force of 46.77 N, MFELS initiates 62.88 N, whereas Coil-Multipole Field Hybrid Electromagnetic Launcher is generating a force of 350.88 N. Hence, using Coil-Multipole Field Hybrid Electromagnetic Launcher the output force can be enhanced for same projectile weight and with same exciting voltage. In Fig. 3(f), the velocities are compared, and it is observed that the coil gun generates a velocity of 1.898 m/s, MFELS produces 2.84 m/s, whereas Coil-Multipole Field Hybrid Electromagnetic Launcher has a velocity of 5.211 m/s. The force and velocity comparisons are made for the same input voltage and dimension. It can be concluded that with Coil-Multipole Field Hybrid Electromagnetic Launcher, output velocity of the launch system can be boosted.

Conclusion

This paper proposed a Coil–Multipole Field Hybrid Electromagnetic Launcher. A detailed discussion on the numerical analysis and characteristic analysis of Hybrid Electromagnetic Launcher are presented. With reference to result analysis, both launchers are equally good for various propulsion applications. For selected projectile weights, difference in propulsion force, launch mechanism, design and projectile velocity has made the comparison of the coil gun and MFELS interesting. It is observed that coil gun is good for medium weighted projectiles and high initial velocities. MFELS is satisfactory for light weighted projectiles and high force applications. These comparison results illustrate the feasibility of adopting a MFELS and coil gun concept to achieve the higher velocities. Along the launch bore of the hybrid launcher, if multi-stage accelerating coils are arranged along with coil gun, the projectile can be accelerated to hypervelocity step by step. This Coil-Multipole Field Hybrid Electromagnetic Launcher can accelerate projectiles from zero to higher velocity without taking help of chemical injectors. The future research will include trailing of various launcher combinations for more sophisticated performance.

CRediT authorship contribution statement

Sri Chandan Kondamudi: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Sandhya Thotakura:** Conceptualization, Methodology, Writing - review & editing. **Mallikarjuna Rao Pasumarthi:** Supervision, Writing - review & editing. **Guduru Ramakrishna Reddy:** Data curation. **Sandesh Mysore Sathyaraj:** Data curation. **X.X. Jiang:** Methodology, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rinp.2019.102786.

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