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Development of a Compact Electromagnetic Mortar System Coil Gun

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Abstract: In order to build modern weapon systems that are highly precise and low collaterally dam-length (LCD) some kind of next-gen launch system had to be developed. The paper introduced the concept, design, development and performance of a Compact Electromagnetic Mortar System (CEMS)--a device suitable for use in tactical military situations. Combining electromagnetic acceleration, in a coilgun configuration, with the launch of mortar rounds will permit an unprecedented degree of precision, lethality, range and obliquity as compared to today 's conventional mortar techniques that make use of chemical expellant. As it is quite small, foot soldiers can carry it or it can be installed in light vehicles and unmanned platforms. Either way, on the battlefield it adds mobility and flexibility. Capable of high-power bursts released by high-capacity condensers, the ferromagnetic or hybrid armature moves quickly thanks to energy poured into electromagnetic coils are ranged for sequential firing. The principal engineering obstacles that had to be surmounted were that of heat management, the efficiency of energy and power system miniaturization to drive and control reliable fire and control algorithms for accurate firing and sequences targeting.

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I. INTRODUCTION

The increasing demand for high-precision, low-collateral, and rapidly deployable weapon systems in modern warfare has led to the exploration of advanced electromagnetic launch technologies. This paper presents the design, development, and evaluation of a Compact Electromagnetic Mortar System (CEMS) tailored for tactical military applications.

Imagine a mortar—something that traditionally roars with fire, smoke, and a boom you can hear for miles. Now imagine it without all that. No smoke. No fire. Just a pulse of energy and a metal slug flying through the air. That's the Compact Electromagnetic Mortar System (CEMS). A new kind of firepower built not with gunpowder, but with copper coils and capacitors. It's clean, quiet, and deadly accurate.

The idea? Simple. Use electromagnetic force—like a railgun, but on a smaller scale—to launch mortar rounds. The execution? Not so simple. Coils had to be fast. Circuits, smarter. Power systems, lighter. Engineers worked in labs and test fields. They ran cables through sandbags, mounted test units on tripods, watched sparks fly as prototypes fired their first rounds. Some didn't work. Others overheated. A few misfired. But every failure brought insight. Every test, closer to something real.

CEMS isn't just an experiment. It's a response. A solution for tactical teams who can't afford to wait for artillery support. Who need indirect fire but don't want to carry the weight—or the noise—of traditional mortars. And as the tech improves, as energy storage gets better, the gap between "experimental" and "essential" keeps shrinking.

This paper dives into how the system works. The coils, the capacitors, the control logic. The design choices made. The challenges faced. The results that followed. It's not perfect—but it's getting close. And it's pointing toward a future where electromagnetic systems aren't the stuff of sci-fi. They're just standard gear.

II. PRINCIPLES OF WORKING

It starts with silence. No fire. No smoke. Just a surge of current and a thump you can feel more than hear. At the core of the Compact Electromagnetic Mortar System (CEMS) is a simple but powerful idea—use magnetism to throw things. Fast. The system replaces explosive propellants with coils of copper wire, carefully arranged along the launch barrel. These coils, when pulsed with high-voltage electricity, create magnetic fields. Strong ones. Enough to pull a metal armature—or even a specially designed projectile—down the barrel and out into the sky.

The setup looks a bit like sci-fi. And maybe, yeah—it kind of is. But the science behind it? Very real. So here's how it works. Capacitors get charged up first. Takes a few seconds, depending on your power source. Could be a battery. Could be a portable generator. Once charged, the system waits. Target gets locked. Trajectory calculated. Then—bang, but not the traditional kind. The capacitors discharge. Boom.

Massive current floods into the first coil. Magnetic field forms. The projectile moves.

But here's the catch: fire all the coils at once, and you'll fry the system. Timing is everything. The control unit—basically the brain—activates each coil in sequence. Just as the projectile reaches one, the next one fires. Perfect rhythm. Like dominoes, but in reverse. That's what gives it speed. Accuracy. Efficiency.

No need for gunpowder. No need for mechanical recoil systems. And barely any sound. That makes CEMS ideal for covert ops. Urban warfare. Even drone-based deployment. Because let's face it—traditional mortars? They're loud, messy, and leave a heat signature a mile wide. This system? Leaves barely a trace.

Of course, it's not all perfect. Heat buildup is real. Components wear down fast under high stress. And if your power dies? Well, you're carrying dead weight. But the trade-offs? Worth it. Bottom line—CEMS works by turning electricity into kinetic energy. It's electromagnetism in motion. Controlled chaos. Quiet firepower. And with the right tuning, it hits just as hard as the old stuff—only smarter.

A. Modelling of the Electromagnetic Force

In multi-coil electromagnetic weapon designs, improving the velocity of the projectile is a critical objective. One of the primary challenges encountered during early development was the inefficient conversion of electrical energy into kinetic energy—much of the input energy was lost, primarily due to resistive heating and imperfect electromagnetic coupling.

➢ *The Magnetic Energy Density, or the Magnetic Energy per unit Volume, is given by:*

$$W_m = \frac{1}{2} B \cdot H = \frac{1}{2}\mu H^2 = \frac{1}{2\mu} B^2 \qquad (1)$$

➢ *Where:*

- Wm: Magnetic energy density (J/m³)
- B: Magnetic flux density (T)
- H: Magnetic field intensity (A/m)
- μ: Permeability of the medium (H/m)

To model the magnetic field generated by the driving coil, we assume the coil's length is much higher than its radial distance, and the conductor is properly thin. Under these assumptions, the coil can be approximated as a current-carrying solenoid.

➢ *The Magnetic Field Strength H Along the central axis of the Solenoid at a Relative Position x is given by:*

$$H(x) = \frac{1}{2} ni\left[\frac{l-x}{\sqrt{(l-x)^2+R^2}} + \frac{x}{\sqrt{x^2+12^2}}\right] \qquad (2)$$

➢ *Where:*

- n: Number of turns per unit length (turns/m)
- i: Current through the coil
- l: Driving coil Length
- R: Coil Radius
- x: Axial displacement from one end of the coil

Calculating total magnetic energy ain't that simple. You can't just plug into Equation (2) and call it a day. Nope. That only gets you partway. To get the full picture, you gotta dive deeper—like, full volume integration across the entire magnetic field space. Everywhere the field exists. Every twist and turn. That's where the real energy lives.

But here's the thing—most of the time, we don't need the full energy. Not always. What really matters? The change in energy. That tiny variation that happens when something moves. A nudge. A shift. A virtual displacement. That's the moment where electromagnetic force shows up. Right there. It's subtle, but important. Like catching a whisper in a noisy room. And now enters Abe's loop theorem. This one's a lifesaver. According to it, inside a solenoid with steady current, the magnetic field in the centre? Perfectly uniform. Just like the field along the axis. No drops. No weird curves. That's gold for calculations. Makes everything more predictable.

So yeah, the rest of this chapter? It's not just filler. It's the roadmap. A guide to figure out the electromagnetic force using all these pieces—the energy variation, the virtual shift, the field strength. Piece by piece, it builds up. From theory to real numbers. In the end, it's less about solving one big equation—and more about understanding the dance between current, coil, and force. A single virtual displacement of the projectile can be illustrated as Fig. 1.

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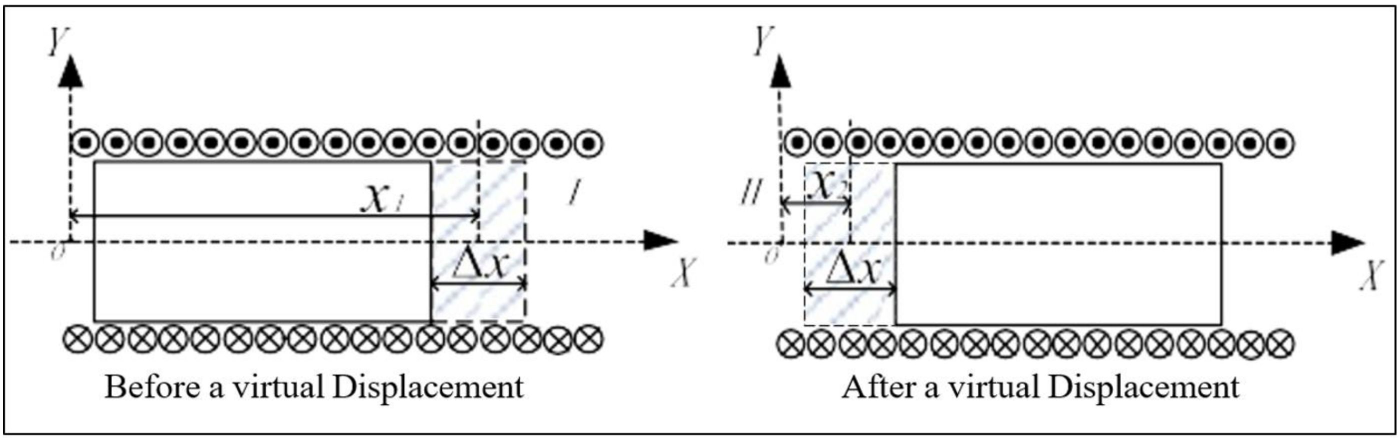

Fig 1 A Graphic Representation of the virtual Displacement.

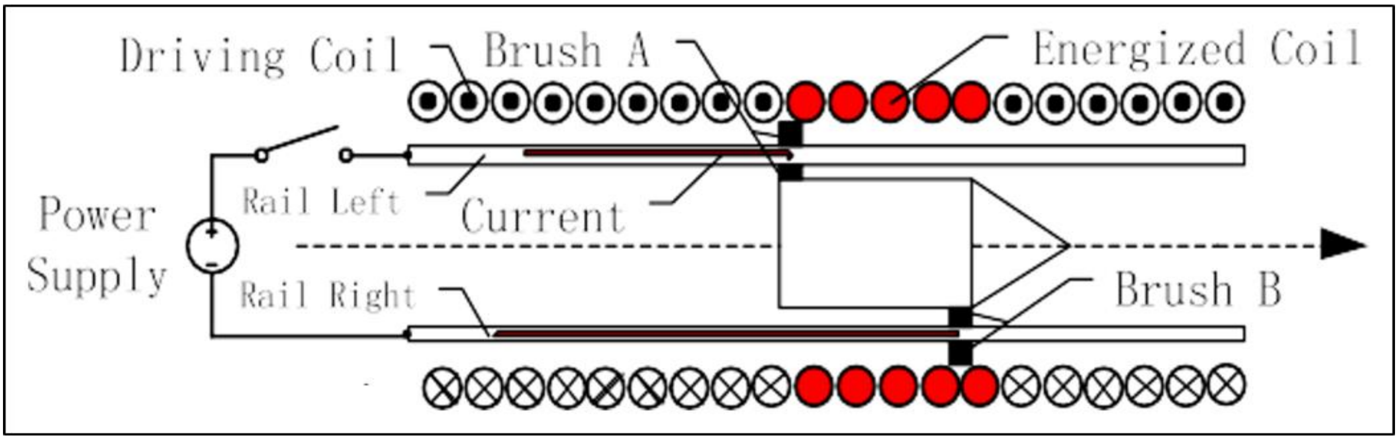

Fig 2 Diagrammatic Sketch of the Special RCG.

Let's break it down in simple terms first. We're dealing with a virtual displacement—just a tiny shift in the projectile's position. This shift causes a change in the magnetic medium. In Section I, the material goes from air to a ferromagnetic substance. In Section II, the reverse happens. So now, we've got two zones with different magnetic properties, reacting differently to the same field.

- *As Given in Equation (3), the Variation in Magnetic Energy due to this Displacement is:*

$$W_m = \iiint [(\mu - \mu_0)(H_1^2 - H_2^2)]\, dV \quad (3)$$

This is where things start getting interesting. This energy difference isn't just a number—it becomes a force when you calculate its derivative with respect to displacement xxx. That brings us to the electromagnetic force:

- *Where:*

- μ represents the magnetic permeability of the ferromagnetic material,
- μ0 denotes permeability of free space (air),
- H1 and H2 are the magnetic field strengths before and after displacement,
- A is the cross-sectional area of the region affected.

Now here's the catch. This equation doesn't apply just anywhere. It only holds up within the driving coil. Specifically, at points inside the magnetic field region where the medium changes. Once you step outside the coil—or too far from its centre—the field drops off. Fast. And the assumptions in (4) start to break down.

- *Final Expression:*

Given the assumptions above, and within valid field regions, the final expression for electromagnetic force acting on the projectile during virtual displacement becomes:

$$F_m = Ci^2 \cdot \left(\frac{1-X_1}{\sqrt{(1-x_1)^2+R^2}} + \frac{X_1}{\sqrt{x_1^2+R^2}}\right)^2 \quad (4)$$

$$-Ci^2 \cdot \left(\frac{1-x_2}{\sqrt{(1-x_2)^2+R^2}} + \frac{x_2}{\sqrt{x_2^2+R^2}}\right)^2 \quad (5)$$

- *Where C represents a constant, its value is*

$$C = \frac{1}{8}(\mu - \mu_0) \cdot n^2 \quad (6)$$

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For the particular RCG analysed within this paper, the brushes on the projectile object of Fig.2 result in the actual "Driving Coil" to move together with the projectile body. It follows that the reluctance of magnetic circuit around the driving coil can be assumed to be constant if the B-H curve of ferromagnetic projectile is idealized as "Piecewise Linear B-H curve". According to the reluctance described herein can be calculated by

$$R = \frac{4g}{\mu_0 \pi \, d p} \tag{7}$$

- *Here's what Each Term Typically Means in this context:*

- R = Magnetic reluctance
- g = Length of the air gap
- μ0 = Permeability of free space
- π = Pi, constant (~3.1416)
- d = Coil Diameter
- p = Projectile Length

- *Moreover, the Connection between Reluctance and Magnetic flux*

$$N_i = \phi R \tag{8}$$

- *Meaning of Each Term:*

- N = Total coil winding count
- i = Current through the coil
- ϕ = Magnetic flux
- R = Magnetic reluctance

- *After that, the static Inductance can be Obtained from the Magnetic Energy Calculation formulas.*

$$L_s = \frac{2}{i_2} \cdot \int_0^{\Phi} Ni \, d\phi \tag{9}$$

The inductance expression in formula (9) is applicable only to the stationary states of ferromagnetic projectiles, for moving projectiles, a time-varying or dynamic inductance should be used.

$$L_d \quad \frac{d\psi}{di} \quad \frac{2i\Delta W_m - 2W_m\Delta_i}{i^2 \Delta i} \tag{10}$$

In real-world use, the results from formula (9) and the formula (10) is inaccurate due to flux leakage and reduce down the complexity of nonlinearity. Researches commonly rely on the finite-element method to calculate the inductance with exact measurement.

III. COMPONENTS

A. *I want to Balance Performance, Safety, Affordability, and ease of Integration.*

- *Power Supply*

These are essential to build the high-energy pulses needed to fire the coil.

- Super capacitors (e.g., 2.7V 500F or 16V 500F banks) – Rapid discharge capability
- 12V or 24V Li-ion Battery Pack – Powers capacitors or controller
- DC-DC Boost Converter (600W or higher) – To charge capacitors up to 200–400V
- Diodes (High-voltage, fast recovery) – Prevent back EMF from damaging components
- High-current IGBT or MOSFET (e.g., IRFP260N or IGBT module) – Acts as a switch for the coil

B. *Electromagnetic Coil System*

- *These Accelerate the Projectile.*

- Copper Wire (AWG 18–24 magnet wire) – To wind coils
- PVC or Acrylic Launch Tube – Non-conductive material to hold coils and guide projectile
- Iron or Soft Steel Projectile – Ferromagnetic and cylindrical, fits closely in the tube
- Coil Formers – 3D printed or plastic pipe sections for winding

C. *Control Circuit*

- *This Manages Coil Activation and Timing.*

- Arduino Uno / Mega / STM32 – Easy for timing control and sensor input
- Optocoupler (e.g., PC817) – Isolate control logic from high voltage side
- Hall Effect Sensors (e.g., A3144) – Detect projectile position to trigger next coil
- Gate Driver IC (e.g., IR2110) – Used to safely switch the high-power MOSFET or IGBT
- Capacitor Charging Indicator (LED or LCD) – Display capacitor charge status

D. *Mechanical & Structural*

- *Ensures Stability and Modularity.*

- Laser-cut or 3D printed frame – For housing electronics and coil assembly
- Heat-resistant Epoxy / Glue – For securing coils
- Tripod / Mount Platform – To stabilize your setup during firing
- Projectile Loading Mechanism – A simple breech-loading system or tube-loader

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E. Safety and Cooling

➢ *Even a Student Project needs solid Safety.*

- Emergency Cut-off Switch – Big red button for safety shutdown
- Fuse (e.g., 10A–30A) – To protect from current overload
- Heatsinks + Small DC Fans – Cool the coil area and power electronics
- Insulating Gloves & Safety Glasses – Required during testing
- Acrylic Shield / Plexiglass Cover – To prevent accidental contact during operation.

IV. SYSTEM BLOCK DIAGRAM OVERVIEW

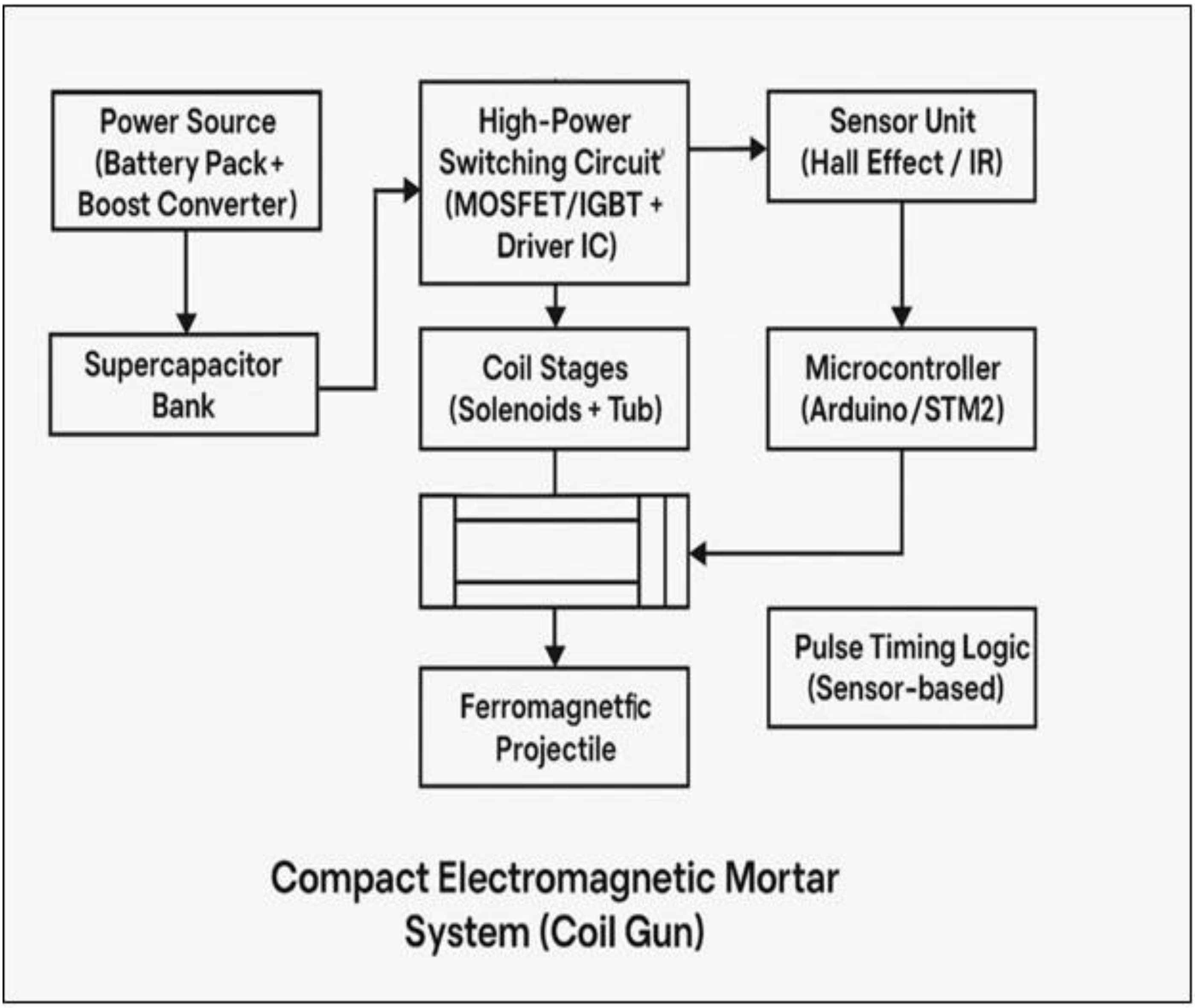

Fig 3 Block Diagram of the system

➢ *Explanation of Each Block*

- Power Source: Supplies low-voltage DC (e.g., 12V–14.8V from Li-ion batteries), stepped up using a boost converter.
- Super capacitor Bank: Stores high voltage (200–400V), discharges rapidly into the coil for launch.
- High-Power Switching Circuit: Controls capacitor discharge using MOSFETs/IGBTs + gate driver circuits.
- Coil Stages: Multiple solenoids lined along the launch tube. Activated in sequence.
- Projectile: Made of ferromagnetic material, accelerated through the coils.
- Sensor Unit: Detects projectile position (Hall sensor or IR gate), sends signal to microcontroller.
- Microcontroller: Controls coil activation timing, based on sensor feedback and trigger input.
- Trigger Logic: Manual button, or remote control, triggers the microcontroller to begin the firing sequence.

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V. EXPERIMENT

The inverter part of the system creates high voltage at a high frequency using an oscillator setup that includes a transformer labeled T1, which gets turned on and off by transistor Q1. When you flip switch S1, it sends power into the circuit. Resistor R2 makes Q1 start conducting, letting 12 volts of DC current pass through the primary coil of the transformer (which has 10 loops). This current makes a magnetic field in the iron center of the transformer, which then triggers the secondary coil (500 turns) and the feedback winding (8 turns) to generate their own currents.

The voltage from the feedback winding keeps transistor Q1 in the "on" position while current goes through resistor R1 and capacitor C2. These two parts—R1 and C2—decide the base current and how fast the oscillator flips (its frequency), basically.

When the magnetic flux in the transformer's core maxes out, the coil kinda stops building voltage and the transistor shuts off. After that, the magnetic field in the ferrite just sorta crashes all of a sudden. The induced 600 VAC is then seen in the secondaries of the transformer. Once it gets to that point, the transistor jumps back into action and the cycle goes on.

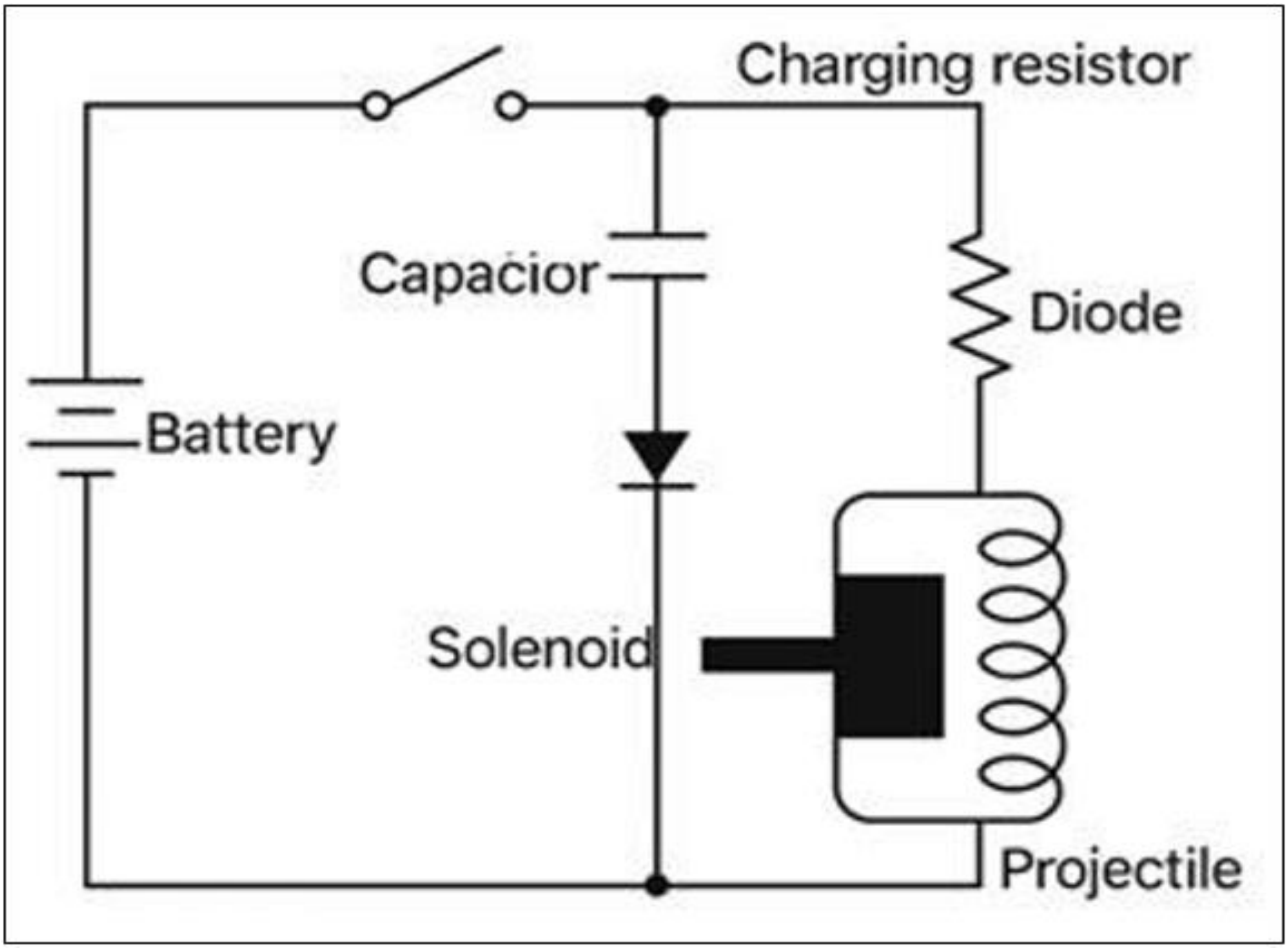

Fig 4 Development of a Compact Electromagnetic Mortar System

The high-voltage AC output from the transformer's secondary coil is boosted and converted to DC — up to 1,200 volts — using a Cockcroft-Walton voltage multiplier. This circuit consists of diodes D1 and D2 and capacitors C3 and C4. The DC voltage produced by the multiplier then charges the capacitor bank through the accelerator coil L1. The final voltage level is regulated by IC1, a 741 op-amp that's set up as a comparator.

The Cockcroft-Walton multiplier is a fascinating piece of circuitry named after Douglas Cockcroft and Ernest Walton. Back in 1932, they used this multiplier design to power a particle accelerator, leading to the first artificial nuclear disintegration ever recorded. This groundbreaking achievement earned them the Nobel Prize in Physics in 1951, awarded for their work in "Transmutation of atomic nuclei by artificially accelerated atomic particles." Interestingly, a Swiss physicist named Heinrich Greinacher had already come up with this type of voltage doubler circuit way back in 1919. That's why it's sometimes also called the Greinacher multiplier.

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The capacitor bank used for energy storage is made up of ten 1,500 µF, 200V capacitors (labeled C8–C17), arranged to create a combined value of 600 µF at 1,000 volts. These capacitors are pretty easy to find from standard electronics suppliers. When charged to 800 VDC, this bank stores about 192 joules of energy. If you go all the way up to 1,000 VDC, it can hold around 300 joules.

But be careful — only charge it to 1,000 volts if you've got an SCR (silicon controlled rectifier) installed that can safely handle that load. The 741 op-amp, set up as a voltage comparator, is used to monitor how much voltage is stored in the capacitor bank. It gets a reference voltage from the 12V DC power source via resistor R10. A voltage divider made up of resistors R3, R4, and an adjustable 100K potentiometer (R11) scales this voltage down by about 1:20 and feeds it to the comparator input. When you're calibrating or operating the coilgun, you can use R11 to fine-tune the detected voltage level.

Once the bank hits the desired voltage, the comparator output switches high, turning on transistor Q2, which also lights up the "ready-to-fire" LED (D6). When Q2 is active, it pulls the base of transistor Q1 to ground, shutting down the oscillation circuit in the transformer and stopping the charging process. If you don't fire the projectile soon after charging, some voltage will slowly leak away, and the comparator will turn the charger back on as needed — you'll see the charge and fire LEDs alternate, showing that the circuit is maintaining the voltage.

After charging, a ferrous projectile is placed into the breech-loading chamber and partially into the coil using a bolt mechanism. The bolt has a small magnet at its tip — strong enough to hold the projectile in place even if the gun tilts, but not so strong that it affects performance.

When the fire switch (S3) is pressed, it sends a signal to the SCR gate, triggering it. This instantly releases all the energy stored in the capacitor bank into the accelerator coil (L1). The resulting electromagnetic pulse propels the projectile through the barrel. To prevent the voltage from flowing backward and damaging components, diode D9 is used for protection.

VI. CONCLUSION

Modern warfare technology has advanced significantly with the creation of the Compact Electromagnetic Mortar System (CEMS), which provides a precision-oriented substitute for traditional mortar weapons. Through the use of electromagnetic propulsion in a coil gun design, CEMS removes the need for chemical propellants, improving range, flexibility, and targeting accuracy while minimizing collateral damage. Its small size increases operational mobility and versatility by making it simple for infantry units to deploy or integrate into lightweight, unmanned systems. CEMS shows that dependable, high-performance electromagnetic launch capabilities may be achieved in a portable package, despite the engineering obstacles, especially in heat dissipation, power system minimization, and control algorithm improvement.

In addition to meeting changing military requirements for accuracy and effectiveness, this system paves the way for a wider use of electromagnetic technologies in tactical weapons. Future research will concentrate on field testing, system optimization, and possible scalability for different mission profiles.

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