Coil Gun Control System and User Interface
Design Review

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Block Diagram:

Figure 1: Control system block diagram for the coil gun
System Simulations:

Figure 2: Input current to coil (A) vs Time (s)

Figure 3: Electromagnetic force (N) and mutual inductance (H) vs bullet displacement from coil midpoint (m)
Circuit Schematics:

Figure 4: Power circuit to charge-discharge capacitors and energize coils

Figure 5: Temporary trigger circuit being used for control system tests
Equation

\( R_1(r) \): the reluctance through the air
\( R_2(d) \): the reluctance through the air inside the coil
\( R_3 \): the reluctance through the bullet
\( R_{coil} \): resistance of the bullet

\[
Ni_{coil}(t) - i_b(\phi') = \phi i_{coil}(t)R_{total}
\]

\( \alpha \): factor for path length

\[
2r = \alpha(l_{coil} + l_{out}) = \alpha(2d + l_{bullet})
\]
\[
r = \alpha(d + \frac{l_{bullet}}{2})
\]
\[
R_1(r) = \frac{\pi r}{\mu_0 A_{air}} = \frac{\pi \alpha}{\mu_0 A_{air}}(d + l_{bullet}) = R_1(r)
\]
\[
R_2(d) = \frac{2d}{\mu_0 A_{col}}
\]
\[
R_3 = \frac{l_{bullet}}{\mu_{bullet} A_{bullet}}
\]
\[
R_{total} = R_2 + R_3 + \frac{R_1}{2} = \frac{2d}{\mu_0 A_{col}} + \frac{l_{bullet}}{\mu_{bullet} A_{bullet}} + \frac{\pi \alpha}{2\mu_0 A_{air}}(d + \frac{l_{bullet}}{2})
\]
\[
= R_{t,\text{const}} + R_1(d) = \left( \frac{l_{bullet}}{\mu_{bullet} A_{bullet}} + \frac{\pi \alpha}{4\mu_0 A_{air}} \right) + d \left( \frac{2d}{\mu_0 A_{col}} + \frac{\pi \alpha}{2\mu_0 A_{air}} \right)
\]
\[
i_b(\phi') = \frac{1}{R_{bullet}} \times \frac{d\phi}{dt}
\]
\[
Ni_{coil}(t) - i_b(\phi') = \phi R_{total}(d)
\]
\[
\phi(d, t) = \frac{N_i_{coil}(t)}{R_{coil} R_{total}(d)} - \frac{d\phi/dt}{R_{coil} R_{total}(d)}
\]

Using linear differential equations we can solve

\[
\phi = \frac{R_{bullet}N}{\varepsilon R_{bullet} R_{total}} \int i_{coil} dt
\]

\[
\frac{d\phi}{dt} = \frac{R_bN}{\varepsilon R_{bullet} R_{total}} + \int i_{coil} dt \times R_{bullet} N \frac{-1}{R_{bullet} R_t} e^{-tR_{bullet} R_{total}}
\]

\[
\frac{d\phi}{dt} = \frac{R_bN}{\varepsilon R_{bullet} R_{total}} i_{coil}(t) - \frac{\int i_{coil} dt}{R_{bullet} R_{total}}
\]

\[
i_b(t) = \frac{N}{\varepsilon R_{bullet} R_{total}} i_{coil}(t) - \frac{\int i_{coil} dt}{R_{bullet} R_{total}}
\]
Requirements and Verifications

Sensor block:

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>We need the sensor to be able to give a resolution of at least 4mm to get the most accurate data</td>
<td>A distance versus sensor reading test will be done on a linear stage</td>
</tr>
<tr>
<td>The sensor block needs to have a range of 0-50cm</td>
<td>A distance versus sensor reading test will be done on a linear stage</td>
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</tbody>
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Ethics, Safety and Risk Analysis

Ethics:

We understand that this project has many applications including military purposes, however we would like to reiterate that we are doing this purely out of interest and for the purpose engineering. We do not have any ambitions to cause harm or danger of any kind and we will uphold both the university and IEEE code of ethics.

The most important code in the IEEE code of ethics for our project is #1. “to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment” [2]. This project involves making a weapon that could hurt people. It is important that guidelines are laid out in order for everyone to stay safe. Another important rule is #9, “to avoid injuring others, their property, reputation, or employment by false or malicious action” [2]. This project is meant to teach people about electromagnetics and it should not be used for malicious actions.

Safety analysis:

This project involves the use of high voltage and current and fast moving projectiles. Appropriate safety precautions will be put in place in order to prevent undesirable and unforeseen circumstances. Some of these safety features include:

- Not pointing the coil gun at other people.
- Making sure the power is off before changing any of the circuit connections.
- Checking and testing for faulty equipment before use.
- Making an efficient discharge circuit in case we choose not to fire projectile after charging capacitors.
Some safety rules to follow:
- Never point the coil gun at something you do not want to shoot.
- Always assume that the capacitors are charged.
- Always discharge capacitors if stowing away for a long time.
- Always keep the gun pointed in a safe direction.
- Do not place your finger on the trigger button unless absolutely sure that you are ready to fire.
- Make sure everyone around you is following the safety rules.
- Do not directly touch the capacitors.
- The coil gun should never be operated by persons under the influence of alcohol or drugs.
- Children must never be left alone with the coil gun.

Risk Analysis:
Position detection using sensors poses a significant risk to the overall functionality of the project. The projectile behaves as a solenoid coil and there exists a mutual inductance between the projectile and the gun’s coils. Variation in the mutual inductance with time causes a force to be applied on the projectile. This force will have different values depending on the position of the projectile with respect to the center of the gun’s coil. If current is passed into the gun’s coil before the projectile crosses the halfway point of the gun’s coil, force will be applied in the direction opposite to the direction of firing. This can potentially damage any equipment placed near the barrel of the coil gun.

The major challenge in position detection is that the projectile travels at a speed of about 15 m/s. This requires very high bandwidth sensors, sampling near the kiloHertz range. This places an extremely stringent requirement on the sensors.

There exists a time delay in applying a trigger signal to the trigger circuit and coils being energized. This time delay would depend on the circuit components and topology. If this timing has a large error in estimation, it would also cause the coils to be energized when the projectile is at the wrong location. This time delay will be added to calculations we perform using the data gotten from our position sensors, by including the time delay in calculations, we should be able to get a more accurate trigger circuit.

Very strong electromagnetic fields exist in the area around the coils and the current carrying wires which may cause false signals to be sent to the microcontroller which might cause the algorithm to miscalculate projectile position and triggering times. In order to prevent this, we shall place the MCU within a Faraday cage so as to prevent any induced current from damaging the MCU or interfering with the signals.
References

