IOWA STATE UNIVERSITY

sdmay19 - 15

Electromagnetic Propulsion Device

Members: Max Balzer, Bret Tomoson, Grant Larson, Brett Nelson, Mark Fowler, Zachee Saleng

Advisor: Mani Mina

Client: Max Balzer

Team Website: sdmay19-15.sd.ece.iastate.edu

Contributions

- Group 1: Mark, Max and Grant worked on the charging circuit either by fixing the current one or making a new one.

- Group 2: Brett, Bret, and Zachee created a document clearly outlining the safety and theory of operation of an electromagnetic propulsion device.

Problem Statement

Demonstrate Electromagnetic Propulsion in the form of a Railgun

Current methods of chemical propulsion have practical limits to how much energy can be output from a fixed barrel size.

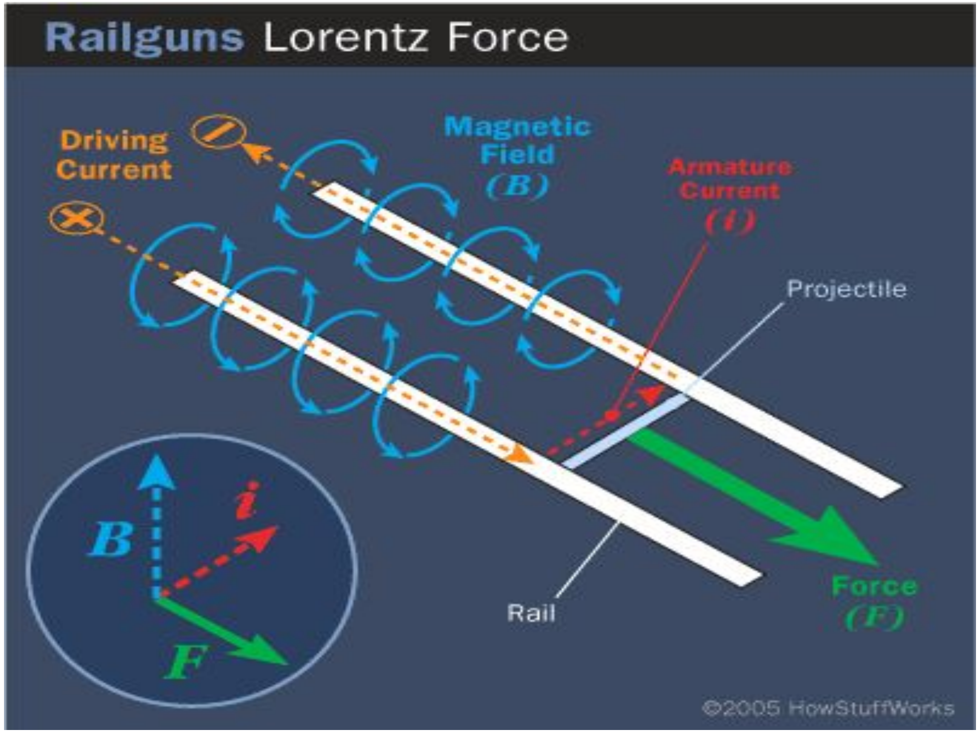
This energy density limits the speed at which a projectile can leave the barrel from a chemical propellant.

Solution

Electromagnetic propulsion can store energy outside of the barrel in a capacitor bank.

This greatly increases the energy density for a given barrel size and allows for much greater muzzle energies to be achieved.

Railgun Overview



Functional Requirements

- Mobily charge capacitor bank with charging circuit
- Discharge capacitor bank when not in use
- Energize rails with capacitor bank
- Push projectile into rails with spring mechanism
- Remotely trigger spring mechanism
- Launch projectile with an induced magnetic field
- Repeat usage quickly and safely
- Safe to operate

Non-functional Requirements

- Convert 12V to 450V with charging circuit
- Charge capacitor bank in under 2 minutes
- Accuracy
- Stable when operating

Design Approach

- **Components that can offer safe and reliable operation**
  - Tensile strength of structural components exceed expected loads
  - Shear strength of fasteners exceed tensile strength of structural components
  - Conductor areas exceed ampacity requirements
- **Materials that are easy and cheap to source**
  - Components were designed around available raw materials
  - The spring mechanism and fasteners are from local stores

Design Approach cont.

- **Designs that can be easily machined and assembled**
  - Fabrication is possible with manual milling and hand tools
- **Safety mechanisms that are quick and reliable**
  - Insulating components prevent contact with high voltages
  - Discharge circuit allows for safe disarming of capacitor bank

Safety Considerations

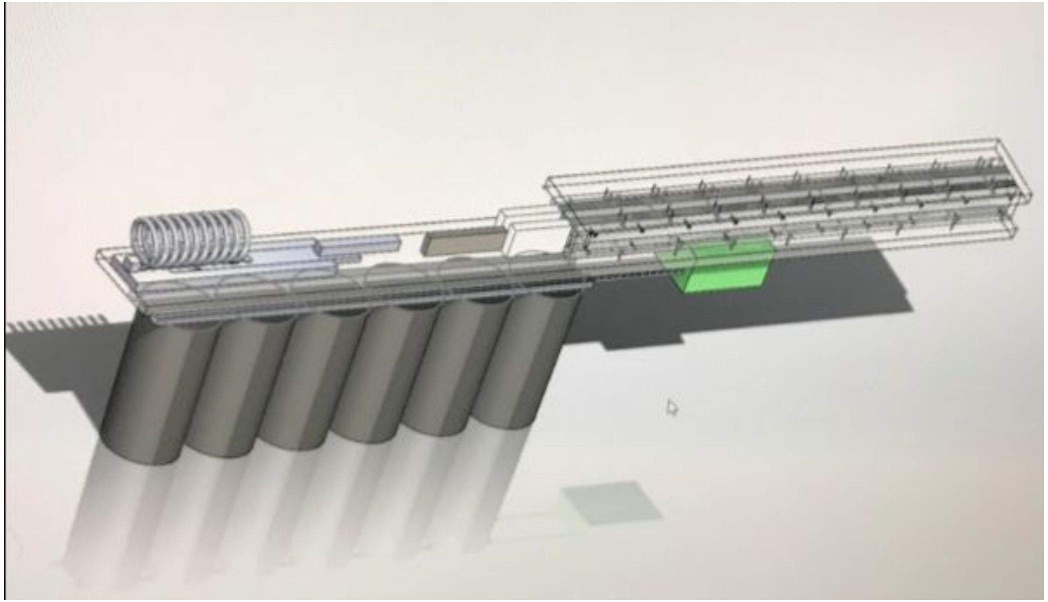
- **Machining and assembly:** Work in a shop with trained professional.
- **Lab testing:** Follow lab safety procedures when testing charging circuit in accordance with the ECPE safety documentation.
- **Testing in the field:** Follow device operation manual and safety procedures only after it has been approved through the correct channels.

Hardware

- Aluminum: 1.5”x0.5”x24”-rails, 1.5”x0.5”x4”-projectile
- Polycarbonate: Structural support & Insulation
- Capacitors: 2 x 450V 16000uF
- Cables: 12AWG battery to Cap bank, 1AWG - Cap bank to rails
- Drawer slide: For spring mechanism
- Charging circuit: Components from ETG and Mouser

Design

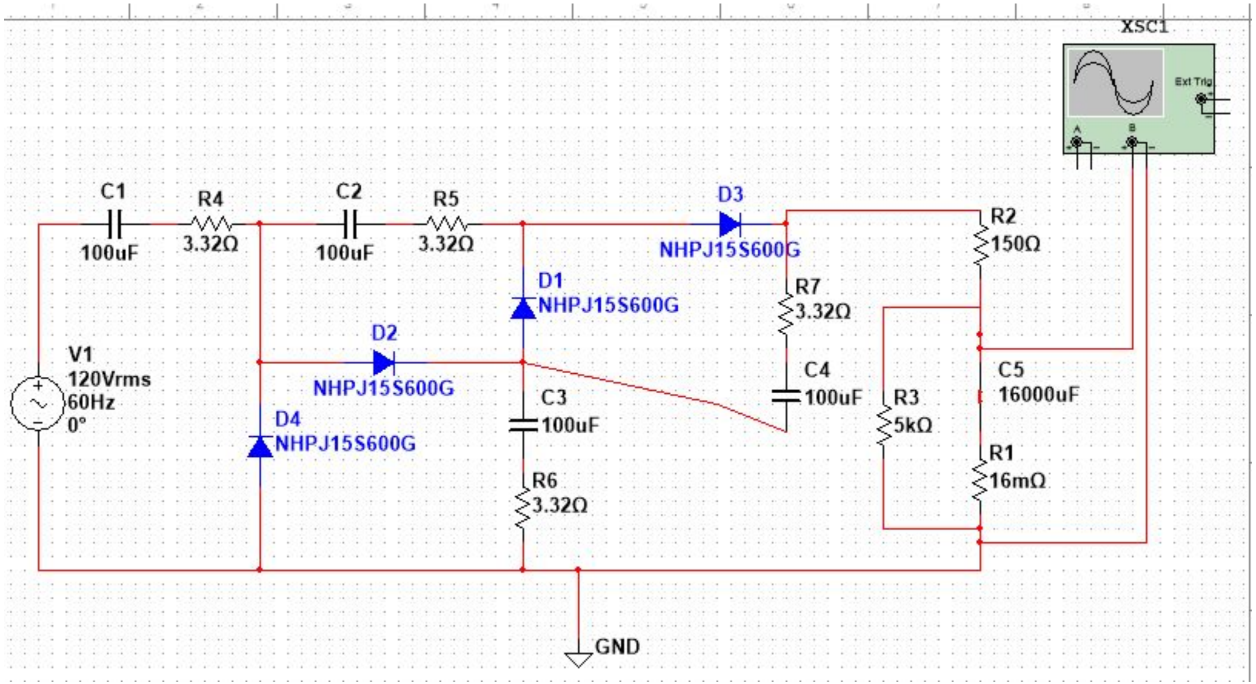
Our design uses capacitors to charge our rails in order to create a magnetic field. From this point, the drawer slide will then be used to give the projectile a push. The projectile will enter the magnetic field, conduct, and be propelled by the magnetic field.



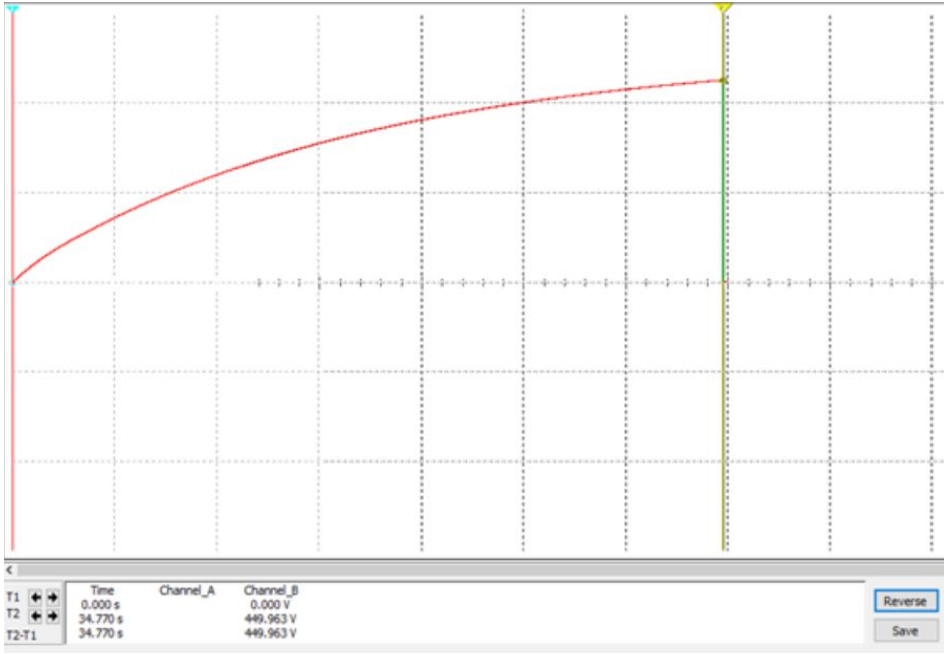
Prototype

- 2 aluminum alloy rails connected by polycarbonate
- Mounted on wood
- Powered by 2x450V 16000 uF capacitors in parallel
- 12VDC input from Deep-cycle battery
- 2-4” Aluminum rectangular prism projectiles

Charging Circuit Design



Charging Circuit Design cont.



Resistance Of Potentiometer	Equation For Voltage
10-900 (ohms)	V = -.0002*R^2 +.4244*R +6.6769
900-3000 (ohms)	V = 156.62*ln(R) -802.64

Formulas

1. Current
2. Magnetic Field
3. Magnetic Force Experienced by the Projectile
4. Force Outwards on Rails

Current through rails

$I = (V_0/R)*e^{-t/\tau}$ Ampere

- V0 = initial voltage
- R = total resistance
- t = time
- T = time constant

Number of Time Constants	Time in seconds	Current at 45V	Current at 90V	Current at 135V	Current at 180V	Current at 225V	Current at 450V
0	0.00E+00	455596.3	911192.6	1366788.9	1822385.2	2277981.5	4555963.0
0.5	1.58E-06	276333.1	552666.3	828999.4	1105332.5	1381665.6	2763331.3
1	3.16E-06	167604.5	335209.0	502813.5	670418.1	838022.6	1676045.1
1.5	4.74E-06	101657.3	203314.6	304971.8	406629.1	508286.4	1016572.8
2	6.32E-06	61658.3	123316.5	184974.8	246633.0	308291.3	616582.5
2.5	7.90E-06	37397.6	74795.2	112192.9	149590.5	186988.1	373976.2
3	9.48E-06	22682.8	45365.6	68048.4	90731.2	113414.0	226828.0
3.5	1.11E-05	13757.8	27515.6	41273.4	55031.3	68789.1	137578.2
4	1.26E-05	8344.5	16689.1	25033.6	33378.1	41722.7	83445.4
4.5	1.42E-05	5061.2	10122.4	15183.7	20244.9	25306.1	50612.2
5	1.58E-05	3069.8	6139.6	9209.4	12279.1	15348.9	30697.8

Magnetic Field

$B=((\mu_0 * I)/(2*\pi*d))*\ln(d/r)$ (Tesla)

- Biot-Savart Law
- μ_0 = Permeability constant
- r = Radius of rails
- d = Distance separating rails
- I = Current

Number of Time Constants	Time in seconds	Magnetic Field at 45V	Magnetic Field at 90V	Magnetic Field at 135V	Magnetic Field at 180V	Magnetic Field at 225V	Magnetic Field at 450V
0	0.00E+00	0.1263	0.2526	0.3790	0.5053	0.6316	1.2632
0.5	1.58E-06	0.0766	0.1532	0.2298	0.3065	0.3831	0.7662
1	3.16E-06	0.0465	0.0929	0.1394	0.1859	0.2323	0.4647
1.5	4.74E-06	0.0282	0.0564	0.0846	0.1127	0.1409	0.2819
2	6.32E-06	0.0171	0.0342	0.0513	0.0684	0.0855	0.1710
2.5	7.90E-06	0.0104	0.0207	0.0311	0.0415	0.0518	0.1037
3	9.48E-06	0.0063	0.0126	0.0189	0.0252	0.0314	0.0629
3.5	1.11E-05	0.0038	0.0076	0.0114	0.0153	0.0191	0.0381
4	1.26E-05	0.0023	0.0046	0.0069	0.0093	0.0116	0.0231
4.5	1.42E-05	0.0014	0.0028	0.0042	0.0056	0.0070	0.0140
5	1.58E-05	0.0009	0.0017	0.0026	0.0034	0.0043	0.0085

Magnetic Field forces on projectile

F=I*L*B (Newtons)

- I = current
- B = magnetic field
- L = length

Number of Time Constants	Time in seconds	Force at 45V	Force at 90V	Force at 135V	Force at 180V	Force at 225V	Force at 450V
0	0.00E+00	35082.52	140330.08	315742.69	561320.33	877063.02	3508252.06
0.5	1.58E-06	12906.14	51624.55	116155.24	206498.21	322653.45	1290613.81
1	3.16E-06	4747.90	18991.61	42731.13	75966.45	118697.57	474790.29
1.5	4.74E-06	1746.66	6986.62	15719.90	27946.49	43666.40	174665.59
2	6.32E-06	642.56	2570.24	5783.03	10280.94	16063.97	64255.88
2.5	7.90E-06	236.38	945.54	2127.46	3782.15	5909.60	23638.42
3	9.48E-06	86.96	347.84	782.65	1391.37	2174.02	8696.09
3.5	1.11E-05	31.99	127.96	287.92	511.86	799.78	3199.11
4	1.26E-05	11.77	47.08	105.92	188.30	294.22	1176.89
4.5	1.42E-05	4.33	17.32	38.97	69.27	108.24	432.95
5	1.58E-05	1.59	6.37	14.33	25.48	39.82	159.27

Force Outwards on Rails

F= (I*2*L)/(2*π *d) (lbs)

- I = current traveling through rails
- L = length of rails
- d = distance between rails

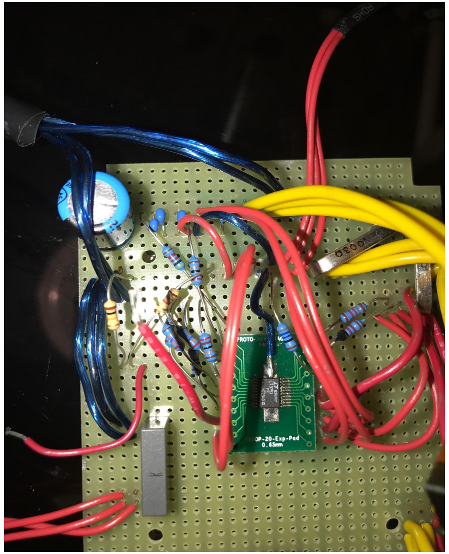
Number of Time Constants	Time in seconds	Outward Force at 45V	Outward Force at 90V	Outward Force at 135V	Outward Force at 180V	Outward Force at 225V	Outward Force at 450V
0	0.00E+00	72.22	288.89	650.01	1155.58	1805.59	7222.36
0.5	1.58E-06	26.57	106.28	239.13	425.11	664.24	2656.96
1	3.16E-06	9.77	39.10	87.97	156.39	244.36	977.44
1.5	4.74E-06	3.60	14.38	32.36	57.53	89.90	359.58
2	6.32E-06	1.32	5.29	11.91	21.17	33.07	132.28
2.5	7.90E-06	0.49	1.95	4.38	7.79	12.17	48.66
3	9.48E-06	0.18	0.72	1.61	2.86	4.48	17.90
3.5	1.11E-05	0.07	0.26	0.59	1.05	1.65	6.59
4	1.26E-05	0.02	0.10	0.22	0.39	0.61	2.42
4.5	1.42E-05	0.01	0.04	0.08	0.14	0.22	0.89
5	1.58E-05	0.00	0.01	0.03	0.05	0.08	0.33

Test Plan

- Charging circuit: Incomplete
- Rails: Length and degradation
- Projectiles: Size and degradation
  - Degrade before rails
  - More surface area contact = better results
- Variable voltage testing: Variac Transformer
- Complications: Safety Procedures, Risk Management (didn’t have our numbers ready to give them), Theory of operation

Current status

- Design is fully built
- Charging circuit too complicated, new circuit too expensive
- Last semester focused on shooting not numbers, focused on numbers this semester



Future Additions

- **Future Additions**
  - Run a full risk management assessment of the project to ensure proper standards are met before testing.
  - Test systems in real conditions with proper safety precautions.
  - Compare calculations with measured results to highlight inconsistencies.
  - Modify components to increase efficiencies.
  - Stress test new design to measure durability.
  - Obtain additional funding to improve:
    - Part tolerances
    - Testing equipment
    - Component replacements for wear testing

Questions

Safety Procedures

- Metal machining: Done by Mike Ryan who owns and operates a metal fabrication shop
- Assembly: No danger in this category. Done mostly off campus

Safety Procedures cont.

Testing:

1) Not placed next to other metal or ammunition.

2) Project secured and stable.

3) No obstructions inside the barrel before projectile is placed.

4) Apply non-destructive testing; making sure no parts move that aren't supposed to move.

5) Familiarizing all personnel how the project works and is designed.

Safety Procedures cont.

Before firing:

1) Project is clear of any metal.

2) Run through procedure of how it will be tested.

3) Lock firing mechanism into place.

4) Charge capacitors by personnel wearing protective gear and attach capacitor bank to rails.

Safety Procedures cont.

During firing:

1) Everyone will be out of range of any effects of the project.
2) Person wearing protective gear will interact with firing mechanism.

After firing:

1) De-energize capacitor bank and rails by person wearing protective gear.
2) Make sure project is intact and no part is out of place.

Testing

- Charging Circuit: Tested multiple times and included multiple different solutions to it not working properly. After last attempt to add necessary components we determined a burnt mosfet is the top guessed cause of inoperability. We came to this conclusion when we tested every aspect of the circuit where connectivity and voltage were supposed to be found and those were all correct.

- No further testing was conducted due to complications. These include Risk Management, safety procedures not approved, and theory of operation not approved.

Outwards Force vs. Poly and fasteners

	Minimum Ultimate Tensile Load (psi)	Shear Strength (60% of Tensile Strength with 80% of proof loading) per ¼" bolt. (lbs)	Total Shear Strength(per rail) (lbs) (14 fasteners)
1/4-28 x 1" black oxide ASTM F-835	145000	3410.4	47745.6

	Tensile Strength: Yield (psi)	Tensile Strength: per fastener(lbs)	Total Tensile Strength (14 Fasteners per sheet)(lbs)
Polycarbonate	8500	1062	14868

Number of Time Constants	Time in seconds	Outward Force at 45V	Outward Force at 90V	Outward Force at 135V	Outward Force at 180V	Outward Force at 225V	Outward Force at 450V
0	0.00E+00	72.22	288.89	650.01	1155.58	1805.59	7222.36

Velocity of Projectile

Initial:

$v_i = \sqrt{(kx^2/m)}$ (m/s)

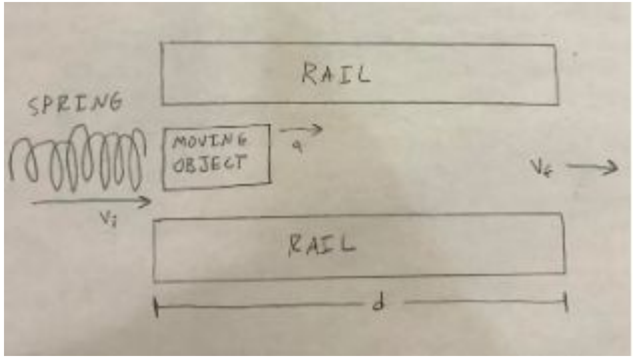
- k = spring rate/constant
- k=(mg)/x
- x = distance pulled back
- m = mass of projectile

Final:

$v_f=\sqrt{(v_i^{2*}2*a*d)}$ (m/s)

a = acceleration

d = distance of rails



m(lbs) =	0.330693	M converted into kg	m(kg) =	0.15	(This is just an estimate)
x(m) 2 inches =	0.0508	(This is just an estimate)			
k =	28.966535	k=(mg)/x	g =	9.81	
Vi =	0.7059	m/s			

Number of Time Constants	Time in seconds	Vf at 45V	Vf at 90V	Vf at 135V	Vf at 180V	Vf at 225V	Vf at 450V
0	0.00E+00	534.00	1067.99	1601.99	2135.98	2669.98	5339.95
0.5	1.58E-06	624.54	1249.08	1873.62	2498.17	3122.71	6245.41
1	3.16E-06	654.71	1309.42	1964.12	2618.83	3273.54	6547.08
1.5	4.74E-06	665.46	1330.92	1996.39	2661.85	3327.31	6654.62
2	6.32E-06	669.37	1338.75	2008.12	2677.50	3346.87	6693.75
2.5	7.90E-06	670.81	1341.62	2012.42	2683.23	3354.04	6708.08
3	9.48E-06	671.34	1342.67	2014.00	2685.34	3356.67	6713.35
3.5	1.11E-05	671.53	1343.06	2014.59	2686.11	3357.64	6715.28
4	1.26E-05	671.60	1343.20	2014.80	2686.40	3358.00	6716.00
4.5	1.42E-05	671.63	1343.25	2014.88	2686.50	3358.13	6716.26
5	1.58E-05	671.64	1343.27	2014.91	2686.54	3358.18	6716.36

Energy stored in capacitors

$E = (\frac{1}{2})CV^2$

- C = total capacitance (Farad)
- V = Voltage stored/charged to (Volts)

Percentage Charged	Volts (V)	Energy Stored in Capacitors (J)
10%	45	32.4
20%	90	129.6
30%	135	291.6
40%	180	518.4
50%	225	810
100%	450	3240

Discharging Capacitors