The Manufacture of an Electromagnetic Rail Propulsion System

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26 December 2013

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INTRODUCTION TO PROJECT

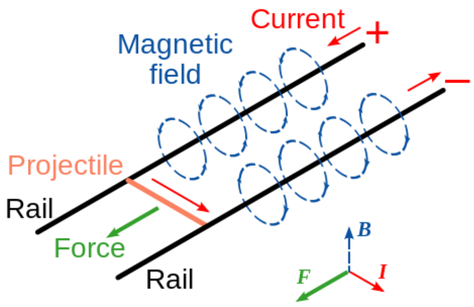


Figure 1: From cite G

Electromagnetic Rail Propulsion System is a kinetic energy divice which uses the electromagnetic launch technology. Traditional cannons are pushed by gunpowder gas pressure to launch the projectile; a Electromagnetic Rail Propulsion System uses the ampere's force in the electromagnetic system to launch the projectile. A Electromagnetic Rail Propulsion System is based on similar principles to the homopolar motor. The Electromagnetic Rail Propulsion System is made by a pair of parallel conducting rails, along which a sliding projectile which is accelerated by the electromagnetic effects of a current that flows down one rail, into the projectile and then back along the other rail. One of important measurements of a kinetic divice is speed. The traditional divice uses chemical explosive to generate force to push the projectile and its maximum speed can only reach 1.7 km/s. Unfortunatly, the initial speed of the conventional artillery is restricted by many factors. For example, if you want to increase conventional artillery's initial speed, the gun pressure has to increase. But theory and practice show that when ammunition quality and an projectile mass ratio is greater than 5 then speed increase at a much slower rate. Transformers 2, the movie shows how the NAVY uses Electromagnetic Rail Propulsion System to attack the transformer which was destroying a pyramid. Electromagnetic Rail Propulsion System projectile once reaches 10Km/s at before. Because of the high speed, Electromagnetic Rail Propulsion System can use in many different fields; like catapult a plane or shoot a flying missile.

MACHINERY MATERIAL SELECTION AND THE REASON

Body material: Phenolic (Garolite 11)

The body material is Phenolic (Garolite 11). G11 is the great material in Garolite series, It is military grade material. The reason I use Garolite 11 because it not conduct and it can bear the high heat, because of the ressistance of the rail, there will generate a lot of heat. Also that kind of material is low coefficient of the thermal expansion.

Rail material: copper beryllium & Projectile: Aluminum

I use copper beryllium as my rail material because it has high electric conduction, it can bear the high heat and low coefficient of the thermal expansion. The most important is it has high hardness.

The material of projectile must be different from the material of rail. From the thesis E can know that copper, aluminum and molybdenum are the materials to choice. Due to price, molybdenum woudn't work. Reason is copper's resistance is the half of aluminum. The second reason is based on following calculation process: Notice the Electromagnetic Rail Propulsion System's output energy is depends on speed and mass.

$$E = \frac{1}{2}mv^2 \tag{1}$$

$$v = at + v_0 \tag{2}$$

Substitute function (2) into function (1)

$$E = \frac{F^2 t^2}{2m} + Ftv_0 + \frac{mv_0{}^2}{2} \qquad (3)$$

$$m = \rho V \qquad (4)$$

Substitute function (4) into function (3).

$$E = \frac{F^2 t^2}{2\rho V} + Ftv_0 + \frac{\rho V v_0{}^2}{2} \qquad (5)$$

From the function (5) we can infer that the way projectile get high energy is to choose low density material,because the mass of projectile is under 1kg (volume is constant).

$$B = \frac{\mu_0 I}{2\pi s} \qquad (6)$$

Function (6) is called Biot–Savart law. The Biot–Savart law is an equation describing the magnetic field generated by an electric current.

$$B(s) = \frac{\mu_0 I}{2\pi s}\left(\frac{1}{s} + \frac{1}{d-s}\right) \qquad (7)$$

$$B_{avg} = \frac{1}{2d}\int_r^{d-r} B(s)ds = \frac{\mu_0 I}{4\pi d}\int_r^{d-r} (\frac{1}{s} + \frac{1}{d-s})ds = \frac{\mu_0 I}{2\pi s}\ln\frac{d-r}{r} \qquad (8)$$

Figure 2: fuction(7)&(8) is came from website G

Function (8) is the magnetic field goes through the whole projectile. r is the radius of the rails, d is the distance between the Centre points of the rails and I is the current in amps through the system. s is the magnetic field at a given perpendicular distance from the end of the wire.

$$F_B = B\,I\,c \qquad (9)$$

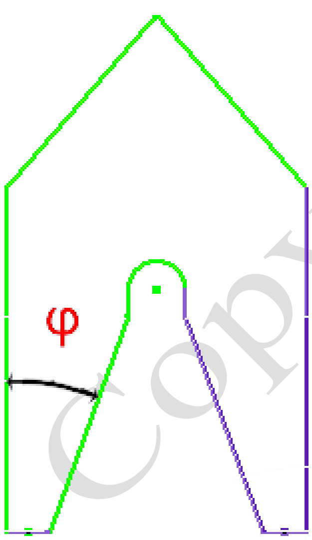
Function (9) is called Ampère's force law. It’s describe the force generate by current pass through the projectile.

$$F_B = I\,d\,B_{avg} = \frac{\mu_0 I^2}{2\pi}\ln\frac{d}{r} \qquad (10)$$

Function (10) is the result of function (8) substitute into function (9)

$$E = \frac{\left(\frac{\mu_0 I^2}{2\pi}\ln\frac{d}{r}\right)^2 t^2}{2\rho V} + \left(\frac{\mu_0 I^2}{2\pi}\ln\frac{d}{r}\right)tv_0 + \frac{m{v_0}^2}{2} \qquad (11)$$

Function (12) is the result of function (10) substitute into function (3). Now, two kind of material has different properties. Aluminum resistance is greater than copper, but compare with each metal’s density; copper is 8.3 g/cm3, aluminum alloy is 2.8 g/cm3 . Because $\mu_0 = 4\pi\times10^{-7}$ T·m/A which is a tiny number, so numerator actually change a little bit but density can change energy a lot. That is the reason I chose the aluminum as projectile and copper as rail material.



The Shape of Projectile

From the thesis E we know that only end part is triangle 、 ladder-shaped is efficient and When φ=20°is most efficient choose. In reality the current cannot be uniformly distribued uniformity or you can say current density uniformity; that because of the skin effect. That causes a lot of problems. First problem is local overheating which will weld the projectile to the rail. The second problem is high local resistance which make Electromagnetic Rail Propulsion System less efficient. Projectile needs to bear the high pressure; this is the kind of design that can satisfy.

Capacitor Connection Choose

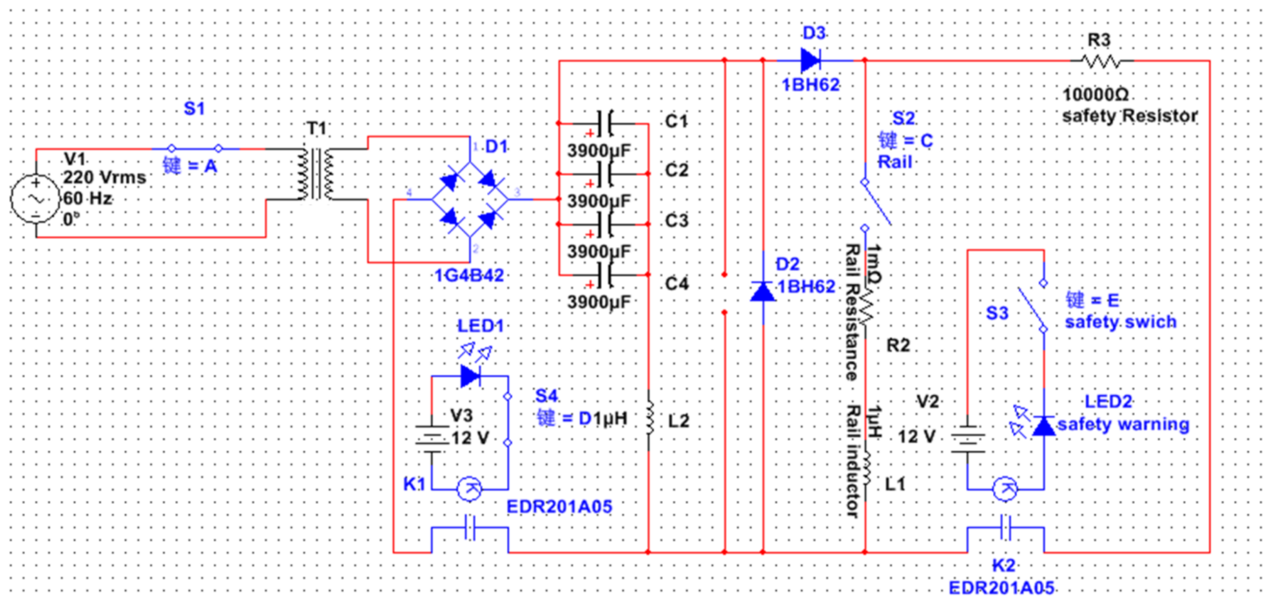


Figure 3: Details is at the APPENDIX page

Capacitor Connection Choose is the problem always confuses me. I use 450v 3900uf capacitor and I have 4 of it. There are two ways to connect: in parallel or in series. Each way capacitor store up same energy:

$$E = \frac{1}{2} C U^2 \tag{12}$$

Function (12) is the formula that calculates the capacitive energy storage. U is the voltage of the capacitor.

$$C_p = C_1 + C_2 + \cdots + C_n \tag{13}$$

Function (13) is the total capacitance when capacitor in Parallel.

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n} \tag{14}$$

Function (13) is the total capacitance when capacitor in series.

$$\frac{E_p}{E_s} = 1 \tag{15}$$

Function (15) is the ratio of two kind of way's energy.

	C(μF)	U(v)	E(J)	R(Ω) *
Parallel(4)	15600	450	1579.5	R/4
Series(4)	975	1800	1579.5	4R

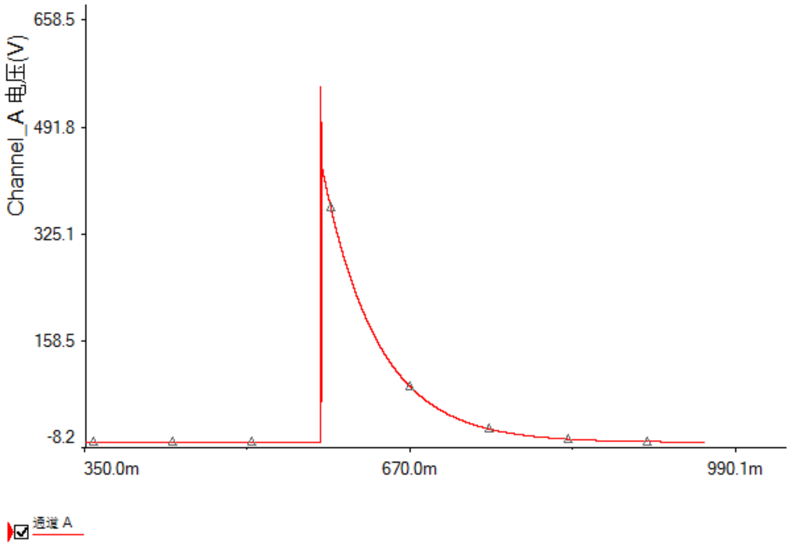
*capacitor internal resistance

The internal resistance of the capacitor, in the series is way efficient than capacitor in parallel. Meanwhile, the capacitor in parallel has low voltage, which means I will spend less money on transformer. That is the reson that I chose the capacitor in parallel even if parallal capacitors have a high current has high current.

Safety circuit

Safety circuit is the design for discharge the capacitor in another way but rail. Once the capacitor has fully charged, there are a lot of energy storge in capacitor, if we don't want to lunch the projectile, we need to use a safety circuit to discharge the capacitor.

Simulate



From the voltage/time graph we can infer that even it has a high current but just in short times. So if we want to keep this high current, we need to use pulse circuit, which is more advance than my sophomore project.

Simulations show that it takes almost 40 minute charge which is a strange phenomenon. The capacitor charging time should be less than this time, so that also is a question that we need to figure out.

RELEVANT DATA CALCULATION

Calculation Hypothesis: No air resistance, resistance of the Rail is 0.001Ω. The current is average current.

$$v = at + v_0 \tag{2}$$

Plug the function (1) in (11), result is function (16).

$$t = RC\ln\left(\frac{U_1 - U_0}{U_1 - Ut}\right) \tag{17}$$

Function (17) is the time that capacitor take to discharge. R is the resistance of the whole circuit system. V_1 is the voltage of full charge capacitor. V_t is the voltage of whole capacitor at "t" time. V_0 is the final voltage of the capacitor.

$$I_{avg} = \frac{Q}{kt} = \frac{U}{kR\ln\left(\frac{U_1 - U_0}{U_1 - U_t}\right)} \tag{18}$$

Function (18) is the average current that passes through whole rail. $k \in \left[\frac{3}{2}, 2\right]$

$$v = \frac{\mu_0\left(\frac{U}{kR\ln\left(\frac{U_1 - U_0}{U_1 - U_t}\right)}\right)^2 \ln\left(\frac{d-r}{r}\right) + F_g}{2\pi\rho V} \cdot RC\ln\left(\frac{U_1 - U_0}{U_1 - Ut}\right) + v_0 \tag{19}$$

Plug the function (17) & (18) in the function (2). It is the final function to calculate the velocity of the projectile(Theoretical). F_g is the force that high pressure air give which is calculate by the website F.

$$v \in [466, 821] m/s$$

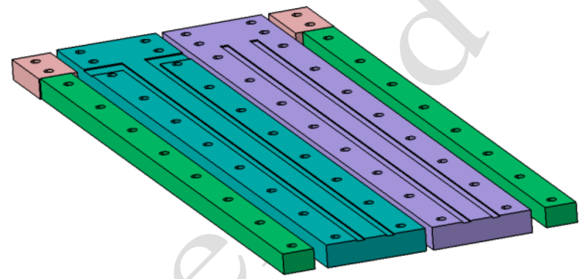
WORKING PROCESS INTRODUCE

Phonolic sheet 24" x 24" .75". Cut sheet into strips using Milling Machine

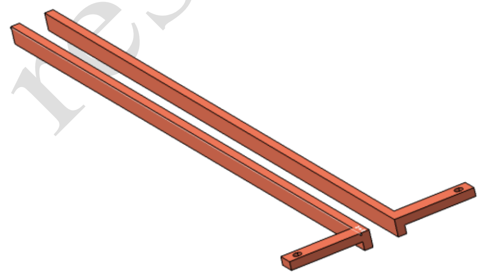
1	**Base Plate**	**608.6 x 85 x 1 19.05**	**G11**
2	Cover Plate	608.6 x 85 x 1 19.05	G11
3	RH Rail Plate	548.6 x 26.65 x 1	G11

		17.05		
4	LH Rail Plate	548.6 x 26.65 x 17.05	1	G11
5	RH Air Channel Rail	61 x 33 X 17.05	1	G11
6	LH Air Channel Rail	61 x 33 X 17.05	1	G11Rail .25” X .75” 20”

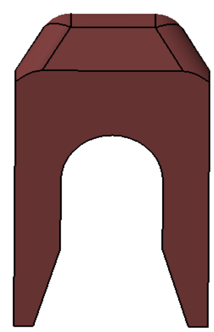
Step



1. Mill Channels into Base plate for rails
2. Mill holes into base plate for bolts
3. Mill Channels into Cover plate
4. Mill Holes into Cover plate for bolts
5. Mill RH Rail Plate
6. Mill Holes RH Rail Plate for bolts
7. Mill LH Rail Plate
8. Mill Holes LH Rail Plate for bolts
9. RH Air Channel Rail

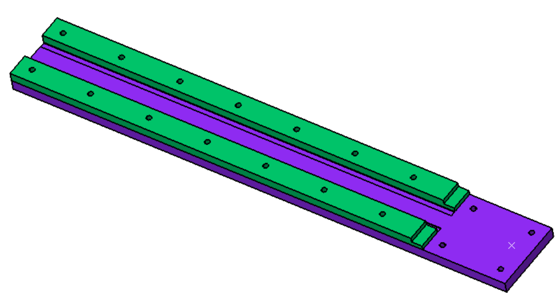


10. RH Rail Cut to length
11. Mill groove for Terminal connection
12. Cut RH Terminal Bar to length
13. Mill groove for Terminal connection
14. Drill hole for Wire Lead
15. Thread Hole for wire lead



16. LH Rail Cut to length
17. Mill groove for Terminal connection
18. Cut RH Terminal Bar to length
19. Mill groove for Terminal connection
20. Drill hole for Wire Lead
21. Thread Hole for wire lead
22. Assemble the LH Terminal Connect to the LH Rail
23. Assemble the LH Terminal Connect to the LH Rail

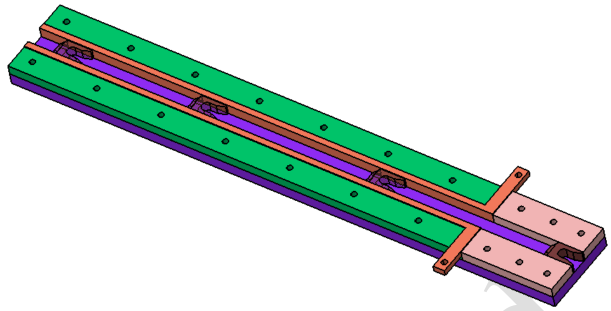
24. Cut Aluminum Blocks
25. Rough mill Aluminum block to shape



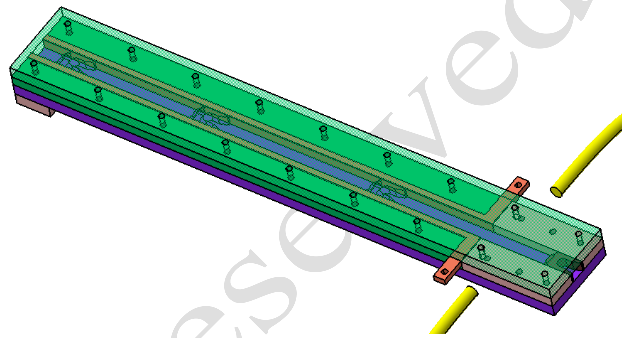
26. Assemble RH Rail Plate to the Base plate
27. Assemble LH Rail Plate to the Base plate

28. Assemble RH Air Channel Rail to Base Plate

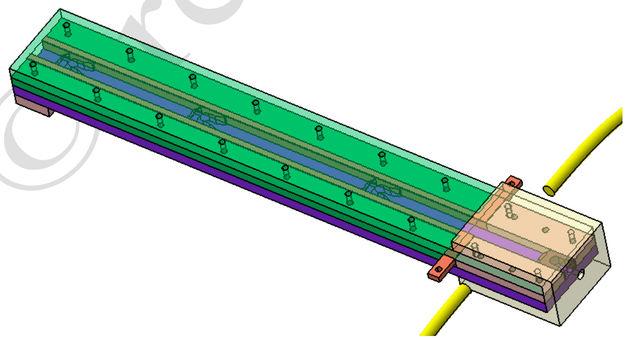
29. Assemble LH Air Channel Rail to Base plate
30. Place RH Rail into groove on Base Plate
31. Place LH Rail into groove on Base Plate



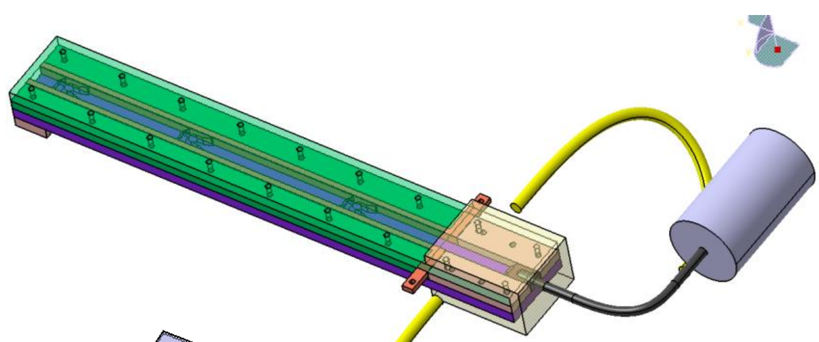
32. Measure Channel
33. Adjust Rough milled Aluminum to fit channel
34. Clamp assembly together
35. Drill locating holes through assembled pieces
36. Dowel pieces together
37. Run aluminum block through channel



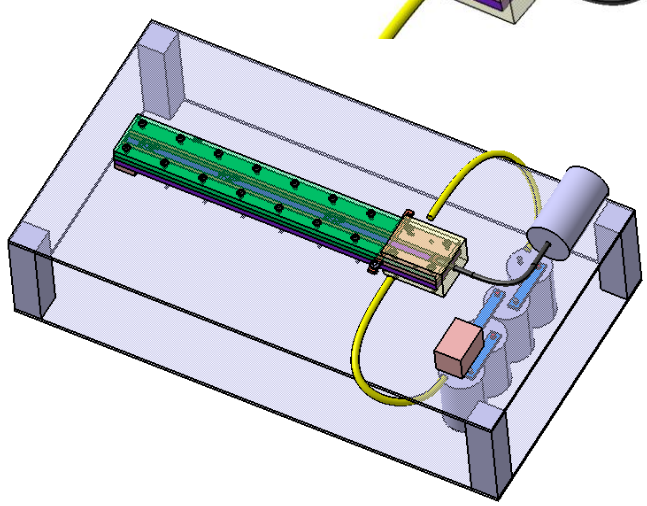
38. Fit Cover Plate to assembly
39. Clamp cover down
40. Dowel the cover to the assembly
41. Bolt Rail Assembly Together
42.



43. Mount Rail Assembly to Upper Base
44. Cut Back Plate
45. Drill Hole for air hose
46. Thread Hole for Air Hose fitting
47. Attach Back Plate to Rail Assembly
48. Attach Air Hose
49. Cut wire to length
50. Attach Wire terminal to wire
51. Screw wire to RH Terminal Bar
52. Screw wire to LH Terminal Bar
53. Assembly switch to air tank
54. Secure air tank to Upper base



55. Assembly of the Electrical Components
56. Cut Bars for CAPACITORS
57. Drill Holes for screw Terminals
58. Drill Hole for wire Screw
59. Attach bars to Capacitors

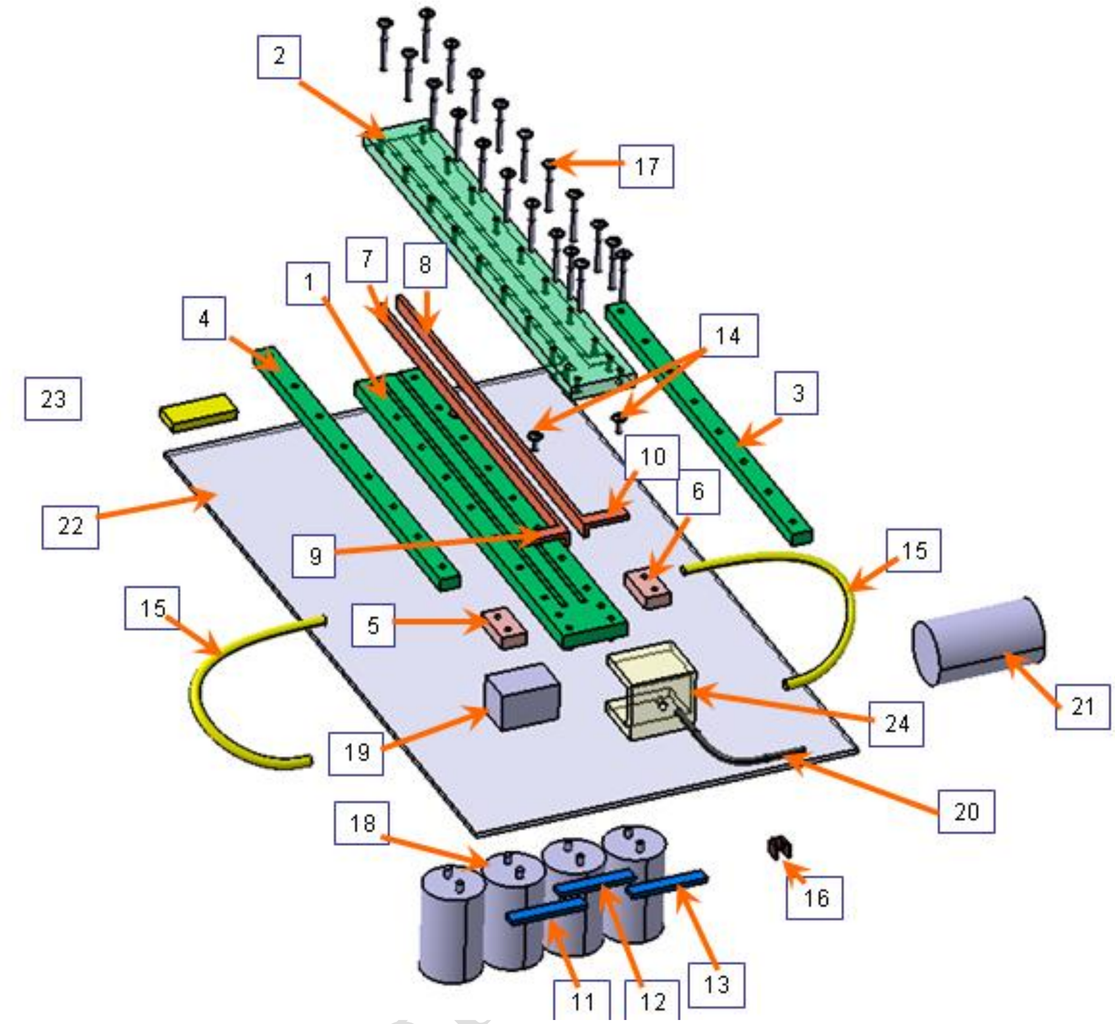


APPENDIX

	Part	Dimensions LWT mm	Quantity	Material
1	Base Plate	608.6 x 85 x 19.05	1	G11
2	Cover Plate	608.6 x 85 x 19.05	1	G11
3	RH Rail Plate	548.6 x 26.65 x 17.05	1	G11
4	LH Rail Plate	548.6 x 26.65 x 17.05	1	G11
5	RH Air Channel Rail	61 x 33 X 17.05	1	G11
6	LH Air Channel Rail	61 x 33 X 17.05	1	G11
7	RH Rail	548.6 x 19.05 x 6.35	1	Beryllium/Copper
8	LH Rail	548.6 x 19.05 x 6.35	1	Beryllium/Copper
9	RH Rail Terminal	60 x 19.05 x 6.35	1	Beryllium/Copper
10	LH Rail Terminal	60 x 19.05 x 6.35	1	Beryllium/Copper
11	Terminal Bar CAPACITORS	100 x 19.05 x 6.35	1	Beryllium/Copper
12	Terminal Bar CAPACITORS	100 x 19.05 x 6.35	1	Beryllium/Copper
13	Terminal Bar CAPACITORS	100 x 19.05 x 6.35	1	Beryllium/Copper
14	Terminal Bolt for Rail	M8 x 18.75	2	
15	wire	12.7 Dia x 400mm	2	
16	Projectile	35 x 19.05 x 17.05	4	Aluminum
17	Bolts	M8 x 66.5	10	
18	CAPACITORS	450v 1800uf	4	ALUMINUM ELECTROLYTIC
19	Voltmeter		1	
20	Air Hose	10 Dia x 230	2	
21	Air Compressor w switch		1	
22	Base Plate	914 x 508 x 10	2	Polycarbon
23	Spacer Block	85 x 38.1 x 12.7	1	PCABS
24	Back Plate	26.65 x 55.1 x 19.05	1	Polycarbon

Circuit Detial

Name	Instruction	Function
V1	The household power supply	power supply
V2	12V battery	power supply
V3	12V battery	power supply
R1	Resistor	To avoid short circuit
R2	Resistor	Rail equivalent resistance
R3	Resistor	Safety resistor
R4	Resistor	Buffer resistor
L1	Inductor	Rail equivalent inductance
L2	Inductor	Buffer inductor
S1	Air switch	Switch on transform circuit
S2	Rail(not switch)	When projectile
S3	Switch	Switch on safety circuit
S4	Switch	Switch on K1
K1	Relay	Switch on charging circuit
K2	Relay	Switch on safety circuit
D1	Rectifier	Change AC to DC
D2	rectification	pulse
D3	rectification	pulse
T1	Transformer	Change the votage
LED	LED	Alert
Ground	Ground	Keep safe



REFERRENCES CITED

A. Wang Ying. Principle of electromagnetic Gun. Beijing: Guo Fang Gong Ye Chu Ban She.1995

B. Li Ting. Theory characteristic research of Electromagnetic Electromagnetic Rail Propulsion System projectile characteristic. Nanjing: Nanjing University of Science and Technology

C. "C17200 Copper Alloys Material Property Data Sheet - Product Availability and Request a Quote." Web.21Nov.2013.

D. "Bi Ao - Sa Fa Er Ding Lv." *baidu*. N.p., n.d. Web. 21 Nov. 2013

E. " Gui Dao Pao Gu Ti Dian Shu She JI" *ZhiMing Liu, JiangSheng sun, Ying Wang*, Journal of test and measurement tecnology

F. http://www.rapidairproducts.com/flowrate.asp

G. "Railgun." *Wikipedia*. Wikimedia Foundation, 17 Nov. 2013. Web. 18 Nov. 2013.