Optimization of a Convex Rail Design for Electromagnetic Launchers

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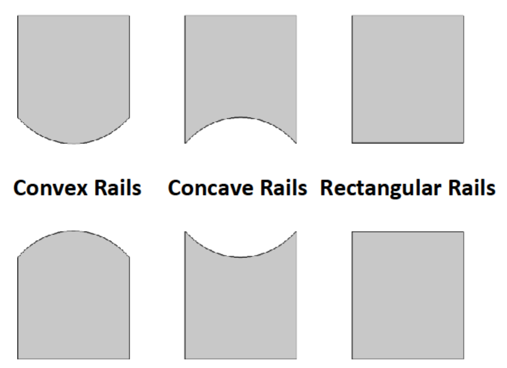
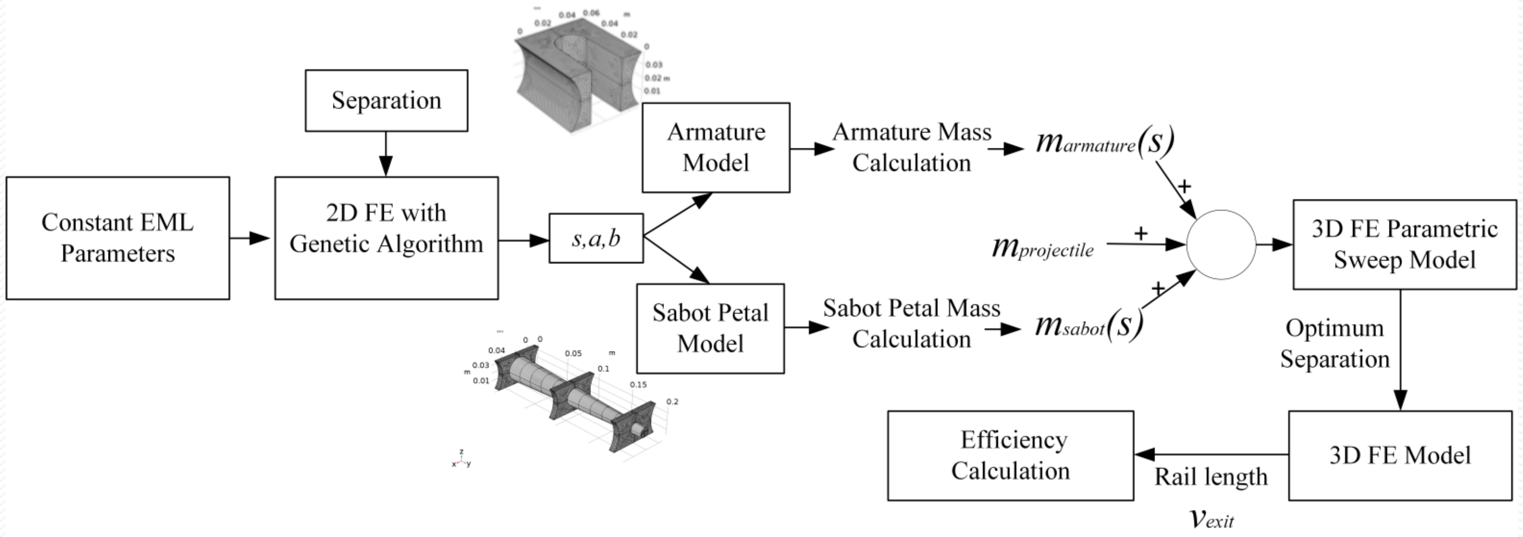




Electromagnetic Launcher System Constants[1]	
Projectile Mass	400 g
Rail Height	40 mm
Rail Width	40mm
Armature Height	40 mm
Pre-load Distance	50 cm
Minimum Rail Separation	40 mm
Maximum Rail Separation	80 mm
Linear Current Density	35 kA/mm
Peak Current	1400 kA

[1] S. Hundertmark, M. Schneider, D. Simicic, and G. Vincent, "Experiments to increase the used energy with the PEGASUS railgun," *IEEE Trans. Plasma Sci.*, vol. 42, no. 10, pp. 3180–3185, Oct. 2014.

Aim of Study

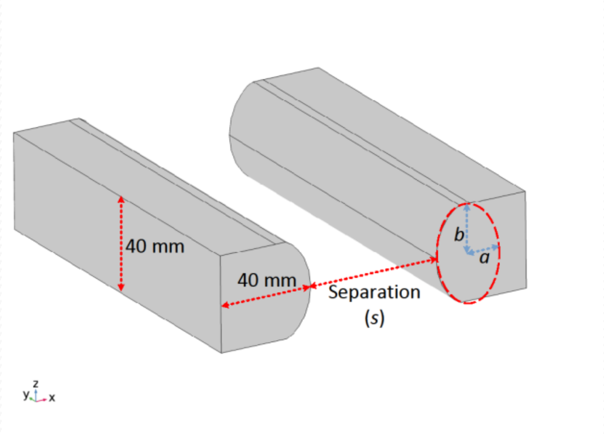
In the literature, convex rail geometries are often studied in terms of the inductance gradient(L'). However, optimization solely on L' neglects the parasitic masses. The aim of this study is to determine a convex rail geometry for a predetermined projectile with homogenized current distribution, maximum exit velocity including the parasitic masses and avoiding down-slope contact transitions.

Study Steps

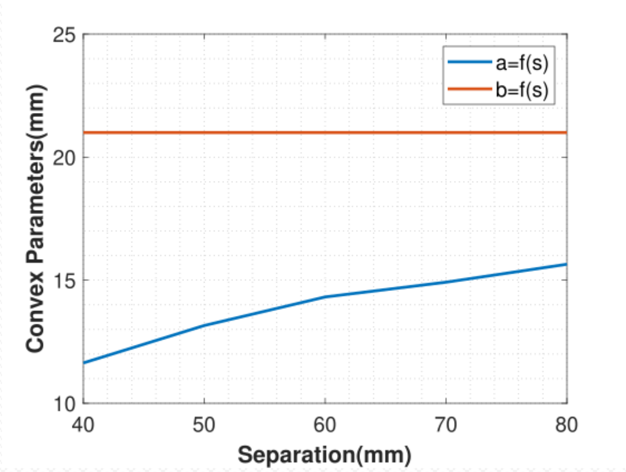
Firstly, using a genetic alghorithm(GA) coupled finite element(FE) model, the rail geometries for uniform current distribution for different rail separations are found. Then, the parasitic masses are calculated and the total projectile masses are calculated. Later using a 3D FE model, the exit velocity of the projectile is calculated. The rail lenght is determined such that the projectile exits the rail when the current at 80% of its peak to avoid down-slope contact transition.[2]

[2] S. Satapathy and H. Vanicek, "Down-slope contact transition in railguns," *IEEE Trans. Magn.*, vol. 43, no. 1, pp. 402–407, Jan. 2007.

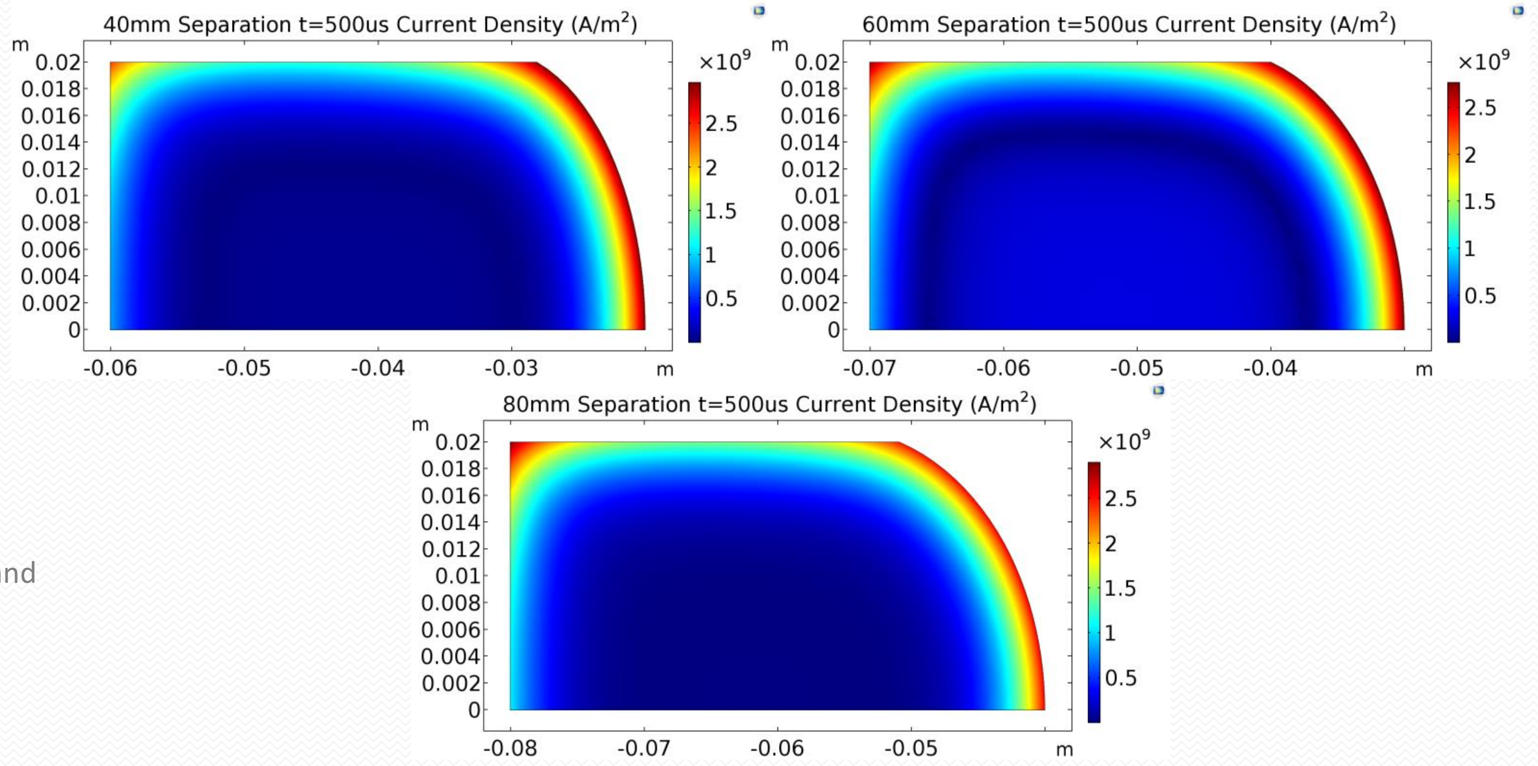
2D GA Coupled FE Results



Geometric parameters of the rail. For the armature geometry the armature length and height are taken as constants. The projectile geometry is constant and enclosed by the sabot petals. The armature and sabot petal geometries are modified according to separation

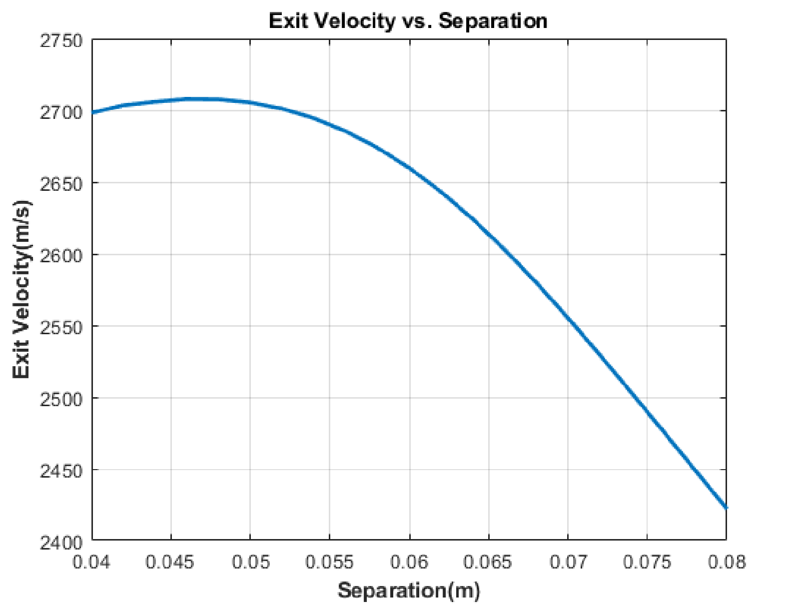


Optimization results for different separation parameters.

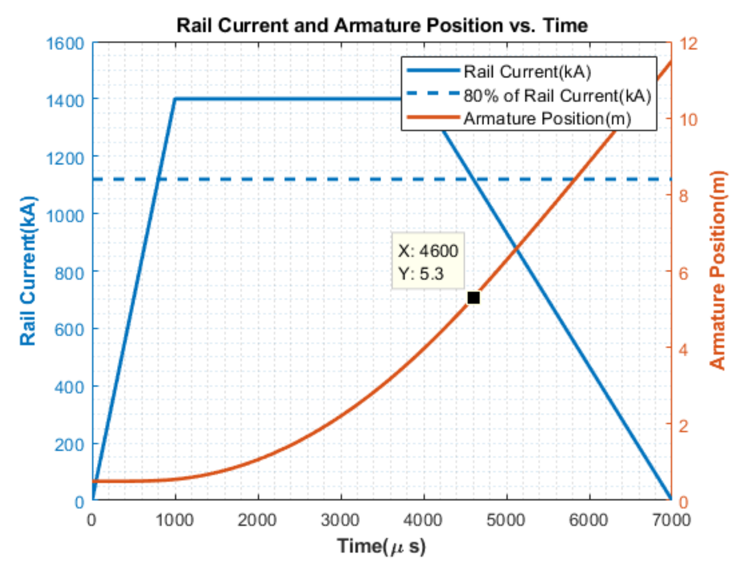


Current density distribution for different separations after GA optimization. The maximum current density decreases with increasing separation due to reduction in the proximity effect. This also results in a more circular inner rail surface.

The presented geometric model is coupled with GA using quarter symmetry to decrease computational cost. For different separation the GA coupled FE model is parametrically iterated. The goal is to achieve uniform current density at the convex surface at t=500us where the skin and proximity effects are most dominant.



Exit velocity vs. separation. Using varying parasitic armature, sabot petals the exit velocity of each launch package at 7 ms.



Total rail length calculation. The rail length is found such that the armature exits the rails when the rail excitation current is at its 80% of its peak to avoid down-slope contact transitions.

Separation(mm)	Exit Velocity(m/s)	Rail Length(m)
40	2239	5.04
50	2310	5.24
60	2200	4.94
70	2048	4.60
80	1816	4.18

Using 3D FE model, all convex rail geometries are simulated with constant current excitation. At the end of the input current(7ms) velocity of each separation is presented. In terms of projectile kinetic energy s=48mm is found as the optimum. The rail length is determined as the 80% of the peak to avoid down-slope contact transitions.

In this study, the rail parameters are optimized in terms of electrical parameters. The armature and sabot geometries are far from optimized. Moreover, mechanical parameters like peak pressure, stress analysis are omitted. Therefore, a similar analysis are also performed for different rail separations to adress a wider audiance.

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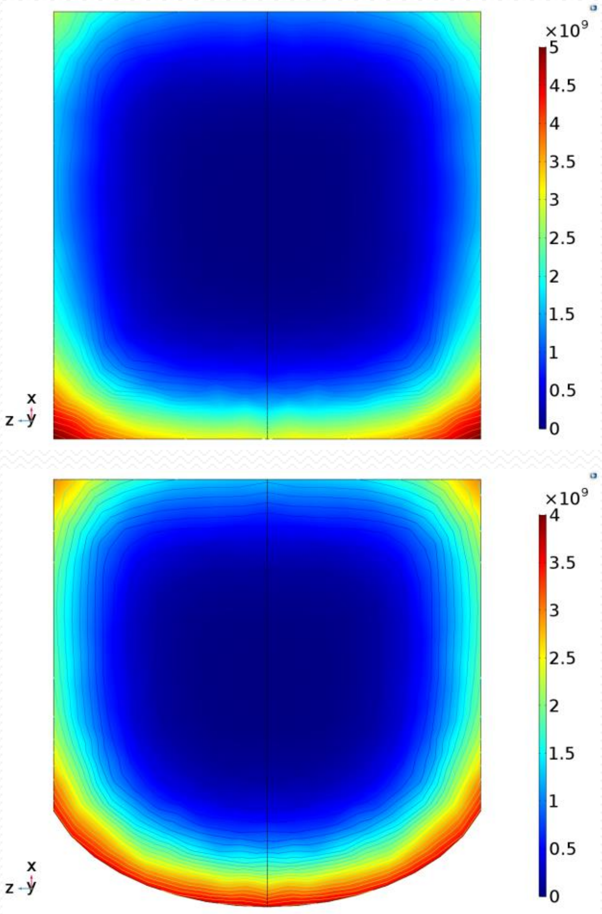
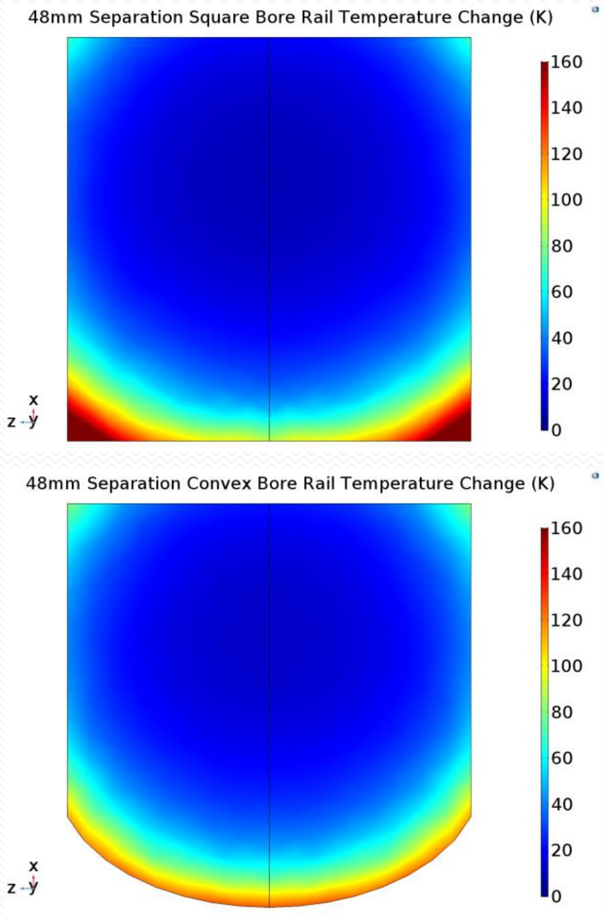


s=48mm square and convex rail distribution (A/mm^2) and flux densities(T) lines at 1000us. (Peak current)

Comparing the square and convex rail geometries with the same rail separation, the current distribution is significantly inproved on the inner rail surfaces. Having locally high current densities on the rail directly results in significant increase in the local temperatures. Clearly the square rail geometry is inferior to convex geometry in terms of temperature increase. While the temperature changes are below the melting point of copper material, here it is important to note that, the presented temperature change is only due to ohmic losses.



Temperature increase for square and convex cross-sections with s=48mm. The maximum rail temparature occurs for square rails with a ΔT=216K. In convex rails, not only the temperature change is uniform but also significantly lower with a maximum of ΔT=120K.

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Thanks!