Electromagnetic Launcher Speed Control with a Multilevel Fast Triggering Time Algorithm (MFTTA)

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In this study, we proposed a novel, efficient multi-level speed control algorithm which solves triggering time problem of electromagnetic launchers.

Fig. 1. 4 MJ Pulse power supply

Fig. 2. EMFY-1 electromagnetic launcher

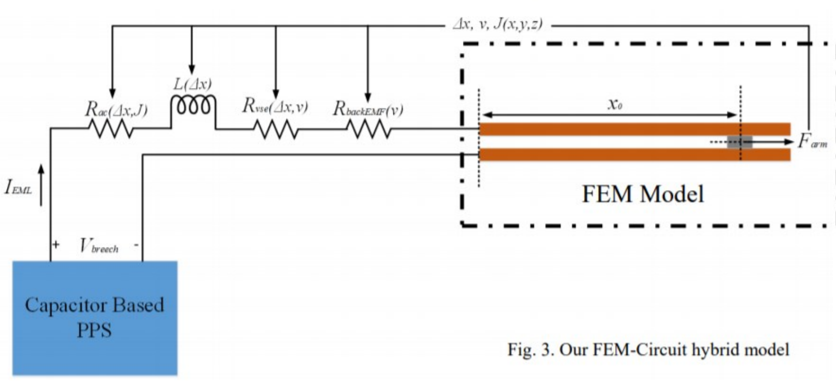


Fig. 3. Our FEM-Circuit hybrid model

Why is triggering time optimization hard?

- × Cost function requires 3D FEM computation, which is time dependent and has convergence issues due to switching devices. ***Therefore, FEM simulations are computationally expensive***.
- × Conversion to 3D FEM to lumped circuits comes with ***errors due to approximations.*** However, tight speed control requires accuracy.
- × In literature, derivative-free algorithms such as GA and PSO used for triggering time optimization due to significant amount of design variables. However, they ***require a large amount function evalutions to converge.*** *(typical 200 population with 50-100 generation, ~10000 simulations)*

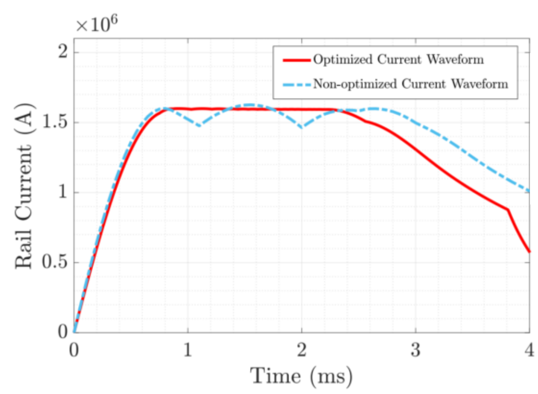
What we do with MFTTA Algorithm

- ✓ We decreased the design variables which enables as to used search algorithm.
  ~10000 simulations to 100-180 simulations
- ✓ Speed-dependent parasitic masses
  which didn't cover in the literature
- ✓ Cover the transient inductance change of the rail
  which increases the accuracy of the model %8
- ✓ Regard transition constraints
  which increases the accuracy of the model

What we can't with MFTTA Algorithm

- × Algorithm success ***still*** is heavy depend on simulation-experiment compabilitiy
- × Speed-dependent parasitic masses can't be generalized.

MFTTA Purpose:



$$\begin{aligned} \min \quad & (v_{desired} - v_{exit})^2 \\ \text{subject to} \quad & I_{ref} \leq I_{max} \\ & I_{exit} \geq 0.5 I_{ref} \\ & |I_{rail} - I_{ref}|_{RMS} \leq \epsilon I_{ref} \quad t \in [t_1, t_2] \end{aligned}$$

Fig. 4: Optimized and non-optimized current waveforms. Optimized current waveform has flat top characteristic which minimize the current oscillations.

MFTTA First Job: Hysteresis Control

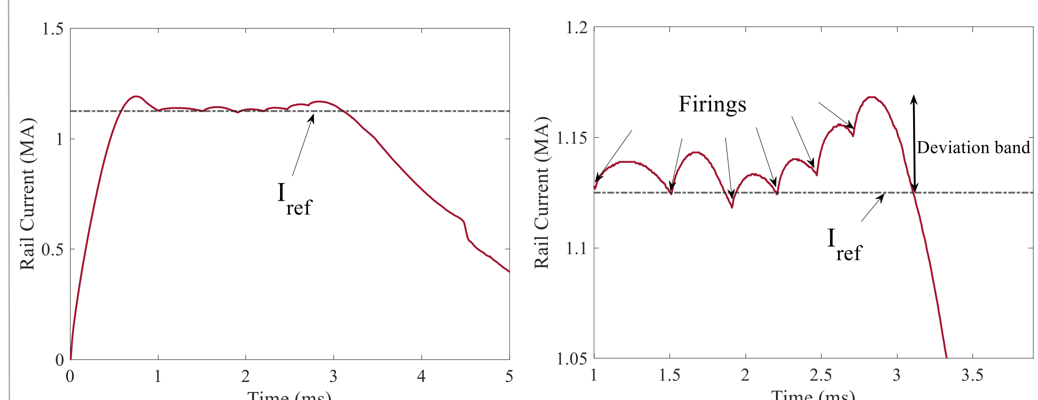


Fig. 5: MFTTA results at the hysteresis part. Experimental verification with real launch.

MFTTA Second Job: Search

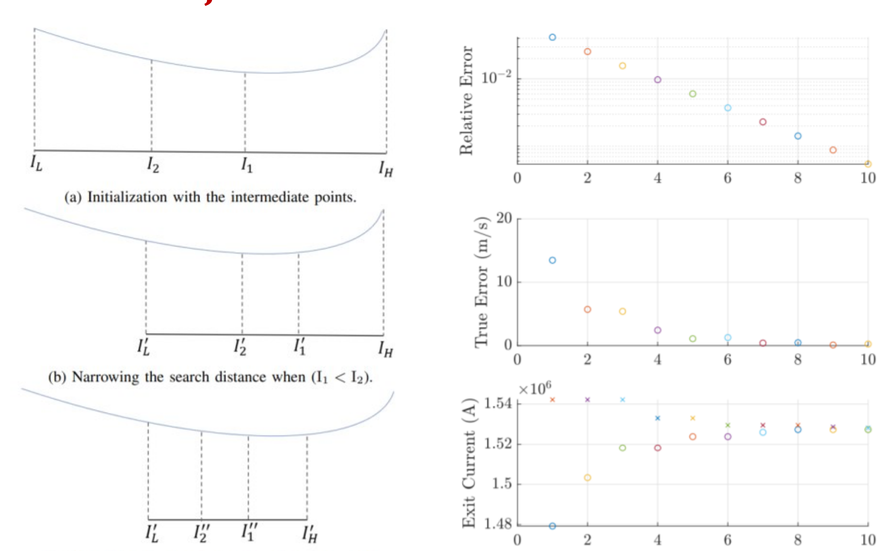


Fig. 6: Golden search algoritm illustration (left), and the intermediate results while searching happening.

Benchmark

The Performance Comparison of the Methods

	GA	PSO	MFTTA
Objective: $v_{desired}$	2500	950	160
Objective: v_{max}	2300	550	18[2]

[1] Each number represent the number of simulations/function evaluations for the given method.
[2] MFTTA use the information that for maximizing v_{max}, the I_{rail} should be pulse shaped current with the magnitude I_{max}.