

Numerical Simulation and Testing of an Electromagnetic Loader for Railguns

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An automatic loader for feeding electromagnetic railguns at high repetition rates is currently being investigated at the French-German Research Institute of Saint-Louis (ISL). The functional principle of the loader is based on inductive acceleration similar to the functioning of a coil launcher. The major advantage of this principle is that it allows a compact design and an almost frictionless injection of the launch package into the railgun, since there is no contact between the stator and the linear moving part. The approach requires two steps of numerical simulation. In a third step the loader is built and tested, and the experimental results are compared with the numerical data. In the first step the basic parameters of the loader and its dimensions are determined by means of a fast-running numerical in-house code written in FORTRAN. It allows for design optimization over a high number of iteration loops. In the second step, the resulting launcher dimensions as well as the time-dependent current profile are used as input data for time-dependent three-dimensional Finite-Element computation (LSDYNA). The mechanical and the electromagnetic solvers are coupled to each other. This stage of the work allows verifying the mechanical consistency of the loader subjected to magnetic pressure, as the material models of the involved structural parts take into account elastic, plastic and strength behavior. The third step consists in testing the most relevant solutions on the railgun facility of the medium caliber launcher RAFIRA (25 mm square caliber) at the ISL laboratory. We could show that the numerical results are in good agreement with those obtained by experimental work.

Index Terms—Electromagnetic acceleration, coil launcher, electromagnetic-mechanical coupling, elastic-plastic deformation

I. INTRODUCTION

THE FRENCH-GERMAN RESEARCH INSTITUTE ISL has been working on electromagnetic acceleration for more than 30 years. Electromagnetic rail launchers of different sizes are currently operated in its laboratories for accelerating payloads and projectiles in the mass range between a few grams and several kilograms (Fig. 1). Velocities of more than 3000 m/s have been achieved. The payload is usually placed in front of the so-called armature, the part on which the driving Lorentz force is acting. Depending on the shape and mechanical strength of the payload, a sabot may be added to ensure the lateral guidance along the bore of the railgun. The armature, the sabot and the payload together are representing the total accelerated mass and are referred to as the launch package.

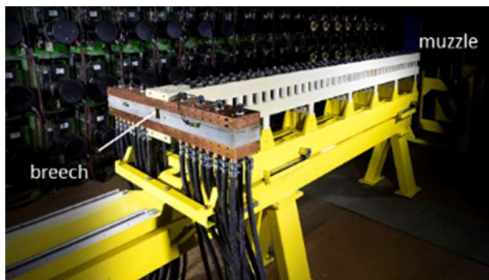


Fig. 1. Electromagnetic RAFIRA and connected capacitive pulsed power supply (background).

In order to bring the launch package rapidly to the start position at the breach of the railgun, a loader device is currently under investigation. Dedicated operational loader techniques do not yet exist for railguns. No weapon system has been fielded until now. Loaders for existing demonstrators or their prototypes are either mechanical devices for operating at low frequency repetition rates or based on electromagnetic

techniques for achieving high repetition rates. Loaders based on the principle of short railguns were investigated earlier at the ISL [1,2]. Repetition rates well beyond 50 Hz have been achieved. Another electromagnetic technique of was chosen for the present study, the acceleration by induction, due to the requirement of a compact design at the railgun breach. In addition, an induction launcher operates almost frictionless, as no electrical sliding contact is needed between the primary driving coil and the secondary moving coil, which also reduces the required energy.

The topics of the present work are the design of the loader at its initial stage of development and the description of the applied methods to achieve this task.

II. NUMERICAL DESIGN OF THE LOADER

The loading device consists of a primary coil, a pulse power capacitor, switches and cables. A suitable mechanical structure for housing the primary coil also ensures guidance for the launch package (see Fig. 2, using surrogates without payload for this test campaign).

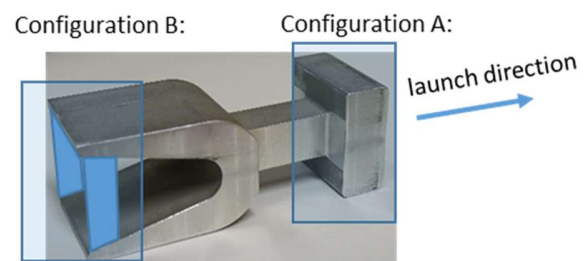


Fig. 2. Launch package surrogate for the loader tests. Configuration A: secondary coil at the front part. Configuration B: secondary coil at the rear part with two vertical bridges added.

A. Fast-running in-house-code for computing the basic loader parameters (step 1)

The fast-running in-house computer code is used for pre-dimensioning the Pulse Power Supply (PPS) and the primary coil embedded in the loader device. In other terms, the corresponding RLC-circuit is coupled to the equation of motion of the launch package. The launch efficiency (Fig. 3) in terms of the kinetic energy for a given injected electric energy is used as target parameter for optimization purposes. Besides the dimensions of the primary and the secondary coil, we essentially obtain the time-dependent shape of the current pulse. The core of the in-house computer code provides rapid but nevertheless quite accurate computation of the self and mutual inductances of the coils. The subroutine is based on Fawzi and Burke [3] using Bartky's transformation for the integration, see Bulirsch [4]. The resulting differential equations are solved by means of fourth order Runge-Kutta method.

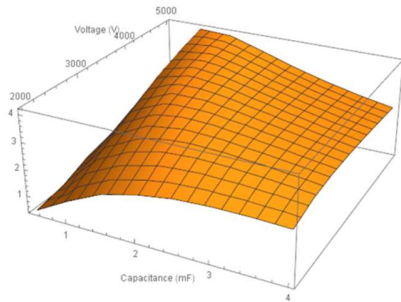


Fig. 3. Example of the optimization process in step 1: launch efficiency of the loader depending on the capacitance and capacitor charging voltage.

B. 3D FEM model for detailed design (step 2)

The preliminary coil dimensions obtained in step 1 in the previous section are transferred into the three-dimensional FEM code LSDYNA, where the transient current pulse from step 1 is used as the load curve for the primary coil. LSDYNA uses the boundary element method (BEM) applied to the Biot-Savart equation for computing the magnetic field and the generated Lorentz force distribution (see “eddy current solver” in [3]). As the electromagnetic solver is coupled to the mechanical solver, the mechanical response of the structure subjected to the strong magnetic pressure is directly accessible.

Two concepts have been studied within this investigation. In configuration A, the secondary coil is located at the front of the launch package (Fig. 2, right). For the secondary coil in configuration B, two vertical bridges were added at the rear part (see Fig. 2, left).

III. EXPERIMENTAL WORK

For the energy supply of the experimental part in step 3, a pulsed power capacitor of 1 mF capacitance and a nominal electric energy of 12.5 kJ were chosen. It is connected to the primary coil of the loader via a thyristor and a crowbar diode. The loader, which is mounted on the railgun breech, is shown in Fig. 4. For the tests using configuration A (front part is used

as secondary coil, Fig. 2), velocities in a range between 10 m/s and 40 m/s were obtained. Numerical 3D simulation and experiment provided similar velocities. The test values were systematically located below the simulation results, which can be explained by friction that was not taken into account in the computation part. Simulation of configuration B provided much lower velocities than configuration A. Moreover, the bridges mounted on the armature were subjected to strong deformation, as can be seen in Fig. 5, left. Since the test surrogate of configuration B was already manufactured, the test was carried out anyway. The launch package with deformed bridges is shown in Fig. 5, right. Although the simulated bridge dimensions and tested dimensions are slightly different, the observed damage is very similar, showing that the applied material models work well.



Fig. 4. Induction loader mounted to the railgun breech.

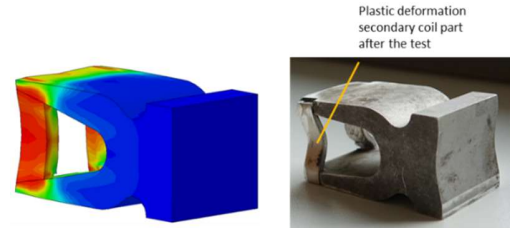


Fig. 5. Comparison between 3D FEM model of step 2 (left, von Mises stress) and launch package surrogate configuration B after the test (right) in step 3.

IV. CONCLUSION

The initial stage of the optimization of a railgun loader is presented in this work. The design procedure using the two-step computation provided results which could be validated by the experiments. The optimization work is ongoing aiming to further increase the injection velocity and the launch efficiency of the loader.

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