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THEORETICAL AND EXPERIMENTAL INVESTIGATIONS REGARDING THE ELECTROMAGNETIC BALLISTIC SYSTEMS

Titica F. Vasile, Mihai J. Nicu
Military Technical Academy, Bucharest, Romania

ABSTRACT
The theoretical and practical limits reached in the development of classic ballistic systems impose the major changes regarding the propulsion of ballistic systems. A new propulsion system can be the electromagnetic propulsion, which uses the electricity as an energy source. In this paper it is elaborated the mathematical model of the projectile motion, on the basis of the physical principles that lay the foundation of the electromagnetic ballistic system (rail gun). By the solving of the mathematical model it is obtained, finally, the variation of projectile velocity versus time. The validation of the mathematical model was done by the comparing of the experimental data met in the international specialty literature with theoretical results.
Keywords*:* electromagnetic ballistic system, rail gun, coil gun, mathematical model, projectile velocity

1. INTRODUCTION
Theoretical and practical limits that were reached in the development of classic ballistic systems have imposed major changes regarding the propulsion of ballistic systems. A new propulsion system can be the electromagnetic propulsion. The electromagnetic propulsion uses electricity as source of energy, but the form in which the energy is transferred to the projectile differs according to the construction type of the electromagnetic gun [6]. These electromagnetic guns can be: electromagnetic gun with rails (rail gun); electromagnetic gun with coil (coil gun). Basically, an electromagnetic gun with rails is composed from an energetic source of continuous current, two conducting rails and projectile armour (Fig.1). The two conducting rails are constructed by material with a good electric conductibility and a diameter big enough to offer the necessary stiffness for the whole ensemble.
The rails are supposed to resist to the Joule effect that appears at the current passing, to which is

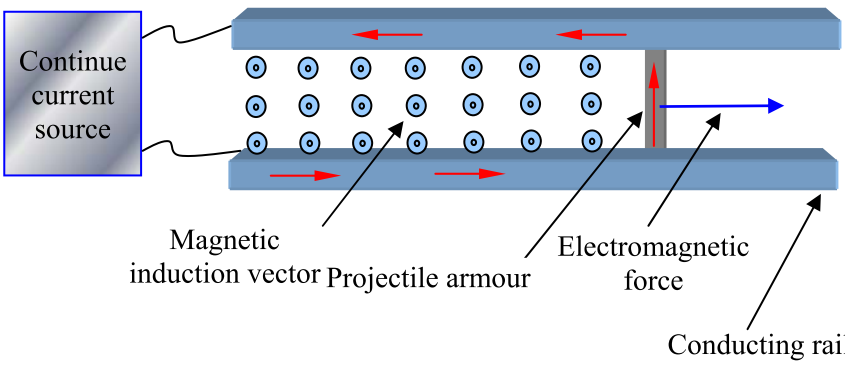

Figure 1. Scheme of the electromagnetic gun with rails

added the thermal energy generated by the strong abrasion between the guiding rails walls and the projectile. Aproximatively 50% of the source electric energy is dissipated into heat form, resulting from the electrical resistance of the rails. Also, the rails must resist to the launched propulsive force of the projectile that, according to the action and the reaction principle, will act with the same force, not only on the projectile, but also on the rails [4]. In the present paper is elaborated a mathematical model of projectile motion in an electromagnetic gun with rails.

2. ELECTROMAGNETIC FORCE IN AN ELECTROMAGNETIC GUN WITH RAILS

Following relation gives the magnetic field generated by a conductor passed through by current i, in a point P placed at a certain distance from the first one:

$$\vec{B} = \frac{\mu_0 i}{4\pi y} \frac{X}{\sqrt{X^2 + y^2}} \left(d\vec{x} \times \vec{r} \right). \quad (1)$$

In the case when $y << X$, from relation (1) it is obtained the relation of the magnetic field generated by a conductor passed by an electric current at the distance y from this one. Considering the distance between the two conducting rails w and the thickness of the rail α, the equation of the magnetic field generated by the two conducting rails of the linear launch in a point along the armature becomes [1]

$$\vec{B} = \frac{\mu_0 i}{4\pi} \left(\frac{1}{2a + w + y} + \frac{1}{y} \right) \vec{u}_B . \quad (2)$$

The interaction between electric current and magnetic field lays at the basis of the technology of linear installation. This interaction is known under the name of electromagnetic force. For the electromagnetic force that acts on the projectile and gun carriage respectively, it is obtained

$$F = \frac{\mu_0 i^2(t)}{4\pi} \ln \frac{(w+a)^2}{a^2} = \frac{1}{2} L' i^2(t). \quad (3)$$

3. THE OHM LAW FOR THE ELECTROMAGNETIC GUN WITH RAILS

Theoretical, the rail gun electric circuit is consisted of a capacitors battery supplied in continue current, a tension rising transformer through a bridge rectifier, two conducting rails and the projectile armature (Fig 2).

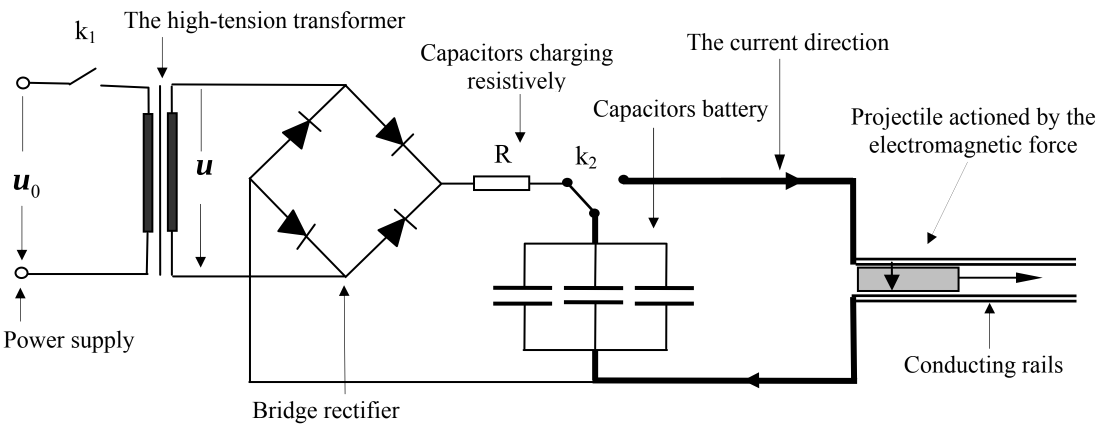

Figure 2. Principle electric draft of the rail gun

The Ohm law is written for instantaneous values of the rail gun circuit, in the presence of the capacitors batteries, equivalent ohm resistance and system inductivity, as follows [3]

$$R \cdot i + U_c = -L \frac{di}{dt} . \quad (4)$$

By solving the equation (4) in the hypothesis of the ideal oscillating circuit in which the charge of the circuit is canceled, it is obtained the following solution:

$$i(t) = I_0 \sin(\omega t) . \quad (5)$$

When the capacitors battery is discharged, after that the current reaches the maximum value I_0 one consider that the power source (the capacitors battery) is disconnected. This hypothesis allows that the equation (4) to be written as follows [3]:

$$R \cdot i + L\frac{di}{dt} = 0 . \quad (6)$$

By integration of the equation (6), it is obtained

$$i(t) = I_0 e^{-\frac{R}{L}t} . \quad (7)$$

4. PROJECTILE VELOCITY IN A RAIL GUN

Taking into account the relation (3), with the aid of fundamental equation of mechanics one can write the relation for the projectile acceleration. So, during the capacitive discharge the relation is

$$a_c = \frac{dv_c}{dt} = \frac{1}{2m} L' I_0^2 \sin^2(\omega t) \quad (8)$$

and during the inductive phase is

$$a_i = \frac{dv_i}{dt} = \frac{1}{2m} L' I_0^2 e^{\frac{-2R}{L}t} . \quad (9)$$

On the basis of equations (8) and (9), correlated with the motion moment, the projectile's velocity within the installation is calculated, thus:

$$v_c = \frac{1}{4m} L' I_0^2 \left(t - \frac{\sin(2\omega t)}{2\omega} \right), \quad (10)$$

during the capacitive discharge, and

$$\Delta v_i = \frac{L' I_0^2}{4m} \frac{L}{R} \left(1 - e^{\frac{-2R}{L}(t - t_c)} \right), \quad (11)$$

during the inductive phase. The initial velocity is obtained with the aid of relations 10) and (11), which were particularised for the end of the capacitive discharge and of the inductive phase

$$v_g = \frac{L' I_0^2}{4m} \left(\frac{\pi\sqrt{LC}}{2} + \frac{L}{R}(1 - f)^2 \right), \quad (12)$$

where f represents the fraction of the maximum current established to exist in a circuit when the projectile leaves the rail gun. The equations and relations derived from the above presentation form the mathematical model of projectile motion in a rail gun. The study of the projectile motion along the conducting rails of the rail gun is made in the absence of the frictional force.

5. RESULTS AND CONCLUSIONS

For the validation of the mathematical model of projectile motion in a rail gun, the theoretical results obtained with the aid of this mathematical model and experimental data obtained by the Physics Department of the Postgraduate Naval School from Monterey, California with an experimental rail gun having the length of conducting rails of 1.2 m are compared [1].

The main characteristics of this experimental rail gun with the length of conducting rails of 1.2 m are following: tension of capacitors battery U_0=10.000 V; equivalent capacity of capacitors battery C=1.5E-01 F; mass of the projectile m=1.45E-01 kg; equivalent resistance of the electric circuit R=3E-03 Ω; distance between conducting rails w=6.25E-03 m; thickness of the rails α=3.125E-03 m; gradient of the inductance L'=4.3944E-07 H/m; unitary inductance of the electric circuit L=3.4841 E-06 H/m.

In figure 3 is presented comparatively the variation of current intensity versus time for experimental data (red colour) and theoretical results (blue colour).

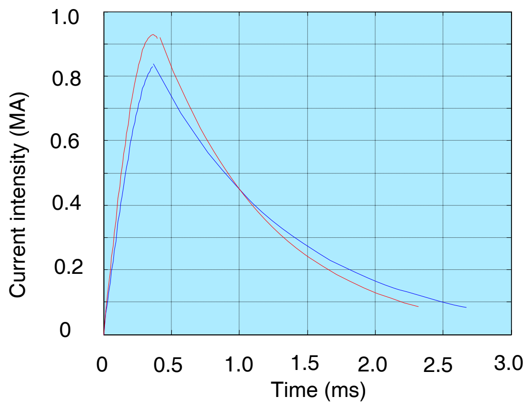

Figure 3. The variation of the current intensity

Also, in figure 4 is shown comparatively the variation of projectile velocity versus time for experimental data (red colour) and theoretical results (blue colour).

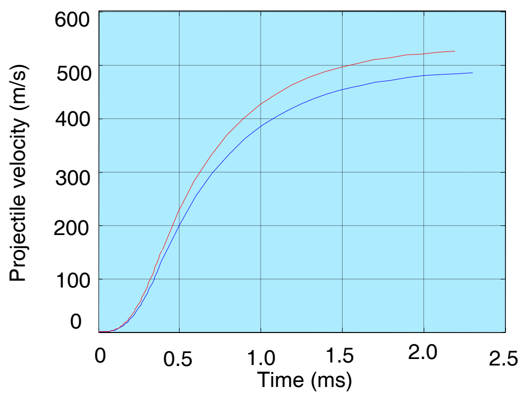

Figure 4. The variation of the projectile

One can see from figures 4 and 5 that is there a good agreement between experimental data and theoretical results for an extant linear electromagnetic installation. The deviations of the theoretical results comparatively with the experimental data result particularly from different values of the inductances In conclusion, despite of a small deviations between experimental data and theoretical results, the mathematical model of projectile motion in a rail gun, can be used for the study of the motion of projectile in such rail gun.

6. REFERENCES

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