STUDY THE ACCELERATING MACRO-PARTICLE BY USING ELECTROMAGNETIC FIELD

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Abstract

A theoretical investigation is carried out to study accelerating macro-particle using electromagnetic field in a launcher system.

The launcher system consist of two parallel conductor (rails) connected by conductor metal called armature. The current of rails is generated by using capacitor bank and inductor.

In this study, the equivalent electrical circuit were analyzed theoretically to calculate the current profile and used to calculate the velocity of accelerating particle.

The results of this study have shown that the peak current in the rails was 104 kA with time 45.2 μs at storage energy 21.6 kJ, which accelerating particle to velocity 970 m/s at particle mass 1 mgm.

The results of present analysis are then compared with the publishes experimental results, which are approximately in agreement with it.

Introduction

There are a number of application that required acceleration macro-particle to a very high speeds such as in an industry applications, coating, space research and military applications [1,2,3,4]. Upon current technology needs, the particle speeds in excess of 10 km/s can be obtained only by the use of electromagnetic energy [5].

The simplest device of the electromagnetic launching is the DC rail gun where the accelerating force is the Lorentz force, resulting from a current flowing orthogonally to a self-generated magnetic field, and deliver energy to accelerate the macro particle.

The purpose of this paper is present a theoretical calculation of current profile from storage energy, capacitor bank, and the relation with particle velocities.

Description for the assumption launcher system

The assumption launcher system consists of a pair parallel conductor (rails) separated by a distance (D) and connected by a movable conductor, called armature, which acts as a sliding switch or electrical short between the rails. By passing a large current I generated by a current source (capacitor bank) down to the first rail through the armature and back along the second rail, a large magnetic field B is built up behind the accelerating particle due to the Lorentz force f [6,7]

$$f = \frac{1}{2} L' I^2 \qquad (1)$$

where L' is the self inductance per unit length for the rails and I is the current of the rails as shown in Fig.(1)

The electrical circuit is shown in Fig.(1), which consists of a power supply used for charged the capacitor bank through special type of switch like spark gap switch or crowbar switch to discharge the bank. I nductor L is put in series with the bank to determine the discharge time for the current in the rails.

Theoretical formulation and calculation

1.The accelerating force

The conservation equation of motion in launcher system may be derived by a Lagrangian formulation ζ [6].

$$\zeta = T - V \qquad (2)$$

where T is the kinetic energy and V is the electromagnetic potential energy. Obeys Lagrange's equation of motion [6]

$$\frac{d}{dt}\left(\frac{\delta\zeta}{\delta x^{\bullet}}\right) - \frac{\delta\zeta}{\delta x} = 0 \qquad (3)$$

For a parallel geometry accelerating system, as shown in Fig.(1), the energy stored inductively in the rails V is

$$V=\frac{1}{2}\,L_{(x)}\,I^2 \quad \text{.......................................(4)}$$

where $L_{(x)}$ is the inductance as a function of length and I is the current in rails .

The kinetic energy stored T is

$$T=\frac{1}{2}\,m\,x^{\bullet} \quad \text{..(5)}$$

where m is the mass of accelerating particle and $x^{\bullet}$ is the velocity of particle .

Substituting equation (5) and equation (4) in equation (2) and further substituting into equation (3) [6], then

$$m\,x^{\bullet\bullet}\ -\frac{1}{2}\,I^2\,\frac{dL}{dx}=0 \quad \text{.............................(6)}$$

which may be rearranged to the more familiar form to equation (1)

$$f=\frac{1}{2}\,L'\,I^2$$

2. The current in the rails

It can be calculated the current I in the rails by applying Kirchhoff's low for the equivalent circuit as shown in Fig. (2).

$$V_o=R\,I+L\frac{dI}{dt}+\int\frac{I}{c}dt \quad \text{......................(7)}$$

And taking the differential

$$R\frac{dI}{dt}+L\frac{d^2I}{dt^2}+\frac{I}{C}=0 \quad \text{.............................(8)}$$

The general solution for equation (8) is

$$I=A\exp(m_1t)-B\exp(m_1t) \quad \text{...................(9)}$$

where A and B are constant and

$$m_1=\left(-\ \frac{R}{2L}+\frac{\sqrt{R^2-\ 4L/\ C}}{2L}\right)$$

$$m_2=\left(-\ \frac{R}{2L}-\ \frac{\sqrt{R^2-\ 4L/\ C}}{2L}\right)$$

at t = 0, equation (9) become,

$$I=A\ (\exp(m_1\,t)-\ \exp(m_2\,t)\ ) \quad \text{...........(10)}$$

By taking the differential equation (10) and substituting

$$\frac{dI}{dt}=\frac{V_o}{L}$$

then,

$$A=\frac{V_o}{L(m_1-m_2)} \quad \text{..............................(11)}$$

If we assume

$$\left.\begin{aligned} m_1&=-k_1+jk_2\\ m_1&=-k_1-jk_2\end{aligned}\right\} \quad \text{.................................(12)}$$

$$k_1=\frac{R}{2L}\quad,\qquad k_2=\frac{\sqrt{R^2-\ 4L/\ C}}{2L}\quad \text{and}\quad j=\sqrt{\ -1}$$

by substituting equation (11) and equation (12) in equation (10), then

$$I=\frac{2V_o}{R\sqrt{r^2-\ 1}}\exp(\ -\frac{Rt}{2L})\sin(\frac{R}{2L})\sqrt{r^2-1}\ \ t$$

$$\text{..............................(13)}$$

Where

$$r^2=\frac{4L}{cR^2}$$

Equation (13), can be written

$$I=\frac{2V_O}{(R_b+R_r)\sqrt{r^2-1}}\exp(-Tt)\sin\left(\sqrt{r^2-1}\ \ Tt\right) \text{.....(14)}$$

where R_b is the total resistance for the capacitor bank, R_r is the total resistance for the wire, R is the total resistance, V_O is the charged voltage, t is the time and T= (R/2L) where $R=R_b+R_r$.

The self-inductance per unit length for the rails

If we consider two parallel conductor as shown in Fig. (3), then the self –inductance L′ is given by [8].

$$L'=\frac{\mu_o}{\pi}\left(\frac{1}{4}+\ln\frac{D}{a}\right) \text{..............................(15)}$$

where μ_O is the permeability of free space, a is the radius of the conductor and D is the separated distance between the conductor.

In the case for system under study which is the conductors (rails) are rectangular cross sections as shown in Fig.(4)

$$x\,y=\pi\,a^2$$

$$a=\sqrt{\frac{x\,y}{\pi}} \quad \text{..(16)}$$

where x and y are the width and highness for the rails respectively, then the self-inductance per unit length L′ is

$$L' = 1.x10^{-7}\left[1 + \left(4\ln\left(\frac{D}{\sqrt{xy/\ \pi}}\right)\right)\right] \quad ....(17)$$

The accelerating particle velocities

It can be calculated the velocity for the accelerating particle v by using equation (1)

$$f = \frac{1}{2} L' I^2$$

$$m\frac{dv}{dt} = \frac{1}{2} L' I^2 \quad ....(18)$$

$$dv = \frac{1}{2m} L' I^2 dt$$

Results and Conclusions

A computer program written in Fortran language by using a software Fortran power station V4 for compiling, linking and exacting for calculation the rails current profile and the velocities for the accelerating particle by using equations (14), (17) and (18).

Fig.(4) shows the results calculations from the computer program for the current rails profile by using an experimental data for the electric circuit and the system dimensions as shown in Table (1) [9]. It is notice from the figure that the peak current I_{max} = (104) kA at time (45.2) μs, which is approximately in agreement with the experimental results of Hewkin et al [9] in Fig.(5), which is the best test for the theoretical results.

Fig. (6) shows the velocity of accelerating particle as a function of time, using the data in Table (1). It is notice that at t = (45.2) μs, which is the current at this time at maximum value (see Fig.(4)), the velocity of particle reaches to (970) m/s. There is a similarity behavior for the Fig.(6) with Weeks et al experiment [6] as shown in Fig. (7).

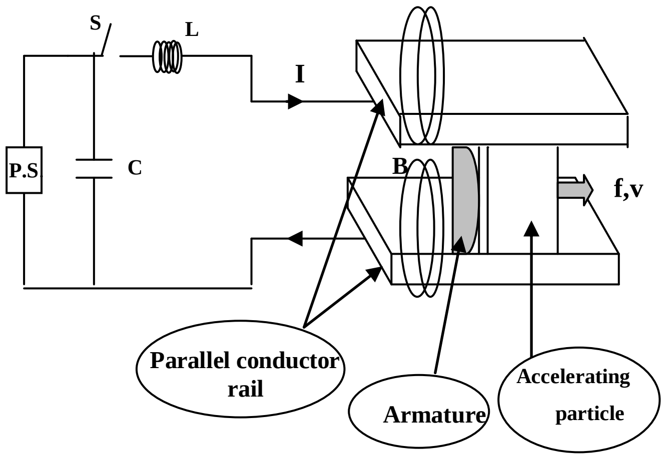

Fig.(1) : A schematic drawing for launcher system and electrical circuit under study.

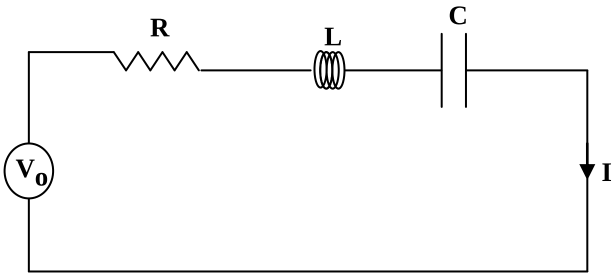

Fig.(2) : Equivalent electrical circuit for the system.

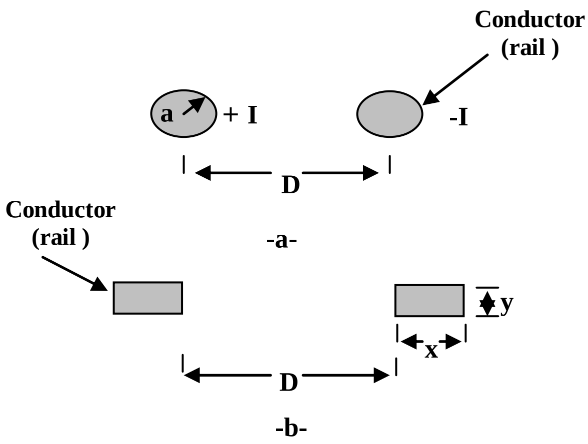

Fig.(3) : a- A sectional view for two parallel conductors [8].
b-A sectional view for the rails in the launcher system under study.

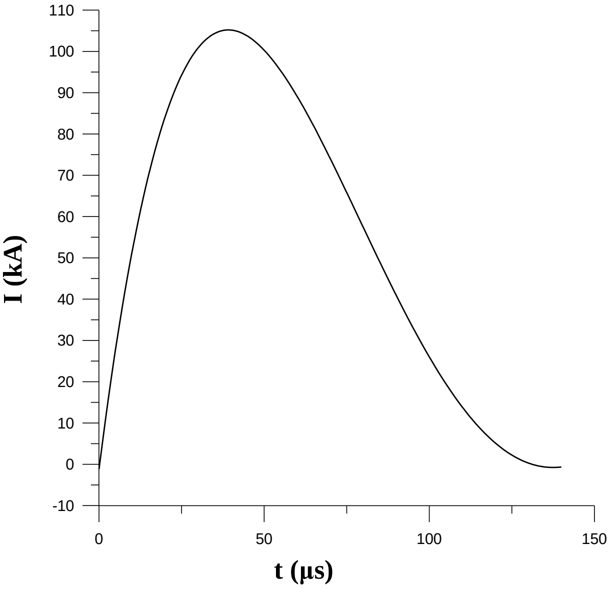

Fig.(4) : Theoretical current profile for the launcher system under study.

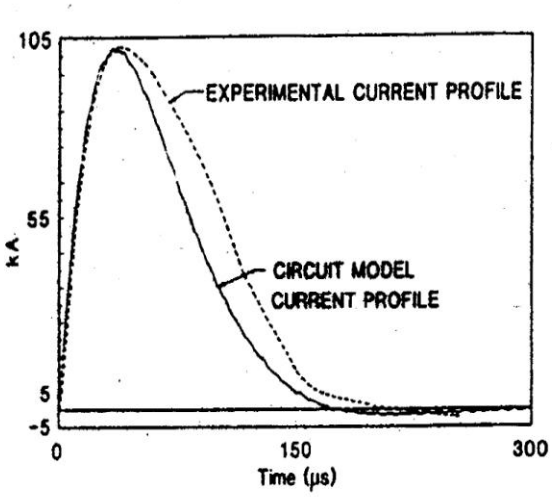

Fig.(5): Current profile for experimental and theoretical Hewkin et al model [9].

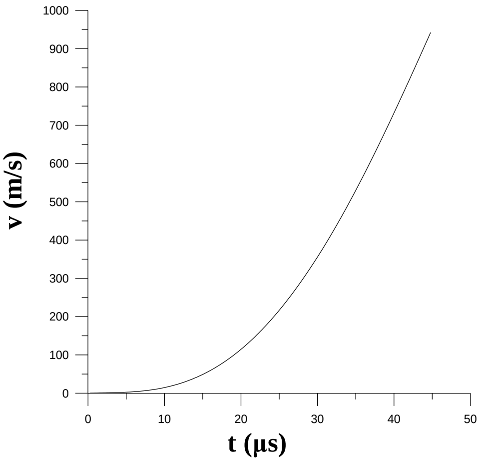

Fig.(6):Theoretical velocities for accelerating particle of mass (1) mgm as a function of time for the launcher system under study.

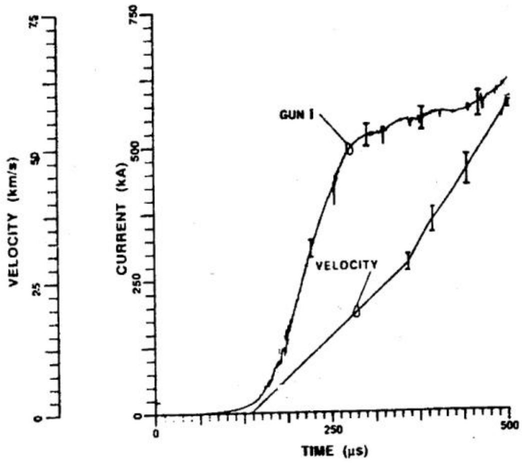

Fig. (7) : Accelerating particle velocity and the current rail as a function of time for Weeks et al experimental [6].

Table (1)
Experimental data for the electrical circuit and the dimensions for the launcher system from Hewkin [9] which are used in computer program.

m	1 mgm
V_o	20 kV
R_b	0.1 Ω
R_r	0.1 Ω
L	1 μH
C	108 μf
D	12 mm
x	5 mm
y	1 mm

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الخلاصة

تم أجراء بحث نظري لدراسة تعجيل جسيم صغير بأستخدام مجال كهرومغناطيسي في منظومة أطلاق .

تتألف منظومة الأطلاق من موصلين متوازيين (سكة) وقد ربطت فيما بينها بواسطة معدن يسمى بالقاذف .

أن التيارالكهربائي للسكة يجهز بواسطة مجموعة متسعات مع ملف .

في هذه الدراسة تم تحليل الدائرة الكهربائية نظريا لحساب التيار ، وقد أستخدمت قيم التيار لحساب سرع تعجيل الجسيم .

نتائج هذه الدراسة بينت بأنه قد تم ال حصول على قيمة عليا لتيار السكة بمقدار 104 kA وبزمن قدره 45.2 µs وبطاقة خزن 21.6 kJ لتعجيل جسيم وزنه 1 mgm الى سرعة 970 m/s .

نتائج التحليل النظري لهذه الدراسة قد تمت مقارنتها مع نتائج عملية وكانت مقاربة لها تقريبا.