International Journal of Recent Advances in Multidisciplinary Topics
Volume 5, Issue 6, June 2024
https://www.ijramt.com | ISSN (Online): 2582-7839

Design and Implementation of an Electromagnetic Power Cylinder using the Gauss Cannon Principle

Luis Alberto Martinez Olvera[1], Roberto Ademar Rodriguez Diaz[2*], Adrian Cardona Sanchez[3], Ricardo Rodriguez Figueroa[4]

[1]*Master Degree Student, Master of Science in Industrial Engineering, National Technological Institute of Mexico, TES de Coacalco, Coacalco de Berriozabal, Mexico*

[2,3,4]*Professor, Master of Science in Industrial Engineering, National Technological Institute of Mexico, TES de Coacalco, Coacalco de Berriozabal, Mexico*

***Abstract*: This article defines the stages of design, modeling, and simulation of an electromagnetic propulsion system for a translational displacement cylinder. The main objective is to simplify, optimize, and economize translational mechanical motion generation systems by adapting and implementing a Gauss cannon in the propulsion system, which does not require a large number of elements to work nor significant maintenance efforts. The methodology consists of an analysis, modeling, and simulation process of the electrical subsystem, the mechanical subsystem, and the electromechanical coupling to understand the dynamic response of the overall system and detail the relationship between the most determining variables of the electromagnetic propulsion system. Matlab-Simulink software was used for the simulation process and obtaining response curves. The results show a significant relationship between the input current from the discharge of the electrolytic capacitors and the speed and acceleration of the piston inside the cylinder, as well as demonstrating that design criteria in the system play a very important role in the efficiency of the propulsion system, from the capacitance of the capacitors in the Gauss cannon, input voltage, magnet wire gauge, number of turns, piston mass, and friction coefficient. This study provides a solid foundation for understanding and subsequently constructing the system, as well as implementing control techniques to ensure the best performance and its implementation in the industrial sector.**

***Keywords*: Dynamic response, Electromagnetic propulsion system, Gauss cannon, Matlab-Simulink software, Translational displacement cylinder.**

1. Introduction

Translational mechanical motion systems are essential in various industrial sectors, including automotive, food, electrical, and packaging. They are commonly utilized in processes such as packaging, manufacturing automation, production machinery, and conveyors, among others. Therefore, enhancing and innovating these systems directly impacts industrial process efficiency.

Although pneumatic and hydraulic systems are widely used in productive sectors, they have drawbacks such as pressure losses, increased component count, higher maintenance costs, speed fluctuations, and safety concerns, especially in hydraulic systems due to high pressures [1]-[3].

To address these challenges, there is a focus on replacing fluid power drives, such as compressed air and oil, with an electromagnetic propulsion system incorporating the Gauss cannon principle. This system aims to displace the piston with increased speed, efficiency, and simplicity [4], [5].

This article concentrates on analyzing, modeling, and simulating an electromagnetic propulsion system for a translational mechanical motion cylinder using the Gauss cannon principle. The primary objective is to enhance the operation and components of this linear motion system.

To achieve this objective, the article will first conduct a comprehensive analysis of the laws and principles governing hybrid systems to achieve piston displacement through the appropriate magnetic field. Subsequently, specific research objectives will be defined, and a methodology for creating models using graphical programming techniques will be presented. Additionally, the article will showcase results obtained from simulations using the Simulink tool in Matlab. Finally, the study will conclude with defined conclusions and recommendations for future system improvements.

2. Methodology

The present article presents the development of the modeling, simulation, and results of the dynamic response of the electromagnetic impulse system of a power cylinder using the Gauss cannon principle, as well as the different subsystems that integrate it.

A. Electromagnetic Propulsion Subsystem

Based on the principle of the Gauss cannon to generate an electromagnetic field inside an acrylic cylinder that allows displacing a mass of low-carbon, high-magnetic properties steel 1018.

*Corresponding author: ademar@tesco.edu.mx

B. *Gauss Cannon Charging and Discharging Circuit*

The Gauss cannon charging and discharging circuit consists of a series of capacitors connected in parallel, which function to receive energy from a power source and store the charge between their plates to subsequently release it at a defined time. The more discharge current is present, the greater the amount of electromagnetic energy generated inside the coil. For the simulation of this circuit, Proteus software [6] was used. With a 12-volt supply to a circuit of 3 capacitors of 10,000 μF in parallel, a maximum output current of 1.87 Amperes is obtained, as shown in Figure 1.

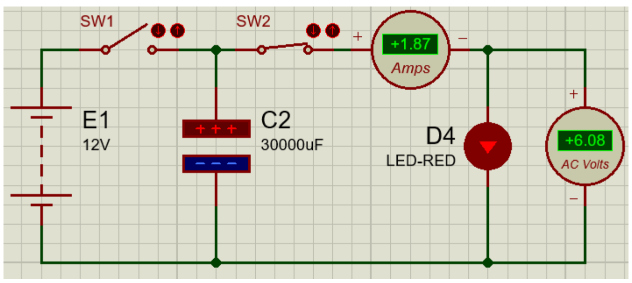

Fig. 1. Maximum discharge current

To analyze the discharge time of the capacitor circuit, the model of an R-C series system is employed, which relies on Kirchhoff's voltage law stating that the sum of voltage drops equals the voltage rises. Thus, equation 1 can be summarized as:

$$i(t) = \frac{1}{R}\left(E(t) - \int i(t)\,dt\right) \tag{1}$$

Where $i(t)$ represents the current as a function of time, $E(t)$ the voltage as a function of time, and R the resistance.

With a calculated resistance of 6.42 Ω and an equivalent capacitance of 30,000 μF, a maximum discharge time of less than 1 second is obtained. The simulation was carried out using Matlab-Simulink software [7] through graphical block programming, as shown in Figure 2.

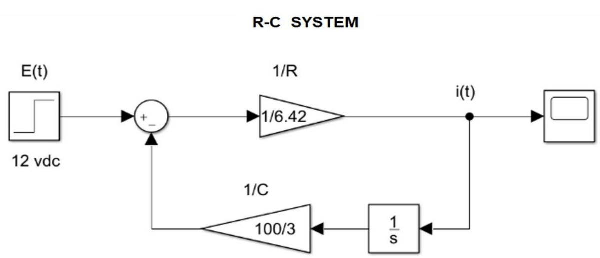

Fig. 2. Block diagram of the power feeder circuit system

C. *Modeling and Simulation of the Hybrid System.*

For the modeling of the Hybrid system (Mechanical - Electrical System), the modeling of a solenoid is taken as the basis. The solenoid system is defined in 3 fundamental parts: the electrical part, the electromechanical coupling, and the mechanical system [8].

The differential equations modeling an RL electrical system and a Mass-Damper mechanical system with the following response functions are considered.

$$\frac{di(t)}{dt} = \frac{1}{L}\left(E(t) - Ri(t)\right) \tag{2}$$

$$\frac{d^2x}{dt} = \frac{1}{m}\left(F_s - b\frac{dx}{dt}\right) \tag{3}$$

Where '*L*' is the inductance, 'f_s' is the electromotive force proportional to the current in the coil, and the term '*b(dx/dt)*' denotes the damping caused by the friction of the piston on the friction surface.

The calculation of the inductance and resistance of the electromagnetic propulsion system was performed for a coil with a length of 100 mm, resulting in 175 turns of 23-gauge magnet wire, with an inductance of $11309.06\ \mu H$, a resistance of $2.0112\ \Omega$ and a magnetic induction of $2.277x10^{-3}\ T$.

For the mechanical system, the calculation of the piston and rod mass was performed, taking the material density as 1018 steel for the piston and Nylacero for the rod. The equivalent mass was found to be 0.1598 kg, making it very lightweight, and the force required to displace this mass will be 0.3229 N.

Below is the block diagram of the three subsystems that make up the overall system. Figure 3 illustrates the integration of the electromagnetic propulsion subsystem (R-C, R-L), the electromechanical coupling, and the linear motion mechanical subsystem.

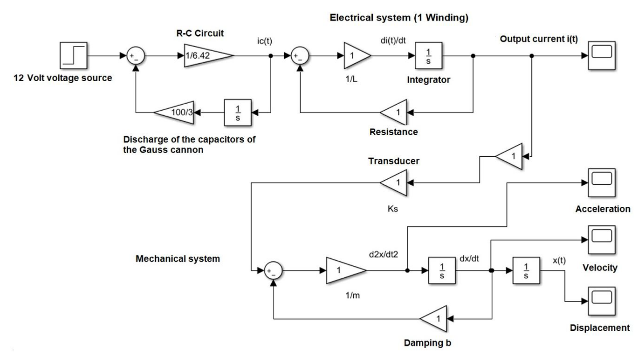

Fig. 3. Block diagram of the system

3. Results

The results of the present project consist of the different simulations in the Simulink-MatLab tool [7] of the subsystems that make up the electromagnetic power cylinder. The subsystems are composed of:

1. Electrical R-C System (Power Supply)
2. Electrical R-L System (Electromagnetic Pulse)
3. Mechanical System

A. *Simulation of the Electrical R-C System*

The simulations conducted in Simulink on the power supply system present the characteristic curve shown in Figure 4.

With a 12-volt source, a very rapid discharge time can be observed, around 0.9 to 1 second, with a maximum current of approximately 1.87 Amperes, meaning that from 0 to 0.2 seconds, the maximum current will be reached, gradually decreasing as time progresses, converging to zero even before 1 second.

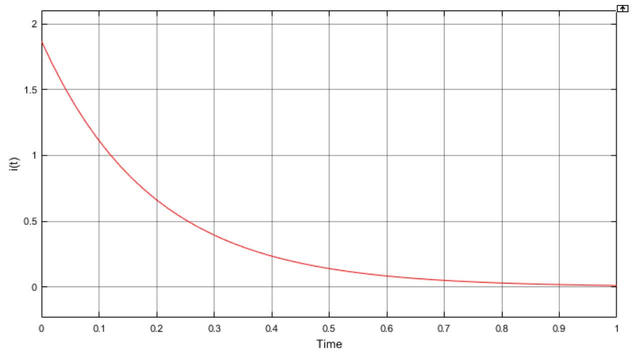

Fig. 4. Dynamic response of the power supply system

B. Simulation of the R-L System (Electromagnetic Pulse)

The R-L system, which consists of the winding that will surround and cover the mechanical element intended to be displaced by the generated electromagnetic energy, exhibits a current response circulating through said winding with the following response dynamics.

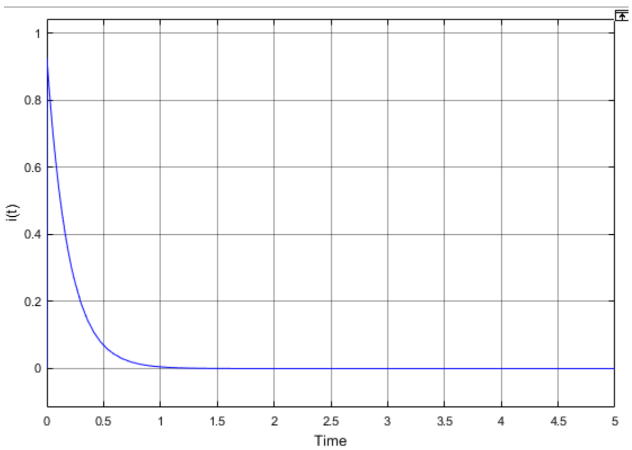

Fig. 5. Dynamic response of the R-L system

It can be observed an initial current of approximately 0.9 Amperes, which decreases rapidly, converging to zero amperes around 1.5 seconds. It can be concluded then that the maximum current flowing through the winding will be very brief since the discharge in the capacitors occurs very rapidly. This means that there is no risk of overheating the winding as the current flow is neither very high nor constant.

C. Simulation of the Mechanical System

The mechanical system consists of the moving mechanical element (Piston) and considers the friction constant between the displacement material and the mass material. The Position, Velocity, and Acceleration curves of the mass (Piston) are presented in the following figures.

The dynamic response of the position establishes, according to the response graph, that the displacement of the mass will be close to 0.76 m, meaning 76 cm of maximum displacement, and this will occur within a time frame between 3 and 4 seconds. This ensures effective displacement within the cylinder.

In figure 7, the dynamics of the velocity response curve are shown, which between 0 and 1 seconds has a maximum velocity of 0.7 m/s, subsequently decreasing until converging to 0 m/s at 4 seconds. This is because the capacitors have been completely discharged, and there is no more current circulation through the winding.

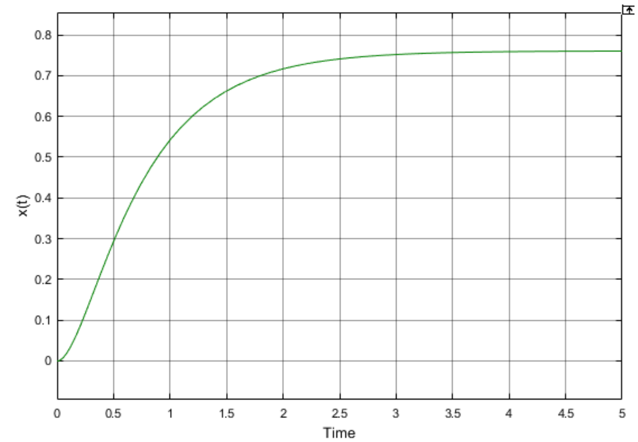

Fig. 6. Dynamic response of the mass position

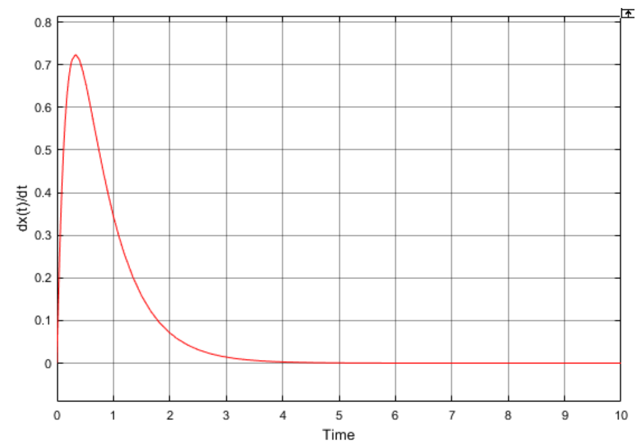

Fig. 7. Dynamic response of the mass velocity

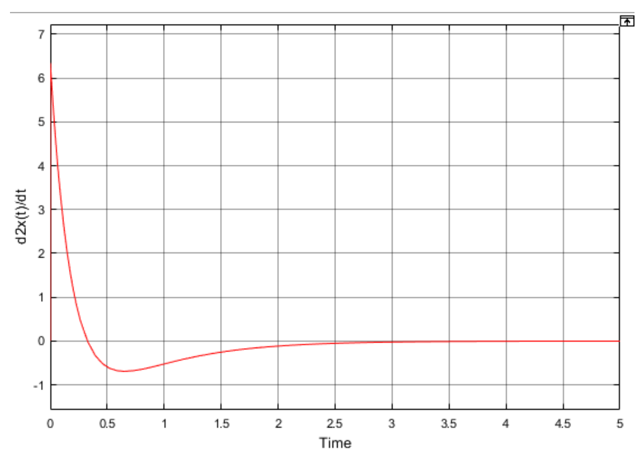

Fig. 8. Dynamic response of the mass acceleration

Next, in figure 8, you can visualize the behavior of the acceleration of the piston within the winding. A very large acceleration impulse is observed at t=0, which does not last long; immediately, it begins to decelerate and converges to zero in less than 0.5 seconds. Therefore, it can be concluded that the system will have large peaks of acceleration and velocity, but they will be of very short duration. These impulses will manage to displace a mass of approximately 150 grams to a maximum of 70 cm within the cylinder.

4. Conclusion

According to the response graphs analyzed using the Simulink tool, it is possible to conclude that the amount of supplied energy and its accumulation for subsequent release play a crucial role in the system. The greater the amount of voltage supplied to the electromagnetic propulsion subsystem, the higher the input current to the R-L circuit. The duration of this energy is very brief, less than 1 second, due to the discharge time of the capacitors, but it is efficient in generating a significant acceleration boost and higher velocity with each excitation volt at the input.

It can also be concluded that the number of capacitors in the electromagnetic propulsion circuit does not influence the amount of energy supplied to the R-L circuit but rather affects the delay of the time constant of the dynamic response curve. In other words, a higher number of capacitors result in a smoother and less violent discharge curve compared to a lower number of capacitors. Therefore, it is generally concluded that there is a direct relationship between electromagnetic impulse, acceleration, velocity, and displacement with the amount of supplied voltage. However, the performance of these parameters can be improved by adding more capacitors in parallel to smooth out the response curve and achieve a longer energy discharge duration in the R-L circuit.

References

[1] W. K. Panofsky, M. Phillips, "Classical electricity and magnetism", 2nd ed., Courier Corporation, North Chelmsford, unites states, (2005), 50-450.

[2] E. M. Purcell, & D. J. Morin, "Electricity and magnetism", 3rd ed., Cambridge, United Kingdom, Cambridge university press, 2013, 80-805.

[3] B. Crowell., "*Electricity and magnetism* (Vol. 4)". ed. 2.1, Fullerton California, United States, Light and Matter, 2000, 20-145.

[4] N. N. Rao, Fundamentals *of electromagnetics for electrical and computer engineering*. 1st ed. New Jersey, Unites States, Prentice Hall, 2009, 30-402.

[5] F. T. Ulaby, Electromagnetics for Engineers. 1st ed., London, United Kingdom, Pearson, 2004, 50-389.

[6] M. A. Jose Prieto, A. M. Pernia, P. J. Villegas Saiz, J. A. Martin Ramos, & F. N. García, "*Iniciacion a proteus 8 paso a paso",* 1st ed., Oviedo, Espana, Servicio de Publicaciones de la Universidad de Oviedo, 2018, 20-88.

[7] C. M. Moler, "Numerical Computing with Matlab", 1st ed., Pennsylvania, United States, Society for Industrial and Applied Mathematics (SIAM), 2004, 30-302.

[8] G. R. Hernandez, Introduction to Control Systems, 1st ed., London, United Kingdom, Pearson Education, 2010, 50-485.