



UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A PULSED LAUNCHER SYSTEM

MOHD REZAL MOHAMED

FK 2007 65



DEVELOPMENT OF A PULSED LAUNCHER SYSTEM

MOHD REZAL MOHAMED

**MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA**

2007



DEVELOPMENT OF A PULSED LAUNCHER SYSTEM

By

MOHD REZAL MOHAMED

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science**

November 2007



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
of the requirement for the degree of Master of Science

DEVELOPMENT OF A PULSED LAUNCHER SYSTEM

By

MOHD REZAL MOHAMED

November 2007

Chairman : Syed Javaid Iqbal, PhD

Faculty : Engineering

Launcher is a device used to launch a projectile. Launcher requires energy to operate and it could be air pressure, compress spring, chemical or electromagnetic energy. Normal launcher applies an explosive to launch a projectile like rocket and bullet. It produces a loud sound, smoke and fire when the explosion occurred. This will shorten the lifetime of barrel and launch pad when the explosion erodes it. Thus to overcome this problem, a launcher is design to launch a projectile without producing a loud sound, explosion and fire. A pulsed launcher system is design using single coil with complete switching circuit, projectile, control circuit, and capacitor bank. The purpose in designing this launcher is to launch a projectile and obtaining the highest projectile speed of designed launcher with correct value of capacitor bank and projectile position. Experiments and simulations are done to identify the relationship between voltage, capacitance, and projectile initial position. Results are obtained by collecting data and tabulated in graphs. Based on the results it found that the coil current increase when the voltage and capacitance of the capacitor bank is increases and vice versa. The projectile speed is decreasing when the projectile initial position is more than half of the coil length. The position of the projectile with a correct value of capacitor bank is obtained for the designed launcher to operate with highest



projectile speed. In this research, a 16 mH coil give a highest projectile speed of 23.07 ms^{-1} (horizontal motion) and 11.62 ms^{-1} (vertical motion) when the coil is supply with 680.2 V, 286 uF capacitor bank at 1 cm projectile initial position inside the coil. The energy conversion from electric energy to kinetic energy is low, 10.05 % for horizontal motion and 2.55 % for vertical motion. The launcher requires more energy to launch the projectile at vertical motion to overcome the gravitational force.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBINAAN SEBUAH SISTEM PELANCAR DENYUT

Oleh

MOHD REZAL MOHAMED

November 2007

Pengerusi : Syed Javaid Iqbal, PhD

Fakulti : Kejuruteraan

Pelancar adalah alat yang digunakan untuk melancarkan peluncur. Pelancar memerlukan tenaga untuk beroperasi dan ia mungkin dari tekanan udara, pegas mampat, tenaga kimia atau elektromagnet. Pelancar biasanya menggunakan bahan letupan untuk melancarkan peluncur seperti roket dan peluru. Ia akan menghasilkan bunyi yang kuat, asap dan api apabila letupan berlaku. Ini akan memendekkan jangka hayat tiub tong dan alas pelancar apabila letupan menghakisnya. Oleh itu untuk mengatasi masalah ini, satu pelancar direka untuk melancarkan peluncur tanpa menghasilkan bunyi yang kuat, letupan dan api. Sistem pelancar denyut dihasilkan menggunakan satu gegelung dilengkapi dengan litar pensuisan, peluncur, litar kawalan, dan bank kapasitor. Tujuan pelancar ini dihasilkan adalah untuk melancarkan peluncur dan mendapatkan kelajuan tertinggi peluncur bagi pelancar yang dihasilkan pada nilai bank kapasitor dan posisi peluncur yang betul. Ujikaji dan simulasi telah dijalankan untuk mengenalpasti hubungkait antara voltan, kapasitan, dan kedudukan permulaan peluncur. Keputusan diperolehi dengan mengumpulkan data dan menjadualkannya didalam graf. Berdasarkan kepada keputusan, didapati arus gegelung akan meningkat apabila voltan dan kapasitan bank kapasitor meningkat dan sebaliknya. Kelajuan peluncur akan berkurangan apabila kedudukan

awal peluncur lebih daripada separuh daripada panjang gegelung. Kedudukan peluncur dengan nilai bank kapasitor yang tepat telah diperolehi supaya pelancar yang dihasilkan beroperasi dengan kelajuan peluncur yang tertinggi. Didalam penyelidikan ini, gegelung 16 mH menghasilkan kelajuan tertinggi peluncur 23.07 ms^{-1} (gerakan mendatar) dan 11.62 ms^{-1} (gerakan menegak) apabila gegelung dibekalkan dengan 680.2 V, 286 μF bank kapasitor pada kedudukan awal peluncur 1 cm didalam gegelung. Perubahan tenaga daripada tenaga elektrik kepada tenaga kinetik adalah rendah, 10.07 % untuk gerakan mendatar dan 2.55 % untuk gerakan menegak. Pelancar memerlukan tenaga yang banyak untuk melancarkan peluncur pada gerakan menegak bagi mengatasi daya tarikan graviti.

ACKNOWLEDGEMENTS

A sincere appreciation is delivered to my project supervisor Dr. Syed Javaid Iqbal and committee group Dr. Norhisam Misron and Mrs. Jasronita Jasni for their invaluable guidance, construction suggestions and encouragement throughout the duration of this project.

Lastly, I would like to express my sincere appreciation to my family for their love, patience and supports which have enable me to complete the project successfully.

I certify that an Examination Committee has met on 2nd November 2007 to conduct the final examination of Mohd Rezal Bin Mohamed on his Master of Science thesis entitled “Development of a Pulsed Launcher System” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the student be awarded the relevant degree. Members of the Examination Committee were as follows:

Sudhanshu Shekhar Jamuar, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Senan Mahmud Abdullah, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Samsul Bahari Mohd. Nor, PhD

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Kaharudin Dimyati, PhD

Associate Professor
Faculty of Engineering
Universiti Malaya
(External Examiner)

HASANAH MOHD GHAZALI, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date : 29 January 2008

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Syed Javaid Iqbal, PhD

Lecturer

Faculty of Engineering

Universiti Putra Malaysia

(Chairman)

Norhisam Misron, PhD

Lecturer

Faculty of Engineering

Universiti Putra Malaysia

(Member)

Jasronita Jasni, MSc

Lecturer

Faculty of Engineering

Universiti Putra Malaysia

(Member)

AINI IDERIS, PhD

Professor and Dean

School of Graduate Studies

Universiti Putra Malaysia

Date : 21 February 2008

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

MOHD REZAL BIN MOHAMED

Date:

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENTS	vi
APPROVAL	vii
DECLARATION	ix
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF ABBREVIATIONS	xviii
CHAPTER	
1 INTRODUCTION	1.1
1.1 Project Overview	1.1
1.2 Problem Statement	1.2
1.3 Objectives	1.3
1.4 Thesis Outline	1.3
2 LITERATURE REVIEW	2.1
2.1 Introduction	2.1
2.2 Preview of Previous Research	2.1
2.3 Launcher	2.3
2.3.1 Electromagnetic Launcher	2.4
2.3.2 Coilgun	2.4
2.3.3 Railgun	2.5
2.4 Pulsed Linear Launcher	2.5
2.5 Pulsed Generator	2.6
2.5.1 Capacitor Bank	2.7
2.5.2 Equivalent Series Resistance, ESR	2.7
2.6 Projectile	2.8
2.6.1 Ferromagnetic Material	2.8
2.6.2 Energy Loss in a Ferromagnetic Core	2.9
2.7 Coil	2.10
2.7.1 Inductance of the Coil	2.10
2.7.2 Axial Field of a Finite Coil	2.11
2.8 Coil Driving Circuit	2.12
2.9 Discussion and Conclusion	2.17
3 METHODOLOGY	3.1
3.1 Development of Pulsed Launcher	3.1
3.2 Design Parameters of Pulsed Launcher	3.2
3.3 Coil Design and Properties	3.2
3.3.1 Magnetic Field Measurement	3.3
3.3.2 Inductance Measurement	3.4
3.3.3 Thrust Measurement	3.4



3.4	Coil Driving Circuit Design	3.6
3.5	Capacitor Bank Design	3.7
	3.5.1 Parallel Charging and Series Discharging	3.7
3.6	Thyristor and Pulse Trigger Circuit Design	3.10
	3.6.1 Determination of Thyristor Rating	3.10
	3.6.2 Thyristor Trigger Circuit	3.10
	3.6.3 Series Thyristor Design	3.12
	3.6.4 Snubber Circuit	3.13
3.7	Charging Circuit Design	3.15
	3.7.1 Charging Control Circuit Design	3.15
	3.7.2 Current Limiting Resistor	3.17
3.8	Discharging	3.17
3.9	Freewheeling Diode	3.18
	3.9.1 Series Diode Design	3.18
3.10	Barrel Type	3.20
3.11	Projectile Type	3.20
	3.11.1 Projectile Design	3.20
3.12	Coil Current Measurement	3.21
3.13	Projectile Speed Data Collection	3.22
3.14	Overall Schematic	3.24
3.15	Discussion	3.26
4	RESULT AND DISCUSSION	4.1
4.1	Introduction	4.1
4.2	Coil	4.3
	4.2.1 Coil and Projectile Specification	4.3
	4.2.2 Coil Magnetic Flux Density	4.5
	4.2.3 Coil Inductance	4.7
	4.2.4 Force Energized by Coil	4.9
4.3	Capacitor Bank	4.11
4.4	Thyristor and Pulse Trigger Circuit	4.13
4.5	Coil Current	4.15
4.6	Speed Detection at Horizontal Motion	4.24
4.7	Speed Detection at Vertical Motion	4.32
4.8	Energy Conversion	4.38
4.9	Discussion	4.42
5	CONCLUSION AND SUGGESTION	5.1
5.1	Conclusion	5.1
5.2	Suggestion for Future Work	5.2

REFERENCES

APPENDICES

BIODATA OF THE AUTHOR

LIST OF PUBLICATIONS



LIST OF TABLES

Table		Page
2.1	Comparison between Each Mode of RLC Circuit	2.16
3.1	Unijunction Transistor 2N2646 Specification	3.11
4.1	Equipment Used to Collect Coil Specification	4.3
4.2	Pulsed Launcher Coil Specification	4.4
4.3	Projectile Specification	4.5
4.4	Total Voltage Applied by Pulsed Launcher	4.11
4.5	Equivalent Series Resistance (ESR) for Capacitor	4.11

LIST OF FIGURES

Figure		Page
2.1	Basic Coilgun System	2.4
2.2	Basic Railgun System	2.5
2.3	Basic Principle of Pulsed Linear Launcher	2.5
2.4	Traveling Wave Pulsed Linear Launcher	2.6
2.5	ESR of Capacitor Bank	2.7
2.6	Ferromagnetic Material	2.8
2.7	An Air Core Coil	2.10
2.8	Cross Section of Multi-Layer Air Core Coil	2.10
2.9	Solenoid in Cross Section View	2.11
2.10	RLC Circuit Driven by the Charge of the Capacitor	2.12
2.11	Over Damped Current Response	2.14
2.12	Under Damped Current Response	2.15
2.13	Critically Damped Current Response	2.15
3.1	Design Outline of Pulsed Launcher System	3.1
3.2	Coil Magnetic Flux Density Measurement	3.3
3.3	Coil Inductance Measurement	3.4
3.4	Equipment Set Up for Thrust Measurement	3.5
3.5	Area Chosen to Simulate using FEMM	3.6
3.6	Discharge Capacitor Bank to Coil using Thyristor	3.6
3.7	Parallel Charging and Series Discharging using Switch	3.7
3.8	Charging Capacitor Bank in Parallel and Discharge in Series	3.8
3.9	Trigger Circuit	3.10
3.10	Two Thyristor Connect in Series	3.12



3.11	Series Connected Thyristor with Parallel Resistor	3.12
3.12	Snubber Circuit	3.14
3.13	Charging Circuit for Capacitor Bank	3.15
3.14	Mono-Stable Timer	3.16
3.15	Relay used to Charge Capacitor Bank	3.16
3.16	Freewheeling Diode	3.18
3.17	Series Connected Power Diode with Parallel Resistor	3.19
3.18	Projectile Configuration	3.21
3.19	Current Sensor Measure Coil Current	3.21
3.20	Horizontal Projectile Speed Measurement Configuration	3.22
3.21	Vertical Projectile Speed Measurement Configuration	3.23
3.22	Flowchart to Obtained Highest Projectile Speed	3.24
3.23	Overall Schematic for Pulsed Launcher System	3.25
4.1	Pulsed Launcher System	4.1
4.2	Front Panel of the Pulsed Launcher System	4.2
4.3	Coil for Pulsed Launcher	4.4
4.4	Projectile	4.4
4.5	Flux Density of Coil	4.5
4.6	Coil Magnetic Flux Density	4.6
4.7	Inductance of Coil	4.7
4.8	Actual and Fitted Inductance of Coil	4.8
4.9	Two-Dimensional Axisymmetric Domain for Coil	4.9
4.10	Coil Thrust Plot for Experiment and FEMM	4.10
4.11	Five Manual DPDT Switches	4.12
4.12	30 Pieces of Electrolyte Capacitor	4.12



4.13	Manual DPDT Switches Set in Series or Parallel	4.13
4.14	Two Thyristor SKT50/12E and Power Diode 70HF120 Connect in Series	4.13
4.15	Hardware of Trigger Circuit for Thyristor SKT50/12E	4.14
4.16	Pulse Gate Signal from Trigger Circuit	4.15
4.17	Coil Current Waveform Obtained Using Current Sensor	4.16
4.18	Sensor Output Voltage Proportional to the Sensing Current	4.16
4.19	Schematic to Measure Coil Current	4.17
4.20	Coil Current obtained from Pspice	4.18
4.21	Coil Peak Current obtained from Experiment	4.18
4.22	Coil Peak Current obtained from Pspice	4.19
4.23	Coil Peak Current obtained from Matlab	4.19
4.24	Coil Peak Time obtained from Experiment	4.20
4.25	Coil Peak Time obtained from Simulation	4.21
4.26	Power Delivered from Source to Load	4.21
4.27	Simulation of Energy Distribution for Pulsed Launcher using Pspice	4.23
Speed Detection at Horizontal Motion		
4.28	Projectile Travel Time for 680.2 V, 286 uF, 1 cm Projectile Initial Position	4.26
4.29	Projectile Speed for C = 286 uF (Matlab)	4.28
4.30	Projectile Speed for C = 565 uF (Matlab)	4.28
4.31	Projectile Speed for C = 853 uF (Matlab)	4.28
4.32	Projectile Speed for C = 1147 uF (Matlab)	4.29
4.33	Projectile Speed for C = 1428 uF (Matlab)	4.29
4.34	Maximum Projectile Speed for Simulation	4.29
4.35	Projectile Speed for C = 286 uF (Experiment)	4.30

4.36	Projectile Speed for $C = 565 \text{ uF}$ (Experiment)	4.30
4.37	Projectile Speed for $C = 853 \text{ uF}$ (Experiment)	4.30
4.38	Projectile Speed for $C = 1147 \text{ uF}$ (Experiment)	4.31
4.39	Projectile Speed for $C = 1428 \text{ uF}$ (Experiment)	4.31
4.40	Maximum Projectile Speed for Experiment	4.31

Speed Detection at Vertical Motion

4.41	Projectile Speed for $C = 286 \text{ uF}$ (Matlab)	4.34
4.42	Projectile Speed for $C = 565 \text{ uF}$ (Matlab)	4.34
4.43	Projectile Speed for $C = 853 \text{ uF}$ (Matlab)	4.34
4.44	Projectile Speed for $C = 1147 \text{ uF}$ (Matlab)	4.35
4.45	Projectile Speed for $C = 1428 \text{ uF}$ (Matlab)	4.35
4.46	Maximum Projectile Speed for Simulation	4.35
4.47	Projectile Speed for $C = 286 \text{ uF}$ (Experiment)	4.36
4.48	Projectile Speed for $C = 565 \text{ uF}$ (Experiment)	4.36
4.49	Projectile Speed for $C = 853 \text{ uF}$ (Experiment)	4.36
4.50	Projectile Speed for $C = 1147 \text{ uF}$ (Experiment)	4.37
4.51	Projectile Speed for $C = 1428 \text{ uF}$ (Experiment)	4.37
4.52	Maximum Projectile Speed for Experiment	4.37

Energy Conversion

4.53	Maximum Capacitor Bank Total Energy, E_c	4.39
4.54	Maximum Energy Transferred to Launch Projectile, W_p at Horizontal Motion (Experiment)	4.39
4.55	Maximum Energy Transferred to Launch Projectile, W_p at Vertical Motion (Experiment)	4.39
4.56	Maximum Energy Transferred to Launch Projectile, W_p at Horizontal Motion (Simulation)	4.40

4.57	Maximum Energy Transferred to Launch Projectile, W_p at Vertical Motion (Simulation)	4.40
4.58	Maximum Energy Conversion, % at Horizontal Motion	4.40
4.59	Maximum Energy Conversion, % at Vertical Motion	4.41



LIST OF ABBREVIATIONS

AC	Alternating Current
AWG	American Wire Gauge
DC	Direct Current
DPDT	Double Pole Double Throw
emf	Electro Magnetic Force
ESR	Equivalent Series Resistance
FEMM	Finite Element Magnetic Method
GI	Galvanized Iron
IC	Integrated Circuit
IGBT	Insulated Gate Bipolar Transistor
IR	Infrared
LED	Light Emitting Diode
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PCB	Printed Circuit Board
RMS	Root Mean Square
SCR	Silicon Controlled Rectifier
SWG	Standard Wire Gauge
TTL	Transistor-Transistor Logic



CHAPTER 1

INTRODUCTION

1.1 Project Overview

Launcher is a device used to launch a projectile. Launcher requires energy to operate and it could be air pressure, compress spring, chemical or electromagnetic energy. The electromagnetic launcher converts energy from electrical to mechanical through the action of magnetic field.

The title of thesis is “Development of a Pulsed Launcher System” requires studying and developing launcher characteristics that enable a projectile to move along the tube. The tube is placed inside the coil that can be energized. The projectile is moved by induced force. There is no electrical contact between the projectile and the coil.

A pulse power supply is needed to energize the coil. A capacitor bank produces the pulse supply for the coil. Parallel and serial combinations of electrolyte capacitors are required for optimizing coil efficiency. Coil energy conversion efficiency is the percentage ratio between energy converted to move the projectile with energy stored in the capacitor bank. A charging control circuit is designed to control the capacitor bank charging time. Discharging the capacitor bank creates a large current through the coil for a short period. This current-pulse energized the coil that acts as an electromagnet to attract the projectile inside the coil for that moment.

An arcing will be produced when an inductive load is connected to the capacitor bank. A solid-state device is used as a switching device to reduce the arcing and power loss. A distance sensor is used to detect the projectile movement and sent the data to the oscilloscope. The oscilloscope will record the travel time when the projectile travel along the sensor. The projectile speed is obtained by dividing the travel length with the travel time of the projectile. This projectile speed data is used to determine the launcher efficiency. A coil current is measured with different value of capacitor bank using current sensor. The coil current data is used to measure the peak time and the peak value for calculating the correct current-pulse timing in the coil. The projectile moves with maximum speed at correct timing.

1.2 Problem Statement

Normal launcher used an explosive to launch the projectile like rocket and bullet. The high energy produces by the chemical reaction in the explosive material able to move the projectile with a high speed. There are disadvantages of using this method and one of the problems is, it produces a loud sound when explosion occurred. A smoke and fire also come out. The lifetime of the barrel and launch pad is short and need to be replaced when the explosion erode it. Thus, a non-explosive launcher is required to overcome this problem. The proposed launcher should be able to move the projectile without producing loud sound, explosion and fire. In this launcher almost no heat is produced.

1.3 Objectives

The objectives of this project are:

1. To design and develop a Pulsed Launcher System.
2. To identify relationship between voltages of capacitor bank, capacitance of capacitor bank and projectile position with a certain fixed coil dimension and parameters.
3. To get an optimized value of voltage and capacitance of capacitor bank and projectile position with a certain fixed coil dimension and parameters.

1.4 Thesis Outline

This thesis is divided into five chapters and each chapter is described separately. The thesis introduction is describes in Chapter 1. The basic content of the thesis is described in this chapter including the thesis objectives. Chapter 2 of the thesis is about the literature review of the previous research and basic knowledge of the components and hardware used in the design. The research methodology is explained in Chapter 3 with overall design method used in this design is also described detail including the control circuit, switching circuit, capacitor bank, and the coil. Experimental results of launcher are discussed in Chapter 4. During the experiment, a lot of data is collected which is plotted and then analyzed. Result of these data and analysis is discussed in Chapter 4 while conclusion and suggestion for future work in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Linear launcher is like a conventional motor in which the projectile moves in the linear direction rather than in the rotation [1-5]. This kind of launcher may have a set of solenoids, which are placed along the moving object. This looks like a tubular launcher, which primarily consists of a simple row of coaxial coils.

2.2 Preview of Previous Research

A physical model for a single stage reluctance accelerator is developed from basic principles and cast in variation (Lagrangian) form [6]. A mathematical model for reluctance launcher is formulated by considering the three armature states inside the coil for single stage reluctance accelerator. Experiments and simulations are done to compare the results and identify the armature speed using different armature materials. A 25 g mild steel armature has a velocity of 18.9 ms^{-1} when the single stage reluctance accelerator is connected to 104 V, 40000 μF capacitor bank using a power transistor switch. The energy conversion from electric energy to kinetic energy is low, approximately 9 %.

The reluctance accelerator [6] is upgraded by modeling it using finite-element solver [7]. In this system equations describe the time domain finite element model of a reluctance accelerator to reduce the computation time and give a result approximate to reality which is better than the model used in previous reluctance



accelerator. The eddy current effect is included in the model whereas the previous research not.

An analysis of five stage pulsed linear induction launcher has been studied. A developed formulation for the electromagnetic analysis of system with conductors in relative motion has been applied to the pulsed linear induction launcher [8]. The skin effect, the thermal and mechanical stresses and the possible rise of transversal motion instabilities have been taken into account. The application of the formulation to the axisymmetric configuration is straightforward and results in an increased computation speed of one order of magnitude. A 68.2 g aluminium armature has a final speed of 226 ms^{-1} when the launcher is supplied with 10, 12, 15, 18, and 20 kV of 125 μF capacitor banks for each stage.

A triggered vacuum switches, TVS is used for designing a three stage reconnection electromagnetic launcher [9]. It has advantages over the spark gaps. It has smaller volume, no need maintenance, no auxiliary gas system, and less electromagnetic interference. The launcher have a 10 % energy conversion when it is supplied with 4500 V, 1.44 mF capacitor bank which give a highest speed of 41 ms^{-1} for 160 g aluminium projectile.

All the previous research used a big capacitor in their design. A solid state device is used as a switching component to connect the capacitor bank with the coil except paper [9] used a vacuum switches. The launcher energy conversion is low, less than 10 % and projectile speed is depend on the value of voltage and capacitance of capacitor bank, material and weight of projectile, and stage, whether single coil or multiple coils. It seems that previous research does not study on the projectile initial position inside the coil. Although they succeed to launch the projectile at desired