PERFORMANCE COMPARISON ON PID AND MIT RULE APPROACH FOR ELECTRO-PNEUMATIC POSITION SYSTEM

NURUL IZZATI BINTI MEDON

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PERFORMANCE COMPARISON ON PID AND MIT RULE APPROACH FOR ELECTRO-PNEUMATIC POSITION SYSTEM

NURUL IZZATI BINTI MEDON

This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Plant & Maintenance)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this project report entitled “Performance comparison of PID and MIT rule approach for electro-pneumatic position system” is the result of my own work except as cited in the references.

Signature	:	……………………………………..
Name	:	……………………………………..
Date	:	……………………………………..

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant & Maintenance).

Signature	:	....
Supervisor's Name	:	....
Date	:	....

DEDICATION

This final year report is dedicated to families and loved ones for they are the ones who inspire me to finish this report. I would like to dedicate this report to my parents, Medon bin Ahmad and Zainab binti Kassim. This final year project would not have been possible without their love and continuous support.

ABSTRACT

Pneumatic system is one of fluid power system that commonly used in industry which generated by electrical source and normally called as electro-pneumatic system. This system convert the electrical energy to the mechanical energy in order to create motion. Normally, this system need a proper control system because of the high sensitivity of the system. There are various controllers that can be used in controlling the electro-pneumatic system and the performance is differ depends on the criteria of the performance required. In this project, the performance needed is to control the position of the electro-pneumatic system. The proper modelling of pneumatic system has been explained using derivation of mathematical modelling. All aspects in modelling the system such as the component of the system, the disturbances and sensitivity of the system as well as the nonlinearity of the system are considered. PID controller and MIT rule are the controllers that have been investigated in this project. The strategy in designing the controller is also has been discussed. PID controller used Ziegler-Nichols method as strategy to control the system while MIT rule used Model Reference Adaptive Control (MRAC) as the control strategy. From both controllers, the performance in position control of the system is analyzed. The performance characteristics used to evaluate the best controllers are the rise time, settling time, percentage overshoot, peak time and steady state based on the system response. The response is obtained from the simulation of the plant system in MATLAB Simulink software. The comparison of both controllers has been analyzed in this project.

ABSTRAK

Sistem pneumatik adalah salah satu sistem kuasa bendalir yang biasa digunakan dalam industri yang dijana oleh sumber elektrik dan biasanya dipanggil sebagai sistem elektro-pneumatik. Sistem ini menukar tenaga elektrik kepada tenaga mekanikal untuk mewujudkan pergerakan. Biasanya, sistem ini memerlukan sistem kawalan yang sewajarnya kerana mempunyai sensitiviti yang tinggi. Terdapat pelbagai pengawal yang boleh digunakan dalam mengawal sistem elektro-pneumatik dan prestasi yang didapati adalah berbeza bergantung kepada kriteria prestasi yang dikehendaki. Dalam projek ini, prestasi yang diperlukan adalah untuk mengawal kedudukan sistem elektro-pneumatik. Pemodelan sistem pneumatik telah dijelaskan dengan menggunakan terbitan pemodelan matematik. Semua aspek dalam pemodelan sistem seperti komponen sistem, gangguan dan sensitiviti sistem serta ketaklelurusan sistem telah dipertimbangkan. Pengawal PID dan peraturan MIT adalah pengawal-pengawal yang telah dikaji dalam projek ini. Strategi dalam merekabentuk pengawal juga telah dibincangkan. Pengawal PID menggunakan kaedah Ziegler-Nichols sebagai strategi untuk mengawal sistem manakala peraturan MIT menggunakan Rujukan Kawalan Penyesuaian Model (MRAC) sebagai strategi kawalan. Dari kedua-dua pengawal, prestasi dalam pengawalan kedudukan sistem dianalisa. Ciri-ciri prestasi yang digunakan untuk menilai pengawal yang terbaik adalah masa naik, masa penetapan, peratusan terlajak, masa puncak dan keadaan mantap berdasarkan tindak balas sistem. Tindak balas yang diperolehi daripada simulasi sistem dalam perisian MATLAB Simulink. Perbandingan kedua-dua pengawal telah dianalisa dalam projek ini.

ACKNOWLEDGEMENT

In the name of Allah, Most Gracious, Most Merciful, thanks to the Almighty for giving me the strength, determination and patience to complete the final year project.

I want to express my gratitude to Mr Zairulazha bin Zainal as my final year project supervisor on tutoring, counseling and assistance provided during the preparation of this project. I am thankful for his patience and advice while leading me in doing this project from starting until completing the project. A big thank you goes to my family who always give words of encouragement and unwavering support for me to continue my studies until the end. Not forgetting, my course mates who always encourage me, provide moral supports and give me memorable moments during my study here.

Finally, I would like to thank Universiti Teknikal Malaysia Melaka for giving me opportunity to complete this project as one of the requirement in obtaining the Degree of Mechanical Engineering specializing in Plant and Maintenance.

CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PMA	Pneumatic Muscle Actuator
LQR	Linear Quadratic Regulator
IPA	Intelligent Pneumatic Actuator
P	Proportional
PI	Proportional Integral
PID	Proportional Integral Derivative
DMRAC	Direct Model Reference Adaptive Controller
MIT	Massachusetts Institute of Technology
IAE	Integral Absolute Error
MRAC	Model Reference Adaptive Control
MATLAB	Mathematical Laboratory
DCV	Directional Control Valve
Z-N	Ziegler-Nichols

LIST OF SYMBOL

m_S	Mass Spool
c_S	Viscous Friction Coefficient
k_S	Spring constant
k_{fc}	Coil Coefficient
x_S	Spool displacement
i_c	Coil Current
C_f	Non-dimensional coefficient
R	Gas Constant
T	Temperature Constant
V_1	Volume At First Chamber
V_2	Volume At Second Chamber
V_{pc}	Total Volume Piston Chamber
P_1	Pressure At First Chamber
P_2	Pressure At Second Chamber
P	Pressure Drop
A_1	Area Piston At First Chamber
A_2	Area Piston At Second Chamber
M_T	Total Mass Piston And Load

N	Newton
A_P	Cross sectional area of piston
$\dot{x}_s$	First derivative of displacement spool
$\ddot{x}_s$	Second derivative of displacement spool
x_P	Piston displacement
$\dot{x}_P$	First derivative of piston displacement
$\ddot{x}_P$	Second derivative of piston displacement
$\dddot{x}_P$	Third derivative of piston displacement
K_P	Proportional Gain
K_i	Integral Gain
K_d	Derivative Gain
K_u	Ultimate Gain
T_u	Ultimate Period
T_r	Rise Time
T_s	Settling Time
T_p	Peak Time
m_p	Peak Amplitude
ω_n	Natural Frequency
ζ	Damping Ratio
y_m	Reference Model Output
y	Actual Plant Output
γ	Adaptation Gain

CHAPTER 1

INTRODUCTION

1.1 Background

From last few decades, a number of applications have been introduced to mankind in order to improve the productivity in industry comprehensively where pneumatic is one of them. Pneumatic system, which generates from the principle of fluid power is a system that uses compressed air in order to contribute work to the power transmission (Gill, Kumar and Kumar, 2015). Pneumatic comes from Greek word “Pneuma” which means “Breath”. This is due to the similar process of breathing and pneumatic wherein breathing, the air entered the body and released back to the surrounding while in pneumatic, the air from atmosphere is compressed in compressor and moves the specific parts or equipment where the equipment is considered as part of the machine and runs the whole system of the machine (Barala, Tiwari and Kumar, 2014). Several applications of the pneumatic system include packaging, open and closing doors, metal forming and clamping (Gill, Kumar and Kumar, 2015).

Electro-pneumatic system, on the other hand, is a system that worked by using air pressure and controlled by an electrical circuit in order to create forces and enhanced the motion of the system. It combines electrical and pneumatic system in one unit. The system varies with the general pneumatic system which the common pneumatic system only consists of a pneumatic system with several units. The early production of electro-pneumatic control systems was widely used in the industry of process control such as packaging, assembly and also in production. Type of components used in electro-pneumatic control system includes a timer, relays, counter and digital logic while pneumatic control system uses logic valve, stepper, sequencer etc. The motion of electro-pneumatic control is faster compared to normal pneumatic control because of the usage of electricity.

Electro-pneumatic controllers have some advantages over pneumatic controller systems which are:

- Fewer costs of electrical equipment than pneumatic equipment
- The system is controlled using electronic programmers and process computers.
- Control signal is reduced to control significant loads
- High reliability (Elsatar, 2010)

There are various applications of the electro-pneumatic system in the industry that can be divided into several types which are temperature control, level gauge, transportation, filling and packaging (Elsatar, 2010). In electro-pneumatic position system, the main focus is to control the movement of the cylinder. In order to control the movement, a controller is needed. PID controllers, defined as the Proportional Integral Derivative controller is used widely in the industry of process to control the desired position in the plant. It is known as the most desired and simple method and more popular rather than other controlling methods (Bansal, Patra and Bhuria, 2012). PID control is often used to build automation systems that are complicated such as energy production, manufacturing, and transportation where it is made from the combination of sequential functions, selectors, logics and simple function blocks (Astrom, 2002).

Meanwhile, MIT rule was started in 1960 by the researchers from Massachusetts Institute of Technology (MIT) where it can be used to design a controller using Model

Reference Adaptive Control (MRAC) from various systems including pneumatic systems. The controller design is sensitive to the changes in amplitude at reference input but it can provide a competent result. The use of MRAC is to design the controller so that the parameter that is being controlled can be adjusted in order to track the reference model from the actual plant that has the same reference input (Jain and Nigam, 2013).

1.2 Problem Statement

The modelling and designing controller plays a very important role in order to improve the dynamic as well as the static behaviour of the pneumatic system. For decades, numerous studies have been carried out regarding modelling and controller design for pneumatic systems. However, fewer studies have been carried out based on PID and MIT rule. This study looks into designing a controller based on PID and MIT rule approach for electro-pneumatic position system. The system, which has difficulties to control and always in inaccurate position is because of its non-linearity behaviour whereas the non-linearity occur due to the high frictions and the compressibility of air. Hence, restricting the use of the system in a high-performance control system (Roslan, 2015)

To design the required plant system with the implementation of the controller, mathematical modelling, control method and a software such as MATLAB is needed to analyse the performance of the system through simulation by considering two major criteria; a system with an application of controller and a system without an application of controller. The modelling, controlling and simulation techniques need to be developed so that the operating cost and energy consumption in a specific system could be reduced. By considering a good design of the controller, the performance of pneumatic system could be increased in terms of the positioning control.

1.3 Objective

The objectives of this project are as follows:

1. To design a control system for electro-pneumatic position system
2. To investigate the performance of the electro-pneumatic plant system without applying controller into the system.
3. To compare the performance of PID controller system against MIT rule approach in Model Reference Adaptive Control (MRAC) system.

1.4 Scope of Project

The scopes of this project are:

1. This project will only focus on the position or the movement of the cylinder in the system
2. The mathematical model of the system will be changed from nonlinear to linear using derivation method.
3. The simulation of PID controller and MIT rule are using MATLAB Simulink Software.
4. MRAC method will be used to distinguish the differences between actual plant and reference plant based on MIT rule approach that used to minimise the error function and tracking the perfect time between reference plant and actual plant output.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The uncertainties of pneumatic systems including their highly nonlinear characteristics make the systems difficult in achieving high performance. The nonlinearity occurs due to the flow of air and the friction force between the piston and the cylinder. Before exploring deeper to the main objectives of the paper, some background studies are presented in order to get a better understanding of the system and also the controllers. The review started with the attributes of the pneumatic system, followed by several applications of the pneumatic system, then focused on how the electro-pneumatic modelling system occur and finally the design of the controller that was implemented in the pneumatic system.

2.2 Attributes of Pneumatic System

There are many attributes of pneumatic actuator rather than hydraulic, that makes pneumatic actuator is attractive to be used in a difficult situation or in a certain environment (Ali, Mohd Noor, Bashi and M H Marhaban, 2009). Instead of using water as a source of energy in the hydraulic system, the source of energy used in the pneumatic actuator is based on air. Since air can be obtained freely, always available and does not require an external source to run the system, this lead pneumatic actuator to the front leaving the hydraulic actuator behind with conventional actuator that uses magnet, water and require external source in order to run the whole system (M.F. Rahmat *et al.*, 2011).

Electro-pneumatic systems are often chosen in automation industry due to various advantages which are low cost and clean operation as well as easy to handle based on electrical control and power translation in the system (Shih and Tseng, 1995). Pneumatic systems can be used in many applications since the system could provide a high dynamic response in order to position load and to extend the force needed for moving the load (Ali, Mohd Noor, Bashi and M H Marhaban, 2009) where the systems are also good in performance. The higher power-to-weight ratio by pneumatic actuator makes the air density is lesser than water density, thus, the weight-to-power ratio is also decreasing and the effectiveness of the system can be increased.

However, most of the pneumatic systems are in nonlinear form which most probably because of the compressibility of air inside the system, the characteristics of valve fluid flow itself and the Coulomb friction that higher than normal that makes the position control of pneumatic actuators are hard to accurate (M F Rahmat *et al.*, 2011).

2.3 Application of Pneumatic System

There are many applications of pneumatic system in the industry. Several researchers have proposed various applications regarding the pneumatic system due to its' availability in the market and the system does not require a high cost.

(Brubaker, 2015) presented a modern pneumatic braking control that combines the pneumatic valves and electronics valves in a single system. The system which consists of electronic valves improved the current pneumatic braking system with providing a better stability of the system and decreased the stopping distance and wheel slip when accelerating. The modern system was considered because of the existing models that did not explain clearly on how the effect of the dynamic response of the device related to the internal components. The modern system of foot brake valve was designed by considering several aspects, such as the difference in operating conditions and how the nominal systems react with nominal units.

A highly nonlinear Pneumatic Muscle Actuator (PMA) was proposed by (Zhao, Zhong and Fan, 2015) for position control by developing a phenomenological model to understand the physical behaviour of PMA based on Duhem Model. Duhem Model provides an analytical description of a smooth hysteresis behaviour where it describes two major components inside PMA which are a linear component and hysteresis component force. PMA experienced difficulty in controlling position because it consists of several physical properties that made the system become nonlinear such as force, pressure and displacement.

2.4 Electro-Pneumatic Modelling System

In designing an electro-pneumatic system for position control, modelling is the most important parts that need to be considered. Since most of pneumatic systems are in nonlinear form, the result obtained are sometimes unnatural and hard to achieve accuracy and produced an error. Hence, linearization is needed to be done in order to get the most accurate position control without error. Based on the previous studies made by researchers, there are several methods used in modelling which is system identification and derivation. System identification was used when such parameter could not be measured or identified and needed to estimated experimentally while derivation is from proposed equation that needs to analyse in order to get transfer function of the whole system.

(Richer and Hurmuzulu, 2001) developed a high-performance pneumatic force actuator system that consists of dual acting pneumatic actuators and four-way proportional spool valves to control the actuator. The aim was to gain an accurate model of the pneumatic system using proportional spool valve while considering several nonlinear