اونيۏرسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

POSITION TRACKING CONTROL OF SLIDER CRANK MECHANISM USING FUZZY PID CONTROLLER

Sharil Izwan Bin Haris

Master of Mechanical Engineering (Automotive)

2016

POSITION TRACKING CONTROL OF SLIDER CRANK MECHANISM USING FUZZY PID CONTROLLER

SHARIL IZWAN BIN HARIS

A report submitted
in fulfillment of the requirements for the degree of
Master of Mechanical Engineering (Automotive)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

APPROVAL

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

Signature	: ....
Supervisor Name	: PROFESOR DR. GHAZALI BIN OMAR
Date	: June 2016

DECLARATION

I declare that this report entitled "Position Tracking Control of Slider Crank Mechanism Using Fuzzy PID Controller" is the result of my own research except as cited in the references. This report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

Name : SHARIL IZWAN BIN HARIS

Date : June 2016

DEDICATION

To my beloved mother, father, wife and children.

ABSTRACT

Slider crank mechanism (SCM) is an arrangement of mechanical parts which are consist of the slider, connecting rod and crank. It is designed to convert straight-line motion to rotary motion or vice versa and is widely used in engineering fields such as the combustion engine, water pump, compressor and robotics. This research focused on the kinematic analysis of SCM that studying the tracking position control. Both simulation and experimental method have been done to achieve the research target. In the simulation, the proportional-integral-derivative (PID) controller is presented with the enhancement by fuzzy logic control, in order to make the controller strategy more adaptive. The experiment was carried out with hardware in the loop simulation (HILS) to examine the controller performance. The simulation results show that the performance of PID with fuzzy logic control is more robust than the PID controller in variable parameters. Experimental results have proven the effectiveness of proposed controller. In general, it can be concluded that the Fuzzy PID controller has superior tracking performance in position control of SCM. With the intention of enhancing the controller performance, some recommendations have been highlighted.

ABSTRAK

Mekanisme engkol gelincir (SCM) adalah susun atur bahagian-bahagian mekanikal yang terdiri daripada papan gelongsor, rod penghubung dan engkol. Ia direka untuk menukar gerakan garis lurus kepada gerakan putaran atau sebaliknya dan digunakan secara meluas didalam bidang kejuruteraan seperti enjin pembakaran, pam air, pemampat dan robotik. Penyelidikan ini adalah menjurus kepada analisis kinematik pada SCM yang mengkaji mengenai kawalan pengesanan kedudukan. Pelaksanaannya yang melalui kaedah simulasi dan ujikaji telah dilakukan untuk mencapai matlamat penyelidikan. Didalam simulasi, pengawal proportional-integral-derivative (PID) telah diterbitkan dan dipertingkatkan dengan kawalan logik Fuzzy bagi menghasilkan strategi kawalan yang lebih adaptif. Eksperimen dijalankan dengan kaedah perkakasan dalam simulasi gelung (HILS) bagi tujuan meneliti prestasi pengawal. Keputusan simulasi menunjukkan prestasi PID dengan kawalan logik Fuzzy adalah lebih kukuh berbanding dengan pengawal PID khususnya dalam parameter yang pelbagai. Keputusan daripada eksperimen telah membuktikan keberkesanan pengawal yang dihasilkan. Secara umumnya, dapatlah disimpulkan bahawa, pengawal Fuzzy PID mempunyai prestasi yang terbaik didalam kawalan pengesanan kedudukan pada SCM. Bagi tujuan meningkatkan prestasi kawalan, beberapa cadangan telah diketengahkan.

ACKNOWLEDGEMENTS

I would like to express my sincerest gratitude to my supervisor, Professor Dr. Ghazali Bin Omar from the Faculty of Mechanical Engineering, UTeM for his guidance, support, and constant encouragement during my research. I would also like to thank to Mr. Fauzi Ahmad the lecturer from Faculty of Mechanical Engineering, UTeM for providing invaluable input on many aspects of my research and contributing his knowledge, time and effort throughout this research.

My appreciations are also addressed to Majlis Amanah Rakyat (MARA) for give the opportunity for me to further study and sponsor the scholarship. Special thanks go to the Faculty of Mechanical Engineering, UTeM especially Makmal Kawalan dan Sistem Elektronik Kenderaan for providing the equipment's and work station.

I also thank to my colleagues at the Kolej Kemahiran Tinggi MARA, Masjid Tanah, Azhar Ibrahim and Mohd Rasyidi for being a very good sharing partner during my research. Thanks also to my employer, Kolej Kemahiran Tinggi MARA, Masjid Tanah for giving me the permission in doing this research.

Finally, my deepest grateful and thanks go to my dear parents, Haris Osman and Noorlia Omar, my family, Wan Aminah, Adam Syami, Auni Sofiya and Afif Syamil. Their long sacrifice, patience, encouragement and prays have contributed to my success.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

θ	-	Crank angle
θ	-	Representation of fuzzy parameters (center and spread)
φ	-	Connecting rod angle
$\dot{\theta}$	-	angular rate of rotor
σ_j^i	-	Spread (deviation) of the membership function
b_i	-	Output membership function for *i*-th rule
b_m	-	Viscous damping, friction coefficient
B	-	Damper constant
c_j^i	-	Center (mean) of the membership function
de	-	derivation of error
e	-	errors
l	-	Delay time
E	-	Electromotive force (EMF)
I	-	Current flow
J	-	Armature moment of inertia
J_m	-	Motor armature moment of inertia
K	-	torque constant
L	-	Connecting rod length
L	-	Inductance
L_a	-	Armature inductance

k_b - Motor back-electromotive force constant,

k_t - Motor torque constant

K_b - EMF constant

K_d - Derivative gain

K_i - Integral gain

K_p - Proportional gain

R - Crank radius

R - Resistor

R_a - Armature resistance

T - Time constant

T_1 - Reaction torque

T_e - Motor torque

T_l - Torque of the mechanical load

V_{in} - Motor terminal voltage

V_{in} - Voltage in

X - Piston displacement

X_a - Piston actual displacement

X_d - Piston desired displacement

x_j^i - input of fuzzy

RMS - Root Mean Square

SCM - Slider Crank Mechanism

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1. Overview

Slider crank mechanism (SCM) is a mechanical arrangement which is consist of a crank, connecting rod and slider. A crank is an arm operates in reciprocating motion and attached to the rotating shaft. The other end of the crank which is attached by a pivot is the connecting rod and the slider is located at the end of the rod. Connecting rod works by two motions which are the part attached to the crank is moving in a circular motion, while the other end is usually constrained to move in a linear sliding motion. According to Farzadfour et al. (2013) the SCM is designed to convert the motion of rotation to translation motion or vice versa. The mechanism is used widely in engineering fields such as diesel and gasoline engine, water pump and compressor (Komaita et al., 2008) and robotic (Chang et al., 2013).

In the present, the researchers which are implemented in SCM mostly concentrated on kinematic and dynamic analysis (Farzadfour et al., 2013). In kinematic analysis, the research is executed with studying the displacement, velocity and acceleration, while the dynamics analysis the force and torque have to take into account. Liu et al. (2010) identified that the response parameters in SCM analysis depend on length, mass, damping frequency and external piston force. These responses can be represented by a mathematical model which is acquired according to derivation equation from Hamilton and Lagrange principle (Tanik, 2011, Huang et al., 2010, Lin et al., 2001, 1998). The mathematical model, then been converted into a MATLAB SIMULINK model in order to simulate the response of the system.

1.2. Motivation of Study

In order to satisfy certain requirements for motion response of SCM, the mechanism needs to be supervised by a control system (Li et al., 2012). Two common conditions, always in the concentration of SCM control motion are Slider Motion Control (SMC) and Crank Motion Control (CMC) (Farzadfour et al., 2013). In SMC the approaches adopt by researchers are optimal control (Varedi et al., 2015), sliding mode control (Fung et al., 2009), Proportional-Integrated-Derivative (PID) control (Ahmad et al., 2011), adaptive control (Lin et al., 1997), tracking control (Fung et al., 2002), inverse control (computed torque control) (Faraji et al.,2013) and observer based control (Chou et al., 1998), while for CMC the approaches are going through of computed torque control (El-Badawy, 2011), variance control (Saitoh et al., 2007), energy control (Komaita et al., 2008) and genetic-fuzzy inverse control (Farzadfour et al., 2013).

Besides that, some researchers have adopted the approach of fuzzy logic control such as fuzzy and sliding mode (Fung et al., 1999), analytical study of fuzzy control (Beale et al., 1998), control chaotic response by fuzzy logic controller (Sood, 2005) and fuzzy neural network (Lin et al., 2001). From that, the results showed the fuzzy controller can give a better response for SCM.

From the above discussion, even though extensive researches on the SCM have been made, it is obvious to say that further study with different methods could be carried out in order to make the SCM motion control more effectiveness. According to it, this research is concentrated on tracking position control of slider crank mechanism which is controlled by fuzzy logic control combined with PID controller. The selection is made based on simplicity in the design and implementation of PID controller compared to the previous controller, but some enhancement should be proposed because the conventional PID controller is lacking in robustness with external disturbance and varying parameter (Lee et al., 2004). At the same time, the controller also cannot achieve the desired result in the nonlinear system. For that reason, the fuzzy logic control is added to make the PID controller more adaptive in order to overcome the weakness. Besides that, in developing the SCM system, the source of motion should be included. Previous researchers have combined the slider crank model with the permanent magnet (PM) synchronous servo motor (Lin et al., 2001, 1998) and stepper motor (Ahmad et al.,2011). For this research the combination with direct current (DC) motor is applied and from that, it is expected the proposed controller method has better tracking capability and effectiveness in SCM motion.

1.3. Objective

The objectives of this research are:

a) To derive and model the slider crank mechanism in MATLAB SIMULINK Software.

b) To develop a control strategy for position tracking of slider crank mechanism.

1.4. Scope of the Research

The scopes of this research are:

a) The Modelling of the slider crank mechanism as well as the control strategy development is simulated through MATLAB/SIMULINK software.

b) The parameters for the slider crank mechanism were selected based on the slider crank mechanism that has been used by Ahmad et al. (2012). The maximum amplitude can be reached by the system is 10 cm.

c) The basic control for the position tracking of slider crank mechanism is developed based on the conventional PID controller with the enhancement using fuzzy logic control.

d) The experimental study of the performance of the proposed control strategy to the slider crank is limited to the hardware in the loop simulation only.

e) The assessment of the proposed control strategy to the system is only observed through the capability of the system in producing the same input function such step, saw tooth and sine function.

1.5. Structure and Layout of Thesis

This thesis is organised into five chapters. The thesis contains an introductory chapter which gives a brief introduction on slider crank mechanism and its usage in the mechanical system. This chapter presents about previous research findings leading to the objectives of this study. Each chapter in this thesis ends with a brief summary outlining the achievements and findings that were established in the chapter. The remainder of this thesis is organised as follows:

Chapter 2: This chapter presents the literature reviews on related subjects concerning this thesis. It includes the basic design of the slider crank, the actuator that has been used and the method for evaluating the slider crank mechanism control. Review on recently published articles related to slider crank control is also presented. Finally, the potential of using intelligent control for position tracking of slider crank is discussed.

Chapter 3: The methodology used in this research is described in this chapter. The issue regarding the mathematical modelling of the slider crank, the DC motor and the simulation in MATLAB SIMULINK will be extensively reviewed. Furthermore, the control strategy development, such as PID and Fuzzy PID is also presented. The questions on how and why to the Fuzzy controller is used will also be described in detail. Finally, the experimental setup for HILS will be described in the last section.

Chapter 4: This chapter presents the results and a discussion of the study. It consists of performance evaluation of position tracking slider crank using PID, Fuzzy PID controller and validation of the proposed controller using HILS. The potential benefit of the proposed controller structure will then have been discussed and finally presented.

Chapter 5: This chapter summarises the works done in this entire study, infers conclusions that can be drawn, highlights of the study contribution and concludes with recommendations for future research work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will explain some resources which are related to this research for provides to the reader, the platform of research background. The chapter begins with the literature of slider crank mechanism (SCM) which is focused on function, parts and operation of SCM. The control strategy has also been stressed in this chapter. The previous controller in SCM and proposed controller scheme are fully described. This chapter also presents the mechanism used to operate the SCM and experimental analysis. It includes the types of electric motor used and method of experimental approach. As a summary, the suitable control strategy is proposed at the end of the chapter.

2.2 Slider Crank Mechanism (SCM)

SCM is a mechanical mechanism which is widely used in the mechanical field such as pumps, compressors, steam engines, feeders, crushers, punches and injectors (Anis, 2012). According to the Ranjbarkohan *et al.*, (2011), SCM is the base of dynamic mechanism in internal combustion engine. The mechanism linkage consists of the crank shaft, slider block and connecting rod as shown in Figure 2.1.

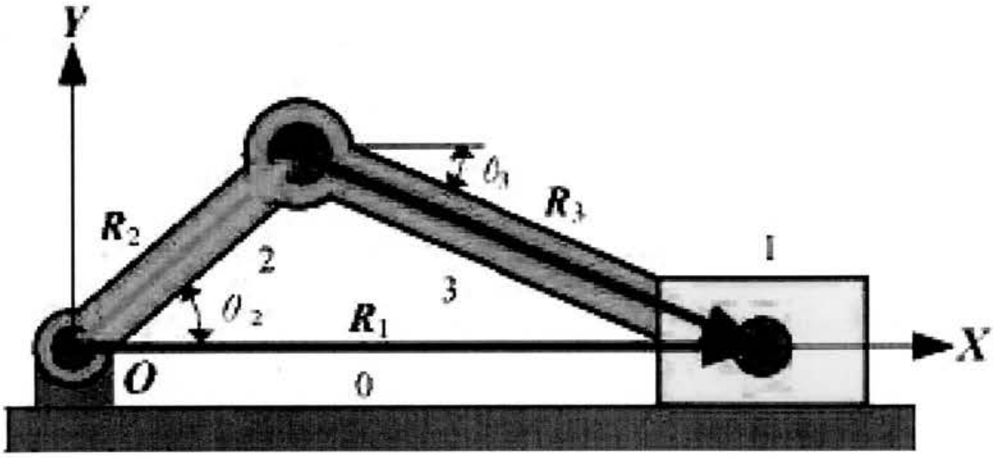

Figure 2.1: SCM (Qian *et al.*, 2011)

The principle operation of the mechanism is according to the motion converting from rotational to translational (Farzadfour *et al.*, 2013). The analysis of motion in SCM has been studying in many years. Liu *et al.*, (2010) have studied the kinematics and dynamics analysis of slider crank through simulation. Ranjbarkohan *et al.*, (2011) have studied the kinematics and dynamics analysis of slider crank in the combustion engine and Erkaya *et al.*, (2010) have studied the kinematics and dynamics analysis through experiment. According to Qian *et al.*, (2011) the kinematics analysis include the study of the displacement, velocity and acceleration of the SCM. This research concentrates on displacement analysis.

2.3 Previous Study of SCM

According to Farzadpour *et al.*, 2013 the research study of SCM especially in position control can be divided into two types such as slider motion control (SMC) and crank motion control (CMC). In SMC the approach of optimal control, sliding mode control, proportional integrated derivative (PID) control, adaptive control, tracking control, inverse control and observer based control have been implementing. While in CMC the approach has been done are computed torque control, variance control and energy control.

2.3.1 SMC Control

2.3.1.1 Optimal Control

Chou *et al.*, (2003) proposed the on-line optimal control algorithm in a SCM system. The target is to estimate the system parameters without any numerical pre-processing and without repeatedly computing the matrix inversion in order to reduce the computer memory and computing time.

2.3.1.2 Sliding Mode Control

Fung *et al.*, (2009) focus on trajectory tracking of SCM, toggle mechanism and quick return mechanism by using sliding mode control algorithm. The target in this paper is the system can archive the trajectory tracking with desired input torques on the constrained surfaces with specific constraint forces.

2.3.1.3 Proportional-Integral-Derivative (PID) Control

Ahmad *et al.*, (2011), Kao *et al.*, (2006) and Chuang *et al.*, (2006) focused the research in position tracking of SCM by using PID controller. They used differences methods of tuning PID controller. Ahmad *et al.*, (2011) used Ziegler Nichol's Method while Kao *et al.*, (2006) and Chuang *et al.*, (2006) used the self-tuning method. Kao *et al.*, (2006) developed their controller by using the particle swarm optimisation (PSO) algorithm approach and Chuang *et al.*, (2006) apply the self-experience approach. Both researchers implemented the control strategy based on PC tuning in controlling the position of the coupling system for the motor mechanism.