POSITION TRACKING OF SLIDER CRANK MECHANISM BY USING PID CONTROLLER.

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SUPERVISOR DECLARATION

"I hereby that I have read this thesis and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)"

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This report prepared to fulfill the requirement of graduation in Bachelor in Mechanical (Automotive)

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledge."

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Special for my beloved parents

Mr. Sariman B. Aris and Mrs. Kamisah Bt. Basiron

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ABSTRACT

The control design using simulation is one of the techniques to control and analyze the performance and the effectiveness of the controllers. The simulation run and built in MATLAB/SIMULINK software based on the mathematical equation. The SIMULINK software capable to model the mathematical equation informs of block diagram which is the block diagram contain the operation and codes represented. This research presents a study on the position tracking response of a Proportional-Integral-Derivative (PID) controlled the slider crank mechanism which is driven by a two phase stepper motor. In this study, the Newton Second Law of motion has been applied to formulate the mathematical equation of motion where the connecting rod and the crank are assumed to be rigid. The proposed control system is using PID controller to obtain the desired result according the input function. There are several input function that has been used to monitor the performance which are sine wave, saw tooth, square and step function. The result shows that, the position tracking control structure model is able to give a good response. Then, the slider crank mechanism developed to study experimentally as well as to validate the result from the simulation. The results show that, the slider crank mechanism is able to track the desired displacement.

ABSTRAK

Reka bentuk kawalan menggunakan simulasi adalah salah satu daripada teknik-teknik untuk mengawal dan menganalisis prestasi dan keberkesanan pengawal. Struktur model telah dibina dan di simulasikan dalam perisian MATLAB / SIMULINK berdasarkan persamaan matematik. Perisian SIMULINK mampu untuk memodelkan persamaan matematik dalam bentuk gambarajah blok yang mengandungi operasi dan kod. Kajian ini membentangkan kajian mengenai pengesan kedudukan yang dikawal oleh kawalan "Proportional-Integral-Derivative" (PID) pada mekanisme engkol gelincirr yang didorong oleh satu dua.-fasa motor. Dalam kajian ini, hukum kedua Newton gerakan telah digunakan untuk merumuskan persamaan matematik gerakan di mana batang penyambung dan engkol adalah dianggap tegar. Sistem kawalan yang dicadangkan menggunakan kawalan PID untuk mendapatkan hasil yang diingini mengikut kemasukan fungsi. Terdapat beberapa kemasukan fungsi yang telah digunakan untuk memantau prestasi iaitu "sine wave", "saw tooth", "square" dan "step function". Hasil menunjukkan bahawa, kawalan pengesanan kedudukan model struktur dapat memberi sambutan yang baik. Seterusnya, mekanisme engkol gelincir dibangunkan untuk mengkaji eksperimen serta untuk mengesahkan keputusan daripada simulasi. Keputusan menunjukkan bahawa, mekanisme engkol gelincir dapat mengesan anjakan yang dikehendaki.

TABLE OF CONTENT

LIST OF FIGURE

NO.	TITLE	PAGE

LIST OF TABLES

LIST OF SYMBOL

L	=	Length of connecting rod
R	=	Length of Crank shaft
φ	=	Angle Of Crank
θ	=	Angle of Crank
x	=	Displacement of piston from top dead center
N	=	Ratio between L and R.
S	=	Steps per revolution
n	=	No. of pole pairs
m	=	No. of stator phases.
$\Delta\phi$	=	Stepping angle
K_m	=	The motor constant, depending on the design of the motor.
$\emptyset(t)$	=	The actual rotor position.
$\emptyset_{oj}$	=	The location of the coil j in the stator.
$I_j(t)$	=	The current in the coil as function of time.
V_{emf_j}	=	The electromotive force induced in the phase j.
ω	=	The rotational velocity of the rotor.
V_u	=	Operating value (voltage).
R	=	The resistance of the coils.
L	=	The inductance of the coils.
E	=	Electric time constant.
T_m	=	Total torque.
K_p	=	The proportional gain
PB	=	The range of error
K_t	=	The integral gain.
K_d	=	The derivative gain

LIST OF ABBREVIATION

PM	=	Permanent Magnet
PID	=	Proportional Integral Derivative
PLCs	=	Programmable Logic Controllers
DCSs	=	Distributed Control Systems
HILS	=	Hardware In The Loop Simulation
NI	=	National Instrument

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The slider crank mechanism is a basic structure in mechanical application. It used to convert the rotational motion into translational motion. The example of its application see as important part in compression ignition engine (diesel engine) and spark ignition engine (gasoline or petrol engine). The response of the slider crank is depend on mass, length, damping, external piston force and frequency. The slider cranks mechanism driven by stepper motor to transfer the rotational motion into translational motion.

Nowadays, advancements in magnetic materials, semiconductor power devices, and control theory have made the Stepper Motor drive plays important role in motion-control application in the low-to –medium power range. The desirable features of the PM synchronous servo motor are its compact structure, high air gap flux density, high power density, high torque-to-inertia ratio, and high torque capability. Moreover, compared with an induction servo motor , a PM synchronous servo motor has such advantages as higher efficiency, due to the absence of rotor losses and no-load current below the rated speed, and it is decoupling control performance is much less sensitive to the parametric variation of the motor.

However the control performance of the PM synchronous servo motor drive is still influenced by the uncertainties of the controlled plant, which usually comprise unpredicted TABLE plant parametric variation, external load disturbances, unmodelled and non linear dynamics. One of the controllers named Proportional Integral Derivative (PID) controller, which has been widely used in the industry because of its simple structure and robust performance within a wide range of operating condition. However, the real time condition is cannot be predicted as same as controlled in software such as PID controller. Therefore, the real time experimental results will be compared to the simulation result to study the similarities between both in position tracking of slider crank mechanism.

In this paper, the formulation and dynamic behavior of PM synchronous motor coupled with a complexity mechanical system is introduced where a slider crank mechanism system is actuated by a PM synchronous servo motor is investigated.

1.2 PROBLEM STATEMENT

The problem of this research is ignited from the similarities between MATLAB/SIMULINK model and real time Position tracking model. Therefore, to solve the problem by showing the comparison between MATLAB/SIMULINK result and experiment result.

1.3 OBJECTIVE

The objective of this research is to study the effectiveness of Proportional Integral Derivative (PID) Controller in position tracking of slider crank mechanism in Simulink Matlab software and experimental assessment.

1.4 SCOPE OF STUDY

1. Modeling and stimulate of slider crank mechanism powered by the stepper motor in MATLAB/SIMULINK software.
2. Control design by simulation of slider crank mechanism.
3. Position tracking Control of slider crank mechanism experimentally.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In many control systems, the aims are to design a control such that output can be controlled by giving the desired signals at the input. For example the vital of need a controller is to alignment of the front wheel of a vehicle follows that the input give by driver, the temperature of furnace follows a given set point and many others application. There are some factors that should always consider that affecting control system, they are choices of the controllers (Algorithms), tuning of controllers, selection of control variable, selection of performance index, the types of sensor used to measure error , actuators involve, the disturbance and environment, control configuration, design technique and the nonlinearity of the controller. There are a lot of controllers used nowdays such as conventional controllers, predictive controllers, adaptive controllers and intelligent controllers. Example of conventional controllers is PID controller, the example of predictive controllers is smith predictor, example of adaptive controllers is self tuning PID controller and the example of intelligent controllers is fuzzy logic controller. These controllers can be simulates in MATLAB/SIMULINK model as they develop from the mathematical equation.

2.2 SLIDER CRANK MECHANISM

The slider crank mechanism is a basic structure in mechanical application. It is also widely used in practical application (Nagchaudhuri, 2002; Fung *et al.,* 1999; Ranjbarkohan *et al.,* 2011). For examples, are the typical applications of velocity control. Hence, the slider crank mechanism considered in this study is based on the basic operation of engine which consists of a crankshaft, *R*, connecting rod, *L*, and piston. The purpose of the slider-crank mechanism is to convert rotational motion of the crankshaft to the linear motion of the piston. Like shown in figure 2.1, the kinematic of slider crank mechanism can be described in equation (2-1) to (2-6) according to Ahmad Fauzi (2011)

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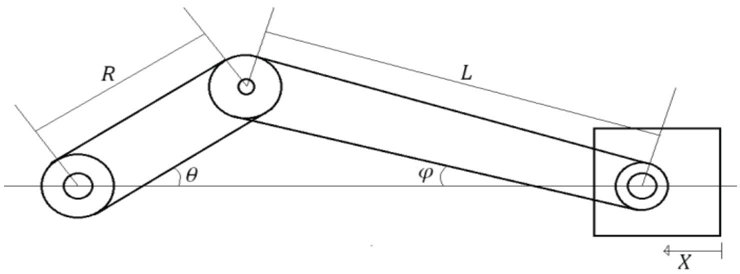

Figure 2.2: Slider Crank Mechanism

(source from : Ahmad Fauzi (2011)

The piston displacement from top dead centre, *x*, can be determined from the geometry of the mechanism, in terms of the lengths of the connection rod, *L*, and crank, *R*, and the crank angle, . From the geometry and noting that θ = φ= 0 when *x* = 0, *x* can be expressed as:

$$X = R - R\cos\theta + L - L\cos\varphi \qquad (2\text{-}1)$$

Also from the geometry, it can be expressed that

$$L\sin\varphi = R\sin\theta \qquad (2\text{-}2)$$

and,

$$[L\cos\varphi]^2 = L^2 - [L\sin\varphi]^2 \qquad (2\text{-}3)$$

Substituting for L sin φ from Equation (2-2) into Equation (2-3) and let θ as the only variable on the right hand side of the expression,

$$[L\cos\varphi]^2 = L^2 - [R\sin\theta]^2 \tag{2-4}$$

Equation (2-4) can be substituted into Equation (2-1) to obtain the kinematic equation for the slider crank mechanism as shown in equation (2-5)

$$X = R - R\cos\theta + L - \sqrt{L^2 - [R\sin\theta]^2} \tag{2-5}$$

Equation (2-5) rearrange by denoting parameter n. where n is the ratio between length of connecting rod (L), to the radius of crankshaft (R).

Where, $N = \frac{L}{R}$

$$X = R \left\{1 - \cos\theta + n\left[1 - \sqrt{1 - \left(\frac{\sin\theta}{n}\right)^2}\right]\right\} \tag{2-6}$$

2.3 TWO PHASE STEPPER MOTOR

According to Alexandru Morar (2003), stepper motors are simple, robust and reliable and are well suited for open or close loop controlled actuator. Stepper can be found in machine tools, typewriters, printers, watches and many others. In space applications stepper motor are mainly used as actuators of pointing mechanisms for antennas, mirrors, telescope or complete payloads. In order to investigate the dynamics of mechanism driven by stepper motor a model had to be created. The electromechanical behavior of a stepper motor was described by control loops. This software calculates the dynamics of rigid and flexible bodies including the control loop dynamics. It generates the equation of motion and the transfer function numerically. Stepper motor is usually used in connection with gear, hence a gear model as well as electrical and mechanical stiffness, friction and resistances are considered.

The principle of a 2-phase stepper motor is given in the figure 2. The rotor is a permanent magnet consisting of 1 pole pair. When the windings of one phase are energized, a magnetic dipole is generated on a stator side. For an example, if phase 2 is active (phase 1 is switched off), winding 3 procedures an electrical south pole and winding 4 an electrical north pole. Figure 2.3 from Alexandru Morar (2003), shows the rotor is in stable position with phase 2 only powered

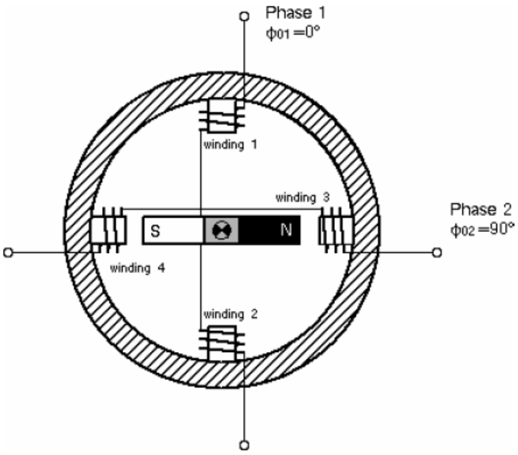

Figure 2.3: Principle of 2 phase stepper motor

According to Alexandru morar (2003), the number of steps per revolution of the rotor is calculated as:

$$S = 2.n.m \qquad (2\text{-}7)$$

Where, n is the number of rotor pole pairs and m is the number of stator phases. For the hybrid stepper motor, n is half the number of rotor teeth.
The stepping angle is:

$$\Delta\emptyset = \frac{360}{S} \qquad (2\text{-}8)$$

For the example of we have n=1 and m=2. So that we have 4 steps per revolution and a stepping angle of 90 degrees. If a sinusoidal characteristic of the magnetic field in the air gap is assumed, the contribution of each phase I on the motor torque T_{mj} can be written as:

$$T_{Mj} = K_m.sin\left[n\emptyset(t) + \emptyset_{oj}\right].I_j(t) \qquad (2\text{-}9)$$

Where:

K_m is the motor constant, depending on the design of the motor.

$\emptyset(t)$ is the actual rotor position

$\emptyset_{oj}$ is the location of the coil j in the stator

$I_j(t)$ is the current in the coil as function of time.

The current $I_j(t)$ in the coil is function of the supplied voltage U_j and the coil properties. A general equation between U_j and $I_j(t)$ is given by:

$$V_{uj} = V_{emf_j} + R.I(t) + L\frac{dI(t)}{dt} \qquad (2\text{-}9)$$

Where:

$V_{emf_{j_j}}$ the electromotive force induced in the phase j.

R is the resistance of the coils

L is the inductance of the coils.

The emf in each coil can be expressed as:

$$V_{emf_j} = k_m.\sin\left[n\emptyset(t) + \emptyset_{oj}\right].\omega \qquad (2\text{-}10)$$

Where ω is the rotational velocity of the rotor.

Resistances and inductances of all coils in the motor are the same so that no indices are required. The differential equation can be expressed in the LAPLACE domain as shown in the equation below:

$$I = \frac{U}{L_s + R} \qquad (2\text{-}11)$$

The total torque produced by the stepper is:

$$T_m = \sum_{j=1}^{m} T_{Mj} \qquad (2\text{-}12)$$

Considering the equation of motion of the stepper motor

$$\sum_{j=1}^{m} T_{Mj} = j\frac{d\omega}{dt} + D\omega + T_F \qquad (2\text{-}13)$$

2.4 PROPORTIONAL INTEGRAL DERIVATIVE (PID) CONTROLLER

A Proportional Integral Derivative (PID) controller is a three term controller that has a long history in automatic control field, starting from the beginning of the last century (Bennett, 2000). Due to its intuitiveness and its relative simplicity, in