"I hereby declare that I have read through this report entitle "Disturbance Observer-Based Motion Control of Direct Drive Motors" and found that it ahs comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)"

Signature : …………………………………………….

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Date : …………………………………………….

DISTURBANCE OBSERVER-BASED MOTION CONTROL OF DIRECT DRIVE MOTORS

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A report submitted in partial fulfilment of the requirement for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2013

I hereby declare that I have read through this report entitle "Disturbance Observer-Based Motion Control of Direct Drive Motors" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ACKNOWLEDGEMENT

First of all, I would like to thank to my supervisor, Dr. Chong Shin Horng who always guided and support me throughout the final year project. Her guidance helped me all the time of research and writing of this thesis. Besides that, she also provides us a nice and comfort place to do our research.

Besides that, I would like to thank to all the lecturers that have been taught me before. Without them, I cannot gain the fundamental knowledge and complete this project.

Last but not least, I would like to thank to master students who will taught me about the Matlab Simulink. My fellow friends also always help and support me when I face problem in my final year project. I am grateful to all my family members.

ABSTARCT

In this project, the design of a disturbance observer for a positioning table which is actuated by direct drive motor is considered. Direct drive motor is the driving part that directly connected to the driven part without using gearbox. The advantages of direct drive motor are frictionless, high efficiency, noise reduction and high torque is produced at low speed. However, the direct drive motor has its limitation which is sensitive to the disturbance and parameter variation. Therefore, a control method that is robust and has low sensitivity to disturbance is proposed in this project. The disturbance observer is designed as the feedback controller to estimate the disturbance and parameter variation. Besides that, PD controller is designed. The motion control performance such as tracking control and positioning performance of PD controller with disturbance observer (PDDO) is evaluated and compared with a PID controller. Both of the tracking control and positioning control are tested with different mass and force coefficient. The positioning performance of PDDO is more robust compare to PID controller.

ABSTRACK

Dalam projek ini, pengawal pemerhati gangguan direka untuk jadual kedudukan yang digerakkan oleh motor pemacu langsung. Motor pemacu langsung adalah tiada gear di perantaraan pemandu dan pendorong motor. Kebaikan motor pemacu langsung adalah geseran dikurangkan, kecekapan ditingkatkan, gangguan dapat dikurangkan dan menghasilkan tork tinggi apabila kelajuaan adalah rendah. Namun, motor pemacu langsung mempunyai keburukannya, iaitu sensitif pada gangguan dan perubahan parameter. Oleh itu, satu sistem kawalan yang mantap dan mempunyai sensitiviti rendah terhadap gangguan dicadangkan dalam project ini. Pengawal pemerhati gangguan diguna sebagai maklum balas dalam sistem untuk menganggar gangguan dan perubahan parameter. Prestasi kawalan gerakan seperti kawalan pengesanan dan pretasi kedudukan yang menggunakan PD dengan pemerhati gangguan (PDDO) dan pengawal PID dibandingkan dalam projek ini. Kedua-dua prestasi kawalan gerakan diuji dengan perubahan jisim dan pekali tenaga. PDDO lebih mantap berbanding dengan kawalan PID dalam pretasi kedudukan.

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M	-	Mass
b	-	Friction
K_m	-	Force constant
Ia	-	Current
PD	-	Proportional derivative controller
PID	-	Proportional-integral-derivative controller
PDDO	-	Proportional derivative with disturbance observer
DOB	-	Disturbance observer
T_s	-	Settling time
T_r	-	Rise time
e_{ss}	-	steady state error
%OS	-	Percent of overshoot
ζ	-	Damping ratio
S_d	-	Dominant poles

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, the use of direct drive system is increasing in industrial, such as robots arm, machine tools, chip mounters, semiconductor manufacturing system, trucked drilling machine and so on. In direct drive system, there is no gear box or ball screw between the driving part and driven part, the friction between the driving part and driven part is reduced. However, direct drive system is more sensitivity to parameter variation and disturbance as compared to others motors those have reduction gear.

In order to overcome the sensitivity of direct drive system, some traditional controller such as adaptive time-optimal position controller, linear quadratic control, and acceleration feedback control are used. However, there is a limitation by using conventional controllers [1]. Therefore, to achieve the desired performance of system, advanced motion control such as precision position control and path tracking control are widely used in industrial.

One of the popular controllers that applied in industrial is disturbance observer (DOB). The concept of DOB is the disturbance can be compensated by feedback of the observed disturbance [2]. The advantages of the disturbance observer are robust against parameter variations and simple structure [3, 4]. Figure 1.1 shows the basic idea of disturbance observer, where *r*, *e*, *u*, *x*, *d* are reference input, error signal, control signal, system output and disturbance. It estimates the disturbance from output *x* and control signal *u*. The estimated disturbance is added to the input to cancel the effect of disturbances [4].

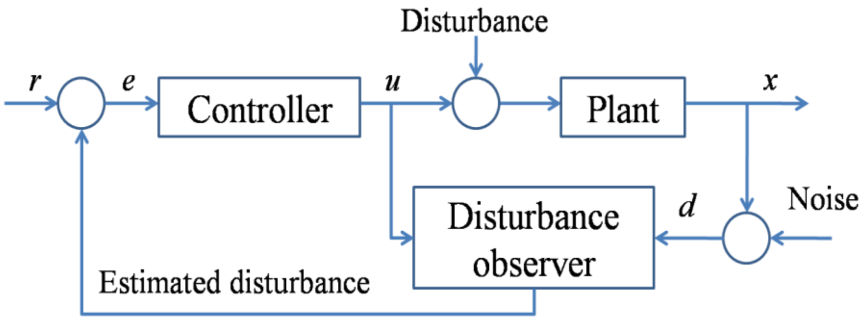

Figure 1.1: Basic idea of disturbance observer (DOB).

In this project, direct drive system with PDDO (PD + DOB) will be tested with different mass, force coefficient and disturbance force to examine the robustness of the system. Besides that, the performance of system with PDDO will be compared with PID controller.

1.2 Problem Statement

Direct drive motor is the driving part that directly connected to the driven part without using gearbox. Direct drive system is widely used for robots arm, machine tools, chip mounters, semiconductor manufacturing system, precision milling machines, precision assembly robots and so on [5]. However, direct drive systems are sensitive to disturbance and parameter variation as compared to others motors those have reduction gear. Direct drive system does not have gear box in the system. Therefore, the friction element becomes low, which will lead to low damper and low stiffness, where the system becomes more sensitive, with a little changes in parameter, the system will be easily affected.

A controller which has high disturbance rejection characteristic and low sensitivity to disturbance is considered. Therefore, motion control of direct drive systems with disturbance observer and proportional derivative (PD) controller, also known as PDDO, is proposed in this project. Disturbance observer is used to estimate the disturbance and parameter variation of the motor. PD controller is used to compensate the transient performance of the system. Disturbance observer is designed at the feedback path to improve the robustness of direct drive system.

1.3 Objectives

The objectives of this project are:

- To design PD controller and disturbance observer (PDDO) for direct drive systems.
- To evaluate the positioning and tracking control PDDO controller and compare with PID controller.
- To examine the robustness of the proposed controller.

1.4 Scope

- To study about direct drive systems and disturbance observer.
- To design disturbance observer and PD controller for positioning control of direct drive system.
- To validate the motion control performance (positioning control and tracking control) with propose controller of system.
- To examine the robustness of system (test with different mass and disturbance force).
- To compare motion control performance of disturbance observer with PID controller.

CHAPTER 2

DIRECT DRIVE SYSTEM AND CONTROLLERS

Direct drive motor is the driving part that directly connected to the driven part without using gearbox. The concept of direct drive system is shown in Figure 2.1(b). In Figure 2.1(a), there is a gear between the driving and driven part in conventional motor, while in Figure 2.1(b), there is no gear between the driving and driven part. In other words, the driving part is directly connected to driven part.

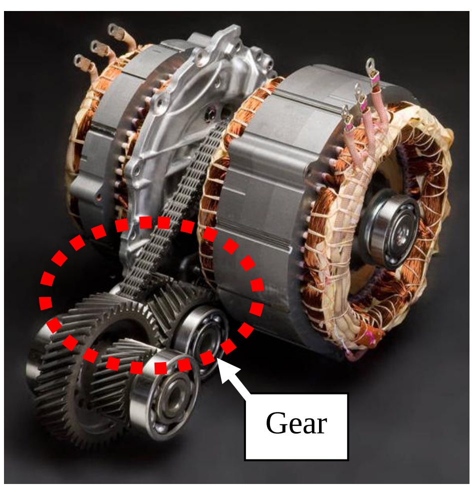

Figure 2.1(a): Motor with gear[1].

Figure 2.1(b): Direct drive motor[1].

[1] http://alternativefuels.about.com/od/2010hybridreviews/ig/2010-Toyota-Prius-photos.-6Hz/Prius-transaxle-comparison.htm

The applications of direct drive system are robots arm, machine tools, chip mounters, semiconductor manufacturing system, disk drive system, wind turbine and so on. The advantages of direct drive system are almost free from friction, easy to realize for precise, high speed and safe motion [6]. Unfortunately, direct drive system always sensitive to disturbance and parameter variation [7].

Voice coil motor (VCM) is one of the examples of direct drive system that widely used in the industrial. The structure of voice coil motor is shown in Figure 2.2. There is the permanent magnet at the fixed coil part (stator). When the current is supplied, the magnet is energized and induced the current to move the rotor. Therefore, there is non-contact between rotor and stator in VCM.

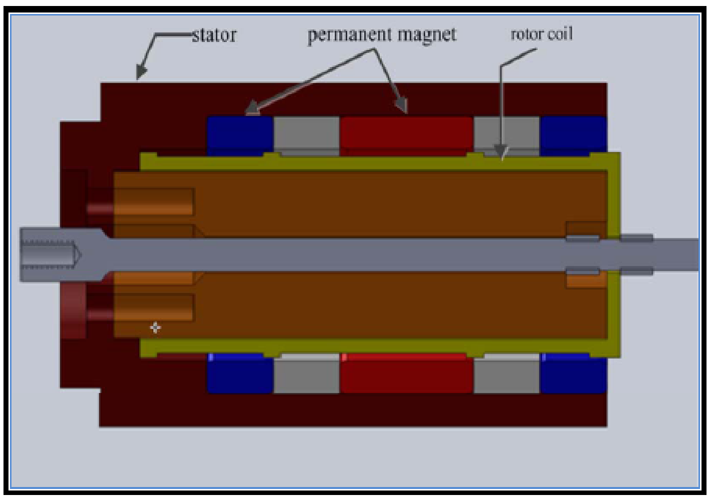

Figure 2.2: Mechanical structure of VCM [8].

As a result, the working principle of VCM can reduce the friction and backlash of the system. The advantages of VCM are faster dynamic response and higher accuracy, simple and rigid structure [8]. In recent years, VCM has widely applied in hard disk drive system [9] and direct drive valve system [10]. Due to the behavior of VCM, a lot of positioning control system also using VCM as the plant, such as X-Y planar nano-motion table system [11]. Therefore, precision position control becomes important in direct drive system.

Bufler et al. [12] has proposed an adaptive time-optimal position controller for a direct drive DC motor with the design based on the model reference adaptive approach, leastsquares recursive estimator is used to estimate the disturbance. It is not influence by variation of parameter but just can apply for step input.

Besides that, S.K.Jong et al. [13] has proposed a robust digital position control, which is linear quadratic controller with load torque observer. The advantage of this controller is the disturbance can be rejected. However, torque observer contains current due to consider a load torque as the unknown input, it is too much noisy to be used in digital controller or observer [13, 14]. After that, a torque controller [15] is used to eliminate the torque ripple. The limitation of torque controller is approach quite complex and it just reduces the torque ripple. In addition, acceleration feedback control is proposed by J.D.Han et al. [16]. This controller can eliminate the torque disturbance, but the high gain acceleration feedback control is needed. Sliding mode controller (SMC) also widely applies in the direct drive system. SMC has less sensitivity to the disturbance force and parameter variations. However, the noise caused by SMC will affect the system performance [17].

Conventional controllers have the limitation to overcome the sensitivity of direct drive system. In order to reduce the sensitivity of the direct drive motor to parameter variations and disturbance, disturbance observer (DOB) is introduced by K. Ohnishi et al. [18, 19]. DOB can estimate the unknown disturbance and has low sensitivity to disturbance, in other word, the control system is robust. The structure of DOB is simple and low sensitivity to the parameter variations and disturbance. Therefore, it is more robust compare to other control system for rejecting disturbance and compensating uncertainties of the plant [20]. However, it still has a disadvantage, which is noise of estimated disturbance influence the position response. A low pass filter is added at the state feedback of the DOB to reduce the noise.

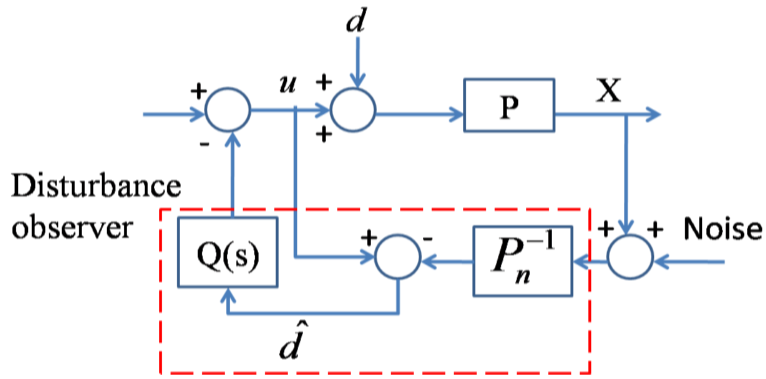

Figure 2.3: Block diagram of plant with disturbance observer (DOB).

Figure 2.3 shows the block diagram of disturbance observer (DOB), where P is plant, d is the disturbance, u is the control signal, X is the output signal, P_n^{-1} is inverse of nominal plant and Q(s) is low pass filter. DOB estimates the disturbance based on output signal, X, and control signal, u. The advantages of disturbance observer are required less computation effort, not require other additional sensor, robust against parameter variations and simple structure [4, 18, 19]. DOB is simple and easy to design compare to conventional phase lead-lag compensator. The feedback of the estimated disturbance, $\hat{d}$, makes the control system nominal [19]. Besides that, disturbance can be compensated efficiently by feedback of the estimated disturbance.

The characteristic of DOB depends on the filter time constant and relative degree of filter. The smaller the relative degree of the low pass filter, the robustness becomes better [20]. In designing the nominal plant and low pass filter, the relative degree of filter should be the equal to or greater to the nominal plant, so that the control system can become robust [22, 23, 24]. Relative degree of nominal plant should not more than one in order to achieve the robust of control system [22]. Besides that, the bandwidth of filter must be wider than mechanical system to show a good disturbance rejection performance. However, the bandwidth for disturbance rejection not only depends on the cut-off frequency of DOB but also the parameter variations [24].