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PRACTICAL POSITIONING CONTROL OF A ONE MASS ROTARY SYSTEM

Rozilawati Binti Mohd Nor

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ROZILAWATI BINTI MOHD NOR

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DECLARATION

I declare that this thesis entitled "Practical Control of a One Mass Rotary System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality as a fulfillment of Master of Science in Electrical Engineering.

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATION

I specially dedicated this thesis to my lovely family.

ABSTRACT

One mass rotary system, is a mechanism that commonly used in industries. Hence for this research, a robust and practical controller design for a one mass rotary system is discussed. The controller is designed and improved based on the conventional structure of the Nominal Characteristic Trajectory Following (NCTF) controller. The continuous motion NCTF (CM-NCTF) controller is proposed for a point to point (PTP) positioning system. The CM-NCTF controller comprising a nominal characteristic trajectory (NCT) and the proportional integral (PI) compensator element. It is designed without knowing the exact model and parameters of the system. The design procedure is applicable, easy to understand and has a simple controller structure. The NCT is constructed from open loop experiment responses while PI compensator is designed experimentally based on the system stability graph.The effectiveness of the proposed controller in positioning and tracking control performance is evaluated experimentally. The experiment was done using various input to examine the controller performance towards parameter variation. While, the controller robustness is evaluated by applying different load into the system to examine system sensitivity towards the disturbance. Then, the effect of positioning, tracking and robustness are compared to the PID and the conventional NCTF controllers. The CM-NCTF controller demonstrates good positioning response by having less steady state error, shorter settling time and also small or zero overshoot in comparison to the PID controller. Besides, the CM-NCTF controller performs better tracking control performance when various input frequencies are applied to the system. The proposed controller is proved to have a good positioning, smoother tracking and less sensitivity towards the disturbance. In conclusion, the CM-NCTF controller is more accurate and robust than the PID controller.

ABSTRAK

Sistem berputar merupakan mekanisma yang lazim digunakan dalam industri. Dalam kajian ini, reka bentuk pengawal mantap dan praktikal untuk sistem berputar dibincangkan. Pengawal ini direka dan diperbaiki berdasarkan struktur pengawal konvensional ciri-ciri mengikut lintasan nominal (NCTF). Pengawal gerakan berterusan NCTF (CM-NCTF) pengawal adalah dicadangkan untuk sistem ini dari satu titik ke satu titik (PTP). Pengawal CM-NCTF terdiri daripada ciri-ciri lintasan nominal (NCT) dan pemampas berkadar (PI). Ia direka bentuk tanpa mengetahui model yang tepat dan parameter bagi sistem tersebut. Prosedur reka bentuk pengawal ini mudah difahami dan mempunyai struktur kawalan yang mudah. NCT dibina dari eksperimen data dari gelung terbuka manakala PI pemampas direka secara eksperimen berdasarkan carta kestabilan sistem. Pengawal yang dicadangkan di aplikasikan kepada kawalan kedudukan dan kawalan pengesanan. Percubaan dilakukan dengan menggunakan pelbagai input untuk mengkaji prestasi pengawal ke arah perubahan parameter. Selain itu, keteguhan pengawal turut dinilai dengan menggunakan beban yang berbeza ke dalam sistem untuk memeriksa sistem sensitiviti terhadap gangguan. Kemudian, kesan kedudukan, pengesanan dan keteguhan dibandingkan dengan PID dan pengawal NCTF konvensional. Pengawal CM-NCTF menunjukkan respon kedudukan yang baik dengan menghasilkan ralat yang kecil, pantas menghabiskan pergerakan dan memiliki ralat kedudukan yang kecil atau kosong berbanding dengan pengawal PID. Selain itu, pengawal CM-NCTF mempunyai prestasi yang lebih baik dalam kawalan pengesanan apabila pelbagai frekuensi input digunakan untuk sistem. Pengawal yang dicadangkan dibuktikan mempunyai kedudukan baik, lancar dan pengesanan sensitiviti kurang terhadap gangguan. Kesimpulannya, pengawal CM-NCTF adalah lebih tepat dan mantap daripada pengawal PID.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION	DETAILS
NCTF	Nominal Characteristic Trajectory Following controller
CM-NCTF	Continuous Motion - Nominal Characteristic Trajectory Following controller
NCT	Nominal Characteristic Trajectory
PID	Proportional, Integral and Derivative controller
DC	Direct current
SMC	Sliding Mode controller
LQR	Linear Quadratic Regulator controller
FSF	Fully State Feedback controller
PI	Proportional and Integral controller
PD	Proportional and Derivative controller
DOB	Disturbance observer
$U(s)$	Conrol signal
K_p	Proportional gain
K_i	Integral gain
$U_p(s)$	Signal into the PI compensator
$\theta_r(s)$	Referent input

$\theta(s)$	Displacement
$\dot{\theta}(s)$	Velocity
$E(s)$	Displacement error
$\dot{E}(s)_{actual}$	Actual error rate
$\dot{E}(s)_{virtual}$	Virtual error rate
t_1 and t_2	Duty cycle time
β	Inclination near origin of NCT
h	Open loop maximum velocity
V	Input voltage
L	Armature inductance
R	Armature resistance
k_b	Motor back electromotive force constant
k_t	Motor torque constant
τ	Torque exerted by an external load
ξ	Damping
ω_n	Natural frequency
$G_m(s)$	One mass rotary system transfer function
$R_c(s)$ and $R_p(s)$	System input
$Y_c(s)$ and $Y_p(s)$	Output position of the system
$D_c(s)$ and $D_p(s)$	External disturbance
L	Closed loop
S	Sensitivity function

T	Complimentary sensitivity function

LIST OF PUBLICATIONS

1- Mohd Nor,Rozilawati and Chong, Shin Horng. 2013.Continuous Motion NCTF Control of a One Mass Rotary System. *2nd International Conference on Electrical, Control & Computer Engineering (InECCE)*, August 27-28, 2013,Kuantan Malaysia.

2- Mohd Nor,Rozilawati and Chong, Shin Horng. 2013. Positioning Control of a One Mass Rotary System using NCTF Controller. *IEEE International Conference on Control System, Computing and Engineering (ICCSCE)*, 2013 IEEE International Conference on, Nov.29 2013-Dec.1 2013, pp.381-386

3- Mohd Nor,Rozilawati and Chong, Shin Horng . 2014. Robustness Evaluation for Point-to-Point Positioning Control of a One Mass Rotary System. *Control, Automation and Systems (ICCAS), 2014 14th International Conference on*, 22-25Oct.2014, pp.375-380

CHAPTER 1

INTRODUCTION

1.0 Introduction

The motion control system has raised the attention of researchers and industries, especially for those who seek for automation development, such as robotic field, machine tools, precision control and manufacturing system. This approach also related to the positioning control development which involving an accurate positioning, high speed performance and precision. For this purpose, a practical controller to overcome this matter has to be designed to have high accuracy, fast response, high performance speed and robust to uncertainties, parameter variations and disturbances. The above mentions are needed to have high quality, high productivity and high system performance, especially for the industry.

Therefore, many studies and researches have been done towards positioning and motion control system. Many types of the controller have been designed and implemented in the real system application. However, the controller design must consider the system linearity and the presence of uncertainties which may cause the instability to the system (Inoue et al., 2014).

The problem may arise from nonlinearities are the system saturation and friction. Saturations produced by the system actuator may cause the slow system performance and affecting the system stability (Slotine, 1991). While, too much friction may cause too large steady state error and limiting output cycles near the reference input (Armstrong-Hélouvry et al., 1994). In recent years, the need of high precision performance has increased drastically. Research has been done with various types of controller to improve the system performance. As an example, the experiment has been done using the pneumatic cylinder system (Hong-Ming et al., 2009), the x-y axis pneumatic cylinder (Chen et al., 2010), the ball screw mechanism (Cook et al., 2008), the switch reluctant motor (Min-Huei et al., 2007), the navigation system (Puls et al., 2009) and much else. As for this research, the positioning control is proposed to a one mass rotary system.

This system consists of a DC servo motor to actuate the system. The DC motors are widely used in industry field, robotic and also home appliance application. It is because of their flexibilities, low cost consumption and high reliabilities especially for positioning system.For the rotary system, many research was done by using various types of controller such as by using Fuzzy Sliding Mode Controller (SMC) (Khanesar et al., 2007), Proportional Integral Derivative Controller (PID) (Kuo et al., 2009), Linear Quadratic Regulator Controller (LQR) (Krishen and Becerra, 2006), Fully State Feedback (FSF) and many else. However, each type of controller will result in different type of performance towards the system. It may have a good positioning performance, but not robust to parameter variation.

In order to improve the controller performance, instead of using a single controller, there is also an approach to hybrid the controller with another type of advances controller such as the Fuzzy-PID controller (Kantawong, 2013), the hybrid of QFT-H^{∞} controller (Nudehi and Farooq, 2007) and many else. It can obtain desired performance, but it also required complex design procedure. From here, it shows that every researcher has their own opinion about the controller performance neither theoretical nor experimental analysis.

Despite the entire controllers suggested successfully control the system, but most of them require exact and accurate model parameters while designing the controller. This thesis presents the design and implementation of the Continuous Motion Nominal Characteristic Trajectory Following (CM-NCTF) Controller for positioning and tracking control. The CM-NCTF controller is proposed because of its characteristic which does not require an exact model and parameter of the plant, easy to handle, easy to design and adjust and also shows the higher robustness performance.

1.2 Problem statement

Precision positioning systems are important to many industrial applications such as machine tools, measuring machines and semiconductor manufacturing systems, medical application equipment and many else. In conventional, designers often improve mechanism features for high linearity and high motion control performance. For this purpose, a practical control that has a simple design and controller structure was designed which can produce fast response, small or nearly zero overshoot, high robust performance and excellent accuracy. Most of the industries are still using the classic controller because it has a simple structure, easy to design and adjust instead of using an advanced controller. To overcome this matter, the CM-NCTF Controller is proposed and the system performance was compared with the PID and the conventional NCTF controller. This research done in order to propose a simple controller design procedure by avoiding a complex control structure and system parameters while perform good in positioning and tracking control performance. Other than having a simple design procedure, it also has high robustness characteristic too. This requirement may solve the control problem for both linear and non-linear systems.

1.2 Objectives of research

The aims of this research were mainly focused on experimenting positioning system in motion control.

1- To propose a CM-NCTF controller for a one mass rotary system.

2- To validate the motion performance and the robustness of the proposed CM-NCTF controller in position and tracking motions.

3- To compare the positioning performance of the conventional NCTF and the PID controller with the proposed CM-NCTF controller.

1.3 Contributions of research

The contributions of the research are by designing a practical controller with the simple design procedure without knowing exact model parameters which troublesome the researchers compared to others advanced controller. It is not only simple to design but also have a superior positioning performance and robustness to parameter variation. Other than that, instead of using a conventional structure of the NCTF controller, this research proposed to improve the controller to the CM-NCTF controller in order to yield a better positioning and tracking performance for a one mass rotary system. Overall, the research is believed to improve the quality of the system and be able to reduce or eliminate the disturbance occurred in the system. The proposed method also can increase the efficiency of the system performance neither in positioning and tracking control.

1.4 Scope of research

The scope of this research is to limit and guide the research focus so that the stated objectives can be achieved first without too many obstacles. This research only focuses on controller design with existing hardware of a one mass rotary system. For this fundamental study, the CM-NCTF controller is proposed for position and tracking control experiment of a one mass rotary system. The proposed controller then were compared with the conventional NCTF controller and the Proportional Integral and Derivative (PID) Controller. The controller is evaluated based on experimental results of positioning control, tracking control and robustness experiment. Different amplitude, frequency and mass use for each experiment without considering the disturbance as an additional input to the step input. It is because, the various input use as listed above enough to show the controller performance towards the system. However, the sensitivity of the system has still effected by the disturbance but proven only by the simulation. The whole experiment is computed by using MATLAB.

1.3 Contributions of research

This thesis content of five main chapters which consists of introduction in chapter one, literature review in chapter two, Nominal Characteristic Trajectory Following (NCTF) controller concepts and design procedures in chapter three, result and discussion in chapter four and conclusion in chapter five.

The first chapter is briefly explained about the research background, problem statement, research objectives, the contribution of research and research scope. For the deeper knowledge about this research, the second chapter explains details about the related issues of this research by doing a literature survey based on previous and current research study.

As for the third chapter, it explains on research methodology for the controller design. This chapter include of the control theory and also design procedures of the Nominal Characteristic trajectory Following (NCTF) controller. After the controller has been successfully designing, the result of the controller performance will be shown in