SYSTEM IDENTIFICATION MODEL AND PREDICTIVE FUNCTIONAL CONTROL OF AN ELECTRO-HYDRAULIC ACTUATOR SYSTEM

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Specially dedicated to my beloved family

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ABSTRACT

The nonlinearities, uncertainties, and time varying characteristics of electro-hydraulic actuator (EHA) have made the research challenging for precise and accurate control. In order to design a good and precise controller for the system, a model which can accurately represent the real system has to be obtained first. In this project, system identification (SI) approach was used to obtain the transfer function that can represent the EHA system. Parametric system identification method was utilized in this research as it emphasizes more on mathematical than graphical approach to obtain the model of the system. Multi-sine and continuous step signals were used as the input for the identification process. The models obtained were validated using statistical and graphical approach in simulation and experimental works to decide which model can represent the EHA system more precisely. Predictive functional control (PFC) was proposed and implemented for position control of the EHA. Besides, an optimal proportional-integral-derivative (PID) controller tuned by particle swarm optimization (PSO) was implemented in simulation and experimental work as comparison with the proposed controller. A comprehensive performance evaluation for the position control of the EHA is presented. As expected from the PFC main objective which is to realize closed-loop behaviour close to first order system with time delay, the experimental work conducted shows the controller capability to reduce the overshoot value by 87% as compared to the PID-PSO. The findings also demonstrated that the steady-state error was reduced by 37% and smaller integral absolute error (IAE).

ABSTRAK

Parameter tak lelurus, ketidaktentuan, dan ciri-ciri yang berbeza-beza mengikut masa bagi penggerak elektro-hidraulik (EHA) telah menyebabkan penyelidikan yang mencabar untuk kawalan yang tepat. Dalam usaha untuk merekabentuk pengawal yang baik dan tepat untuk sistem berkenaan, model tepat dan boleh mewakili sistem sebenar perlu diperolehi terlebih dahulu. Dalam projek ini, pendekatan pengenalan sistem (SI) akan digunakan untuk mendapatkan persamaan matematik yang boleh mewakili sistem EHA itu. Kaedah pengenalan sistem parametrik telah digunakan dalam kajian ini kerana ia lebih menekankan kepada matematik daripada pendekatan grafik untuk mendapatkan model sistem. Multi-sinus dan isyarat langkah berterusan telah digunakan sebagai input untuk proses pengenalan. Model-model yang diperolehi disahkan menggunakan pendekatan statistik dan grafik dalam kerja-kerja simulasi dan eksperimen untuk menentukan model yang boleh mewakili sistem EHA yang lebih tepat. Kawalan fungsi ramalan (PFC) telah dicadangkan dan dilaksanakan sebagai kawalan kedudukan EHA. Selain itu, pengawal kadaran-kamiran-terbitan (PID) yang optimum ditala oleh pengoptimuman kawanan zarah (PSO) telah dilaksanakan pada simulasi dan ujikaji sebagai perbandingan dengan pengawal yang dicadangkan. Satu penilaian prestasi yang komprehensif untuk mengawal kedudukan EHA turut dikemukakan. Seperti yang dijangka daripada objektif utama PFC yang menyedari tingkah laku gelung tertutup dekat dengan sistem tertib pertama dengan kelewatan masa, eksperimen yang dijalankan menunjukkan keupayaan pengawal untuk mengurangkan nilai terlajak sebanyak 87% berbanding PID-PSO. Hasil kajian juga menunjukkan bahawa ralat keadaan mantap telah dikurangkan sebanyak 37% dengan pengurangan terhadap kesilapan kecil mutlak (IAE).

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LIST OF ABBREVIATION

EHA	-	electro-hydraulic actuator
SI	-	system identification
DOF	-	degree of freedom
PFC	-	predictive functional control
PID	-	proportional-integral-derivative
P	-	proportional
PI	-	proportional-integral
ARX	-	auto-regressive exogenous
ANFIS	-	adaptive neuro-fyzzy inference system
N-M	-	nelder-mead
GA	-	genetic algorithm
PSO	-	particle swarm optimization
AWPSO	-	adaptive weight particle swarm optimization
ARC	-	adaptive robust control
SMC	-	sliding mode control
ZPETC	-	zero phase error tracking control
MPC	-	model predictive control
GPC	-	generalized predictive control
DMC	-	dynamic matrix control
M-GPC	-	modified generalized predictive control
MAC	-	model algorithm control
EHAC	-	extended horizon adaptive control
CTC	-	computer torque control
FPFC	-	fuzzy predictive functional control
EUM	-	eliminating unstable mode
UAV	-	unmanned aerial vehicle
ATV	-	all-terrain vehicle

PFC-O	-	predictive functional control with observer
DAQ	-	data acquisition
ARMAX	-	auto-regressive moving average with exogenous input
OE	-	output error
BJ	-	box-jenkins
PRBS	-	pseudo random binary sequence
RMSE	-	root-mean-square-error
MSE	-	mean-square-error
ACF	-	auto-correlation function
CCF	-	cross-correlation function
FPE	-	final prediction error
AIC	-	akaike’s information criterion
ISE	-	integral square error
DSMC	-	discrete sliding mode control
LQR	-	linear quadratic regulation

LIST OF SYMBOLS

A	-	System matrix of discrete-time state-space
B	-	Input matrix of discrete-time state-space
C	-	Output matrix of discrete-time state-space
ess	-	Steady-state error
$e(k)$	-	Error vector
Kp, Ki, Kd	-	Gain of PID controller
G	-	Transfer function of the deterministic part of the system
$G(z)$	-	Discrete transfer function
H	-	Transfer function of the stochastic part of the system
I	-	Identity matrix
ni	-	Coincidence horizon
n	-	Number of step ahead prediction
N	-	Number of sample
OS	-	Overshoot
P, H	-	Vectors of right dimension
T	-	Lag
Tr	-	Rise time
Ts	-	Settling time
u	-	Control law
V	-	Loss function
$u(k), y(k)$	-	System input and output for linear discrete-time model
$\hat{y}$	-	Approximate output value
$\bar{y}$	-	Mean output value
y	-	Actual output value
θ	-	Set of model parameter
ω	-	First order lag
ψ	-	Tuning parameter of PFC algorithm

λ	-	Eigenvalues
z^{-1}	-	Backward shift operator
G^o	-	Observer matrix
a_i , b_i	-	Real coefficient
A_m	-	System matrix of discrete-time for plant state-space model
B_m	-	Input matrix of discrete-time for plant state-space model
C_m	-	Output matrix of discrete-time for plant state-space model
e_k	-	White noise of the system with zero mean
k_a , k_b	-	Model orders
K_{ob}	-	Observer gain
n_a	-	Number of approximated parameter
P_{xx}, H_{xx}	-	Matrices of right dimension
r_k	-	Actual set point
T_d	-	Time constant
u_{msine}	-	Multi-sine input signal of system identification
u_k	-	Input vector of discrete-time state-space
u_{pfc}	-	PFC control law
x_m	-	State variables for plant state-space model
$\hat{x}_m$	-	Estimated state variables for plant state-space model
$\tilde{x}_m$	-	Closed-loop observer error
x_k	-	State variables of discrete-time state-space
y_k	-	Output matrix of discrete-time state-space

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Fluid power control is an old and well-recognized discipline which deals with the transmission and control of energy by means of a pressurized fluid. It is contributed by the needs to control the increasing amount of power and mass with higher speeds and precision. The discipline can be traced back to 250 B.C with the invention of water clock by Ctsebios, an Alexandrian inventor [1]. The invention opened path to various industrial applications using water as the working fluid. In the modern day, the demand to control high power levels with more accuracy and faster control produced a combination of hydraulic servomechanisms with electronic signal processing which then called electro-hydraulic. Compared to pure mechanical or fluid signals, electronic medium in electro-hydraulic system allows the information to be transduced, generated and processed more easily while maintaining the delivery of power at high speeds by the hydraulic servo [2]. An electro-hydraulic actuator (EHA) is one of the most widely used applications of electro-hydraulic technology which play a very crucial part in shaping the modern era.

There are many features and advantages of EHA compared to other popular actuator types such as pneumatic and electrical motor. The main advantage of EHA is the high force delivered by the actuator over the weight and size. This gives EHA an upper hand when precise motion control is desired while space and weight are limited such as in the transportable industrial field. Unlike electrical actuator, the EHA can maintain high loading capabilities for a longer period of time [3]. These advantages have contributed to the increasing demands for various fields of applications including earth moving equipment, manufacturing equipment, and flight applications. However, the main issues in applying the EHA to any application is the dynamic behaviour that cause tracking errors and phase lag during the position tracking process [1].

The issues that cause dynamic behaviour of EHA are uncertainties, time-varying and highly nonlinear due to nonlinear flow and pressure characteristics, backlash in control valve, actuator friction and variation in fluid volume due to piston motion and fluid compressibility [1, 5]. These make the modelling and controller designs for position control of EHA becoming more complex.

EHA control issues could be categorized into position and force control problems. However, EHA position control problem is more attractive because of the wide range of applications. Thus, this research study will be focused on improving the position control of EHA system.

1.2 Problem Statement

The problem statement of this study can be expressed as follows:

"An identification process and a predictive controller are necessary to control position of the EHA system due to its nonlinearities and uncertain characteristics"

1.3 Research Objectives

The followings are the objectives of this research.

(i) To obtain transfer function that represents the EHA using system identification (SI) technique.

(ii) To study and implement Predictive Functional Control (PFC) scheme for position control of the EHA system.

(iii) To conduct numerical simulation and real-time experiment for analyzing the performance of the controller with comparison to PID controller.

1.4 Scope of Work

This followings are the scopes of the research.

(i) The position tracking of EHA is conducted for the linear type of motion (1-DOF) and controlled with proportional valve.

(ii) Mathematical model of the EHA system is linear type.

(iii) Performance analysis of the implemented controller performed in simulation and validated with optimized PID controller.

(iv) EHA used with 250mm actuator stroke, 8L/min maximum flow rate, 230 bar pressure.

1.5 Contribution of the Work

From the literature work conducted, it is obvious that there are significant issues related to the identification and control of EHA system particularly for position control that need to be investigated further. Several contributions can be made in identification and control strategy based on the problem statements discussed. The main research contributions from this study are as follows:

(i) A new mathematical model that represent the developed EHA workbench using System Identification (SI) technique.

(ii) A new control scheme for position control of EHA using predictive functional control (PFC)

1.6 Organization of the Project Report

Chapter 2 presents the literature review of the related works regarding the research topic. The chapter starts with discussion on the types of valves used for transmission system. Next, the mathematical modelling of EHA system using system identification method is presented. Then, various control strategies that have been implemented on EHA specifically for position control is highlighted. At the end of chapter, predictive functional control (PFC) is reviewed for its possibility to be used in this research.

In chapter 3, methodology approaches used in this research are presented. Overall system setup which explain the workbench, data acquisition method and components used are discussed in detail. Then, the mathematical modelling using system identification technique is presented which include the model type, input signal and the validation of the model obtained. This chapter explained the state-estimator design approach using closed-loop estimator. The proposed control strategy for EHA positioning which is predictive functional control (PFC) is presented.

Chapter 4 presents the results and discussion on the simulation works and real-time experimental works conducted in this research. First, the result obtained from mathematical modelling using system identification is presented for two types of input signals which are multi-sine and continuous step. The model that can represent the EHA system is then selected using graphical approach. This chapter also presents the result for state-estimator or observer designed. Then, the result and discussion on the tuning of PFC algorithm and optimized using PID using PSO are presented. Result and discussion for the implementation of PFC algorithm in simulation and real-time experiment are also discussed. The result of the proposed controller is then compared and validated with the optimized PID.

Chapter 5 summarizes the research findings and the recommendation of future research based on this study.

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