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قســـم هـنـدســـــــة الســيـــــارات

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إعــــــداد

مهندس / شريف عبدالفتاح عوض الباز

حاصل على ماجيستير العلوم في الهندسة الميكانيكية

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AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF AUTOMOTIVE ENGINEERING

Optimization of a Displacement Controlled Linear Hydraulic Actuator Utilizing Mechatronics Approach

A Thesis submitted in the Partial Fulfillment for the Requirement of the Degree of PhD in Mechanical Engineering

By
Sherif Abdel Fattah Awad Elbaz
MSc in Mechanical Engineering 2009

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Date: / / 2018

STATEMENT

This thesis is submitted as partial fulfillment of Ph.D. degree in Mechanical Engineering, Faculty of Engineering, Ain Shams University.

The work included in this thesis was carried out by the author during the Period from 2014 to 2018, and no part of it has been submitted for a degree or qualification at any other scientific entity.

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

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List of Publications

1. Sherif Elbaz, Moatasem Shahin, Mohamed Abdel Aziz, Ibrahim Elsherif, and Nabila Elnahass "Model Identification of Displacement Controlled Linear Actuator in Hydraulic System" Military Technical College International Journal" Letter of Acceptance.
2. Sherif Elbaz, Moatasem Shahin, Ibrahim Elsherif, Mohamed Abdel Aziz, and Nabila Elnahass "Design and Experimentation of Test Rig to Characterize Hydrostatic Drive for Linear Actuator" IJRET-International Journal of Research in Engineering and Technology, Volume 6, Issue 9; September 2017

ABSTRACT

Displacement controlled hydraulic systems present an effective approach to improve the efficiency of fluid power systems. This approach prevents fluid throttling, which is a major case of power dissipation, by minimizing the use of control valves in circuits. This approach could play an important role in industry and mobile hydraulics in the near future to overcome the problems associated with fossil fuel especially pollution. The work presented in this thesis describes developing, measuring, modeling, and controlling of a displacement controlled hydraulic linear actuator. A practical hydraulic circuit is developed with a small number of common components, and is suitable for many practical applications.

The linear actuator is controlled by changing the swash plate angle of the variable displacement pump which in turn changes the pump delivery. A complete test rig with all necessary instrumentations is designed to measure, monitor, record, and control the hydraulic circuit using mechatronics principals (mechanical, electrical/electronic, and information technology). Model identification is conducted to find the transfer function based on practical measurements. The calculated data were compared with measured results obtained through an extensive experimental program which proved the validity of the model. Two types of controllers are selected and many input signals with different shapes are fed to the system. Good tracking performance is observed between the desired, and the output signals. Experiments are done in different loads to simulate practical conditions and all the data are displayed on line during experiments. Two types of software are used, the first one is made by Visual Basic/Labview packages and the other is done by Matlab Real Time Windows Target toolbox. This work shows a simple solution to the problem arising when using hydraulic cylinders in closed hydraulic circuit which presents a good approach to hydraulic circuit design. Also shows a way to practically identify system transfer function without using analytical methods. During this process, two types of controllers, namely PID and fuzzy tuned PID, were heavily used deployed and compared.

CONTENTS

NOMENCLATURES

Symbol	Description	Unit
q_{L1}	Flow to load number one	m^3/s
A	Hydraulic Cylinder Area	m^2
A_p	Cross sectional area of a single piston	m^2
D	piston rod diameter	m
E	Modulus of elasticity	Pa
F	Acting force	N
G(S)	Transfer function in Laplace domain	
G_p	Pump flow gain	
J	second moment of area	m^4
K	Reynolds number	
K_d	Derivative gain	
K_i	Integral gain	
K_p	Proportional gain	
L	Hydraulic cylinder displacement	m
L_k	Free buckling length	m
N	Number of pistons in the machine	
N_B	Length of generated PRBS	
n	Pump angular speed	revolution/sec
n_B	Number of bits in the shift register	
N_s	Safety factor	
P	Pressure	N/m^2
P_A	Pump Port A pressure	N/m^2
P_B	pump Port B pressure	N/m^2
P_{Boost}	Boost pump pressure	N/m^2
P_d	Discharge pressure of the pump	N/m^2
P_{do}	Steady state discharge pressure of the pump	N/m^2
P_{in}	Pump input power	Watt

P_{L1}	Pressure inside cylinder one	N/m^2
P_{L2}	Pressure inside cylinder two	N/m^2
P_{Ls}	Load sensing pressure	N/m^2
P_{Ls}	Load sensing pressure	N/m^2
P_{out}	Pump output power	Watt
Q	Pump flow	m^3/sec
Q_d	Volumetric flow rate out from the discharge chamber	m^3/sec
q_{L2}	Flow to load number two	m^3/s
Q_{po}	Steady state volumetric flow rate from the pump	m^3/sec
R	Yield strength of the piston rod material	N/m^2
r	Piston pitch radius	m
S_e	Hydraulic cylinder max extracting velocity	m/sec
S_r	Hydraulic cylinder min extracting velocity	m/sec
s	Laplace operator	
T	Total length of generated PRBS	sec
v_g	Pump displacement volume per revolution	cm^3/rev
V_h	Fluid volume in the discharge chamber	m^3
Vol_{diff}	Volume difference between the cylinder piston side and rod side	m^3
ΔP	Pressure difference	N/m^2
η	Efficiency	
η_v	valve efficiency	
ε_p	Overall Efficiency	
ω	Angular velocity of input shaft	rad/sec
α	Swash plate angle	rad
λ	slenderness ratio	
μ	Volumetric efficiency	
e	Error	
$e(t)$	Change of error	

LIST OF ABBREVIATIONS

Abbreviation	Description
A/D	Analog to Digital
AI	Analog Input
AO	Analog Output
BTU	British Thermal Unit
CBV	Counter Balance Valve
D/A	Digital to Analog
DAAPP	Dual-Acting Axial Piston Pump
DAQ	Data Acquisition
DC	Displacement Controlled
dc	Direct Current
DCA	Displacement Controlled Actuator
DSP	Digital Signal Processing
ECU	Electronic Control Unit
EFM	Electro-hydraulic Flow Matching
EM	Electrical Motor
EP	Electro Proportional
FFT	Fast Fourier Transform
FGS	Fuzzy Gain Scheduling
FSW	Fuzzy Set-point Weighting
FTPID	Fuzzy Tuned PID
GA	Genetic Algorithm
HM-LS	Hydraulic Metering Load Sensing
IAE	Integrated Absolute Error
ICE	Internal Combustion Engine
I/O	Input Output
IMC	Internal Model Control
lpm	Liter per minute
LS	Load Sensing