Design of Electro Hydraulic Actuator

A Thesis Submitted to the College of Graduate Studies at Partial Fulfillment of the Requirements for the Degree of M.Sc in Mechatronics Engineering

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To: my country

parents

Patience:

wife

To my little Aseel
ABSTRACT

In this research, a non-linear model for the guide vane electro hydraulic actuator of turbine no.4 at Rosaries Hydro Power Station has been developed using MATLAB/SIMULINK integrated environment, and the performance of the model is compared with the real plant using a state feedback controller and a PID controller with the same (PID) gains as built in the real plant. The performance of the two controllers is investigated.

To understand the dynamic behaviors of the system, it has been represented by 3rd order differential equations defining the dynamics of plant, and using a fact that the dynamic pressure changes in the hydraulic cylinder chambers becomes linearly dependent on cylinder chambers volumes above and below some prescribed cut off frequencies, the order of system equations reduced to 2nd order. Then these equations were used to design the state feedback controller, so as to control the non-linear model.

For the position control of the single rod hydraulic actuator, state feedback gains are determined by using the linear reduced order system equations.

The dynamic performance of the system is investigated by running open loop and closed loop frequency response and step response tests.
المستخلص

في صياغ هذا البحث، تم تطوير نموذج حاسوبي لا خطي لمشغلة حاكم أبواب التوربينة رقم (4) بمحطة توليد كهرباء الروصيرص، باستخدام حزمة برامج (MATLAB\SIMULINK) المتکاملة. تمت مقارنة أداء النموذج مع المشغل الحقيقي مرة باستخدام متحكم التغذية الراجعة لحالة النظام، وأخرى باستخدام متحكم بنفس المعاملات المستخدمة في متحكم المشغلة الحقيقية. ومن ثم تمت مقارنة أداء المتحكمين.

لفهم الإستجابة الديناميكية للنظام تم تمثيله بمنظومه معادلات من الرتبة الثالثة، و بالإستفادة من حقيقة أن تغييرات الضغط الهيدروليكى أمام وخلف مكبس المشغلة تصبح مرتبطة خطيا فوق و تحت تردد قطع محدد. تم خفض رتيبة معادلات النظام إلى الرتبة الثانية. ومن ثم استخدمت هذه المعادلات لتصميم متحكم التغذية الراجعة لحالة النظام للتحكم في النموذج اللاخطي.

للتحكم في موقع المشغلة الهيدروليكية أحادية المكبس، تم تحديد كسب الحلقة الراجعة لكل متغير حالة باستخدام معادلات خطية للنظام من الرتبة الثانية. ومن ثم تمت مناقشة أداء النظام بالتحقق من الإستجابة الترددية لحالتى الحلقة المفتوحة والمغلقة، والإستجابة لإشارة الخطوة.
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SYMBOLS

\( \Delta p \) Differenti al Pressure
\( p_A \) Cap end hydraulic cylinder chamber pressure
\( p_{A,ss} \) Steady state cap end hydraulic cylinder chamber pressure
\( p_{A,ss,ext} \) Steady state cap end side cylinder chamber pressure while extending
\( p_{A,ss,ret} \) Steady state cap end side cylinder chamber pressure while retracting
\( p_B \) Rod end side chamber pressure
\( p_{B,ss} \) Rod end side hydraulic cylinder chamber pressure
\( p_{B,ss,ext} \) Steady state rod end side cylinder chamber pressure while extending
\( p_{B,ss,ret} \) Steady state rod end side cylinder chamber pressure while retracting
\( p_L \) Load pressure
\( \overline{p}_L \) Normalized load pressure
\( p_s \) Supply pressure
\( p_t \) Oil sump tank pressure
\( q \) Volumetric flow rate
\( q_1 \) Flow rate through valve orifice opening 1
\( q_2 \) Flow rate through valve orifice opening 2
\( q_3 \) Flow rate through valve orifice opening 3
\( q_4 \) Flow rate through valve orifice opening 4
\( q_A \) Flow rate entering the cap end side of the hydraulic cylinder
\( q_{A,ss} \) Steady state flow rate entering the cap end of the hydraulic cylinder
\( q_B \) Flow rate exiting from the rod end side of the hydraulic cylinder
\( q_{B,ss} \) Steady state flow rate exiting from the rod end of the hydraulic cylinder
\( q_L \) Load flow rate
\( y \) Output vector
\( z_k \) Discrete output vector
\( A \) System matrix
\( A_{ext} \) System matrix for the extension of hydraulic cylinder
\( A_{ret} \) System matrix for the retraction of hydraulic cylinder

XIV
\( \bar{P} \)  Normalized power transmitted to the system
\( \bar{P}_{\text{max}} \)  Maximum power transmitted to a load
\( \bar{P}_{\text{loss,RV}} \)  Normalized power lost on the relief valve
\( \bar{P}_{\text{loss,fcv}} \)  Normalized power lost on the flow control valve
\( \mathbf{T} \)  Transformation matrix
\( \mathbf{T}_{\text{ext}} \)  Transformation matrix for extension of hydraulic cylinder
\( \mathbf{T}_{\text{ret}} \)  Transformation matrix for retraction of hydraulic cylinder
\( V_A \)  Hydraulic cylinder cap end side volume
\( V_B \)  Hydraulic cylinder rod end side volume
\( \alpha \)  Hydraulic cylinder chambers volume ratio for a fixed cylinder position
\( \gamma \)  Hydraulic cylinder area ratio
\( \phi \)  Dynamic pressure change ratio of the hydraulic cylinder chambers
\( \lambda \)  Normalized spool position
\( \rho \)  Hydraulic oil density
\( \omega_n \)  Natural frequency
\( \bar{q}_{L} \)  Normalized load flow rate
\( q_{\text{max}} \)  Maximum flowrate through the valve
\( t \)  Time
\( u \)  Reference valve spool position signal in terms of voltage
\( u_{\text{spool}} \)  Valve spool position
\( u_{\text{max}} \)  Maximum allowable valve spool position
\( u_{\text{ext}} \)  State feedback control signal for the extension of the hydraulic cylinder
\( u_{\text{ret}} \)  State feedback control signal for the retraction of the hydraulic cylinder
\( x \)  Hydraulic cylinder position
\( x' \)  Hydraulic cylinder velocity
\( x'' \)  Hydraulic cylinder acceleration
\( X \)  State vector
\( \zeta \)  Damping ratio
\(A_A\) Hydraulic cylinder cap end side area
\(A_B\) Hydraulic cylinder rod end side area
\(B\) Input matrix
\(B_{\text{ext}}\) Input matrix for the extension of hydraulic cylinder
\(B_{\text{ret}}\) Input matrix for the retraction of hydraulic cylinder
\(C\) Output matrix
\(C_d\) Valve orifice discharge coefficient
\(I\) Identity matrix
\(k_v\) Valve flow gain
\(k\) State feedback gain vector
\(k_{\text{ext}}\) State feedback gain vector for the extension of the hydraulic cylinder
\(k_{\text{ret}}\) State feedback gain vector for the retraction of the hydraulic cylinder
\(k_{x2_{\text{ext}}}\) State feedback gain vector for the retraction of the hydraulic cylinder
\(k_{x4_{\text{ext}}}\) Linearized valve spool position gain of orifice 4 for extension
\(k_{p2_{\text{ext}}}\) Linearized valve pressure gain of orifice 2 for extension
\(k_{p4_{\text{ext}}}\) Linearized valve pressure gain of orifice 4 for extension
\(k_{x1_{\text{ret}}}\) Linearized valve spool position gain of orifice 1 for retraction
\(k_{x3_{\text{ret}}}\) Linearized valve spool position gain of orifice 3 for retraction
\(k_{p1_{\text{ret}}}\) Linearized valve pressure gain of orifice 1 for retraction
\(k_{p3_{\text{ret}}}\) Linearized valve pressure gain of orifice 3 for retraction
\(M\) Controllability matrix
\(M_{\text{ext}}\) Controllability matrix for the extension of hydraulic cylinder
\(M_{\text{ret}}\) Controllability matrix for the retraction of hydraulic cylinder
LIST OF ABBREVIATIONS

ABBREVIATIONS

AC       Alternating Current
CP       Constant Pressure
CQ       Constant Flow
DC       Direct Current
EHA      Electro Hydraulic Actuator
EHT      Electro Hydraulic Transducer
PID      Proportional Integral Derivative
RHP      Rosaries Hydro Power Station
RV       Relief Valve
SFC      State Feedback Controller
TF       Transfer Function