International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:3, No:8, 2009

Comparative Analysis of Different Control Strategies for Electro-hydraulic Servo Systems

Ismail Algelli Sassi Ehtiwesh, and Željko Đurović

***Abstract*—**The main goal of the study is to analyze all relevant properties of the electro hydraulic systems and based on that to make a proper choice of the control strategy that may be used for the control of the servomechanism system. A combination of electronic and hydraulic systems is widely used since it combines the advantages of both. Hydraulic systems are widely spread because of their properties as accuracy, flexibility, high horsepower-to-weight ratio, fast starting, stopping and reversal with smoothness and precision, and simplicity of operations. On the other hand, the modern control of hydraulic systems is based on control of the circuit fed to the inductive solenoid that controls the position of the hydraulic valve. Since this circuit may be easily handled by PWM (Pulse Width Modulation) signal with a proper frequency, the combination of electrical and hydraulic systems became very fruitful and usable in specific areas as airplane and military industry.

The study shows and discusses the experimental results obtained by the control strategy (classical feedback (PID) & neural network) using MATLAB and SIMULINK [1]. Finally, the special attention was paid to the possibility of neuro-controller design and its application to control of electro-hydraulic systems and to make comparative with classical control.

***Keywords*—**Electro-hydraulic systems, PID, Neural network controller.

I. Introduction

THE widespread use of hydraulic circuitry in machine tool applications, aircraft control systems, and similar operations occurs because of such factors as positiveness, accuracy, flexibility, high horsepower-to-weight ratio, fast starting, stopping, and reversal with smoothness and precision, and simplicity of operations.

The operating pressure in hydraulic systems is somewhere between 145 and 500 *lb/in²* (between 1 and 35 MPa) [2]. In some special applications, the operating pressure may go up to 10,000 *lb/in²* (70 MPa). For the same power requirement, the weight and size of the hydraulic unit can be made smaller by increasing the supply pressure. With high pressure hydraulic systems, very large force can be obtained. Rapid-acting, accurate positioning of heavy loads is possible with hydraulic systems. A combination of electronic and hydraulic systems is widely used because it combines the advantages of both electronic control and hydraulic power. Moreover, the operating conditions of, and the disturbance acting on, hydraulic systems vary in a complicated fashion; for instance the valve, oil and load parameters may vary significantly.

Normally these parameters are not precisely known or time-variant for a great variety of reasons, *e.g.*, temperature-dependent behavior. All these properties and facts make the control design and tuning difficult. The main objectives for closed-loop control of hydraulic servo-systems are [3]:

- Linearized input-output behavior, which is consistent over the whole operating range.
- Sufficient damping in order to get better step response.
- Control bandwidth improvement, as much as allowed by the dynamics of the hydraulic system and the robust stability requirements imposed by unmodelled dynamics, as well as by parameter variations and disturbances.
- The size of the mechanical components and the flow rates should be kept at least unchanged.

An ideal controller would thus be robust against parameter and disturbance variations, and lead to best performance simultaneously. In practice, however, a *trade-off* has to be decided depending on the application at hand.

Many industrial controllers for an HSS achieve high bandwidth with fixed gain control laws by over-sizing the cylinder diameter in order to increase the effective stiffness of the fluid in the cylinder. This requires larger and more costly components and higher fluid flow rates in order to move a load at a given speed. A better approach to obtaining a fast response is to model the dominant dynamics of the system, and then to use an approach is that, to achieve a given bandwidth, the mechanical components are smaller, the required flow rates are less, and the overall system is therefore much less expensive.

The main purpose of the study is to analyze the most relevant properties of the electro-hydraulic servo system shown in the Fig. 1, and to make an analysis of the control strategies that may be used for the control of these types of servomechanism. The idea is to evaluate, through detailed simulation, several types of controllers that may be used for this purpose. Classical feedback control design Standard P (Proportional action), PD (Proportional & derivative action), and PID (Proportional, integral & derivative action) controllers with possibilities for the P and I action in the parallel branch are going to be examined. Also, some new, more artificial strategies as neural network controllers should be included in the analysis. The presentation of the experimental results (Output) of the system will be shown by tune several types of control.

Ismail Algelli Sassi Ehtiwesh is with the Department of Mechanical Engineering – 7th of April University, Surman, Libya (e-mail: ismaeil_ehtiwesh@yahoo.com).

Željko Đurović is with the University of Belgrade, Faculty of Electrical Engineering, Belgrade, Serbia (e-mail: zdjurovic@etf.bg.ac.yu).

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:3, No:8, 2009

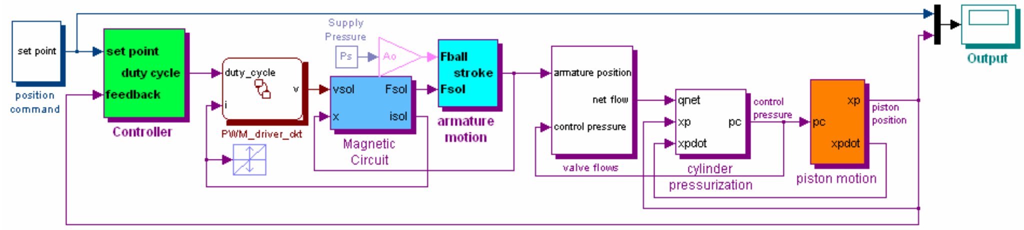

Fig. 1 Electro-hydraulic servomechanism

II. Classical Feedback Control Design

Mathematical model of the plant controlled by PID controller that can be derived, it is possible to apply various design techniques for determining parameters of the controller that will meet the transient and steady state specifications of the closed loop system. However, if the plant is so complicated that its mathematical model cannot be easily obtained, then an analytical approach to the design of a PID controller is not possible. Then we must resort to experimental approaches to the tuning of PID controllers. The process of selecting the controller parameters to meet given performance specifications is known as controller tuning. ***Ziegler*** and ***Nichols*** [4] suggested rules for tuning PID controllers to set values of proportional gain K_P, integral time T_i and derivative time T_d based on experimental transient step responses response characteristics of the plant.

The tuning rules based on *Ziegler-Nichols* should be used only as a first approximation, and since the electro-hydraulic servo-mechanism usually is so quite nonlinear, the theoretical control methods applied on the system couldn't give good results. So, after the first tuning, the final tuning usually has to be done manually.

Table I shows the gains PID controllers that tuned by *Ziegler-Nichols* tuning rule based on step response of plant. These results give only the first approximation tuning, and since the system is quite nonlinear, first tuning doesn't give good results as shown in Fig. 2. Table II shows the final tuning of controllers that tuned manually to have the best results and Fig. 3 shows the output of the system with PID controller that were tuned manually.

TABLE I
First Tuning of PID Controller

K_p	K_i	K_d
430	0.153	0.035

TABLE II
Final Tuning of PID Controller

K_p	K_i	K_d
480	5	0.05

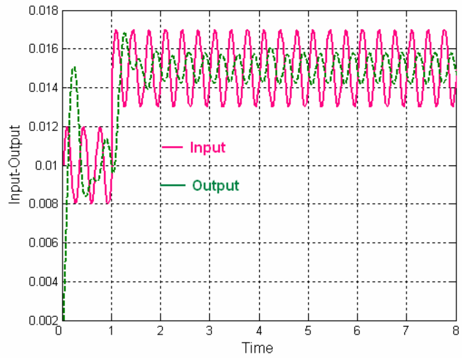

Fig. 2 Output of the system with first tuning of PID controller

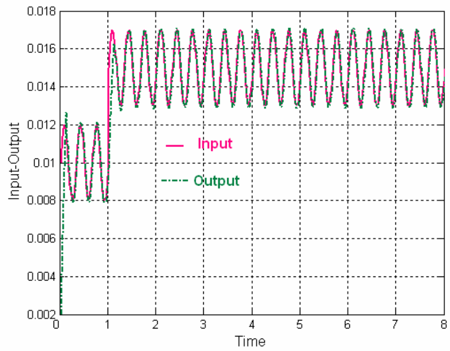

Fig. 3 Output of the system with final tuning of PID controller

III. Neural Network Controller

- The first step was to collect the relevant signals that may be used for training of neural network. The question was what relevant signals may be used to train network to behave properly and what behavior may be considered as proper. The idea was to force the network to perform similarly as well tuned PID controller.
- The second step was to choose the type of the reference signal fed to the close loop system with tuned PID controller, in order to generate the training set. So, the signal presented in Fig. 4 was chosen to contain and involves steady state properties of the system, but also basic dynamical characteristics had to be involved.
- The following step was to decide how many and what inputs should be fed to the neural network. Now, when the nature of neuro-controller inputs and outputs were determined, it became easy to generate the training set.

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:3, No:8, 2009

The reference signal given by Fig. 4 is fed to the closedloop system with PID controller shown in Fig. 5 and the signals {$e[k]$, e [k-1], $y[k]$}, k = 1, 2,… N are collected as training input signals and the signal {$m[k]$}, k = 1, 2… N is collected as training target signal [5].

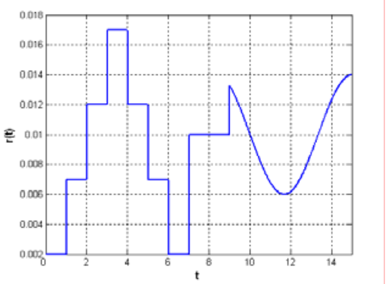

Fig. 4 Reference signal

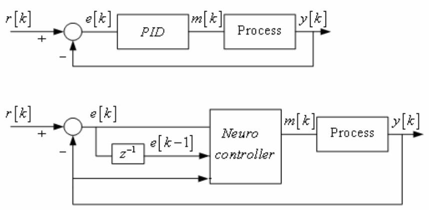

Fig. 5 The structures of closed-loop with PID and neuro-controller

The following step to design the structure of network. The activation function for the nodes in the hidden layer was 'tansig' while the output node was with 'pure line' activation function.

Having in mind some experience with the training of neural network, it was decided to use *'Levenberg-Marquard'* algorithm for the back-propagation error method. Finally, it was necessary to choose the number of nodes in the hidden layer. It was clear that the 'optimal' number can be found by 'try and error' approach [6]. In this context *optimal* means the minimum number of nodes that provides satisfied results (good fitting of target signal). So, the first try was with 5 nodes. Of course, it was not possible to get this type of result immediately, since the convergence of mean-square-error depends significantly on the starting point (network initialization). It was obvious that this kind of neuro-controller was not able to generate good results in the closed-loop. In order to make the proper selection of nodes number in the hidden layer, the following experiment has been performed. The number of the nodes was changed from 1 to 20, and for each of these structures the network has been training for enough number of epoch (1000 epochs) and the best results were saved. So, it was decided to adopt number of nodes in the hidden layer to be 8.

- The final step in design of a network was to check if another hidden layer can help. It was decided to introduce another hidden layer, and In order to check if the increasing of number of nodes in the second hidden layer can improve the performance of neuro-controller, we again made the experiment where the number of nodes in the first hidden layer was kept to be 8 and we changed the number of nodes in the second hidden layer starting from 1 and ending in 10. The obtained result is presented in Fig. 6. So it is clear that the proper structure giving the satisfactory result is a network with 3+8+5+1 structure (3 input nodes, 8 nodes is first hidden layer, 5 nodes in second hidden layer and 1 node in output layer) and the mean-square error after 5000 epochs.

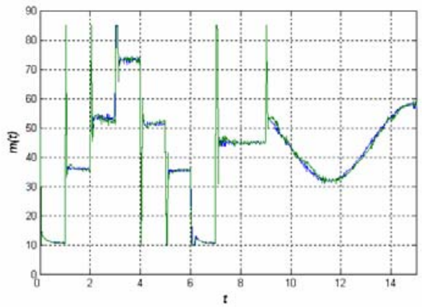

Fig. 6 Target and obtained results for the network

Now, when the structure of neuro-controller was selected and corresponding parameters were calculated, it was possible to make the close-loop system with the neuro-controller in line. Using neural network controller in the closed-loop electro-hydraulic servo system, with the reference signal used for neural network training gives the output of the system shown in Fig. 7.

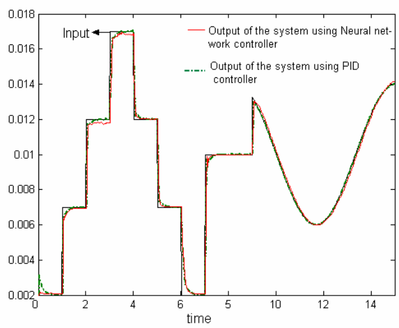

Fig. 7 Output of the system

The following experiment had to check the capability of the network to control the system for some other type of reference signal. Making some changes in the input as shown in Fig. 8, the same experiment has been performed. Fig. 8 represents the changed reference signal, the system output obtained by using PID controller and neuro-controller. In this case the difference between these two outputs becomes obvious. The reason for that is simple: the network was not trained for the reference with values between 0.002 and 0.004, and it is able only to interpolate the expected output. To check this reasoning, it was decided to extend the training reference signal and to make a mixture of the references given by Fig. 8 and Fig. 7 and to repeat the training procedure.

Fig. 9 presents the training control sequence and the output of the network, while Fig. 10 presents the reference, output of the system with PID controller and output of the system with neuro- controller. So, one can say, the difference between these three signals is almost negligible.

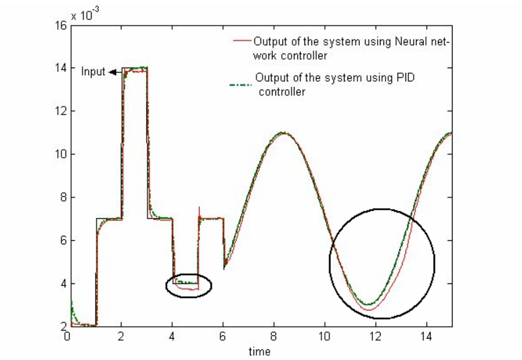

Fig. 8 Output of the system

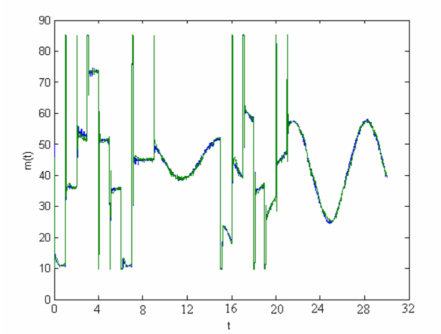

Fig. 9 Training output comparing with the goal

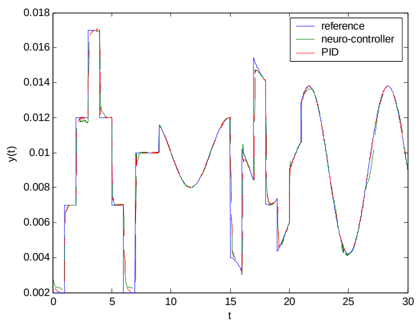

Fig. 10 Output of the system

IV. Conclusion

Finally, the special attention was paid to the possibility of neuro-controller design and its application to control of electro-hydraulic systems. Several questions had to be answered in order to design the proper neuro-controller. The first important question was what should be the inputs to such controller. Making several 'try and error' attempts, the answer was that the controller should have the information about the error signal, delayed error signal and system output (piston position). After that it was necessary to decide about the number of hidden layers, the number of nodes in the layers, the activation functions in the nodes and the algorithm for network training. Few analyses regarding the number of nodes in the layers have been accomplished giving the pretty clear answer that the network should contain two hidden layers with eight nodes in the first and five nodes in the second layer.

These answers have been obtained after the long systematic and tedious experiments, where the number of nodes have been changed and checking the actual criteria. The adopted criteria for network training quality were the computed mean square error between the network output and the desired output signal.

Also, the activation function of 'tansig' type was selected and Levenberg-Marquardt back-propagation algorithm for network training. Another important question was how to design the training set for network training. The most simple and most logical choice was to push the network to behave similar as PID controller. So, with the proper reference signal, the output of the PID controller was saved and used as a training (desired) set for the procedure of neural network training. The obtained results were promising, since the training procedure resulted in the mean square error less than 0.8%. In other words, it seemed that the network learnt to behave very similar as classical feedback controller.

Two additional analyses were accomplished. The first one was to check if the network is able to preserve good behavior even if the reference signal is changed. It was concluded that the performances of the closed-loop system is changed in that case, not significantly but noticeable. And it was clear, if the reference signal used for the training of neural network is more reach and longer, although the training procedure takes more time, the quality of regulation becomes improved. The other important performed analysis was related to the appearance of disturbance.

References

[1] K. Singh and G. Agnibori. System Design Through Matlab, Control toolbox and Simulink. Springer, 2000.
[2] Jelali and Kroll. Hydraulic Servo-systems, Modeling, Identification and Control. Springer, UK, 2002.
[3] H. E. Merritt. Hydraulic Control Systems. John Wiley&Sonns, USA, 1967.
[4] K Ogata. Modern Control Engineering. Aeeizh, USA, 2002.
[5] D. Pham and L. Xing. Neural Networks for Identification, Prediction and control. Springer, 1997.
[6] Simon Haykin. Neural Networks. Macmillan, USA, 1994.
[7] K. Astrom and B. Wittenmark. Computer controlled Systems. Prentice-Hall, 1991.
[8] P. Wasserman. Neural computing Theory and Practice. Van Nostrand Reinhold, New York 1991.