POSITION CONTROL FOR (PPDCV) USING PID & FUZZY SUPERVISORY CONTROLLER

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ABSTRACT

Pilot Proportional Directional Control Valve (PPDCV) is mostly used for control the Cement Industries. Accuracy and precision without any disturbance for position control of the actuator is the goal for engineering applications. This paper presents explain mathematical model for (PPDCV) and position controller for hydraulic actuator that move the clinker cooler.PID controller with fixed parameters is used for position control with normal condition. In our system, the parameters of the system may be varying with time, pressure source of the system. It may cause disturbance. However, PID controllers are good for position control with transient response and reduce steady state error. It could not reduce disturbance. To eliminate the disturbance problem, Fuzzy supervisory control (FSC) is used in this work with special adjustment. FSC will tune PID parameters online and can handle with parameters variation. The simulation experiment is performed using Matlab and Simulink.

Keywords: PPDCV; Clinker Cooler Servo System; PID; FSC; Modeling & Simulation

INTRODUCTION

Pilot Proportional Directional Control Valve (PPDCV) has been used in modern industrial applications. Because a minimal actuating force for the proportional pilot valve will cause a large force to moving the main stage for high flow applications. PPDCV give ability to apply big forces for industrial applications. The dynamic behavior of PPDCV is similar to the electro-hydraulic valve that is highly nonlinear due to the phenomenon such as pressure-flow characteristics. PID controller or any it's component is most popular controller used in industry application because they can improve both the transient and steady state error.

In the traditional PID control system, the parameters K_p, K_i and K_d are fixed during the operation, so that PID cannot satisfy the performance requirement under nonlinear complex system and uncertainty parameters, unavailable accurate system model, or too complicated to use for control purpose. To cope all these problems, PID parameters K_p(proportional gain),K_i(integral gain) and K_d(derivative gain) should be tuned online. Fuzzy logic is used as supervisory controller to tune PID parameters online where input from expert acts for this parameters tuning. It provides an alternative to the PID.

It is a good tool for the control of systems that are difficult to model. It can cover a wider range of operating condition than PID and can operate with noise and disturbance with different nature. Another important of Fuzzy is short rise time and small overshoot. Fuzzy has been successfully used in the complex ill-defined process with better performance than PID controller.

A lot of literature used Fuzzy on the controller for hydraulic system. Deticek used a control strategy based on fuzzy logic and conventional control approach for hydraulic drive [1].

Seraphin C. et al used fuzzy logic for actuated hydraulic system fault detection [2]. Some researchers used hybridization of two controller fuzzy and PID for electro-hydraulic. Saban et al. used hybrid fuzzy PID controller with coupled rules (HFPIDCR) for position control of the hydraulic system [3]. Pornjit P. et al. enhanced the performance of electro-hydraulic servo system by hybrid of Fuzzy and PID [4].

Many researchers discussed a problem of adaptive fuzzy for hydraulic. Lee and Cho develop an adaptive fuzzy controller for a hydraulic forging machine in which the process was nonlinear, non-stationary and time invariant [5].Ranjit et al. used robust adaptive fuzzy control with self-tuning adaptation gain in feedback loop to cope with parameters variation and disturbance in the hydraulically actuated robot mechanisms [6]. Zulfatman and M.F.Rahman developed self-tuning fuzzy PID controller to improve performance of the electro-hydraulic actuator [7].

They obtained the mathematical model by using system identification. Hatem E. at el. used like our proposed control that is supervisory fuzzy control to regulate PID parameters on-line in his application of 5 DOF robot arms [8]. Liang et.al also used fuzzy adaptive PID control but the online tuning is the change of PID parameters [9]. Some researcher used two controllers: Fuzzy controller and fuzzy self-tuning PID in the hydraulic system such as such as Kwanchai [10].

Fuzzy Set Theory was formalized by Professor LoftiZadeh at the University of California in 1965 as a way to characterized non probabilistic uncertainties. Fuzzy logic used in controller by pioneering research of Mamdani in 1973.Combining the simplicity of PID controller and the robustness of fuzzy logic controller can achieve high control performance in a simple manner. This tuning is known as supervisory PID controller or Fuzzy self-tuning PID (Pedrycz, 1993, 1995).

Although the PPDCV is used in industrial product, there is no relatively literature available in on the modeling and analysis of this component. This paper will discuss molding of PPDCV and the problem of the position controller of the actuator for PPDCV system in the development of electro-hydraulic clinker cooler servo system for cement industries.

In our research we use two types of controller that are PID controller and fuzzy supervisory controller (FSC) for position control of actuator the new pilot proportional directional control valves (PPDCV) of this system and study the robustness of these controller for the closed loop system under different condition. The fuzzy supervisory control (FSC) will solve some of the problems that occur in the system such as disturbance.

BACK GROUND OF CLINKER COOLER SERVO SYSTEM

Development Stages System

In the development of electro-hydraulic clinker cooler servo system for cement industry plant, there are a many stages. At 1982, the clinker cooler of the cement industry began using (on-off switch) electro-hydraulic conventional system. At 2007, the cement industry used PPDCV instead of (on-off switch) with size of the pilot proportional valve was (6 NG) and size of the main valve was (16 NG) in this system as shown in Fig.1 that was used in Tasloga cement factory in Sulaimaniya-Iraq. At 2011,the cement industries also use PPDCV but with other size that is the size of the pilot proportional valve is (10 NG) and size of the main valve is (25 NG) in this system as shown in Fig.2 that used in Mass Cement Factory - Bazyan also in Sulaimaniya-Iraq.

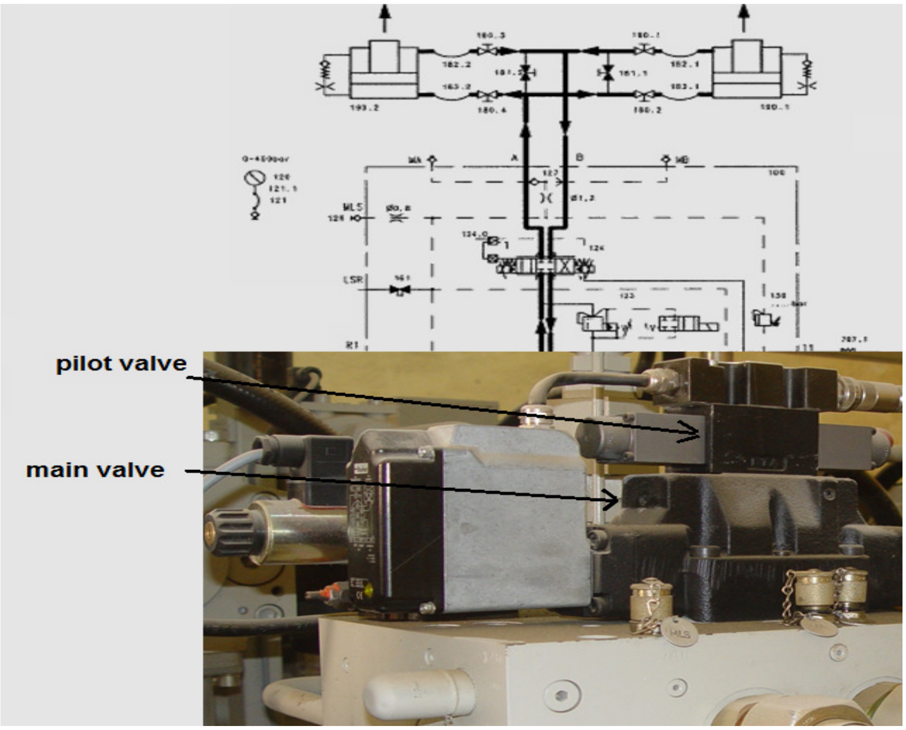


Figure 1. PPDCV small size in Tasloga cement factory (Polysius) in Sulaimaniya-Iraq

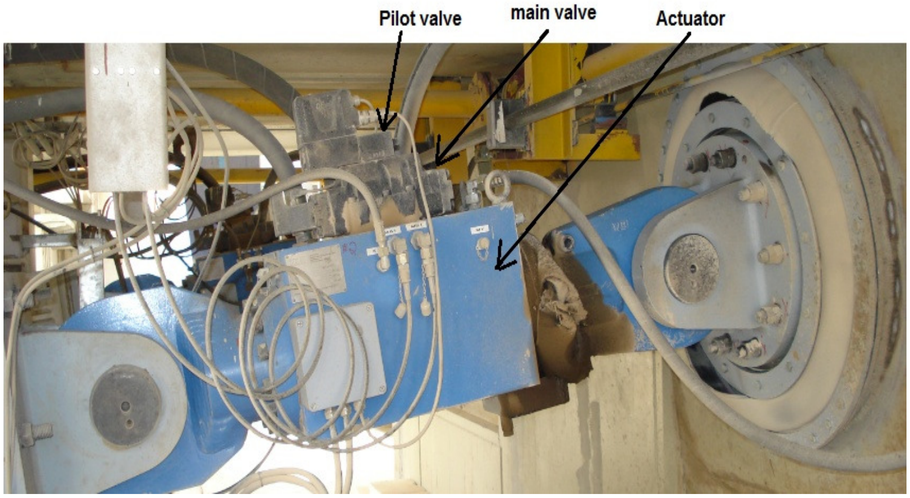


Figure 2. PPDCV new big size in Mass Cement Factory in Sulaimaniya-Iraq

System Description

A schematic diagram of PPDCV in the clinker cooler is the subject of consideration in this work is shown in Figure 3.The position of the actuator cylinder is measured with a displacement transducer built into the cylinder and the measured signal is used to compare with desired input for the realization of the controller algorithm. The pilot valve is four way 3- position proportional directional control valve and the main valve is also four way 3-position proportional valve.

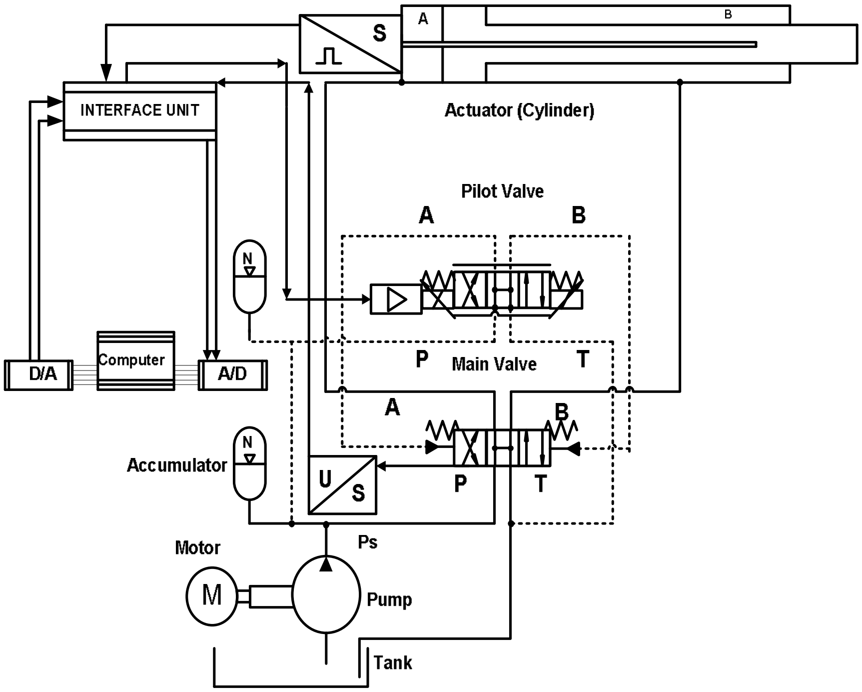


Figure 3. Schematic diagram for new size PPDCV in Mass Cement Factory

In the PPDCV control system, this position of the actuator is compared to the desired input given by the user .If these values differ, the solenoids of the pilot valve (x_{pil}) are driven by the controller to change pilot flow of the hydraulic fluid that reaches to the main valve. This flow in turn causes a pressure differential (p_1&p_2) on the front surfaces of the control spool of the main stage so that the position of the main valve (x_{main}) is deflected and will change. The position of the main valve changes delivering or letting off pressure oil (p_3&p_4) of the actuator piston side (A) and the actuator rod side (B) of the cylinder, respectively and cause the actuator position (x_{act}) change. This diagram of the system is illustrated in Fig.4.

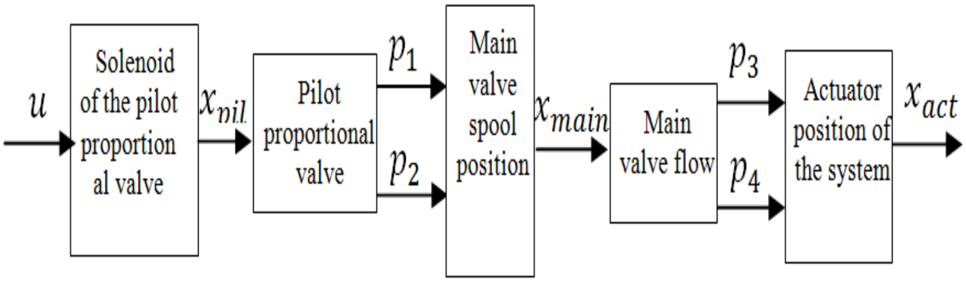


Figure 4. Block diagram of PPDCV

A controller sends signals that vary in the range of -10 to 10 V to the solenoid of the pilot valve. The simplicity and good characteristics such sensors are often applied in technical practice. The system equipment also includes grate drive parameter and tank to supply a hydraulic to the system. The stamping stroke of the actuator clinker cooler is traveling 130 mm stamping distance with speed.

MATHEMATICAL MODEL

The nonlinear dynamic model of PPDCV system shown in the Fig.4 consists of pilot valve that control the main valve and main valve that control to the actuator. Physical law needed to build the dynamic model of this system.

Pilot Valve Equation

The dynamic model of Pilot proportional valve can be described by the second order linear differential equation

$$\ddot{x}_{pil} + 2\xi w_n \dot{x}_{pil} + x_{pil} w_n^2 = k w_n^2 u \ldots\ldots. (1)$$

Where (x_{pil}) is the position of the pilot valve, (u) is the input voltage,(w_n) is the natural frequency, (k) is the pilot proportional valve gain and (ξ) is damping ration of the pilot proportional valve.

The dynamics of almost all practical hydraulic components can be appropriately described by the following equations. The flow through the pilot valve is proportional to the square root of the pressure drop across the port and the area of the pilot valve opening. The pilot valve opening area is proportional to the spool displacement of the pilot and therefore by applying a linear orifice area gradient related to the pilot spool displacement, the flow equations of the pilot valve can be represented by the following term [11]:

For extension

If $x_{pil} \geq 0$

$$q_1 = c_{dpil} w_{pil} x_{pil} \sqrt{\frac{2}{\rho}(p_s - p_1)} \qquad q_2 = c_{dpil} w_{pil} x_{pil} \sqrt{\frac{2}{\rho}(p_2 - p_t)} \ldots\ldots. (2a)$$

For retraction

If $x_{pil} \leq 0$

$$q_1 = c_{dpil} w_{pil} x_{pil} \sqrt{\frac{2}{\rho}(p_1 - p_t)} \qquad q_2 = c_{dpil} w_{pil} x_{pil} \sqrt{\frac{2}{\rho}(p_s - p_2)} \ldots\ldots. (2b)$$

Where q_1, q_2 represent the fluid flows into and out of the pilot valve, respectively,$c_{dpil}$is pilot valve coefficient of discharge, ρ is the fluid density,w_{pil} is width of the pilot valve port,p_s is the pump pressure,$p_1 \& p_2$ is the input and output pressure of the pilot valve respectively and p_t is return pressure

Main Valve Equation

The total volumes of the forward and return chambers $(V_1 \& V_2)$ of the main are given respectively by the following equation below:

$$V_1 = \overline{V_1} + x_{main} A_{main} \ldots\ldots. (3a)$$

$$V_2 = \overline{V_2} - x_{main} A_{main} \ldots\ldots. (3b)$$

$\overline{V_1} \& \overline{V_2}$ are the initial volumes trapped in the side of the main valve forward and return, respectively, x_{main} is the position of the main valve and A_{main} is the effective Area of the main valve.

Since the volume in the pipe is much larger than the volume in the main, the movement of the main spool is considered to be zero

$$V_1 = \overline{V_1} \ldots\ldots. (4a)$$

$$V_2 = \overline{V_2} \ \ldots\ldots \ (4b)$$

From assuming the position of the main valve, the volume equation is

$$V_1 = V_2 = A_{main} \frac{S_{main}}{2} \ \ldots\ldots \ (5)$$

Where $S_{main}$is main valve stroke length. The entrapped volume between the pilot valve and the main valve can be modeled as fluid capacitance $(C_{f1} \& C_{f2})$which can be described as the equation:

$$C_{f1} = \left(\frac{1}{\beta}\right) A_{main} \frac{S_{main}}{2} \ldots\ldots \ (6a)$$

$$C_{f2} = \left(\frac{1}{\beta}\right) A_{main} \frac{S_{main}}{2} \ldots\ldots \ (6b)$$

Where β is effective bulk modulus.

The equation for oil flow through the main valve is

$$q_1 = A_{main} \frac{dx_{main}}{dt} + \frac{1}{\beta} V_1 \frac{dp_1}{dt} \ldots\ldots \ (7a)$$

$$q_2 = A_{main} \frac{dx_{main}}{dt} - \frac{1}{\beta} V_2 \frac{dp_2}{dt} \ldots\ldots \ (7b)$$

Substitute this equation with above equation we conclude

$$q_1 = A_{main} \frac{dx_{main}}{dt} + C_{f1} \frac{dp_1}{dt} \ldots\ldots \ (8a)$$

$$q_2 = A_{main} \frac{dx_{main}}{dt} - C_{f2} \frac{dP_2}{dt} \ldots\ldots \ (8b)$$

If internal and external leakage is neglected, hydraulic pressure behavior for compressible fluid volume is given by the differential equation

$$\dot{p}_1 = \left(\frac{1}{C_{f1}}\right)\left(q1 - A_{main} * \frac{dx_{main}}{dt}\right) \ldots\ldots \ (9a)$$

$$\dot{p}_2 = \left(\frac{1}{C_{f2}}\right)\left(A_{main} * \frac{dx_{main}}{dt} - q2\right) \ldots\ldots \ (9b)$$

On the main side, the force developed by the main valve(f_{main}) is representing the pressure different between the spool of the main, which, in turn result from flow entering and leaving the main valve. This system can be described as the following equation:

$$f_{main} = (\,p_1 - p_2)A_{main} \ldots\ldots \ (10)$$

The mechanical part of the main valve can be described by the following dynamic equation:

$$M_{main}\ddot{x}_{main} = A_{main}(p_1 - p_2) - \dot{x}_{main}b_{main} - x_{main}k_{main} \ldots\ldots \ (11)$$

Where $M_{main}$the mass of the main is valve,k_{main} andb_{main} are main valve stiffness and main valve viscous damping coefficient, respectively.

Now, the dynamics of main can be appropriately described by the equations depended on the position of the main valve and the supply pressure limited .The flow through the main valve is proportional to the square root of the pressure drop across the port and the area of the main valve opening. The main valve opening area is proportional to the main valve spool displacement and therefore by applying a linear orifice area gradient related to the spool displacement, the flow equations of the main valve can be represented by the following term:

For extension

If $x_{main} \geq 0$

$$q_3 = c_{dmain} w_{main} x_{main} \sqrt{\frac{2}{\rho}(p_s - p_3)} \qquad q_4 = c_{dmain} w_{main} x_{main} \sqrt{\frac{2}{\rho}(p_4 - p_t)} \ldots (12a)$$

For retraction

If $x_{main} \leq 0$

$$q_3 = c_{dmain} w_{main} x_{main} \sqrt{\frac{2}{\rho}(p_3 - p_t)} \qquad q_4 = c_{dmain} w_{main} x_{main} \sqrt{\frac{2}{\rho}(p_s - p_4)} \ldots (12b)$$

where q_3, q_4 represent the fluid flows into and out of the main valve, respectively,c_{dmain} is main valve coefficient of discharge,w_{main} is width of the main valve port,$p_3$is the input pressure to actuator in the piston side ,p_4 is the line pressure in rod side.

Actuator Equation

The total volumes of the forward and return actuator chambers are given respectively by

$$V_3 = \overline{V_3} + x_{act} A_{actA} \ldots\ldots (13a)$$

$$V_4 = \overline{V_4} - x_{act} A_{actB} \ldots\ldots (13b)$$

V_3, V_4 are the volumes of fluid trapped at the piston side of the actuator and the rod side of the actuator, respectively. $\overline{V_3}, \overline{V_4}$ are the initial volumes trapped in the blind and rod sides of the actuator,x_{act} is the actuator position,A_{actA} is actuator piston area, A_{actB} is actuator annulus area.

Since the volume in the pipe is much larger than the volume in the cylinder, the movement of the piston is considered to be zero

$$V_3 = \overline{V_3} \ldots\ldots (14a)$$

$$V_4 = \overline{V_4} \ldots\ldots (14b)$$

From assuming the position of the cylinder, the volume equation is

$$V_3 = A_{actA} \frac{S_{act}}{2} \ldots\ldots (15a)$$

$$V_4 = A_{actB} \frac{S_{act}}{2} \ldots\ldots (15b)$$

$S_{act}$is actuator stroke length.

The entrapped volume between the main valve and the actuator can be modeled as fluid capacitance (C_{fA}&C_{fB}) which can be described as the equation:

$$C_{fA} = \left(\frac{1}{\beta}\right) A_{actA} \frac{S_{act}}{2} \ldots\ldots (16a)$$

$$C_{fB} = \left(\frac{1}{\beta}\right) A_{actB} \frac{S_{act}}{2} \ldots\ldots (16b)$$

The equation for oil flow through the actuator is

$$q_3 = A_{actA} \frac{dx_{act}}{dt} + \frac{1}{\beta} V_3 \frac{dp_3}{dt} \ldots\ldots (17a)$$

$$q_4 = A_{actB} \frac{dx_{act}}{dt} - \frac{1}{\beta} V_4 \frac{dp_4}{dt} \ldots\ldots (17b)$$

Substitute this equation with above equation we get

$$q_3 = A_{actA}\frac{dx_{act}}{dt} + C_{fA}\frac{dp_3}{dt} \ldots\ldots. (18a)$$

$$q_4 = A_{actB}\frac{dx_{act}}{dt} - C_{fB}\frac{dP_4}{dt} \ldots\ldots. (18b)$$

Hydraulic pressure behavior of the actuator for compressible fluid volume is given by the differential equation

$$\dot{p}_3 = \left(\frac{1}{C_{fA}}\right)\left(q3 - A_{actA} * \frac{dx_{act}}{dt}\right) \ldots\ldots. (19a)$$

$$\dot{p}_4 = \left(\frac{1}{C_{fB}}\right)\left(A_{actB} * \frac{dx_{act}}{dt} - q4\right) \ldots\ldots. (19b)$$

On the hydraulic actuator side, the actuator force (f_{act}) is represent the pressure different between the actuator piston area and actuator annulus area, which, in turn result from flow entering and leaving the actuator

$$f_{act} = p_3 A_{actA} - p_4 A_{actB} \ldots\ldots. (20)$$

The mechanical part of the actuator can be described by the following differential equation

$$M_{act}\ddot{x}_{act} = (p_3 A_{actA} - p_4 A_{actB}) - \dot{x}_{act} b_{act} - x_{act} k_{act} \ldots\ldots. (21)$$

Where M_{act} is actuator mass, k_{act} is actuator stiffness, b_{act} is actuator viscous damping coefficient.

CONTROLLER DESIGN

This section illustrates the design a controller for control the position of the actuator of (PPDCV) depend on the state equation of the plant model and the desired input. The feedback control system is shown in the block diagram in Figure 5.

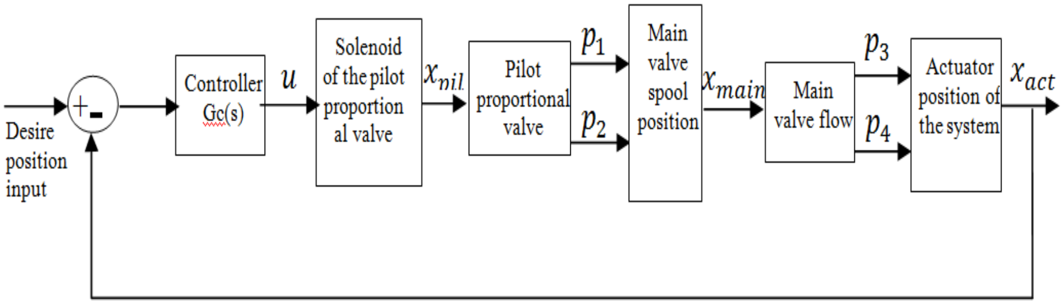


Figure 5. Block diagram of PPDCV with controller design

In the industrial application, conventional controller such as PID is used for many hydraulic systems. However, this controller has linear characteristics and may cause a problem with uncertainty parameters. Controller parameters also are difficult chosen for complex or poorly defined dynamic systems.

Fuzzy controller is also designed based on the knowledge of the controlled system's behavior and human operator's experience. The type of fuzzy used in this paper is fuzzy supervisory controller (FSC). This type will online tune the parameters of the PID controller[12].

PID Controller

This controller proportional-integral-derivative (PID) algorithm is used as the following equation:

$$u(t) = K_p\, e(t) + K_d \frac{d}{dt} e(t) + K_p \int e(t)\ dt \ldots\ldots. (22)$$

WhereK_P,K_D and K_I are, respectively, the proportional, derivative, integral gains, of the controller, *e* is the error between the desire position of the actuator and the actual position of the actuator. The purpose of used this controller in the industrial hydraulic application is simple structure and can satisfy performance behavior for decreasing overshoot, rise and setting time.

Fuzzy Supervisory Controller

Fuzzy supervisory controller (FSC) type will online tune the parameters of the PID controller. Fuzzy supervisory control will solve all these problems that appeared in PID controller. It has robust performance over a wide range of operating conditions because of ability to online adaptation to compensate for unpredicted plant variation, noise, or disturbance.

The object from fuzzy supervisory controller (FSC) used in this paper to control actuator position of PPDCV hydraulic system. FSC will tune PID parameters K_p(proportional gain),K_i (integral gain) and K_d (derivative gain) on-line in PPDCV system based on the equation (22). The closed loop controller including FSC controller and PPDCV plant is shown in Figure 6.

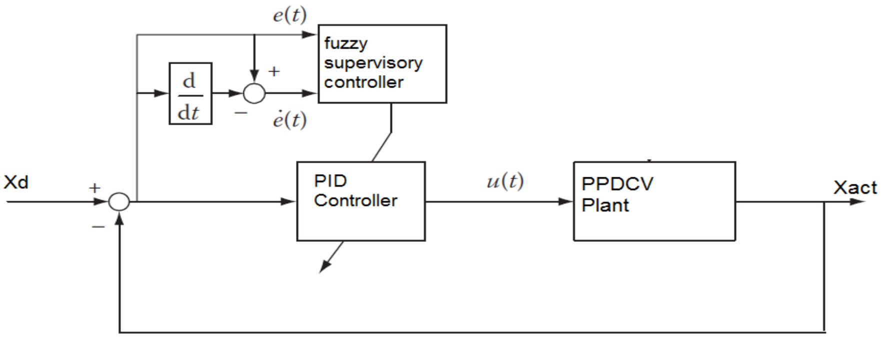


Figure 6. Fuzzy Supervisory Controller (FSC) for PPDCV

These parameters (K_p, K_i and K_d) are adjusted online based on error (*e*) and change of error (*de*) to make a controller action achieve static and dynamic performance. Fuzzy Supervisory controller (FSC) is MIMO controller because it has two inputs and three output variables. The error (*e*) and change of error (*de*) is input to (FSC) controller while the parameters (K_p, K_i and K_d) are output. The block diagram for FSC to tune PID parameters is shown in Fig. 7.

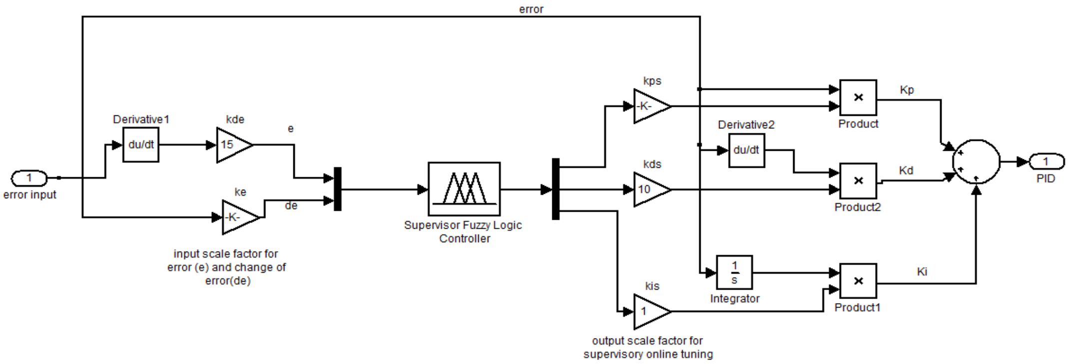
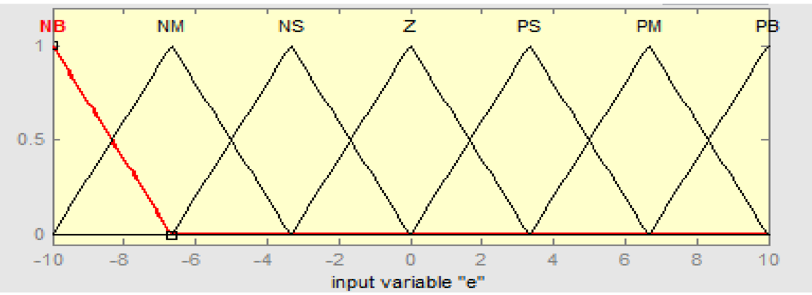


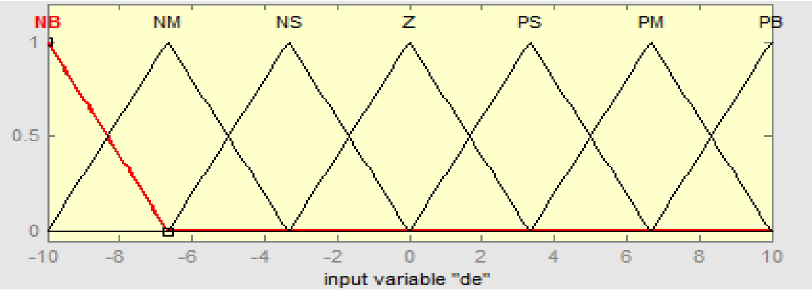
Figure 7. Block diagram of fuzzy supervisory controller (FSC)

All variables must be converted to fuzzy logic linguistic variables. The rang of input variables (*e* and *de*) is [-10, 10] while the output variables K_p, K_i and $K_d$is [0, 10]. All variables must be scaled using input scale factor (*Ke)* for error (*e*) and (*Kde)* for change of error (*de*) while the variables of output scale for supervisory tuning (*kps*) for (K_p), (*kis)* for (K_i) and (*kds*)for (K_d). The entire scale factor is shown in Figure 7. The suitable values for scaling factor are selected depended on the knowledge of the system or sometime by trial and error.

All the input and output variables are implied as linguistic value. Each of the input variables (*e* and *de*) has seven fuzzy set linguistic values. These value are: NB- negative big, NM- negative medium,NS- negative small, Z- zero, PS- positive small, PM-positive medium,PB- positive big. The type of membership function used for input is triangular. These input variables are shown in Figure 8.



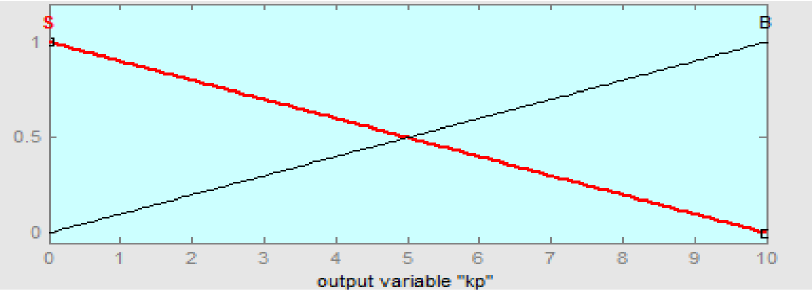
(a) Input variables (*e*)



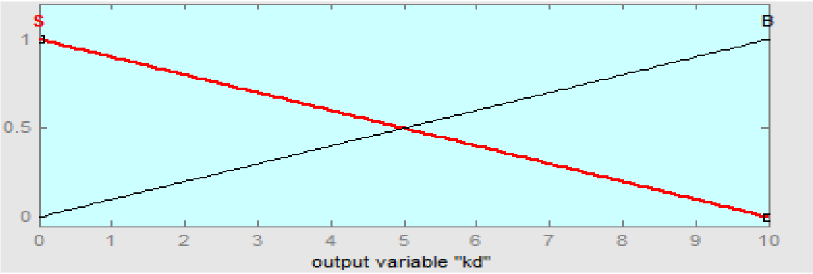
(b) Input variable (*de*)

Figure 8. Input variables for FSC

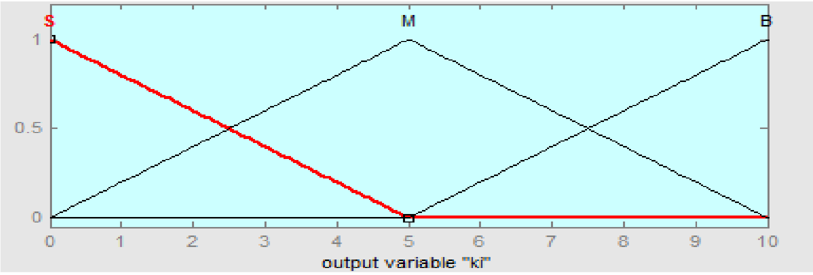
The output variablesK_p, $K_i$have two fuzzy set linguistic values S-small and B-big, while the output variable $K_i$has three fuzzy set linguistic values S-small, M-medium and B-big. The type of membership function used for output is triangular. These output variables are shown in Figure 9.



(a) Output variable (Kp)



(b) Output variable (Kd)



(c) Output variable (Ki)

Figure 9. Output variables for FSC

Supervisory controller has four main components: Fuzzifier, knowledge base, and inference engine and defuzzifier [13], [12]. The general block diagram of fuzzy logic controller component is illustrated as show in Figure 10.Fuzzy control provides a formal methodology for represent manipulation and implementing a human's heuristic knowledge about how to control a system.

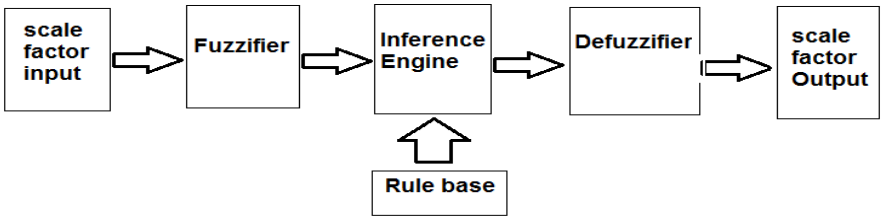


Figure 10. Fuzzy logic controller component

Fuzzifier converts crisp input to the fuzzily signal of linguistic variables. The inference engine is the processor of formulation from given input to an output. It fires relevant control rules. Knowledge base contains rules base and is constructed by a collection of fuzzy rule as if-then. It can be express as Mamdani (max-min) linguistic fuzzy model. The Supervisory fuzzy rule can be specified as: If e is A, and de is B then output variablesK_p, K_i and K_d is C, D, E respectively. Finally the defuzzifier converts fuzzy output domain into the crisp domain. Here, the centroid/center of area method is used for defuzzification.

The principle for design fuzzy rule is dependent of the characteristic of the controller. This can play rule to improve the performance of the system in transient and reduce the error. The fuzzy rule can be generalized according to the practical experience or opinion of expert. The rule base used in this system is in the form of multi-input-multi-output (MIMO). These rules must be selected to guarantee a system with small rise time and small overshoot and no error steady state. These rules base look-up table of K_p, K_i and K_d used in this system are shown in Table 1, Table 2 and Table 3 respectively.

Table 1. Fuzzy Rule for K_p

		Change of Error(De)						
		NB	*NM*	*NS*	*Z*	*PS*	*PM*	*PB*
Error(E)	*NB*	B	B	B	B	B	B	B
	NM	B	B	B	B	B	B	S
	NS	B	S	B	B	S	S	S
	Z	S	S	S	B	S	S	S
	PS	S	S	B	S	S	S	S
	PM	B	B	B	S	S	S	S
	PB	B	B	B	S	S	S	S

Table 2. Fuzzy Rule for K_d

		Change of Error(De)						
		NB	*NM*	*NS*	*Z*	*PS*	*PM*	*PB*
Error(E)	*NB*	B	S	S	S	S	S	S
	NM	B	B	B	B	B	B	B
	NS	B	B	B	B	B	B	B
	Z	B	B	B	B	B	B	B
	PS	B	B	B	B	B	B	B
	PM	B	B	S	B	B	B	B
	PB	S	S	S	B	B	B	B

Table 3. Fuzzy Rule for K_i

		Change of Error(De)						
		NB	*NM*	*NS*	*Z*	*PS*	*PM*	*PB*
Error(E)	*NB*	B	B	B	S	S	S	S
	NM	M	M	S	S	S	M	M
	NS	B	M	M	M	M	M	B
	Z	B	B	M	M	M	B	B
	PS	B	M	M	S	S	S	S
	PM	B	M	S	S	S	M	M
	PB	S	S	S	S	S	S	S

For the initial condition when error (e) is positive big or positive medium, while the error decreases (change of error (de) is negative), so we need move toward the desire response as fast as possible by select K_p is big (B).If the actual output get near by the set input (error (e) is positive small), and the error decreases (change of error (de) is negative),then we need to select $K_p$is small(S) to prevent output from be higher than set input and select K_d is big(B) to reduce the oscillation around the set input. To eliminate the offset between desired and actual, integral gain $K_i$is used in this case. When the actual output becomes higher than desire set input (error becomes negative (NB, NM), while change of error is negative. That means error becomes more negative and causes actual output increase and will become higher. To prevent this case, we need to increase K_p by big value (B) and select K_d big to prevent oscillation and reduce overshoot.

RESULT & DISCUSSION

The simulations are carried out on the PPDCV model given by differential equations which are put together in MATLAB's function with Simulink block diagram format as shown in Figure 11.

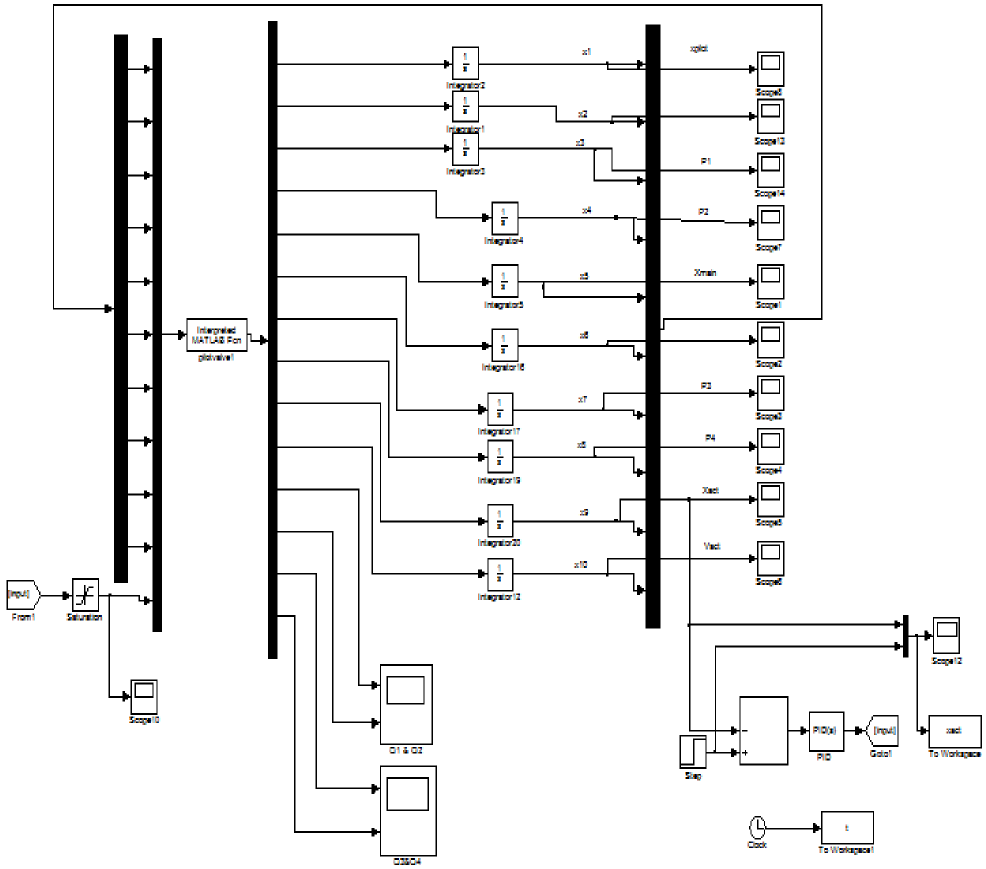


Figure 11. Simulation Block Diagram of PPDCV

The values of the system and observer parameters are given in Table 4. These parameters are used for the dynamic models of the hydraulic system involved designing, control algorithm and the selecting a model structure, choosing a criterion to fit.

Table 4. Physical parameters for PPDCV system

Parameter Name	*Parameter Symbol*	*Parameter Value*	*Unit*
Width of the pilot valve port	w_{pil}	0.001	m
Supply pressure to the pilot valve	p_{s1}	$3 * 10^6$	Pa
Natural frequency of the pilot valve	w_n	120.4	rad/s
Pilot valve gain	k	$4.9e-4$	m/V
Damping coefficient of the pilot valve	ξ	0.7	
Width of the main valve port	w_{main}	0.008	m
Effective bulk modulus	β	$680 * 10^6$	Pa
Hydraulic fluid density	ρ	870	kg/m^2
Pilot Valve coefficient of discharge	c_{dpil}	0.6	
Main valve stroke length	s_{main}	± 15	mm
Area of the main valve	A_{main}	$4 * 10^{-4}$	m^2
mass of the main valve	M_{main}	1.75	kg
Width of the main valve port	w_{main}	0.008	m
main valve coefficient of discharge	c_{dmain}	0.6	
Main valve Viscous damping coefficient	b_{main}	70	N. s/m
Main valve stiffness	k_{main}	700	N/m
Supply pressure to the main valve	p_{s2}	$5 * 10^6$	Pa
Actuator stroke length	s_{act}	0.13	m
Actuator piston area	A_{actA}	0.038	m^2
Actuator annulus area	A_{actB}	0.0192	m^2
Rod actuator mass	M_{act}	50	Kg
Actuator Viscous damping coefficient	b_{act}	8500	Ns/m
Actuator stiffness	k_{act}	900	N/m

In order to perform the output response, we used two different types of the controller. These types are PID controller and fuzzy supervisory controller (FSC). Each type of the controller should be submitted to the two types of input signal. These signal types are step input and sinusoidal input with no system parameters variation. The main subject of the controller is that the actual output of the actuator position tracks the desired input with best performance.

First a closed loop feedback with PID controller is simulated to make the output of the actuator position is tracking with desire step input position that amplitude value is 65 mm as show in Figure 12. The PID controller parameters that obtained previously were implemented on this test.

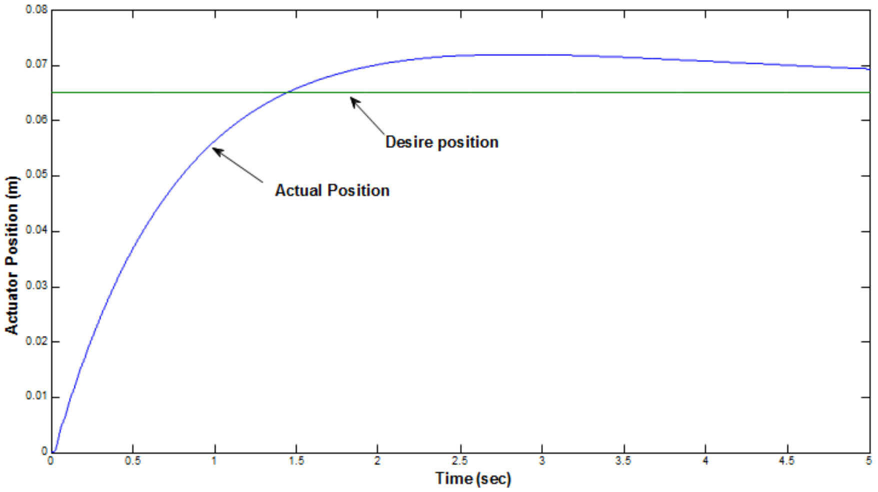


Figure 12. Step response of PPDCV with PID controller

From this Figure, we can see that the convergence between the actual outputs of the actuator position to the desired position is good with small delay in the setting time and minimum overshot.

When FSC is used instead of PID in the same step input, it shows fast response, accurate because this controller can tune PID parameters online according to the error (*e*) and change of error (*de*). This response is illustrated in Figure 13.

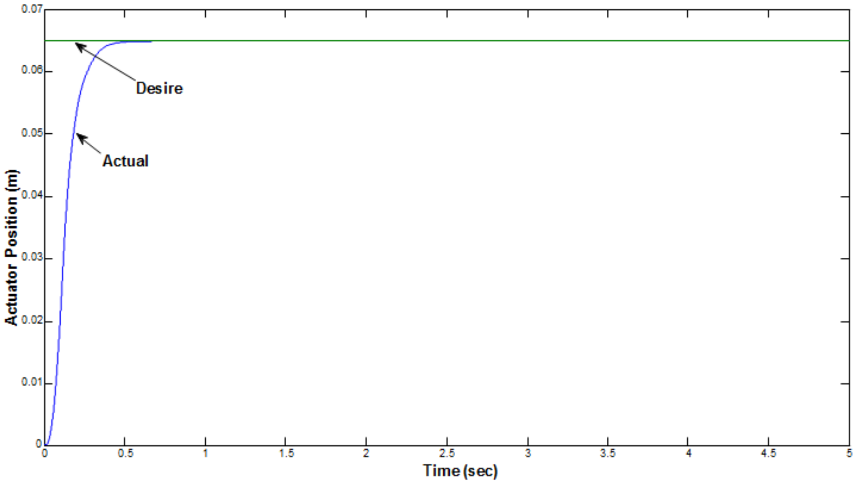


Figure 13. Step response of PPDCV with FSC controller

Second, a sinusoidal input with peak to peak amplitude of 65 mm and PID controller is used to ensure that the piston, and consequently the plant actuator, moved through the greater part of its trajectory as show in Figure 14. It can show good response and convergence between reference and actual output.

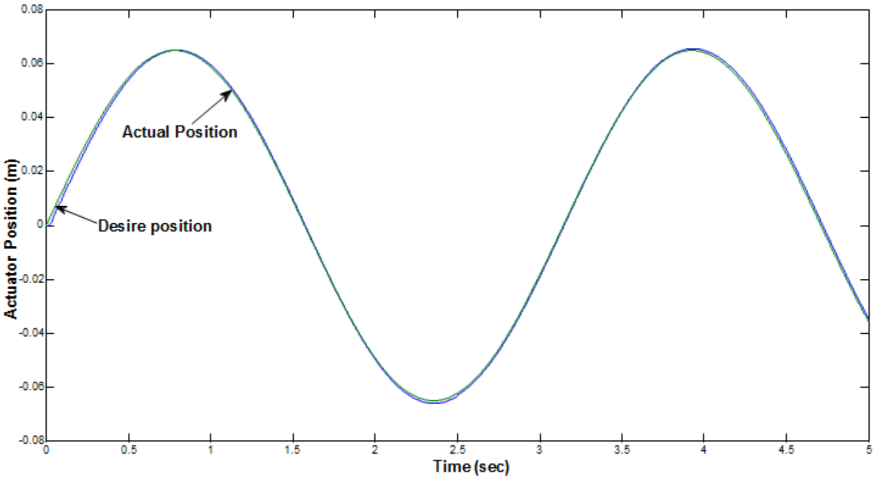


Figure 14. Sinusoidal response of PPDCV with PID controller

When FSC is used instead of PID in second case with same sinusoidal input as shown in Figure 15, It can show that the performance is similar to the performance when used PID controller.

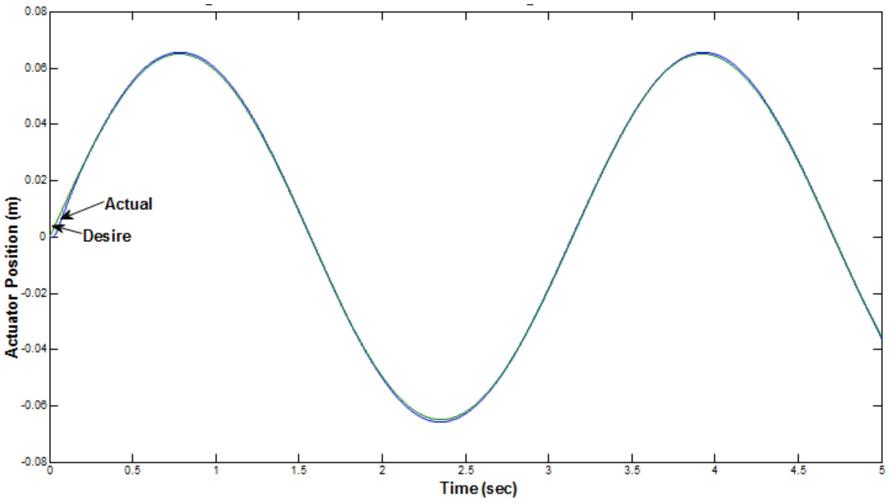


Figure 15. Sinusoidal response of PPDCV with FSC controller

To evaluate the robustness of both types of the controller in controlling the position of PPDCV at different condition that probably happen. The PPDCV is subject to the variation of the pressure sources parameter that occasionally happens and considers of the main problems in system. For variation of pressure source parameter, the pressure of the pilot valve will become (5 MPa) and the pressure of the main valve will become (7 MPa). We must show the effect of this parameter variation on the performance of the system using step input and sinusoidal input.

When using step input with PID controller such as the first case but with parameter variation of the pressure, it can be show that the actual output has disturbance as shown in Figure 16.This disturbance is eliminated when using FSC controller as show in Figure 17.

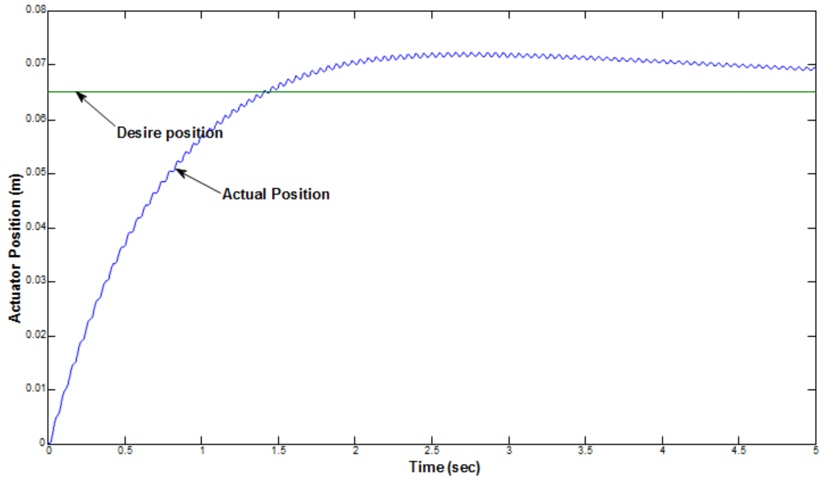


Figure 16. Step response of PPDCV with PID controller with parameter variation

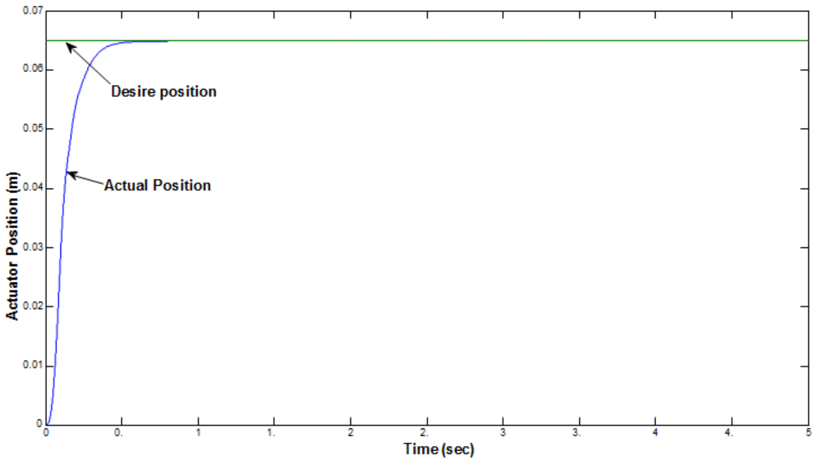


Figure 17. Step response of PPDCV with FSC controller with parameter variation

To evaluate a robust of these types of the controller, a sinusoidal input also used with PID and FSC. It can be shown that PID controller has disturbance while FSC has no disturbance as shown in Figure 18 andFigure 19 respectively.

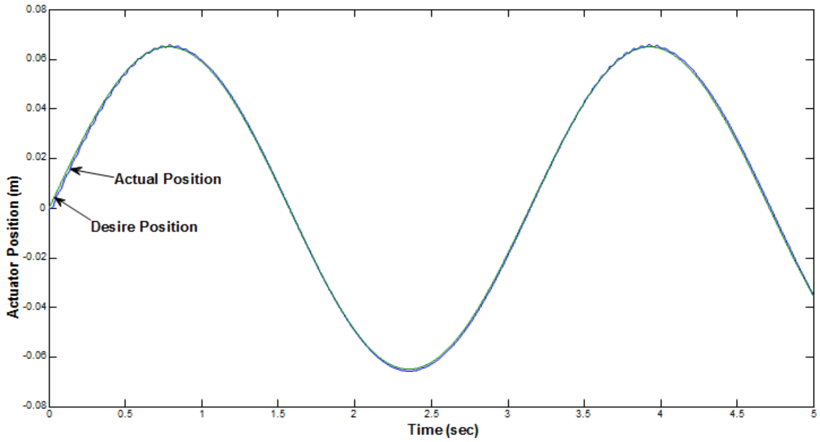


Figure 18. Sinusoidal response of PPDCV with PID controller with parameter variation

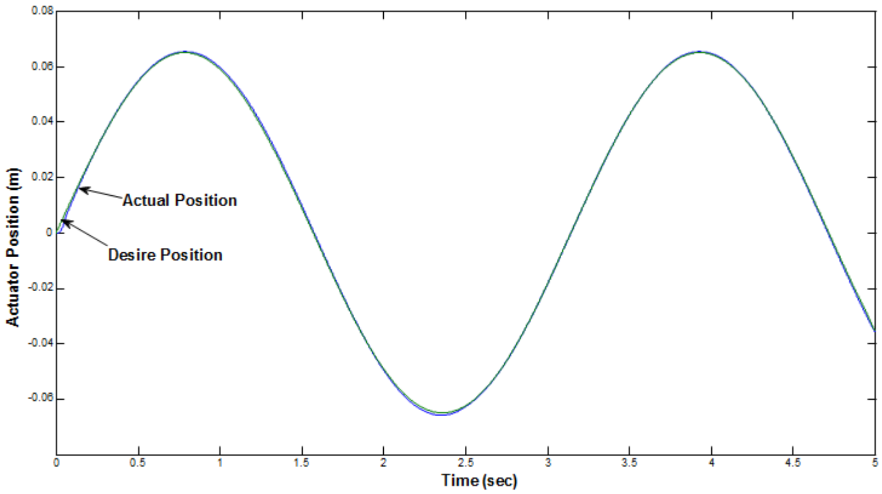


Figure 19. Sinusoidal response of PPDCV with FSC controller with parameter variation

FSC tune PID parameters online during process operation and eliminate the disturbance, so the response of the variation parameter condition is maintained to be similar as the response in the nominal working condition.

CONCLUSION

This research has deal with PPDCV technique that is used in a high power for hydraulic actuators especially in practical applications. Nonlinear mathematical model of PPDCV system has been derived, which has been used in simulation studies for the system dynamic behavior and for controlling.

The actuator position of PPDCV is controlled by fuzzy supervisory controller (FSC) instead of PID controller. PID controller deal with linear system and limited while FSC is used to realize nonlinear system and uncertainty parameters. The parameter variation of the system includes pressure source variation that occasionally happens. When PID controller is used, it will cause a disturbance which considers the main problem happen in the system. The disturbance could harm mechanical component of the system and reduced their life cycles of PPDCV system.

FSC has robustness to the parameters variation of the system. It will eliminate the disturbance that considers the main problem in the PPDCV. The simulation results explain that FSC better performance than PID. The results in the step response simulation always show that FSC controller is better than PID.

Summery, PID could be acceptable in the step and sinusoidal response, but it isn't acceptable when pressure system variation. FSC will satisfy the performance without disturbance through a wide range of operation and variation of the parameters. This performance represents the fast rise time, low overshoot, no disturbance and best tracking precision.

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