Modeling and Simulation Research Position Control of Hydraulic Cylinder using High Speed on/off Valve is Based on the Method PWM (Pulse Width Modulation) of Control Pulse

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Abstract

Application of high speed on/off valve in hydraulic cylinder position control was researched in this paper. A hydraulic circuit is proposed to position control hydraulic cylinder. The duty cycle of pulse control signal is changed according to the displacement of the hydraulic cylinder. Model of high speed on off valve and hydraulic circuit were simulated in Matlab Simulink. The Position and speed curve of hydraulic cylinder were achieved by the means of simulation. The simulation curves show the application ability of high speed on/off valve to position control of hydraulic cylinder and the ability to replace the hydraulic proportional valve.

Keywords: Hydraulic, Position Control, high speed On/off Valve, PWM

1. Introduction

High speed on off valve (HSV) has the advantages of low-cost, compact structure, excellent repeatability, high speed responsibility and the ability to be adjusted by pulse, etc [**1**]. Especially it can be used as the interface between electronic control and fluid flow by pulse control which will be used widely.

In this paper, the hydraulic circuit scheme based on high speed on off valve to control the position of hydraulic cylinder on the analysis of flow characteristics of high speed on off valve was established. The method of PWM signal was applied to generate the control signal. [**2**]

The duty cycle of the PWM signal was changed according to the displacement of the hydraulic cylinder. Simulated research was done based on this scheme, a study of position control in hydraulic cylinder using high speed on off valve was carried out.

2. Hydraulic Circuit Design

The hydraulic circuit in which the position of hydraulic cylinder is controlled directly by HSV was designed. Displacement sensor is installed along a vertically hydraulic cylinder. The displacement signal was used as a basis signal of function to generate the duty cycle of pulse control signal. The hydraulic circuit was shown in Fig. 1.

In this paper, the hydraulic pump was used as a constant flow hydraulic pump. Flow from the system into the hydraulic cylinder chambers was controlled by high speed on off valve. The opening time of HSV was controlled by PWM control pulse, in which the duty cycle of PWM control pulse was changed depending on the displacement of cylinder.

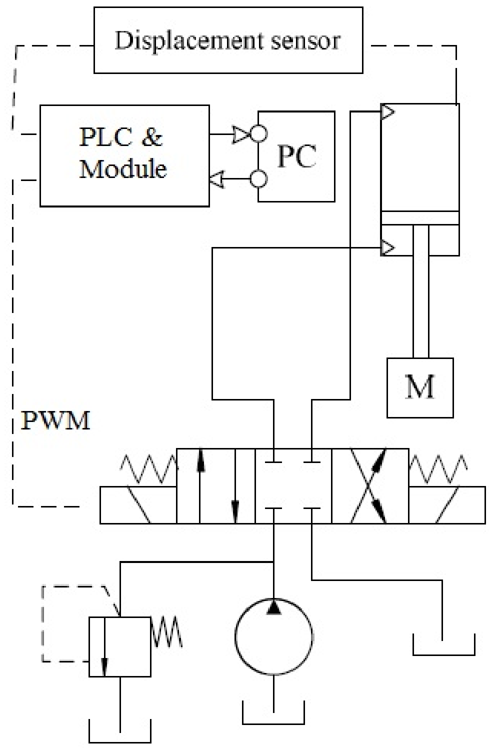

Fig. 1. Hydraulic control circuit

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3. Control Signal Design

HSV is controlled by PWM signal which was produced according to the displacement signal of piston. The duty range of the PWM signal is 25% to 100%. The duty cycles are designed for this circuit, as shown in Eq.1.

$$\boldsymbol{\tau = 0.25 + \frac{e}{\lambda}} \quad (1)$$

Where τ is the duty cycle of PWM signal; e is the displacement error of piston. λ is coefficient of displacement.

4. Mathematical Modeling of HSV

The spool displacement of HS is a function of the pulse width modulation signal (PWM signal) and was determined by the on off characteristics of high speed on off valve and its mathematical model. This function is shown as Eq.2:

$$\overline{\mathrm{xhsv}} = \begin{cases} 0 & \mathrm{T} \in [0, \mathrm{T}_1) \\ \frac{1}{2}\left(\frac{\mathrm{T}_2 + \mathrm{T}_4}{\mathrm{T}_2{}^2}\right)\left(\mathrm{T} + \mathrm{T}_{yc1} - \mathrm{T}_1\right)^2 \mathrm{x}_{vm} & \mathrm{T} \in [\mathrm{T}_1, \mathrm{T}_{12}) \\ \left[\left(\frac{\mathrm{T}_2 + \mathrm{T}_3}{\mathrm{T}_2}\right)\mathrm{T} - \mathrm{T}_1 - \frac{\mathrm{T}_2}{2} + \frac{\mathrm{T}_4}{2} - \frac{\mathrm{T}_1\mathrm{T}_3}{\mathrm{T}_2}\right]\mathrm{x}_{vm} & \mathrm{T} \in [\mathrm{T}_{12}, \mathrm{T}_{on}) \\ \left(\mathrm{T} + \mathrm{T}_3 - \mathrm{T}_1 + \frac{\mathrm{T}_4 - \mathrm{T}_2}{2}\right)\mathrm{x}_{vm} & \mathrm{T} \in [\mathrm{T}_{on}, 1 - \mathrm{T}_{off}) \\ \left(\mathrm{T} + \mathrm{T}_3 - \mathrm{T}_{yc2} + \frac{\mathrm{T}_4 - \mathrm{T}_2}{2}\right)\mathrm{x}_{vm} & \mathrm{T} \in [1 - \mathrm{T}_{off}, \mathrm{T}_{34}) \\ \left[1 - \frac{\left(\mathrm{T} + \mathrm{T}_3 - \mathrm{T}_{yc2} - 1\right)^2}{2\mathrm{T}_4} - \frac{\mathrm{T}_2\left(\mathrm{T} + \mathrm{T}_3 - \mathrm{T}_{yc2} - 1\right)^2}{2\mathrm{T}_4^2}\right]\mathrm{x}_{vm} & \mathrm{T} \in [\mathrm{T}_{34}, 1 - \mathrm{T}_3) \\ \mathrm{x}_{vm} & \mathrm{T} \in [1 - \mathrm{T}_3, 1] \end{cases} \quad (2)$$

Where, T is the duty of the pulse signal; T_1 is delay-closed time; T_2 is move-closed time; T_3 is delay-released time; T_4 is move-released time; x_{vm} is maximum displacement of spool valve.

$T_1=t_1/T$; $T_2=t_2/T$; $T_3=t_3/T$; $T_4=t_4/T$; $T_{yc1}=(T-T_1)T_3/T_2$; $T_{yc2}=(1-T-T_3)T_1/T_4$; $T_{12}=T_1+T_2^2/(T_2+T_3)$; $T_{34}=1-T_3-T_4^2/(T_1+T_4)$; $T_{on}=T_1+T_2$; $T_{off}=T_3+T_4$;

The area of valve opening is shown as Eq.3:

$$\overline{\mathbf{A_{hsv}}} = \frac{\boldsymbol{\pi} \mathbf{D}\overline{\mathbf{x_{hsv}}} \mathbf{sin(2\boldsymbol{\theta})}}{\mathbf{2}} \quad (3)$$

wwhere, $\overline{A_{hsv}}$ is the average valve port area of HSV; D is the diameter of valve ball; θ is the half-angle of valve seat; $\overline{x_{hsv}}$ is the average displacement of valve ball.

The flow that goes through the high speed on off valve is shown as Eq.4:

$$\mathbf{Q_{hsv} = C_d\overline{A_{hsv}}\sqrt{\frac{2(p_y - p_w)}{\boldsymbol{\rho}}}} \quad (4)$$

Where, Q_{hsv} is the flow that through HSV; C_d is the flow coefficient; p_y, p_w are the pressure of rod and no-rod cavity; ρ is the oil density.

Mathematical Modeling of Hydraulic System:

The dynamic mathematical equation of the mechanical system and the dynamic mathematical equation of the hydraulic system are shown as Eq.5 - Eq.8:

$$\mathbf{m\ddot{x} = p_yA_y - p_wA_w + mg - \boldsymbol{\beta}_c\dot{x}} \quad (5)$$

$$\mathbf{\frac{dp_y}{dt} = \frac{\boldsymbol{\beta}_e}{V_{y0} + A_yx}\left(Q_{hsv} - Q_x - A_y\dot{x}\right)} \quad (6)$$

$$\mathbf{\frac{dp_w}{dt} = \frac{\boldsymbol{\beta}_e}{V_{w0} - A_wx}(Q_x - Q_{out} + A_w\dot{x})} \quad (7)$$

$$\mathbf{Q_x = k_c(p_y - p_w)} \quad (8)$$

Where, m is the load mass; A_y is the area of piston in rod cavity; A_w is the area of piston in no-rod cavity; β_c is viscous damping coefficient of oil; g is the gravity acceleration; V_{y0} is the initial volume of rod cavity; β_e is elastic modulus of oil; Q_{hsv} is the flow that flows into th

e rod cavity; Q_x is the leakage flow from rod to no-rod cavity; V_{w0} is the initial volume of no-rod cavity; Q_{out} is the flow that flows out of no-rod cavity; k_c is the leakage flow coefficient.

Table 1. Simulation Parameters

Parameters	Values	Units
A_y	0.000012	m^2
A_w	0.00002	m^2
m	9	kg
β_e	7×10^8	N.s/m
β_c	250	N.s/m
k_c	1.25×10^{-13}	$m^5/(N.s)$
ρ	850	kg/m^3
x	0.2	m
Adjustment pressure of relief valve	3.5	MPa
Maximum displacement of HSV (x_{vm})	0.0013	m
Diameter of valve ball (D)	0.005	m
Half angle of valve seat (θ)	20	deg

5. Simulation Verification

The Simulation parameters of the system are shown in the Table 1.

The dynamic character parameters of HSV are show in the table 2.

Table 2. Dynamics Parameters of HSV

Parameters	Values	Parameters	Values	Parameters	Values
t_1	2	t_2	2.6	t_{on}	4.6
t_3	0.5	t_4	4.1	t_{off}	4.6

The Simulation Model is shown in Fig.2:

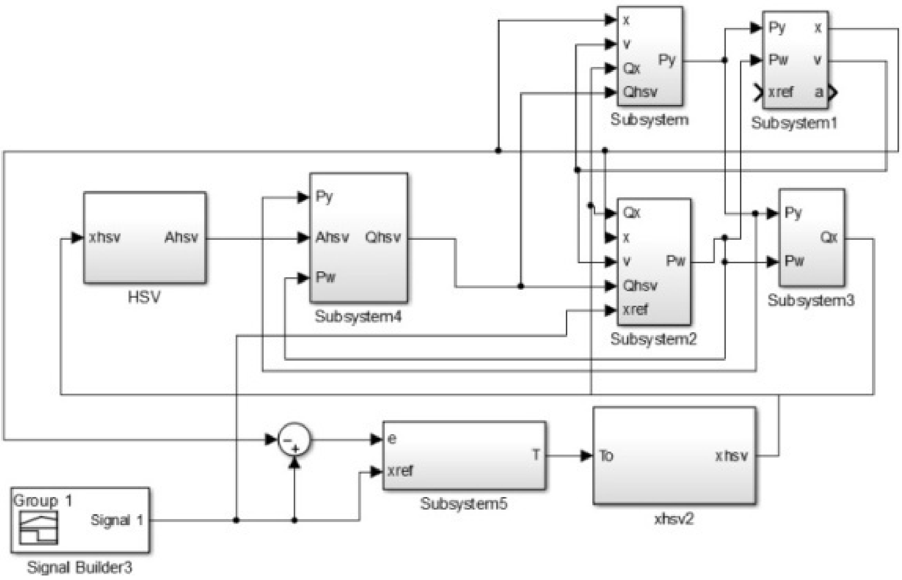

Fig. 2. Simulink Model of hydraulic system

The simulation results are shown in Fig 3 -6:

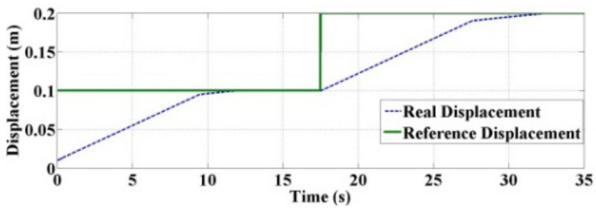

Fig. 3. Displacement curve of piston

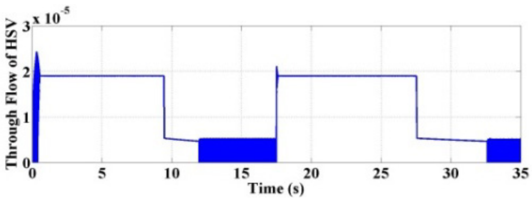

Fig. 5. Through flow of HSV curve

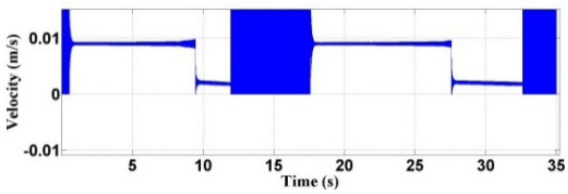

Fig. 4. Speed curve of cylinder

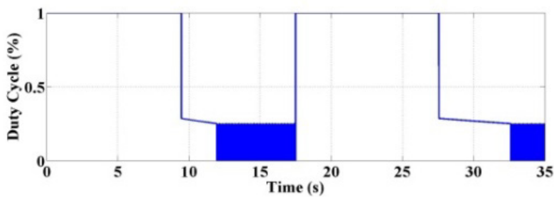

Fig. 6. Curve of the duty cycle

Figure 3 shows that with different present position of the hydraulic cylinder, the simulation result is close to this reference signal with small error. Figure 4 shows the speed of the hydraulic cylinder and figure 5 shows the through flow of HSV. In figure 6, the duty cycle of the control signal is shown. Simulation results show in the first step that the hydraulic cylinder position control can be achieved by HSV using the PWM method of control signal. The duty cycle of control signal was changed according with the displacement of the piston.

6. Conclusion

The research result shows that HSV has the better control effect on the position control of hydraulic cylinder, and the given upper hydraulic circuit is suitable to the small flow system.

Acknowledgments

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