Research on Simulation Analysis of Valveless Hydraulic Servo System

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Abstract. The hydraulic transmission technology is widely used in the industrial field. With the continuous development of microelectronic technology, valveless electro-hydraulic servo technology came into being. Aiming at the problems such as slow response speed and poor displacement tracking accuracy, this paper builds a simulation model of the forward and reverse displacement of the valveless electro-hydraulic servo system, and uses AMESim and simulink software to build the hydraulic part simulation and motor part simulation of the system respectively. A fuzzy PID controller is introduced and simulation is performed with the addition of the fuzzy PID controller to improve the overall performance of the valveless electro-hydraulic servo system.

1. Introduction

As basic parts, hydraulic systems have been widely used in construction machinery, agricultural machinery, aircraft and other equipment. Where hydraulic systems are required, high power is usually required to complete the required work, such as moving materials or lifting weights. The power of these drives is usually generated by a centralized source, usually an internal combustion engine or a high-power motor. Using a fluid power system, power is easily distributed to linear or rotary drives through hydraulic lines [1]. Valveless hydraulic circuits (pump-controlled hydraulic circuits) are more efficient than valve-controlled hydraulic circuits. The pump-controlled hydraulic circuit pointed out by Cleasby and Plummer only consumed 11% of the energy required by the valve-controlled hydraulic circuit to perform the same task [2]. In addition, valve-controlled hydraulic circuits have better dynamic performance. The throttle loss of the valve is one of the main energy losses of the valve-controlled hydraulic circuit currently used in these machines. In order to reduce the energy loss caused by throttling, load sensing technology has been widely used in the field of hydraulic control [3, 4]. However, in a typical excavator, the valve-controlled hydraulic system equipped with load sensing technology still accounts for 35% of the total energy consumption [5]. Because the valveless electro-hydraulic servo system has a larger gap than valve-controlled hydraulic pressure in terms of high precision control, response speed and stability, especially with the continuous progress of society, industrial production has proposed precision control, response speed and stability. In order to meet higher requirements, this paper proposed a valveless electro-hydraulic servo system verified with its simulation.

2. Theoretical calculation and modelling of valveless electro-hydraulic servo system

The valveless electro-hydraulic servo system proposed in this paper mainly includes five parts, namely the load part, the hydraulic transmission part, the servo motor speed regulation part, the PC-side
control part and the signal feedback part [6]. Among them, the hydraulic transmission part is composed of an asymmetric horizontal bar hydraulic cylinder and a two-way quantitative gear pump; The PC-side control part is mainly composed of the master control system software and PCI industrial control card; The servo motor speed control part includes the AC permanent magnet synchronous motor and the Servo driver [1]; the signal feedback part is mainly composed of a displacement sensor, two pressure sensors and a data acquisition card. Figure 1 is the structural block diagram of a valveless electro-hydraulic servo system.

In this paper, the Anchuan SGMGV type motor was used to build the experimental platform. The PMSM was used as the research object to establish a mathematical model. For ease of analysis, iron loss, hysteresis loss, eddy currents, pace harmonics and magnetic saturation are neglected. In this case of distribution, the inductance of equivalent in the coordinated system dq is symmetrical (Ld=Lq=L) when the rotor of the lasting magnet synchronous motor is cylindrical, such as the rotor flux linkage is directional control.

3. Research on Fuzzy PID control of hydraulic position servo system

In this paper, the fuzzy PID control strategy is introduced into the system, and a simulation system platform based on the control system software Simulink and the widely used software AMESim in the hydraulic field is built.

3.1. Simulink-AMESim joint simulation platform

For the construction of hydraulic modules, hydraulic libraries, mechanical libraries, control libraries and other modules are generally used. The hydraulic library brings together the most commonly used hydraulic components, such as pumps, motors, holes, etc., including special valves and complex types of pipes and hoses [2]. The mechanical library provides a large number of basic mechanical components, which are combined together to model various one-dimensional mechanical power systems. The mechanical library can handle a large number of applications, from simple movements of rotating loads to complex phenomena such as friction or collision. The signal and control libraries contain signal or block components, making it possible to build block diagram models [7]. The block diagram model represents the dynamic physical system graphically, and can also be used to generate complex signals to guide the physical system. As shown in Figure 2, and according to the design requirements of the valveless electro-hydraulic servo system, this article builds the platform of the hydraulic part of the system in AMESim software.
Figure 2. Simulation platform of hydraulic part of valveless electro-hydraulic servo system. 
(1- S-function function module; 2- Biaxial rotary load module; 3- Rotation speed sensor module; 4- Torque sensor module; 5- Quantitative pump; 6- Oil tank; 7- Hydraulic check valve; 8- Minute Segment linear signal source module; 9- Signal/force conversion module; 10- Displacement sensor; 11- Single rod asymmetric hydraulic cylinder).

The construction of the simulation platform of the motor part is mainly based on Simulink software. The construction content mainly includes permanent magnet synchronous motor module, motor control algorithm module and fuzzy PID control module. For the permanent magnet synchronous motor module, the vector control algorithm with id = 0, which is the best control for the permanent magnet synchronous motor with permanent magnets on the stator surface is selected. According to the design requirements of the valveless electro-hydraulic servo system, the system motor platform was built in Simulink software, as shown in Figure 3.

Figure 3. Motor part simulation platform of valveless electro-hydraulic servo system. 
(1- S-function function module; 2- Permanent magnet synchronous motor module; 3- Vector control algorithm module with id = 0; 4- Fuzzy PID module; 5- Command input module).

Simulink is implemented through the S function module in and Simulink interface module in AMESim. The two modules can communicate with each other across the software, so as to connect the control model and hydraulic model of the two software to realize the joint simulation of the system. Using SIMULINK simulation platform can easily realize the tracking error and steady-state error analysis. This tracking error and steady-state error analysis is actually made by adding the tracking error calculation link on the basis of the analysis of the system's time domain characteristics.

3.2. Fuzzy PID controller design

PID controller has the advantages of simple structure, clear function and easy implementation, and has been widely used in the field of industrial control [8,9,10]. It is hard using the traditional PID controller to accomplish the desired outcome, which is due to the effects of the time varying factors and non-linear in the system of valveless hydraulic. For these reasons, this paper the traditional PID controller is replaced by using adaptive fuzzy PID controller. The fuzzy PID controller is to adjust the parameters of PID control via the rate of aberration change ec and the aberration e, thus to
continuously adjust the speed of motor, thereby a high accuracy control of position is obtained. Here, the basic principle diagram of the fuzzy PID controller is shown in Figure 4.

![Figure 4. Fuzzy PID controller.](image)

The fuzzy controller in Figure 4 is mainly composed of three parts. They are as follow:

**Fuzzification:** Turn the input value into the input quantity required by the fuzzy controller, and then find its fuzzy quantity according to the scope of the universe in the fuzzifier, and express it with the corresponding fuzzy quantity.

**Database:** Mainly contains the membership function of each linguistic variable and the control law of fuzzy control.

**Fuzzy reasoning:** According to fuzzy set theory, the mathematical logic of general set theory is inferred which is the core of the fuzzy controller.

Linguistic variables are the control objects of fuzzy control. Each language object has a corresponding level of language description, and different discourse domains are the intervals of language variables. According to the principle and structural characteristics of the valveless electro-hydraulic servo control system, this paper takes the displacement error value \( e \) and deviation change rate \( ec \) of the hydraulic cylinder as input variables, and divides them into seven levels, namely \{NB (negative large), NM (negative) Medium), NS (negatively small), ZO (zero), PS (positively small), PM (positively medium), PB (positively large)\}, the value of its domain is \{-1, -0.2, -0.1, 0, 0.1, 0.2, 1\}.

Generally, the choice of membership function is usually selected by experienced engineers or based on statistics and experience. Commonly used methods are empirical method, typical function method, and fuzzy statistical method, etc., this article uses triangle membership function. According to the characteristics of the hydraulic system in this article, the output is divided into five levels: SS, MS, MM, BM, BB, and its theoretic value is \{0, 0.2, 0.4, 0.6, 0.8, 1\}.

When establishing fuzzy PID control rules, it needs to be set according to the characteristics of the controlled object. This article is to avoid these negative features through fuzzy PID for these negative features. Conventional PID control is difficult to make the system avoid these situations. In order to obtain better system effects, this article uses fuzzy PID controller, which is a kind of change PID parameters according to different conditions and has achieved the effect of adapting to the best state of the system.

![Figure 5. Simulation results of step response of PID and fuzzy PID.](image)
3.3. Analysis and Simulation of position tracking and step responses

Aiming at the system proposed in this paper, using Matlab simulink software, fuzzy PID controller and PID controller are proposed including the valveless electro-hydraulic servo design respectively, and the joint simulation platform built in the previous article is used for experiment and analysis. In the valveless hydraulic system, the closed-loop position system results of the step response simulation using the fuzzy PID and PID controller are illustrated in Figure 5.

![Figure 5](image1.png)

Figure 5. The Results of the step response simulation using the fuzzy PID and PID controller.

We can see that the speed of step response of the used closed-loop PID position controller system enlarges as KP and Ki are increased, and the error of the steady state diminishes when Kd is decreased, but overshoot and vibration will occur, which will make the modification time extend. Thereby, using conventional PID controller to adjust the conflicts between adjustment time and response speed is hard. Nevertheless, using the fuzzy PID controller parameter adjustment strategy can achieve optimization between adjustment time, the accuracy of the steady state and response speed. Figure 6 shows the simulation experiment result of the curve-tracking controller when applying the traditional and fuzzy PID controllers, respectively.

![Figure 6](image2.png)

Figure 6. The Results of the curve tracking control under the traditional and fuzzy PID controller.

As illustrated in Figure 6, a lag occurs within the output displacement of the hydraulic system controlled by the traditional PID and fuzzy PID and the tracking target. To easily compare the performance of these two methods, the tracking target phase is ideally delayed (as shown by the dotted line in Figure 6). To achieve the prime position of the tracking curve, the traditional PID needs to delay 0.09s, but the fuzzy PID demands only 0.05s to delay which proves that the fuzzy PID control can eliminate the system's time lag problem more advanced than the traditional PID.

![Figure 7](image3.png)

Figure 7. The error results of curve tracking control under the traditional and fuzzy PID controller.
Figure 7 shows that the error amplitude of the fuzzy PID reaches 10mm, while the traditional PID error curve reaches 20mm. And the maximum error of lag when using traditional PID was eliminated to 8mm, while using fuzzy PID it was eliminated to 5mm. Those futures illustrate that in terms of curves tracking accuracy and slowing down of the time lag in the hydraulic system, the fuzzy PID control is better than the conventional PID.

![Figure 8](image)

Figure 8. Speed variation of hydraulic system under different pipe diameters and speeds.

4. Simulation analysis of hydraulic pipeline characteristics based on AMESim

4.1. Selection of pipeline model and hydraulic pump model
Considering that the actual tubing length is about 1.5 meters and the pipeline diameter is about 18 millimeters, combined with the actual situation of the built simulation platform, the frequency-dependent friction pipeline model HL004 is selected as the pipeline model in this chapter. For the selection of hydraulic pump module, it is relatively easy. According to the bidirectional gear pump selected by the hydraulic platform, select the PEG02 module in the AMESim library.

4.2. Analysis of pipeline inner diameter to pipeline and system stability
The research object of this chapter is the hydraulic pipeline. Under the condition of not passing, different hydraulic pipeline connections are used when designing the hydraulic platform to achieve more precise control of the system. The pipe diameters of 20mm, 15mm, and 10mm were selected for simulation experiments, and the operation status of the hydraulic cylinder was analyzed under different gear pump speeds, that is, different flow pulses. Considering that the rated speed of the motor is between 800 and 1800r / min, six speeds are selected for analysis in this paper, as shown in Figure 8.

![Figure 9](image)

Figure 9. Operating speed of different pipe diameters.
As shown in Figure 9, the 10mm pipe diameter has been maintained at an operating speed of around 8 mm/s. With the increase of the speed, the operating speed has not increased but decreased slightly. When the 15mm pipe diameter is 1400 r/min, the pipeline reaches the limit of 20mm has not been reached in all speeds. As shown in Figure 9, the 10mm pipe diameter has been maintained at an operating speed of around 8 mm/s. With the increase of the speed, the operating speed has not increased but decreased slightly. When the 15mm pipe diameter is 1400 r/min, the pipeline reaches the limit of 20mm has not been reached in all speeds. The increase in speed must ensure that the oil pipe diameter meets the flow rate caused by the increase in speed. Otherwise, not only will the hydraulic operating speed not be increased, but the pipeline will also be increased as well as increasing the friction resistance. As shown in Figure 10, the smaller the diameter of the pipe, the greater the instability of the hydraulic movement, but the fluid and the pipeline are very complicated. This relationship will continue to be studied separately and validated on the platform.

4.3. Analysis of length and system stability of pipeline and system

In this subsection, the tube length is 0.5 meters, 1 meter and 2 meters are used for simulation experiments, and the operation status of the hydraulic cylinder is analyzed under different gear pump speeds, that is also called different flow pulses. Considering that the rated speed of the motor is between 800 and 1800 r/min, six speeds are selected for analysis in this paper, as shown in Figure 11 below.

As shown in Figure 11, (a), (b), (c), (d), (e), (f) are the motor speeds at 800, 1000, 1200, 1400, 1600, and 1800 r/min, respectively. Due to the changes in the operating speed of hydraulic cylinders and through data processing, as shown in Figure 12, the average speed of hydraulic cylinders with different tube lengths at different speeds is shown. This article found that the length of the pipe has little effect on the hydraulic operating speed, but it is still not obvious that the shorter the pipeline, the
smaller the loss in speed, and the faster the hydraulic platform speed is at the same motor speed. As shown in Figure 13, the stability of the operation of the hydraulic cylinder under three different tube lengths was shown. It was found that the extension of the pipeline can alleviate the shock of the hydraulic operation process, but the extension of the pipeline will inevitably increase the friction.

5. Conclusion
In the proposed article first the valveless electro-hydraulic servo system is introduced with simulation model. Combined with the control problems of valveless electro-hydraulic servo system, the fuzzy PID-controller algorithm is introduced into it, and the simulation analysis is carried out in the joint simulation software. For the existing periodic dynamic position error, the system pipelines and pumps are simulated and analyzed. Simulation experiments show that the mathematical model and simulation results are close to the actual working conditions, which can meet the analysis needs of different hydraulic servo control system load characteristics, and improve the efficiency of hydraulic system simulation modelling.

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