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Optimization of Variable Frequency Hydraulic System of Filling Machine Based on Fuzzy Adaptive Control

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Abstract. Aiming at the problem that the variable frequency hydraulic system of a filling machine is high in nonlinearity and weak in stiffness, and the response speed of ordinary PID control is slow, the fuzzy adaptive control strategy is adopted to improve the system performance. Based on the joint simulation of AMESim and Matlab, the expert experience and the PID controller are combined by designing the fuzzy adjuster, so that the controller can automatically adjust the parameters according to the changes of the system working conditions, so as to improve the dynamic characteristics of the system.

1. Introduction

Variable frequency hydraulic transmission is a new type of transmission with electro-hydraulic combined control. The system consists of a frequency converter, an ordinary motor and a fixed pump. The frequency converter is used to adjust the speed of the motor, so that the flow rate can be adjusted by changing the speed of the pump. [1-3] Compared with the traditional throttle control technology, the variable frequency control can greatly reduce the throttling loss and overflow loss, and improve the energy utilization of the system. Therefore, the frequency conversion hydraulic technology has become a research hotspot. This paper aims at the performance problem of an automatic filling machine turntable frequency conversion hydraulic system.

2. Filling machine turntable frequency conversion hydraulic system

The automatic filling machine is a production equipment for liquid filling, in which the turntable is a device responsible for carrying the filling container and cooperating with the production work of the filling head. Due to the large inertia and large load torque, the large-scale filling machine turntable needs a large output torque for the drive unit. Considering the compactness of the whole machine, the size of the drive unit should not be too large. In addition, in order to meet the needs of different production beats and flexible production, the turntable drive system needs to have good speed regulation performance and stability. Therefore, the drive is provided by a variable frequency hydraulic system, which is composed as shown in FIG.1.



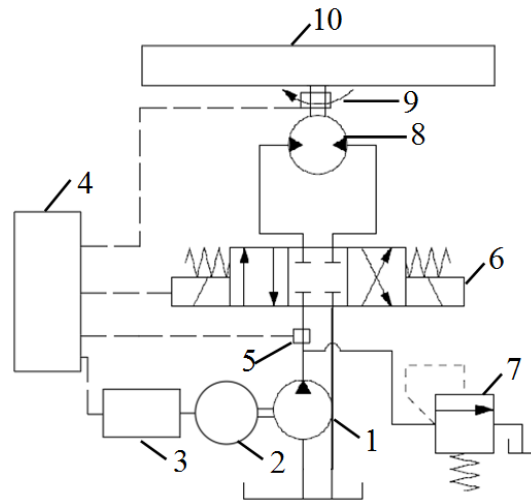


Figure 1. System schematic

1-hydraulic pump, 2-motor, 3-inverter, 4-controller, 5-pressure sensor, 6-directional valve, 7-relief valve, 8-hydraulic motor, 9-encoder, 10-turn

3. Variable frequency hydraulic system modeling

3.1. Variable frequency motor modelling

The inverter adopts the constant voltage frequency ratio control method, and the formula is:

$$f_1 = K_u u_c \quad (1)$$

f_1 - Power frequency;

K_u —voltage to frequency conversion factor;

u_c —the inverter control voltage;

$$U_1 = K_f f_1 \quad (2)$$

U_1 - Motor phase voltage;

K_f - Frequency voltage conversion factor;

Available from formula (1) and formula (2):

$$U_1 = K_f K_u u_c = K_1 u_c \quad (3)$$

Motor torque formula:

$$T_n = \frac{3m_p U_1}{2\pi f_1 R_2'} - \frac{m_p^2 U_1^2 n_p}{40\pi f_1^2 R_2'} = K_2 U_1 - K_3 n_p \quad (4)$$

m_p —the number of motor pole pairs;

n_p —the actual motor speed;

R_2' —the motor is folded to the stator-side rotor per phase resistance;

Motor torque balance formula:

$$J_T \frac{2\pi}{60} \frac{dn_p}{dt} = K_2 U_1 - K_3 n_p - \frac{D_p p_p}{\eta} \quad (5)$$

D_p - Displacement of the pump;

p_p —the outlet pressure of the pump;

η - Mechanical efficiency;

Let $K_4 = J_T \frac{2\pi}{60}$, $K_5 = \frac{D_p}{\eta}$

$$K_4 \frac{dn_p}{dt} = K_2 U_1 - K_3 n_p - K_5 p_p \quad (6)$$

3.2. Load equivalent inertia

To simplify the model, the load is equivalent to the equivalent inertia of the output shaft of the hydraulic motor. The relevant dimensions are shown in Figure 2. Therefore the total equivalent inertia is:

$$J = m_1 D^2 / 4 + n m_2 r^2 \quad (7)$$

m_1 - The quality of the turntable;

m_2 - The quality of the workpiece;

D - Diameter of the turntable;

r - Workpiece radius of gyration;

n - The number of workpieces;

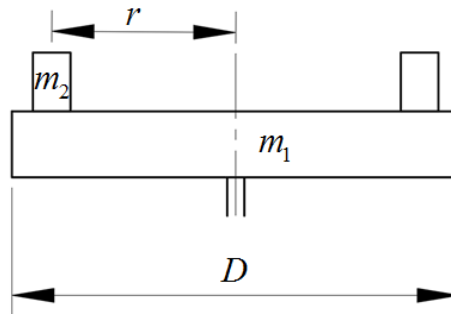


Figure 2. Turntable size diagram

3.3. Hydraulic system modeling

Co-simulation based on AMESim and MATLAB software can give full play to the advantages of the two softwares. AMESim provides a variety of component design libraries to facilitate the simulation of

complex system simulation models in multiple domains; Simulink modules and related toolboxes provided by MATLAB facilitate design simulation of controllers.

According to formulas (1)~(7), the system's variable frequency motor system, mechanical system and hydraulic system can be established by using AMESim signal library, hydraulic library and mechanical library. The controller is built by MATLAB and AMESim data interface module, as shown in Fig. 3. Shown. It is known that the hydraulic pump model is 80SCY14-1B, the hydraulic motor model is BMR-50, the three-phase asynchronous motor model is YX3-132S-6, the inverter model is ACS510-01-07A2-4, and the component parameters in the simulation system are all based on relevant sample data.

4. Fuzzy controller design

4.1. Fuzzy adaptive control principle

The basic principle is based on fuzzy mathematics and fuzzy language for knowledge representation. The expert experience and control strategy are constructed into fuzzy membership function and fuzzy inference mechanism. The fuzzy membership degree of the controller parameters is obtained, and finally the anti-fuzzy processing is used to achieve the optimal PID parameter tuning, so that the system can maintain good performance when the working conditions are widely changed. The working principle is shown in Fig. 4. It can be seen that fuzzy control is a way of imitating people's thinking. It is an intelligent automatic control system for effective control of some controlled processes that cannot construct digital models.

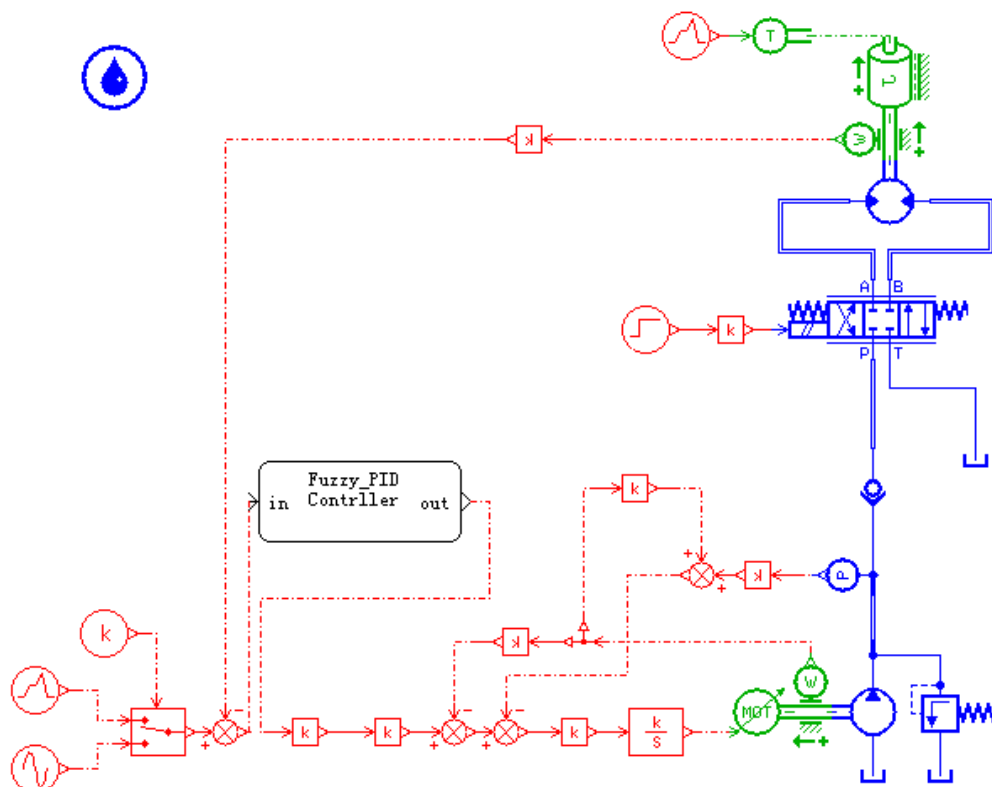


Figure 3. AMESIM simulation model

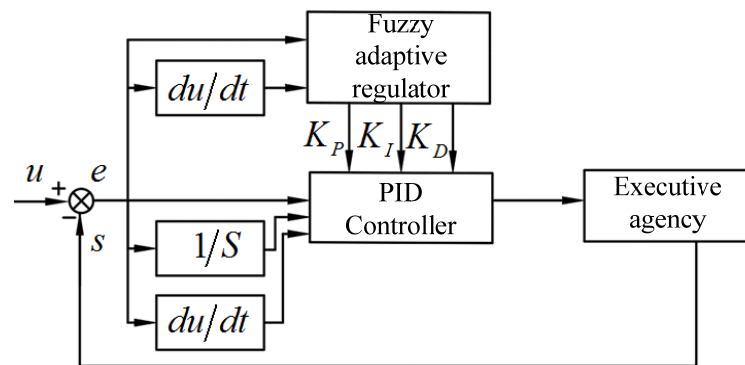


Figure 4. Fuzzy adaptive control principle

4.2. Fuzzy control algorithm

From the algorithm point of view, fuzzy adaptive control is based on the ordinary PID control to increase the fuzzy regulator to achieve adjustment of the PID parameters according to the error and its rate of change, the specific algorithm is as follows:

$$u = K_p e + K_i \int e dt + K_d \frac{de}{dt} \quad (8)$$

$$K_p = K_{p0} + \Delta K_p \quad (9)$$

$$K_i = K_{i0} + \Delta K_i \quad (10)$$

$$K_d = K_{d0} + \Delta K_d \quad (11)$$

In the formula: K_{p0} , K_{i0} , K_{d0} are the controller's proportional coefficient, integral coefficient and differential coefficient initial value, and ΔK_p , ΔK_i and ΔK_d are the correction values of the three coefficients. The fuzzy rules are determined based on the control experience. The specific analysis is shown in Tables 1~3.

Table 1. ΔK_p Fuzzy control rule table

E	EC						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PB	PM	Z	Z
NM	PB	PB	PB	PB	PM	Z	Z
NS	PM	PM	PM	PM	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NM	NM	NM	NM
PM	Z	Z	NM	NB	NB	NB	NB
PB	Z	Z	NM	NB	NB	NB	NB

Table 2. ΔK_I Fuzzy control rule table

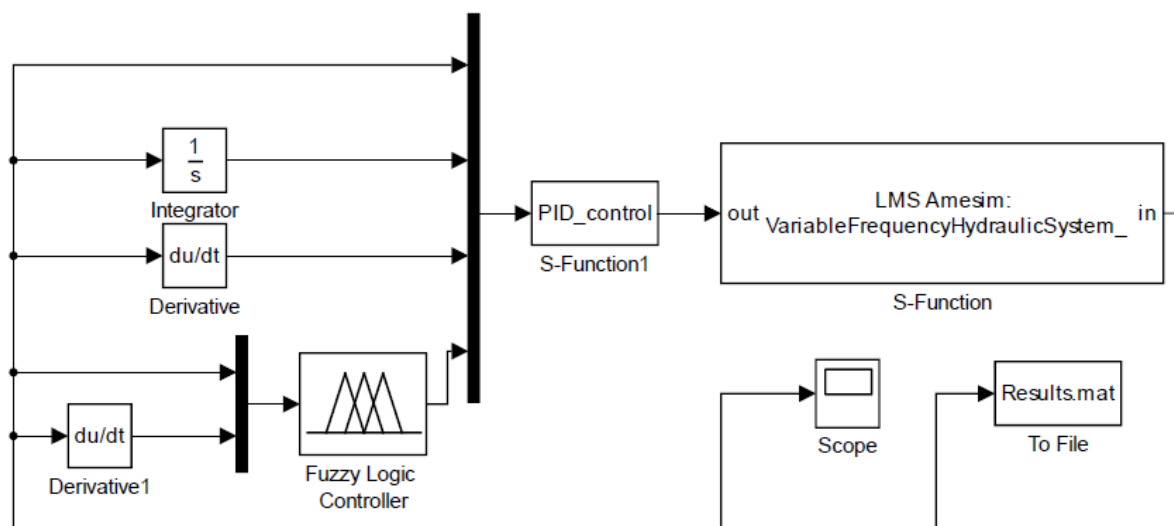
E	EC						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NM	NM	NS	Z	Z
NM	NB	NB	NM	NS	NS	Z	Z
NS	NB	NM	NS	NS	Z	PS	PS
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PS	PM	PB
PM	Z	Z	PS	PS	PM	PB	PB
PB	Z	Z	PS	PM	PM	PB	PB

Table 3. ΔK_D Fuzzy control rule table

E	EC						
	NB	NM	NS	Z	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	Z
NS	Z	NS	NM	NM	NS	NS	Z
Z	Z	NS	NS	NS	NS	NS	Z
PS	Z	Z	Z	Z	Z	Z	Z
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

4.3. Controller Modeling Based on MATLAB

Based on the above analysis, the controller model is built in the Simulink module of MATLAB, as shown in Figure 5. The fuzzy adaptive toolbox and S function are used to create the fuzzy adaptive regulator and the related control algorithm is written.

**Figure 5.** Controller simulation model construction

5. Simulation result analysis

The ramp and step signal excitation system is used to simulate the system startup and abrupt process while increasing the disturbance of the load torque step simulation system.

It can be seen from the simulation analysis that the system using ordinary PID control has obvious fluctuation during the starting process, and the angular acceleration of the turntable has a large amplitude of vibration and impact. After entering the uniform speed stage, about 3% of the overshoot occurs, which tends to stabilize after 0.5 seconds. , as shown in Figures 6(a) and (b). In contrast, the start-up characteristics of the system using analog-digital adaptive control have been significantly improved. The angular acceleration of the turntable is stable after a small fluctuation of 0.3 seconds. The amplitude of the angular acceleration is only about 30% of that of the ordinary PID system. With rapid decay, there is no significant overshoot in the uniform phase, as shown in Figures 6(c) and (d).

In the step excitation, the ordinary PID system has the largest amplitude in 3.5s, and the overshoot is more than 30%. It is stable after repeated oscillations, as shown in Fig. 6(b); the system response of fuzzy adaptive control is after a few oscillations. , quickly stabilized, as shown in Figure 6 (d), and the maximum angular acceleration is only about 60% of the former.

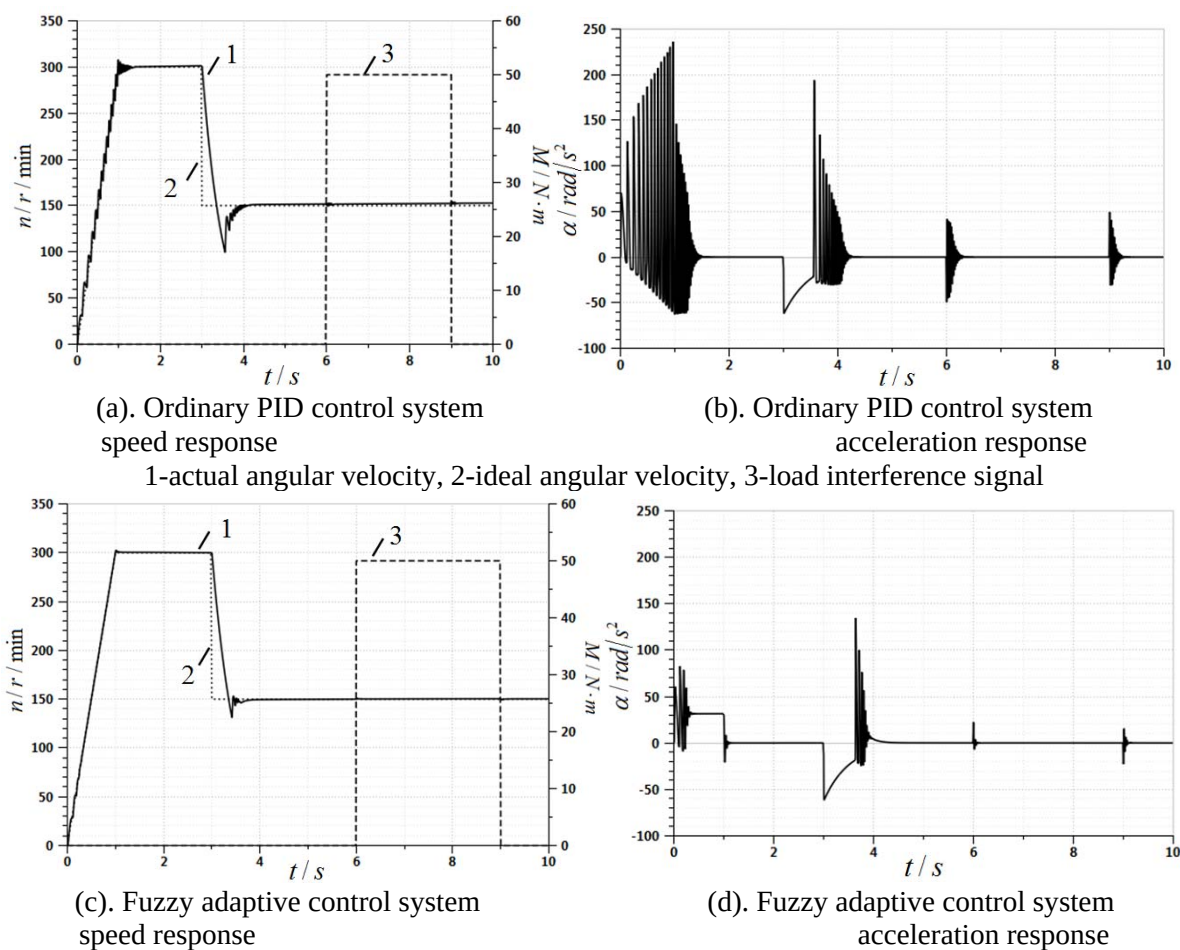


Figure 6. Performance comparison between slope and step signal excitation

Comparing and analysing the load interference signal, it can be seen that the sudden change of the acceleration of the turntable of the ordinary PID system when the load is abrupt is significantly larger than that of the fuzzy adaptive system, and the latter is only about 40% of the former.

6. Conclusion

Aiming at the problem that the automatic variable filling hydraulic system of the automatic filling machine has high nonlinearity, weak stiffness and slow response speed of ordinary PID control, the fuzzy adaptive control strategy is adopted, and the PID parameters are automatically adjusted by

introducing expert experience. Based on AMESim and Matlab construction system and its controller model, the joint simulation analysis shows that the response speed and stability of the fuzzy adaptive system in the startup process and speed adjustment process are significantly improved compared with the ordinary PID system, and the tracking ability of the periodic signal is improved. It has also been significantly improved, especially the robustness has been significantly improved, and it can better adapt to the needs of high-speed, flexible and automated production.

References

- [1] Deng Wei, Liu Lianwei. Research on energy saving of vertical system based on variable frequency hydraulic technology [J]. Machine Tools & Hydraulics, 2014 (20): 54 - 56.
- [2] Pan Xuejiao, Luo Tianhong, Wu Jun, Dong Shaojiang, Li Xiaoxiao, Huang Shifu. Simulation analysis of multi-stage vibrating continuous paving compaction hydraulic transmission frequency conversion system [J]. Machine Tools & Hydraulics, 2015, 43 (4): 62 - 65.
- [3] Huang Minghui, Xiong Huanhuan, Zhao Xiaolin, Duan Jun, Liu Xinliang. Application of fuzzy PID in hydraulic machine position control system [J]. Control Engineering, 2011, 18 (1): 14 - 17.