Design of hydraulic motor speed control system based on co-simulation of AMESim and Matlab_Simulink

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Abstract: In order to design an effective hydraulic motor speed control system, Matlab_Simiulink and AMESim co-simulation technology is adopted to establish more accurate model and reflect the actual system. The neural network proportion-integration-differentiation (PID) control parameters on-line adjustment is utilized to improve system accuracy, celerity and stability. Simulation results indicate that with the control system proposed in this paper, the system deviation is reduced, therefore accuracy is improved; response speed for step signal and sinusoidal signal gets faster, thus acceleration is rapidly improved; and the system can be restored to the control value in case of interfering, so stability is improved.

Key words: speed control system; co-simulation; neural network; proportion-integration-differentiation (PID) control

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A hydraulic drive device is a kind of common transmission device. Compared with other types of transmission devices, it has advantages of high power density, sensitive action and easy realization of stepless speed change control[1]. A hydraulic motor is a common actuator in the hydraulic drive system . There are valve controlled motor and pump controlled motor hydraulic systems using motors as actuators[2].

The valve control motor system has fast response frequency, short regulating time, good dynamic characteristic and high efficiency, therefore it is suitable for the system with small power but fast response speed. Motor speed control is the core of the whole system that has requirements for varied speed. Valve controlled motor system is a complex nonlinear time-varying system. Due to the characteristics of hydraulic oil, temperature, leakage and other factors, it is very difficult to establish a precise mathematical model[3]. Therefore we need to simplify the system to establish a mathematical model in the Matlab simulation. In order to make the mathematical model more accurate, AMESim is adopted. As a result, the hydraulic model is established in AMESim and control part is designed in Matlab_Simiulnk based on co-simulation of AMESim and Simulink. The simulation results are closer to the actual prototype by making full use of the advantages of two kinds of simulation software[4-5].

In the valve control motor controlled system, the proportion-integration-differentiation (PID) controller is usually used to realize the constant speed control of the motor speed. PID controller has the advantage of simplicity, relatively good adaptability and strong robustness, thus it is widely used in the automatic system. But PID controller can only be used in the system with precise mathematical model. For the application system with nonlinearity and time-varying uncertainty, it is difficult to describe the accurate mathematically model. The reasons that the effect of traditional PID controller is not ideal are as follows. On the one hand, the difficulty of determining parameters of traditional PID controller makes performance poor, on the other hand, we need to regulate PID parameters when the system changes. A variety

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of improved PID controllers have appeared with the development of control technology, such as fuzzy PID, expert PID, PID parameter tuning based on genetic algorithm, grey PID, neural network PID[6]. In this paper, PID controller designed based on single neuron control theory is aimed at improving the speed performance of valve controlled motor system using co-simulation of AMESim and Mablab_Simulink.

1 Introduction of valve controlled motor control system

1.1 Control principle of valve controlled hydraulic motor

In this paper, three-position four-way electro-hydraulic proportional valve is used in the valve controlled motor system, and the system structure is shown in Fig. 1.

Motor speed instructions are given by the voltage U_r, and the actual speed of the motor is converted into voltage signal via the speed sensor and then is input to a comparator by means of negative feedback. After calculating the deviation U_e by comparing input voltage signal with feedback signal, the deviation signal is enlarged as the input signal of electro-hydraulic proportional valve. The electrical signals control the valve opening size, correspondingly control the flow and speed of the hydraulic motor. The output shaft of the motor is connected with the pump shaft through the coupling, and the motor can be loaded by a simulation loading system.

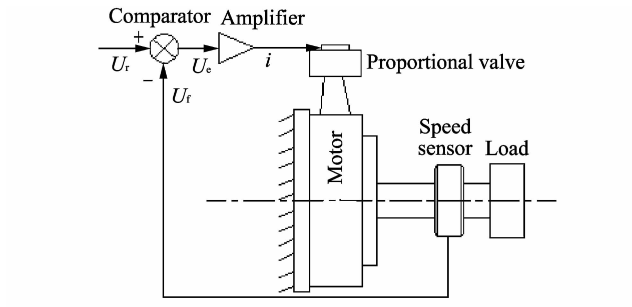

Fig. 1 Structure diagram of electro proportional valve controlled motor speed control system

1.2 Establishment of AMESim simulation model and parameter settings

According to the selected components in the experiment, the model of the system is established in AMESim and the simulation parameters of the components and the system are set. The model is shown in Fig. 2.

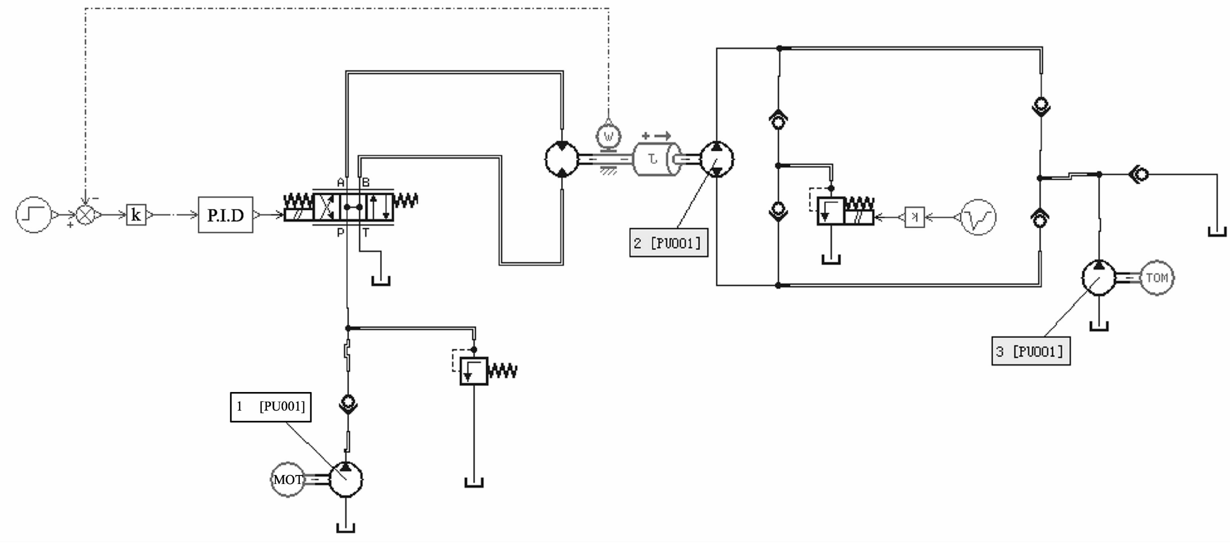

Fig. 2 Model of valve controlled motor system in AMESim

The parameters of the main components in the system are shown in Table 1.

The input signal of the three-position four-way electro-hydraulic proportional valve is the speed of the motor, and K is the coefficient of translating motor speed into electric current. The calculation formula of K can be expressed by

$$K = \frac{40 n_p V_{p_1}}{V_m}.$$

Using the data in Table 1, K=40/1 168.

Table 1 Parameters of main components

Name	Physical quality	Parameter
Motor	Rate speed	n=1 000 r/min
Pump 1	Displacement speed	V_{P_1}=125 mL/r n_P=1 000 r/min
Reversing valve	Maximum flow from P to A	500 L/min
	Pressure drop when at maximum flow rate (from P to A)	80 bar
	Rated current	I=40 mA
Motor	Displacement	V_m=107 mL/r
Pump 2	Displacement	V_{P_2}=125 mL/r
Pump 3	Displacement	V_{P_3}=125 mL/r
Reversing valve	Input expectd speed 500 r/min at 1 s	
Relief valve	Input a current signal with valve of 50 mA at 5 s, and last for 2 s	

2 Co-simulation of AMESim and Matlab_simulink

2.1 Mechanism of co-simulation and generation of *S* files in AMESim

1) In order to realize co-simulation of AMESim and Matlab_simulink, we need three kinds of software: application integration development environment visual studio, Matlab_simulink and AMESim.

The simulation tools in this paper are visual studio 2010, Matlab2012a and AMESim 13. Environment variable are set. The compiler in AMESim is VC++ version Win64. Then the interface file is added in Matlab SET Path.

The co_simulation of AMESim and Matlab_simulink is created through the interface icon in the AMESim interface menu. By connecting *S* function of Matlab_simulink via this interface icon, a simulation model in AMESim is created. By setting the corresponding parameters, *S* function is created, which can be called again in Matlab_simulink through the system compiler. By creating a simulation model in Matlab_simulink, control signal is input. The response curve can be observed after the operation in Matlab_simulink. The AMESim must be in simulation mode in case of the implementation of simulink simulation. You can observe the simulation results by AMESim after the implementation of co-simulation in Matlab_simulink.

2) Create an interface icon in AMESim. The interface has an input named "sudu" and an output named "faxin", connect the interface icon to the AMESim, click model, parameter model in turn, then generate *S*-function file in the working directory of AMESim[7-8].

The simulation model with *S* function generated in AMESim is shown in Fig. 3.

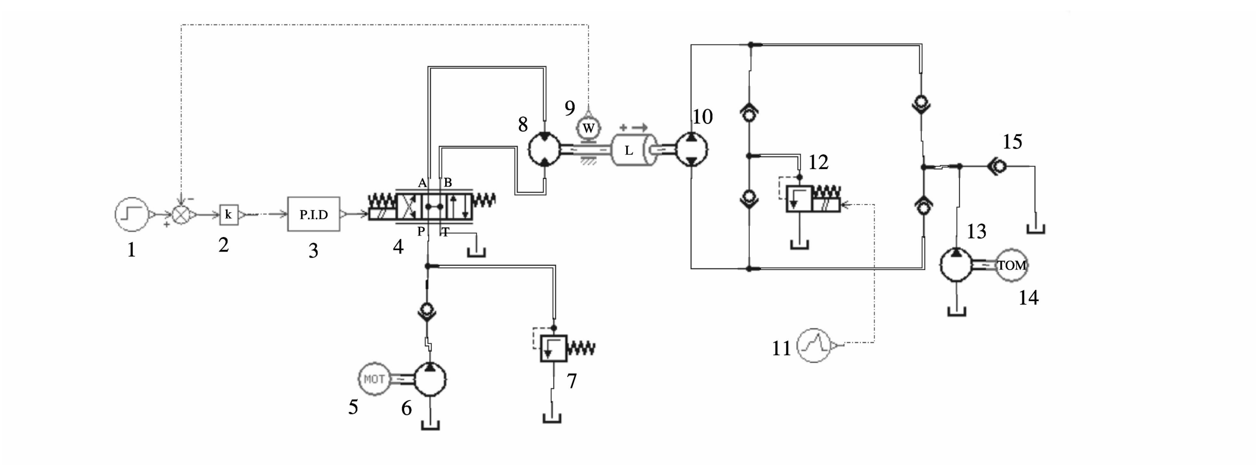

Fig. 3 Simulation model with *S* function

2.2 Establishment of co-simulation model in Matlab_Simulink

Firstly, set Matlab_Simulink working directory the same as AMESim's, and then establish a simulink model. Secondly, define S-functions in the simulink and fill in the name wl_ (AMESim model name and a underlined) in the "S-function name"; Finally, set parameters in the "S-function parameters", of which "1" means generated files and "001" is the sampling interval[9].

The traditional PID control model built in Matlab_Simulink is shown in Fig. 4.

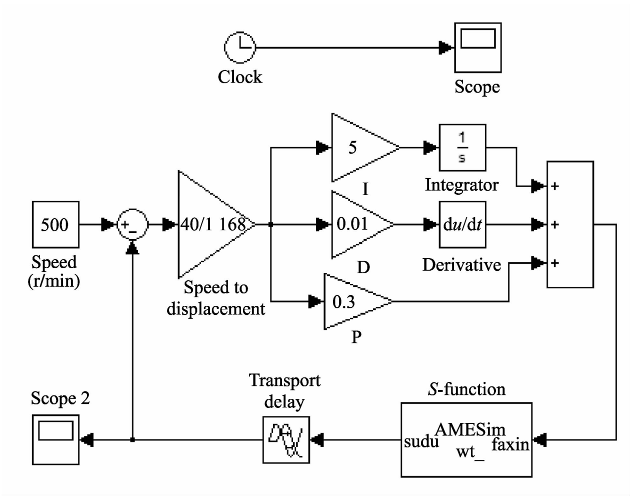

Fig. 4 Traditional PID control model

3 Control method of valve control motor speed control system

3.1 Traditional PID control

The final output of PID controller is based on linear combination after proportional, integral and differential treatment of the comparator error $e(k)$. PID controller has three parameters that determine the final output and the control performance of the system. In this paper, the parameters of PID controller are selected as $P=0.3$, $I=5$ and $D=0.01$. Give the system a step signal with 500 r/min at the first second and input a signal which lasts for 2 s with 50 mA at the 5th second through the simulated loading system, thus the pressure of the loading system is 5 MPa. After simulation, the speed curve of traditional PID control system under step signal is shown in Fig. 5.

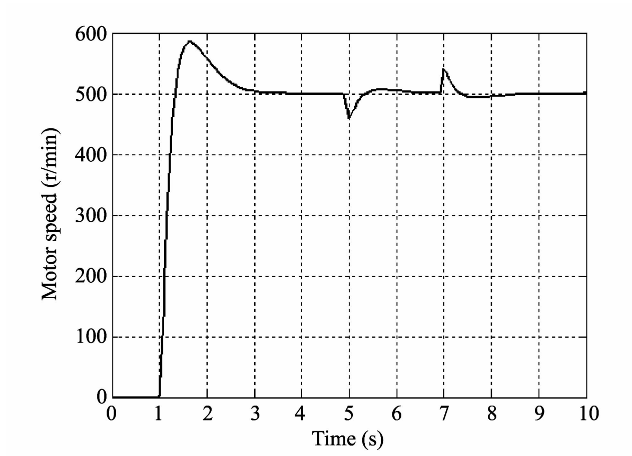

Fig. 5 Response curve of traditional PID controller

It can be seen from Fig. 5 that the adjusting time of the system controlled by traditional PID controller is 2 s and the speed fluctuation of the system is large in case of load disturbance. In order to accelerate the response speed of the system and improve the anti-disturbance ability, the traditional PID controller is replaced by neuron PID controller in this paper.

3.2 Neuron PID controller

Neural network control technology can well solve the control problem of complex, uncertain and nonlinear system. Application of the neural network in the PID controller can solve automatic parameter adjustment difficulties of traditional PID controller and improve the performance of the PID controller. The principle of single neuron adaptive PID control method is shown in Fig. 6.

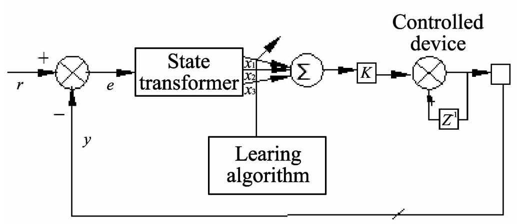

Fig. 6 Principle block diagram of single neuron adaptive PID control method

After getting the deviation signal e by comparison of input signal r with output signal y, the deviation signal is converted and then the x_1, x_2 and x_3 are output. The structure of the state converter is shown in Fig. 7.

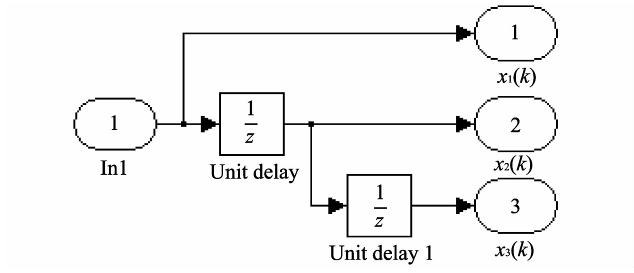

Fig. 7 State converter

After the deviation signal is converted $x_1(k)=e(k)$, $x_2(k)=\triangle e(k)$ and $x_3(k)=\triangle 2e(k)=e(k)-2e(k-1)+e(k-2)$, the supervised Hebb learning algorithm is used in this paper.

3. 3 Improvement of neuron PID control learning algorithm

In practical applications, $e(k-2)$ is not a related factor when PID parameters is in the modification of weight coefficient, and $e(k-2)$ in learning algorithm can lead to a decrease in the convergence rate of PID parameter regulation. According to the practical experience, the modification processes of PID three parameters are closely related to $e(k)$ and $\Delta e(k)$. Therefore, the algorithm formula is revised as

$$w_i(k+1)=w_i(k)+\eta_j e(k)u(k)[e(k)+\Delta e(k)],$$

where $w_i(k)$ is the weighted coefficient of input $x(i)$, $i=1,2,3$; η_1 is the learning rate of proportion; η_2 is the learning rate of integral; and η_3 is learning rate of differential.

3. 4 System model of neuron PID controller

The simulink model based on S-function is shown in Fig. 8.

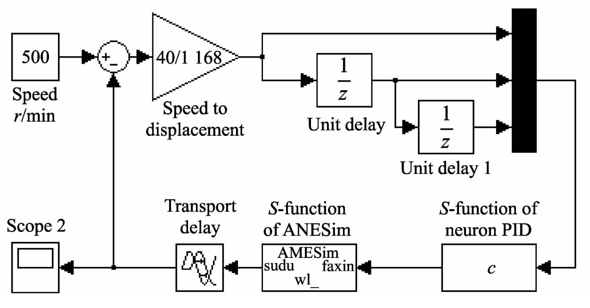

Fig. 8 Simulation of neuron PID control based on S-function

Neuron PID controller can not be expressed directly in the form of transfer function but needs to use S-function module of Matlab_simulink to write S-function of neuron control algorithm[10-11], thus the automatic adjustment of PID parameters can be achieved. Save the control program file as the name *c*.

3. 5 Simulation analysis

In order to verify the superiority of the system with improved algorithm single neuron PID control, firstly, compare and analyze the step response characteristics of the system without load under different control methods. For example, input a step signal with motor speed of 500 r/min at 1st, the step signal response curve is shown in Fig. 9.

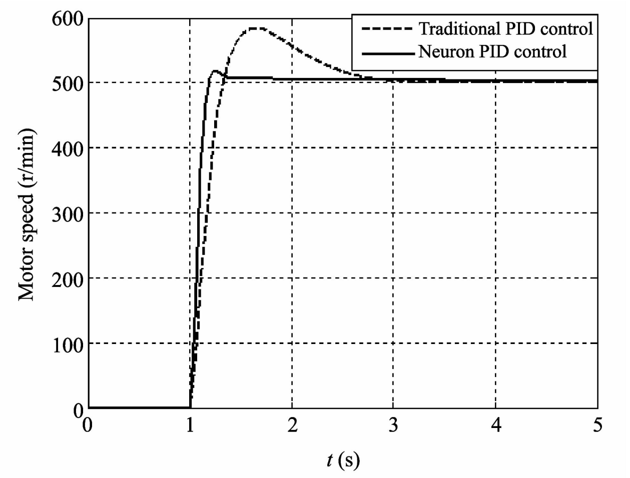

Fig. 9 Comparison of the step response of no load

It can be seen that the response of the system is faster, rise time is shorter, overshoot is decreased significantly, and the adjusting time is reduced from 2 to 0. 5 s.

Giving the proportional relief valve an input signal of 50 mA current through the AMESim simulation loading system at the 5th second, after that the working pressure of the system reaches up to 5 MPa and the input signal lasts for two seconds, the response curve of neuron PID control system is shown in Fig. 10.

It is shown in the response diagram that the rotational speed of the motor drops 2% at the 5th second when the load is applied, and motor speed increases by about 3% at the 7th second when the load is removed. Comparing Fig. 10 and Fig. 5, we can see that the speed vibration is reduced and anti-interference ability is increased for the neural PID control system.

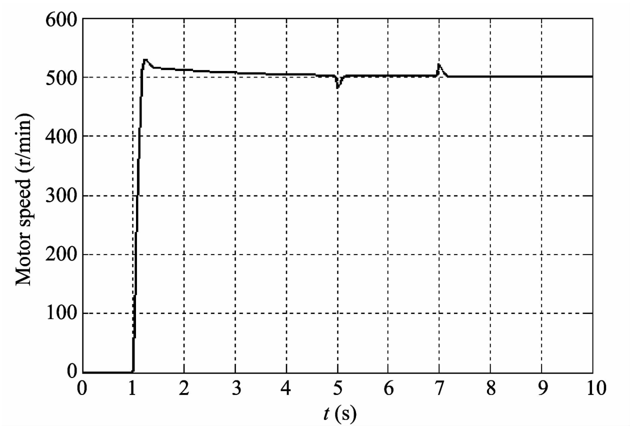

Fig. 10 Response diagram of neuron PID control with load

In practical applications, the valve controlled motor system always has a load and the load is always changing. In addition to the study of the step response and load response characteristics of the system, we need to study the tracking performance of the system. Give the system a sine signal with a period of one second and an amplitude of 500, the curve of the motor speed is shown in Fig. 11.

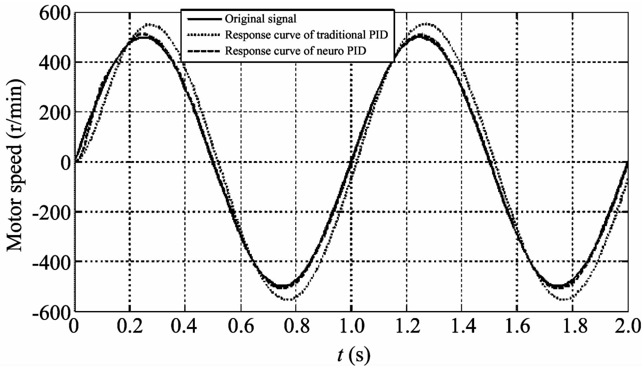

Fig. 11 Comparison diagram of valve controlled motor system without load

The image above shows that the amplitude overshoot and phase lag are reduced, and the follow performance is improved under the input of sinusoidal signal by using improved single neuron PID controller algorithm. The output curve almost completely overlaps the input sinusoidal signal, therefore the system tracking performance is greatly improved.

4 Conclusion

In this paper, we first study the AMESim and Simulink co-simulation technology and establish a co-simulation model, which solves the problem of the traditional Matlab_Simulation that it is difficult to establish a precise mathematical model. By analyzing the deficiency of the traditional PID control method, the single neuron PID controller is utilized to solve the problem that traditional PID controller parameters are difficult to be adjusted. Thus the single neuron PID control algorithm is improved, which accelerates the convergence rate of the PID parameter adjustment. In the system, the response speed is accelerated, the overshoot is reduced and the anti-interference ability is improved. By making full use of the advantages of Simulink control on the basis of the establishment of accurate model PID, the control method of the valve controlled motor speed control system is studied, which has important guiding significance in practical applications.

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基于 AMESim 和 Matlab_Simiulink 联合仿真的液压马达转速控制系统设计

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摘 要： 为设计有效的阀控液压马达转速控制系统，采用 AMESim 和 Matlab_Simiulink 联合仿真技术来建立准确的模型，以更好地反应实际系统。将神经元控制应用于 PID 参数在线调整中，提高了系统的准确性、快速性和稳定性。仿真结果表明，所设计的系统偏差减小，准确性提高；对于阶跃信号、正弦信号的响应速度加快，快速性提高；在系统施加干扰的情况下，能够恢复到控制值，稳定性提高。

关键词： 转速控制系统；联合仿真；神经元网络；PID 控制

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