Design of 20 t forging manipulator clamp rotation hydraulic control system*

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Abstract: This study designs the clamp rotation electro-hydraulic proportional control system of forging manipulator, establishes the mathematical model of the clamp rotation mechanism, and determines the initial parameters of PID controller and the correspondent fuzzy logic system. The modeling and simulation on the clamp rotation control system of forging manipulator are gained by the MATLAB/Simulink and AMESim co-simulation technology. It is verified that the design scheme is reasonable, mathematical model is accurate and system robustness is better based on fuzzy PID control.

Key words: Forging manipulator, Fuzzy PID, AMESim, Electro-hydraulic proportional control system

1. Introduction

Forging manipulator, which is mainly used for clamping forgings and auxiliary forging machine, is the important equipment to achieve forging automation, and an important factor in influencing the development of equipment manufacturing industry[1]. Due to hydraulic drive has advantages of fast response, wide speed range and automatic overload protection, the large-tonnage forging manipulator usually uses hydraulic drives. Clamp rotation is an important feature for the overloaded operation equipment. The clamp rotation property is affected by time-varying operating conditions and the structure of hydraulic system. In order to ensure the quality of forging and increase productivity, the clamp rotation system must rotate fast, smoothly and accurately[2-3]. This article designs the clamp rotation electro-hydrau-

lic proportional control system of 20 t forging manipulator, uses fuzzy PID control strategy for commanding the clamp rotation angular position, and studies the clamp rotation control system through the MATLAB/Simulink and AMESim co-simulation technology simulation.

2. Clamp rotation hydraulic control system and mathematical model

Clamp rotation mechanism is mainly used for achieving forgings free rotation. The forging manipulator clamp rotation hydraulic system schematic diagram is shown in Figure 1. The opening of electro-hydraulic proportional directional valve core controls the spin direction and the speed of hydraulic motor, and then drives the clamp forgings to rotate. Accumulator absorbs vibration produced in the process of forging and relief valve is overload protection. The proportional directional valves and two groups of cartridge valves are used to achieve the clamp positioning and locking. Because the quality of forgings is large, the accumulator check valve and accumulator relief valve design are used to reduce the impact of forging.
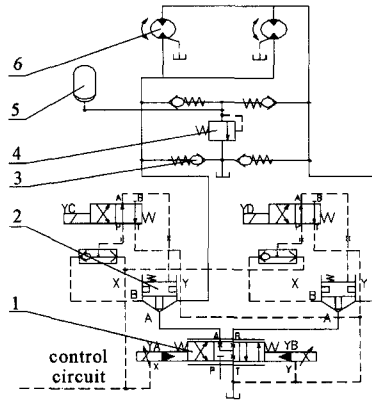
1. proportional directional valve; 2. cartridge valve; 3. check
valve; 4. relief valve; 5. accumulator; 6. motor

Figure 1. Clamp rotation hydraulic system
schematic diagram

Hydraulic power actuators which are composed of electro-hydraulic proportional directional valves, hydraulic motors and load, have a direct impact on the quality of clamp rotation hydraulic system, so determining the mathematical model of valve-controlled motor system is the prerequisite for analysis of the whole driving system [4]. According to the flow equations of electro-hydraulic proportional valve, flow continuity equation of hydraulic motors and hydraulic motors and torque load balancing equations, by deduction, the motor angular displacement expression, which is disturbed by valve core displacement and outside load disturbance at the same time, are gained:

$$\theta_m = \cfrac{\cfrac{K_q}{D_m}X_V - \cfrac{1}{D_m^2}\left(K_c + C_{tm} + \cfrac{V_m}{4\beta_e}s\right)T_L}{\cfrac{V_t J_t}{4\beta_e D_m^2}s^3 + \left(\cfrac{J_t K_{ce}}{D_m^2} + \cfrac{B_m V_t}{4\beta_e D_m^2}\right)s^2 + \left(1 + \cfrac{B_m K_{ce}}{D_m^2} + \cfrac{G V_t}{4\beta_e D_m^2}\right)s + \cfrac{G K_{ce}}{D_m^2}}$$

Where, formula derivation and meaning of the symbol can be found in reference.

In the valve control motor system, motor and ultimate load are connected with rigid gear, so elastic load can be negligible. As it is often the case $\dfrac{B_m K_{ce}}{D_m^2}$ ≪ 1, the simplified hydraulic rotation of the motor shaft on the valve core displacement transfer function can be gotten: $\dfrac{\theta_m}{X_V} = \cfrac{\cfrac{K_q}{D_m}}{s\left(\cfrac{s^2}{\omega_h^2} + \cfrac{2\xi_h}{\omega_h}s + 1\right)}$, in this equa-

tion, $\omega_h = \sqrt{\dfrac{4\beta_e D_m^2}{V_t J_t}}, \xi_h = \dfrac{K_{ce}}{D_m}\sqrt{\dfrac{\beta_e J_t}{V_t}}$.

Technical parameters of valve-controlled motor are shown in Table 1.

Table 1. Technical parameter of valve-controlled motor

Parameter	Value	Unit
Proportional valve flow gain K_q	2.4	$m^3/s/A$
Motor theory displacement D_m	90	ml/r
Motor shaft total inertia J_t	39	$kg \cdot m^2$
Total disclosure coefficient of hydraulic motor C_{tm}	7×10^{-13}	m^5/Ns
Total flow-pressure coefficient of proportional valve K_{ce}	4.3×10^{-12}	$m^5/N \cdot s$
Total volume of two hydraulic motor cavity and connecting pipes V_t	4.7×10^{-3}	m^3
Effective elastic moduli of oil β_e	6.9×10^8	Pa

According to the parameters in the Table 1, it can be gotten that the valve-controlled motor hydraulic system natural frequency ω_h = 110.3 rad/s, hydraulic damping ratio ξ_h = 0.225. So the motor shaft rotation on the valve core displacement transfer function is $\dfrac{\theta_m}{X_V} = \dfrac{3.25 \times 10^8}{s^3 + 49.63s^2 + 12166s}$. It provides the basis for the initial parameters design of PID controller.

3. Clamp rotation angular displacement control algorithm

The smooth precise positioning of clamp rotation directly affects the efficiency and quality of the job of forging, so it is necessary to use the appropriate control algorithm to adjust the rotation static and dynamic performance. Conventional PID control algorithm is simple, but cannot adjust PID control parameters real-time. It is commonly used for Linear Systems and requires precise mathematical model. Clamp rotation mechanism is driven by hydraulic, and the system is time-varying and nonlinear, only establishing approximate mathematical model. Fuzzy PID control algorithm combines features of PID control with fuzzy logic. Online real-time nonlinear adjusting control parameters, and easier realization of algorithms in hardware, are the requirements for a controller meeting clamp rotation system. Therefore a fuzzy PID control algorithm is designed to meet the clamp rotation an-

gular displacement control.

The fuzzy controller contains two inputs of the clamp rotation angle error e and the error change rate ec, and three outputs of PID coefficient increments ΔK_p, ΔK_i, ΔK_d. To facilitate the system simulation, e and ec universe of fuzzy sets are defined as { -1, 1}, similarly ΔK_p, ΔK_i, ΔK_d universe of fuzzy sets are also { $-1,1$ }. The fuzzy inputs variables and outputs variables are divided into seven levels, and using linguistic variables expression is PB, PM, PS, ZO, NS, NM, NB. All membership functions of fuzzy subsets are triangular-shaped curve[5].

The fuzzy PID controller parameters tuning rules are: when the system error is large, larger K_p and smaller K_d should be taken to speed up system re-spond; when system error is middle, smaller K_p and the appropriate K_i and K_d should be taken to have a lower overshoot; when the system error is low, larger K_p and K_d and appropriate K_i should be taken to avoid oscillation near the equilibrium point. The fuzzy inference based on fuzzy rules is used to get a fuzzy set, and then the match fuzzy treatment uses the focus method on fuzzy output variable. According to the different input variables, offline calculation of the exact output corresponding to each fuzzy variable is carried out, making into a fuzzy output control table as shown in Table 2.

In the actual application, the exact current output value of fuzzy controller can be found by checking the table.

Table 2. Fuzzy rule table of K_p, K_i, K_d

	K_p							K_i							K_d						
	NB	NM	NS	ZO	PS	PM	PB	NB	NM	NS	ZO	PS	PM	PB	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO	NB	NB	NM	NM	NS	ZO	ZO	PS	NS	NB	NB	NB	NM	PS
NM	PB	PB	PM	PS	PS	ZO	NS	NB	NB	NM	NS	NS	ZO	ZO	PS	NS	NB	NM	NM	NS	ZO
NS	PM	PM	PM	PS	ZO	NS	NS	NB	NM	NS	NS	ZO	PS	PS	ZO	NS	NM	NM	MS	NS	ZO
ZO	PM	PM	PS	ZO	NS	NM	NM	NM	NM	NS	ZO	PS	PM	PM	ZO	NS	NS	NS	NS	NS	ZO
PS	PS	PS	ZO	NS	NS	NM	NM	NM	NS	ZO	PS	PS	PM	PB	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PS	ZO	NS	NM	NM	NM	NB	ZO	ZO	PS	PS	PM	PM	PB	PB	NS	PS	PS	PS	PS	PB
PB	ZO	ZO	NM	NM	NM	NB	NB	ZO	ZO	PS	PM	PM	PB	PB	PB	PM	PM	PM	PS	PS	PB

4. Co-simulation of clamp rotation hydraulic control system

Clamp rotation control system is a nonlinear systems, with AMESim sophisticated hydraulic components in the component library module, the clamp rotation control system simulation model is established [6], at the same time, based on MATLAB/Simulink, the simulation model of fuzzy PID control algorithm is established. Through the co-simulation technology, the clamp rotation control system simulation is combined with the motion control algorithm simulation, and the real simulation is carried out on the actual condition of the clamp rotation mechanism.

Figure 2 shows the clamp rotating hydraulic system simulation model. The cartridge valve consists of three parts, and its control oil is equivalent for a given signal to control on-off. In the load location, an angular displacement sensor is used for the measurement and feedback, then from the comparison with the set signal, the clamp rotation system angle control can be realized by fuzzy PID controller. Main simulation parameters are as follows: load, 20t forging; working pressure, 10 MPa; system flow, 505 1/min; motor displacement, 107 ml/r; ratio of gear, 4.6.
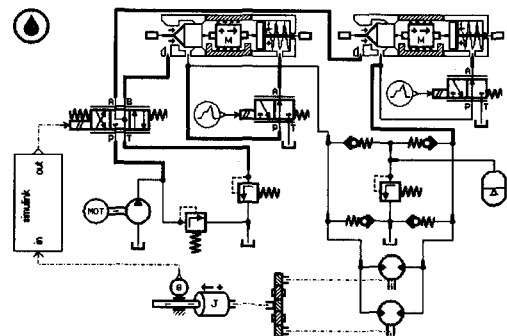

Figure 2. Clamp rotating hydraulic system simulation model

Figure 3 shows the MATLAB/Simulink simulation model of fuzzy PID control algorithm. Based on discrete model, the PID algorithm through co-simulation, exports the algorithm output to simulation ·model of proportional directional valves in the AMESim controlling valve core opening, and ultimately controls
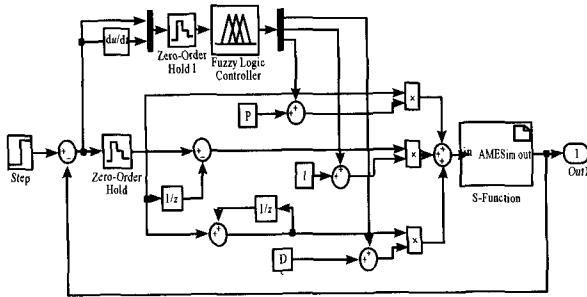
the clamp rotation angle.

Figure 3. Simulation model of fuzzy PID algorithm

5. Simulation and analysis of the results

Design requirements for forging manipulator: clamping fastest spinning of 18 r/min and 1 degree rotation accuracy. Under the same conditions, the fuzzy PID control algorithm and the traditional PID control algorithm are used respectively to simulated study the clamp rotation response characteristics. When the rotation angle entered by the system is 15 degree, 30 degree and 60 degree, both response curves of the clamp rotation mechanism are shown in Figure 4 and Figure 5.
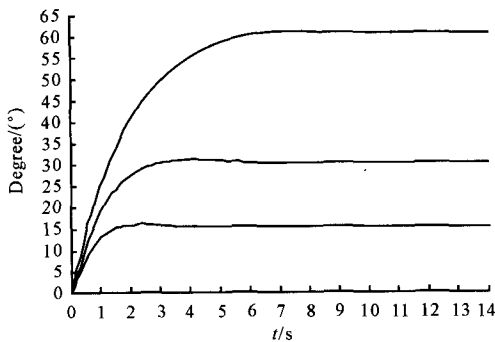

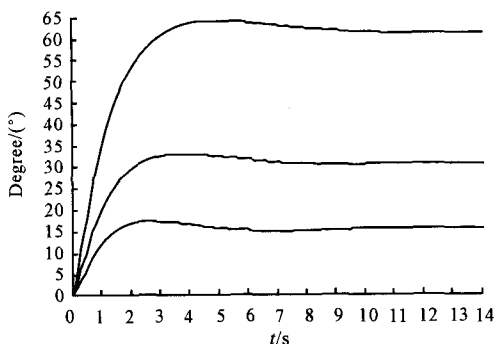Figure 4. Dynamic curve of fuzzy PID control

Figure 5. Dynamic curve of conventional PID control

From the clamp rotation control system response curve, it can be seen: the overshoot of traditional PID control system is larger, the deviation is also larger; the frequency of forging melted down is increased, the forging cycle is extend; the system steady state error increases with increasing enter angle. But the system dynamic performance is improved by fuzzy PID control, the system response time is shortened, and the steady precision is improved.

6. Conclusion

The electro-hydraulic proportional control system is used to realize the forging manipulator clamp rotation. Through MATLAB/Simulink and AMESim co-simulation technology, the clamp rotation hydraulic control system simulation model is built, and the simulation analysis of hydraulic system and control algorithms are achieved. The clamp rotation mechanism dynamic characteristics are analyzed under different control algorithms and different input angle. Simulation results show that the hydraulic control system based on fuzzy PID control algorithm adapts time-varying complex environment, meets the system accuracy requirements, and has high degree of robustness.

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energy of WPD are selected as the inputs of SVM. The gear processing conditions are divided into normal, wear and broken teeth. The SVM successfully classifies the signals of normal, wear, and broken teeth, and which is very effective. In future works, the comparison with other classification methods are recommended.

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基于支持向量机的齿轮故障分类*

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摘要:齿轮是旋转机械中的关键元件。提出了一个基于支持向量机的齿轮多故障分类方法。齿轮状态被划分为正常、齿轮磨损和断齿状态。振动信号的均方根和小波包能量被选作为分类器的特征参数。分类器选用支持向量机(SVM)。SVM具有良好的实用性及多分类能力。实验结果表明:提出的方法能很好地区分齿轮故障。

关键词:齿轮;支持向量机;故障分类;小波包能量

中图分类号:TH133;TP391

20 t 锻造操作机夹钳旋转液压控制系统设计*

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摘要:设计了锻造操作机夹钳旋转电液比例控制系统,建立了夹钳旋转机构的数学模型,确定了PID控制器的初始参数,并在此基础上得出对应的模糊逻辑系统。通过 MATLAB/Simulink 和 AMESim 联合仿真技术对锻造操作机旋转液压控制系统进行建模与仿真研究,结果表明:设计方案合理,数学模型准确,基于模糊PID控制的系统鲁棒性更好。

关键词:锻造操作机;模糊PID;AMESim;电液比例控制系统

中图分类号:TH137