Design of Bi-directional Pump Servo System for Asymmetric Hydraulic Cylinder

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Abstract—In view of the shortcomings of the traditional overflow pressure regulating and throttling speed regulation system, such as large energy loss, high oil temperature and large reversing impact, a servo two-way pump control system for asymmetric hydraulic cylinder is proposed based on Siemens S120. TIA Portal And Starter software are used for the design of hardware configuration and program debugging. SimulationX is used to simulate the stroke process of the hydraulic cylinder, at the same time, experimental verification was carried out, which provides a new idea for the low energy consumption design of hydraulic cylinder servo control system, and has important practical significance.

1. Introduction
The traditional hydraulic cylinder servo control system mostly adopts the electro-hydraulic proportional valve to carry out the stepless speed regulation of the system[1]. Although the PID, fuzzy control or neural network control algorithm is used, the response speed and control accuracy of the system have been greatly improved[2], it is still unable to change the energy loss and temperature rise of the system caused by throttle speed regulation, especially the large load hydraulic system. In order to reduce the energy consumption and impact of the system, this paper uses Siemens S120 servo motor to drive the bidirectional hydraulic pump and control the hydraulic cylinder. Under the premise of ensuring the dynamic quality of the system, the energy consumption and the state switching impact of the system are reduced.

2. Composition and principle
The pump-controlled hydraulic servo system is used to complete the tobacco compression. It mainly drives a bidirectional quantitative motor (pump) through a servo motor, and adjusts the speed and direction of the servo motor through an auxiliary control device. Its schematic diagram is shown in Fig. 1.
(1) Direction control
The direction control of the hydraulic circuit is mainly aimed at the reversal of the piston rod. The direction of transformation is achieved by the forward and reverse rotation of the servo motor.

(2) Pressure control
The maximum pressure of the system is limited to 10Mpa through the safety valve. Based on pressure feedback control and reasonable control strategy, stepless pressure regulation can be achieved by controlling the speed of the servo motor.

(3) Speed control
In the whole working process of the hydraulic circuit, the cavity of pole of the oil cylinder is connected with an oil port of the motor (pump). Before the press-head descends and does not touch the tobacco, the moving speed of the piston rod is determined by the oil flow rate of the rod cavity, namely the rotation speed of the motor; when the press-head contacts the tobacco, the pressure in the rod cavity gradually decreases. When it reaches a certain value, the one-way valve connected to the oil tank is opened, and the motor (pump) sucks oil from the oil tank. The moving speed of the piston rod is determined by the oil flow into the rod cavity, namely the rotation speed of the motor too.

When the piston rod goes up, the motor accelerates, maintains and decelerates, and the piston rod moves smoothly.

(4) Pressure holding
When the piston rod goes down to the end, the hydraulic cylinder enters the pressure holding stage. At this time, the overflow can be reduced by reducing the motor speed corresponding to the minimum flow value required by the system.

3. Control system design
The operation loop of the system in the non-pressurization stage is shown in Fig.2, and the operation loop in the pressure holding stage is shown in Fig.3. The loop contains a speed loop and a current loop. The speed loop adopts PI regulation, which can quickly track the speed input instructions of the system. The current loop can effectively avoid overcurrent and pressure disturbance in the speed regulation process. The difference is that the pressure closed loop is added to the speed loop and the current loop.
in the pressure holding control loop, so as to quickly and accurately track the pressure of the system and meet the process requirements.

Fig.2 Non pressure holding operation loop

3.1. Hardware circuit design
According to the control requirements of the system, this system uses S7-1500 with PID control instructions and strong floating-point operation ability of Siemens as the main controller, uses S120 servo drive as the actuator of speed regulation, and uses the motor module with energy feedback function to further improve the utilization rate of power grid, as shown in Fig4.

PLC receives the signals of buttons, trip switches and sensors, and controls the corresponding actuator action after operation. The motor control is realized by Profinet communication. Profinet communication is based on Ethernet, which has many advantages, such as high real-time, fast communication speed, small jitter, simple and convenient expansion.

CU320 control unit, rectifier module and motor module constitute the servo drive of the system. CU320 is used to realize the vector control algorithm of the servo motor. Rectifier module is used to convert 380VAC to 600VDC and supply to motor module inverter. The control unit adjusts the voltage and frequency of the power supply after the inverter, and then changes the running speed of the motor to realize frequency control of motor speed.
3.2. Software design

In order to realize the tobacco pressing molding process, the motor control operation curve and the external load are shown in Fig. 5. The motor is accelerated to 2000r/min after starting, and drives the cylinder to decline uniformly. When the system pressure reaches the required value, slow down to 0, and PID pressure closed loop control to ensure system pressure. After a certain period, reverse acceleration to 2000r/min and then rise at a constant speed, slow down to 0 after reaching the upper limit. Circular works according to the above process. Program flow chart is shown in Fig. 6.
3.3. **Wincc GUI design**

The GUI can intuitively display the current state information of the system, and can receive and send control instructions. The system consists of five functional areas: the main interface, the alarm information recording and querying interface, the real-time data interface, parameter setting interface, and communication interface. The GUI block diagram is shown in Fig. 7, and the main interface is shown in Fig. 8.

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**Fig. 6 Flow chart of the program**

**Fig. 7 GUI block diagram**
3.4. Hardware configuration
Siemens TIA Portal can quickly realize the hardware configuration of the system, and allocate the IO address of the digital and analog input and output interface and the IP address and Device name of Profinet communication.

3.5. Hardware configuration and debugging of Starter
The Starter software is used to complete the hardware configuration of the Siemens S120 servo control part, including the control mode of the control unit, the encoder parameters, the parameter matching of the motor module, the static parameter identification of the motor, the dynamic parameter identification of the motor and the setting of the communication Profinet message.

3.6. Communication between PLC and S120 based on Profinet
The message communication between Profinet and S120 is divided into two types, periodic communication and non-periodic communication. Periodic communication can only read or write one servo controller parameter in each communication process, such as speed, torque, current, etc., which is realized by DPWR_DAT and DPRD_DAT communication modules; non-periodic communication can read or write multiple parameters in each communication process, using WRREC and RDREC communication module; the message is 'Standard_telegram_1, _PZD-2_2[AI/AO]'. The systemy of this paper uses periodic communication to realize the communication between PLC and S120, and defines the receiving and sending to the DB block data cache.

3.7. PID control pressure holding
The pressure holding by PID control algorithm can overcome external interference. PLC1500 integrates the instruction PID_COMPACT with PID motion control function, greatly simplifies the PID configuration process, and has PID self-tuning function[3], which can quickly tune the PID parameters of the system. MD72 is the given value of holding pressure, and MD64 is the feedback pressure value. After PID calculation, the results are saved in MD60. After transformation, the results are sent to the inverter to adjust the motor speed, so as to maintain constant pressure.
4. Simulation of Hydraulic Servo System

SimulationX software belongs to the advanced modeling environment in engineering system simulation, and it contains rich application libraries, such as signal control library, mechanical library, hydraulic component design library, power transmission library, hydraulic resistance crying, motor and drive library. In this paper, the software is used to build the hydraulic system model shown in Fig. 9. The load in the process of tobacco leaf compaction is simulated by the displacement-force function. The simulation results are shown in Fig. 10.

![Simulation modal of Hydraulic system based on SimulationX](image)

![Simulation results](image)

Fig.9 Simulation modal of Hydraulic system based on SimulationX

Fig.10 Simulation results

The simulation results show the change of pressure and displacement of hydraulic cylinder in the whole process, which provides a reliable basis for matching servo control system, setting PID pressure loop parameters and pressure holding.

5. Experimental test

The maximum speed of the test motor is 1500 rpm under no-load operation. When the speed is increased or decreased, the motor speed curve is slope changed, and the impact of the process can be controlled by changing the acceleration and deceleration time. There is no overload deceleration and speed
mutation. The speed required for PID pressure holding is low, the average value is 30rpm. The results are shown in Fig.11.

Through the test, it can be found that it is basically consistent with the simulation results. The constant pressure is realized by pump-controlled servo, which has many advantages, such as low energy consumption, stable operation, small impact and so on.

6. Conclusion
Taking tobacco packaging as an example, this paper discusses the process of using Siemens S120 servo control system to realize pump-controlled hydraulic servo system, and designs the hardware and software of the system. At the same time, SimulationX is used to simulate the hydraulic system. The simulation results intuitively show the changes of displacement and pressure in the process of hydraulic cylinder movement, which provides a reliable basis for the selection of hydraulic components and the setting of pressure loop control parameters of S120 servo motor control system. At the same time, the experimental verification is carried out to further verify the reliability of the simulation and the feasibility of the system design.

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