DESIGN AND DEVELOPMENT OF MEASUREMENT AND CONTROL SYSTEM OF MECHANICAL-ELECTRICAL-HYDRAULIC INTEGRATION BASED ON PROGRAMMABLE LOGIC CONTROLLER

Jian Chu, Gang Li, Yadong Niu
Joint Lab of Information Sensing & Intelligent Control,
Tianjin University of Technology and Education, Tianjin, 300222, China
Email: uktjpi@163.com

Abstract - Using the advantages of programmable logic controller (PLC) in mechanical-electrical-hydraulic integration, this study designed a measurement and control system based on PLC. The hardware of the system was designed concretely, and its condition monitoring and system control functions were explored to complete data transmission communication. In addition, relevant experiments like system torque control were carried out to verify the feasibility and accuracy of the operation of the measurement and control system, thus to realize real-time error checking and correction. The study results showed that the designed system was satisfactory.

Keywords: PLC; mechanical-electrical-hydraulic integration; measurement and control system; design; industrial personal computer.

1. Introduction

With the development of modern technology, the mechanical-electrical-hydraulic hybrid power technology has effectively integrated the hydraulic transmission technology [1-2] and mechanical and electrical transmission technology according to the development tendency of industrial technology. In addition, it has been extensively applied to industrial manufacturing industries. For example, the American Caterpillar Company applied the Element Management System (EMS) [3] to engineering machinery for the first time in 1973. Up till now, it has been developed into a series of products, and about 60% of the construction machinery products have different monitoring systems. Programmable logic controller (PLC) [4] is a kind of all-purpose industrial control device that integrates microcomputer technique, automatics and communication technology [5-6]. In recent years, the mechanical-electrical-hydraulic integrated system based on programmable logic controller (PLC) has been applied more and more widely due to its advantages. However, whether the system can operate effectively should be evaluated. Therefore, its measurement and control system should be designed, studied and improved.

At present, a lot of researchers in China have carried out relevant studies on the measurement and control system of mechanical-electrical-hydraulic integration based on PLC. For example, Wang Shuangxin in Beijing Jiaotong University carried out a study on remote control and measurement based on Lab VIEW [7]. He realized the communication between Lab VIEW and PLC using serial buses, as well as achieved monitoring on actual objects. Yang Lin et al. [8-9] used Lab VIEW to control the three-phase stepper motor and their study gained acceptance from relevant experts. In this study, we mainly adopted the mechanical-electrical-hydraulic integrative experimental platform as the research object. In addition, based on the PLC, the measurement and control system of the experimental platform was developed using relevant technologies, thus to test the performance of the mechanical-electrical-hydraulic integration system.

2. Design of the measurement and control system

Hydraulic operation principles of the measurement and control system of mechanical-electrical-hydraulic integration based on PLC are composed of three functional modules: power source system, hydraulic drive system [10] and hydraulic loading system. The hydraulic working procedures are shown in figure 1.
The power source system is mainly responsible for power synthesis or single output of the electromotor and the engine. The main functions of the hydraulic drive system are speed changing and torque.

The hydraulic loading system [11] is mainly responsible for simulating authentic load, which is mainly composed of gear pump, proportional loading overflow valve and fuel tank, etc.

**Hardware of the measurement and control system**

(1) PCL is the core of the whole measurement and control system and the Mitsubishi PLC is adopted in this study. It mainly includes power module, CPU module, interface module, signal module, functional module and communication processor, etc. [12]. Its function is to control the system through digital or analog input and output.

(2) Sensors

The torque and speed sensor is installed between a prime motor and its corresponding load. Its function is to measure the speed and torque of the system for the study on output control and system efficiency.

Flow sensor is installed in the in-line and out-line of the closed-circuit motor. Its function is to measure the liquid flow and present the liquid flow in a current signal form through the transmitter.

Temperature sensors are installed in a high and low conduit, a drive fuel tank and a loading fuel tank. The function of temperature sensors is to monitor oil temperature parameters in real time.

Pressure sensors are installed in the high pressure pipeline and the low pressure pipeline. Their functions are to monitor system pressure parameters in real time as well as master the loading state of the system.

(3) Variable pump and variable displacement motor

The structure of the adopted hydraulic pump and the motor is swash-plate axial variable displacement piston. Their functions are to control the displacement and flow direction through controlling electric current.

(4) Proportional overflow valve

The proportional overflow valve used in this study is RZMO proportional overflow valve. Its structure is in cone valve and directly operated type, and it can be used to realize analog loading.

**Condition monitoring function**

As one of the functions of the measurement and control system, the condition monitoring function can effectively monitor signals of speed and torque, flow, temperature and pressure, etc., through sensors. These signals can be displayed in real time in the Lab VIEW measurement and control system through an acquisition card [13-14]. The flow of signal monitoring is shown in figure 2.
The monitoring function also includes the monitoring of the motor power, fluid power and mechanical power of the system in real time, thus to obtain the real-time operating power of the subsystems in specific operating conditions.

(1) Motor power
The actual pressure and current signals after processing are calculated and the equation \( P = \sum_{i=1}^{n} u_i \times i \) is obtained, where \( P \) refers to the motor power, \( u_i \) refers to the instantaneous value of pressure and \( i \) refers to the instantaneous value of current. The real-time energy consumption of the electrical machine can be obtained by calculation and monitoring of the motor power.

(2) Fluid power
The actual pressure and flow signals are used for calculation of the fluid power and the obtained equation is \( P_i = P \times Q \), where \( P_i \) refers to the fluid power, \( P \) refers to the actual pressure, \( Q \) refers to fluid flow (\( m^3/s \)). The power changes along with the change of flow and pressure.

(3) Mechanical power
The actual speed and torque of the variable pump and the variable displacement motor are multiplied. The obtained equation is \( P = 9550 \times T \times N \), where \( P \) refers to the power, \( T \) refers to the torque and \( N \) refers to the speed.

**System control function based on PLC**
The system control function mainly refers to the PLC of the measurement and control system is connected to the relevant intermediate relay through outputting control signals for analog control of some system hardware, thus to control the system. The Lab VIEW software is used to communicate with PLC, thus the operating data during system operation can be collected, processed and displayed in real time. The main controlled hardware includes variable pump, variable motor and proportional overflow valve, etc.

During the analog control of variable pump and variable motor, the ratio electromagnet is used to change the differential pressure of control port. Thus the swashplate angle of the pump can be changed by the variable displacement mechanism, and the displacement can be adjusted. Figure 3 shows the correlation between displacement and control current.
Design and Development of Measurement and Control System of Mechanical-Electrical-Hydraulic Integration Based on Programmable Logic Controller

In the analog adjustment of proportional overflow valve, the system pressure can be regulated steplessly. Its characteristic curve is shown in figure 4.

Figure 3: Correlation between displacement and control current (the left image refers to the variable pump and the right refers to the variable motor)

Figure 4: Control curve of the proportional overflow valve

3. Data transmission and communication based on PLC

PLC is taken as the main control module to realize the data transmission in the measurement and control system. The flow is data transmission and communication of LabVIEW and PLC, PLC internal programming and data communication between PLC and frequency changer.

(1) Communication between Lab VIEW and PLC

The Lab VIEW software is internally installed with RS-232 performance function, and serial communication can be achieved through Virtual Instrument Software Architecture (VISA). In the programming design of the Bluetooth virtual serial port [15], the VISA serial port is initialized first, and the port number, Baud rate and data bits, etc., are set up. Then the serial port is read and written using read-write nodes. After that, the serial port is closed and the operation is terminated. According to the orders provided by PLC, the working conditions of PLC can be intervened through VISA serial port.

(2) PCL and industrial personal computer

After the construction of hardware configuration, the program of communication should be written correctly before the data transmission. The serial communication between industrial personal computer and PLC is realized through CP340.

(3) Communication between PLC and frequency changer

In the program, PLC communicates with the frequency changer. The communication specifications must be determined during the initialization of frequency changer. In addition, every time after the parameter setting, the frequency changer should be reset. Then, according to the parameter setting, the communication is based on the RS485 communication protocol.

Figure 5: RS485 communication protocol
4. Torque control of the measurement and control system

In the experimental design, the industrial personal computer is taken as the upper computer [16] and PLC as the lower computer. The combination of PLC and Lab VIEW can be used to realize the spot remote measurement and control. By directly controlling the motor torque, the feasibility of outputting and verifying the measurement and control system through hybrid power is studied.

Characteristics of direct torque control
1. In motor mathematical models, the flux linkage and torque of direct torque control [17] do not need decoupling control, and the calculated quantity is small and vector control is simple.

2. Stator resistance parameters should be mastered in the direct torque control, and the flux estimation can be performed under the stator flux linkage with the cooperation of motor parameters.

3. Compared with the vector control, direct torque control has a more simplified control structure.

4. In monitoring the motor stator, the voltage and current of direct torque control can directly control the torque and no detection of current or flux linkage is needed; besides, it has better dynamic response.

Simulation of direct torque control
In the experiment in this study, the simulation verification of the direct torque control system of three-phase stepper motor is carried out according to characteristics of the direct torque control. Relevant parameters of the simulation motor are set up: nominal voltage U is 500 V; frequency f is 50 Hz; rated speed V is 1480 r/min; stator resistance R1 is 4.25 Ω; stator inductance L1 is 0.666 H; rotor resistance R2 is 3.24 Ω and rotor inductance L2 is 0.671 H; the mutual inductance L3 between stator and rotor is 0.651 H; the number of pole-pairs n is 2; rotational inertia J is 0.02 N·s² and simulation time t is 2 s. Simulation results are shown in figure 6-9.

Simulation results show that the amplitudes of stator flux linkage and electromagnetic torque [18-19] are controlled within a certain range.
The motor speed has fast dynamic response and the speed is steady. These results verify the feasibility of direct torque control in hybrid power.

Confirmatory experiments of hybrid power output and the design of the measurement and control system

In order to analyze the hybrid power technology, the torque synthesis of the diesel engine and the motor is achieved under the premise of constant load. In the experiment, the motor speed is controlled directly using the direct torque technology, thus to obtain the connection among each element during the hybrid power output as well as verify the feasibility of the measurement and control system. In addition, acollaborative experiment of the system is also designed in the experiment, which uses a platform for experiment to verify the characteristics of direct torque control in hybrid power output. Specific steps are as follows:

1. PLC is connected with the external power source to start the control panel power of the testing system.
2. The PLC system is loaded with the program written by its programming software. The control amplifier of PLC is used to keep its normal operation.
3. The Lab VIEW software is started. The serial port of Lab VIEW software communicates with the PLC. The torque value of Lab VIEW is transferred to S7-300 through the serial port, and then S7-300 is jointed with MM440. Finally, the torque value of motor output is set up.
4. The obtained data from PLC are read by the data acquisition system of Lab VIEW [20] and then processed and preserved. After the experiment, relevant experimental results are obtained. Finally the software and system are shut down and the verification experiment of the whole measurement and control system is completed.

In the verification experiment, PLC is used for programming to realize the direct torque output of the transducer control motor, the output of control amplifier, constant load of system as well as the normal output of motor and dynamic coupling. The speed of motor output and the speed of dynamic coupling output are shown in figure 10-11.

The experiment in this study can basically verify the feasibility of the measurement and control system of the mechanic-electronic-hydraulic integration based on PLC. Thus the system can be extensively applied to mechanical industry production.

5. Conclusion

By using the control experimental platform of mechanic-electronic-hydraulic integration and on the basis of PLC, thus study designs a measurement and control system of mechanic-electronic-hydraulic integration. Such system takes the PLC and sensors as the main hardware, and its functions of working conditions monitoring and system control are developed. Therefore, such system can effectively monitor the speed and torque and flow signals during the system operation, as well as achieve acquisition, processing and display of data in real time. This study also designs relevant experiments of data transmission and system torque control based on PLC. As a consequence, the real-time data transmission of the system and the torque function of the direct control motor are realized. Moreover, the feasibility of the system is verified through a verification experiment. However, the currently designed measurement and control system is not very stable during operation. Therefore, its operating properties should be improved constantly, thus to enable it to be applied to mechanical engineering better.

6. References


