Aluminium Smelter Multifunctional Overhead Crane - Intelligent Servo Control of Hydraulic System

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Abstract

The aluminium smelting industry is currently accelerating its transition toward high-end and intelligent development, with core equipment like multifunctional overhead cranes being in urgent need of technological upgrading. The traditional aluminium tapping operations suffer from low efficiency and high error rates, with such issues as excessive oil temperature, high energy consumption and inadequate motor protection in their hydraulic system. The intelligent servo control hydraulic system is a critical breakthrough. An intelligent servo control hydraulic system integrates servo drives, programmable logic controllers (PLC) and sensors has been developed in order to address the problems in the existing multifunctional overhead crane hydraulic systems, such as excessive oil temperature, high energy consumption and inadequate motor protection. This system effectively eliminates redundant flow and energy loss through precise regulation of flow and pressure, achieving significant energy savings while simplifying system architecture and upgrading protective functions. This paper provides a reference for the intelligent upgrading of the existing multifunctional overhead cranes used in the aluminium smelting industry.

Keywords: Aluminium electrolysis, Multifunctional overhead crane, Intelligent servo control, Hydraulic unit drive.

1. Research Background and Technical Challenges

1.1 Industry Status and Demand for Intelligent Transformation

The aluminium smelting industry is an energy-intensive and capital-intensive industry. Its aluminium production efficiency and intelligent production directly impact national resource strategies and industrial competitiveness. In recent years, with the advent of the Chinese "dual carbon" goals and the advancement of Industry 4.0, the aluminium smelting industry has been undergoing profound transition toward high-end, low carbon and intelligent production. The multifunctional overhead cranes (also known as pot tending machines, or PTMs) perform various critical, high-frequency, and high-intensity tasks, including breaking bath crust, tapping aluminium, changing anodes, raising anode beam busbars, etc. Their performance and intelligence directly dictate the efficiency, energy consumption, safety, and stability of the entire potline. However, the core systems of the traditional multifunctional overhead cranes that are widely used at present, particularly the hydraulic drive system, cannot meet new requirements of intelligent production technically, becoming a major bottleneck that hinders industrial upgrading.

1.2 Analysis of Existing Issues in Hydraulic Drive Systems

The hydraulic system is installed on the overhead crane's rotating mechanism, which operates in a harsh environment above the pot, where the temperature frequently exceeds 50 °C. In addition, under the proportional control mode, the oil pump maintains constant operation at a rated speed with a steady 20 MPa outlet pressure, while the actuator requires 8–12 MPa only. The constant-speed operation of the fixed displacement pump generates 40 % excess flow. When the surplus pressure flow passes through the throttle valve and relief valve, throttling loss and overflow loss will occur, both of which will cause the system to heat up, resulting in high oil temperature. Even with air heat exchangers, cooling effectiveness remains limited, particularly during the summer when hydraulic oil temperature reaches 60–80 ℃. Prolonged high oil temperature severely impacts the service life of the hydraulic fluids, hydraulic components and seals, accelerating seal aging. Additionally, prolonged operation of the air heat exchanger at high oil temperature can easily lead to overheating and burn out the motor of the cooling fan.

The hydraulic system is installed on the overhead crane's rotary mechanism and so the three-phase power supply must be routed through rotary cables to reach the motor control cabinet and as a result circuit phase loss frequently occurs during operation. However, the reliance on thermal relays for the motor phase loss protection leads to motor burnout due to the inability of the thermal relays to offer effective protection in the event of a phase loss. The reason for that is that thermal relays have two major limitations:

1. Detection hysteresis: In the event of a phase loss, enough heat needs to be accumulated to trigger protection, with a response delay of up to 2–3 seconds, making it impossible to achieve millisecond rapid cut-off, and thus resulting in winding overheating and burnout;
2. Inadequate sensitivity: The strong magnetic fields and load fluctuations in the potline can easily cause malfunction.

2. Urgency of Integrated Intelligent Upgrading

An intelligent servo control hydraulic system is proposed to address the problems in the existing hydraulic system as shown in Figure 1.

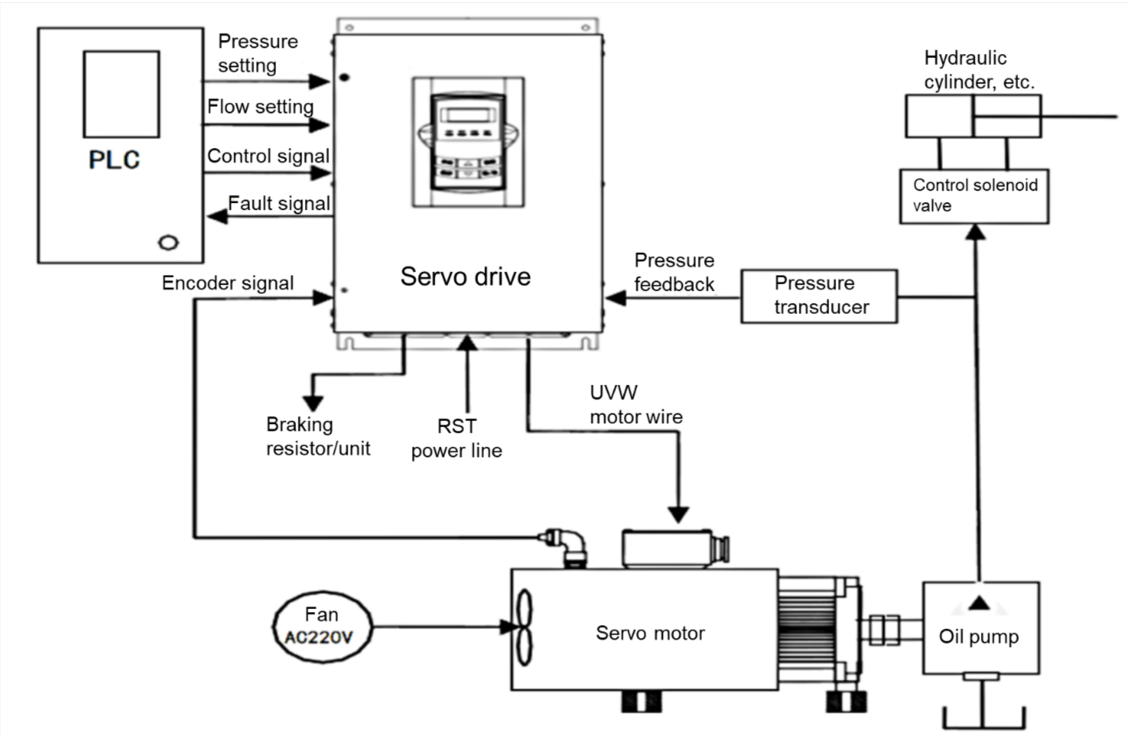

Figure 1. Diagram of intelligent servo control hydraulic system.

The system consists mainly of a PLC, an oil pump, a servo motor, a servo drive, a pressure sensor, a rotational speed sensor, a hydraulic directional valve and accessories. The high-precision pressure sensor is installed at the outlet of the oil pump and the servo drive is housed in the electrical control cabinet. The pressure and flow demand values for each circuit are sent by the

PLC to the servo drive for control. The flow is controlled in a closed loop by the rotational speed and speed sensors and the pressure is controlled in a closed loop by the pressure sensor. The closed-loop control of both pressure and flow is achieved by the servo drive (see Figure 2).

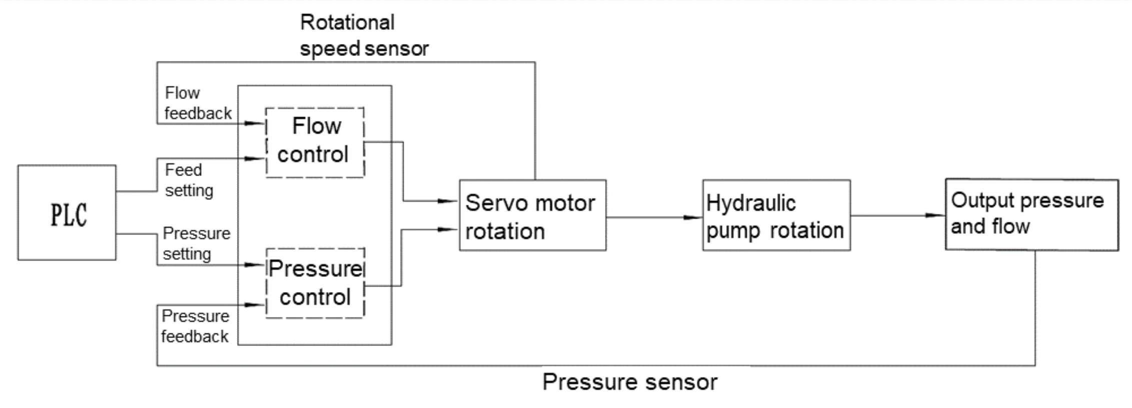

Figure 2. Schematic diagram of working flow of intelligent servo control hydraulic system.

The working flow of the intelligent servo control hydraulic system is as follows:

1) The PLC transmits the required flow and pressure values of each hydraulic circuit to the servo drive based on operation commands received.
2) According to the control signals received from the PLC and in conjunction with the feedback signals from the rotational speed sensor and pressure sensor, the servo drive runs its internal program operations and drives the servo motor to rotate at different speeds.
3) The servo motor drives the fixed displacement pump to rotate, delivering hydraulic fluid with different flow and pressure to drive actuators (hydraulic cylinder or motor), thereby achieving various predetermined motions.
4) The pressure sensor and rotational speed sensors continuously monitor the pressure of the hydraulic system and motor rotation, feeding back the signals to the servo drive to form closed-loop control, enabling the precise control of the output flow and pressure of the hydraulic system.

3. Advantages of Intelligent Servo Control Hydraulic System

3.1 Efficient and Energy-Saving

In the operation process of the traditional proportional control hydraulic system, the hydraulic pump always rotates at a constant speed and outputs a fixed flow rate regardless of whether actuator motion is required or not. When actuator motion is not required or the motion speed is slow, the excess hydraulic oil will flow back to the oil tank through the overflow valve, resulting in energy loss and elevated oil temperature.

The intelligent servo control hydraulic system can adjust motor speed and pump output flow rate in a real-time manner according to actuator motion requirements. When the cylinder and motor actuators are stationary, the servo motor ceases operation with the drive on standby, eliminating excess flow and reducing energy loss. With minimal internal heat generation, this system can achieve thermal equilibrium at approximately 60 °C oil temperature without air heat exchangers under the ambient conditions of 55 °C and is thus suitable for operation in high-temperature environment below 80 °C. This system can achieve the required motor speed within 200 ms of receiving PLC commands. As a result, this system has almost no energy loss and practical applications verify that the intelligent servo control hydraulic system can bring an energy saving of over 70 % compared to the traditional proportional control hydraulic systems (see Table 1).

Table 1. Comparison of energy consumption indicators between intelligent servo control hydraulic system and proportional control hydraulic system.

Indicator	Before Retrofitting	After Retrofitting	Improvement
Energy consumption per day of operation	42.7 kWh	11.4 kWh	-73.3 %
Peak oil temperature	62 ℃	57.7 ℃	-6.9 %

3.2 Simple System Structure and Adequate Protection

The intelligent servo control hydraulic system utilizes servo drivers to drive motors, with the output flow and pressure of the hydraulic system controlled by changing the speed and direction of the motor. Compared with the proportional hydraulic control systems, this design eliminates such components as pressure and flow proportional valves, auxiliary pumps, etc., further simplifying the system architecture. The servo drive also features comprehensive protection functions, including phase loss, overcurrent, overpressure, undervoltage and overheating protections. In the event of system abnormalities, the servo drive will immediately send out alarm signals and ceases operation, effectively protecting both the motor and hydraulic system.

3.3 Precise Pressure and Flow Control

The system pressure sensor and motor speed sensor provide real-time data feedback to the servo drive, which precisely controls output flow and pressure by adjusting the motor speed. It is of great significance to the overhead crane's hydraulic system, allowing such tasks as anode height measurement and slow alignment to be completed with ease.

3.4 Extended Service Life of System Components and Hydraulic Oil

Under the favourable conditions of less system heat generation and lower oil temperature, the service life of the oil pump, valve parts and hydraulic oil can be extended, which can reduce running costs and maintenance workload.

3.5 Easier Fault Diagnosis and Maintenance

The intelligent servo control hydraulic system uses intelligent devices such as servo drives and PLCs and has self-diagnostic capabilities and fault display functions. In the event of system faults, the servo drive and PLC can promptly display fault codes and fault messages, enabling maintenance personnel to quickly diagnose and fix issues.

4. Conclusions

The intelligent servo control hydraulic system uses intelligent devices such as servo drives, PLC controllers and sensors to achieve precise control over hydraulic output flow and pressure. This innovation eliminates excess flow, reduces energy loss by over 70 % and lowers oil temperature by approximately 7 %, delivering significant operational benefits. In addition, the system features a simple structure and has comprehensive protection functions, enabling easier fault diagnosis and maintenance. It can provide a technical route for the intelligent upgrading of the hydraulic system of the existing multifunctional overhead cranes in aluminium smelters. The continuous development of intelligent technologies is poised to broaden the applications and adoptions of the intelligent servo control hydraulic system in more fields.