Research on Large-diameter Electro-hydraulic Rotary Table and Its Control System for Deep-water Drilling Rig

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Abstract. With the rapid development of offshore oil and gas drilling equipment industry, it is imperative to study the technology of large-diameter electrically controlled hydraulic rotary table for deep-water drilling rig. Firstly, the hydraulic rotary table design is carried out, which include mechanical structure, electronic control system and hydraulic system design. Secondly, studying the electric control system. The driving force of the electric hydraulic rotary table comes from the hydraulic system, and its control function is mainly realized by the electric control system. This paper analyzes the input and output of the the hydraulic rotary table's electric control system, completes the design of the hardware system and software system, and puts forward an electric control system scheme of the hydraulic rotary table with perfect function and reasonable configuration. Finally, the conclusion is drawn that the hydraulic rotary table, which is driven by hydraulic motor and rotates at low speed, has the characteristics of compact structure, light weight and large opening size, and can meet the requirement of laying down the riser. It is of great significance to the development of deepwater offshore drilling equipment.

1. Introduction

With the rapid development of oil drilling equipment industry, hydraulic rotary table has been used more and more, especially in the field of offshore drilling equipment, which has gradually become the standard configuration of modern offshore platform deepwater drilling rig. On the offshore platform, the rotary table is mainly used for casing running or up-and-down drilling, in which the rotary table is required to have large supporting capacity and through hole diameter when casing running, suspending drilling tools and movable drilling tools are used, and the hydraulic rotary table is based on conventional rotary table, using hydraulic motor as power, driving the rotary table for low-speed rotation, which has a strong bearing capacity and a low speed[1].

The rotary table in the field of oil drilling equipment mainly refers to the horizontal rotary equipment which can reduce the speed through a pair of orthogonal bevel gear pairs, so that the rotary table can obtain a certain range of speed and torque output. In the process of drilling, the function of the rotary table is to transfer torque and drive the rotary drilling tools[2] [3]. Electro-hydraulic rotary table is a kind of rotary table driving device whose driving force comes from hydraulic system and whose control function is mainly realized by electro-hydraulic system. The electronic control hydraulic rotary table can be divided into three parts: mechanical structure, hydraulic system and electronic control system. These three major parts each play its own unique role, and through functional integration to form a complete rotary table system.
Under the same requirement, the electronic hydraulic rotary table has the advantages of small size, light weight, high integration, safe and reliable operation and so on[4]. In this paper, the structure of the hydraulic rotary table and its electronic control system will be analyzed and studied. Finally, a reasonable rotary table design scheme is given.

2. The structure design of electric control hydraulic rotary table

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2.1. General Scheme

According to the requirements of the working performance parameters such as the rated static load of the open diameter rotary table, the motion and power transfer forms needed to complete the functions such as the forward and reverse rotation motion and the reverse torque release are analyzed, determine the overall design ideas and design scheme of the rotary table design. The stress is laid on the analysis of the strain test of the reduction mechanism, the supporting mechanism, the rotating disk bushing mechanism and the input shaft. The design method and key technology of the gear transmission and the slewing bearing under the conditions of low speed and High Torque are mastered, according to the requirement of rotating disk torque testing, the Torque input-axis strain model is established, and the real-time testing, transmission and analysis unit of Torque information is designed in combination with wireless sensor technology, the torque information of the Rotary Table is transmitted to the driller integrated console and the torque table on the side of the weight indicator to realize real-time display, analysis and alarm.

The paper deals with the key technology of vector speed regulation and anti-rotation of rotary table in rotary table control system, and completes the design of rotary table hydraulic and electric control system. The technical route is shown in figure 1.

![Figure 1. Technical route diagram of rotary table technology research.](image-url)
2.2. Design of mechanical structure
Mechanical structure mainly includes: Upper Cover, base, rotary table device, input shaft assembly, main bushing device, locking device, bevel gear pair and other parts. These components together constitute the mechanical structure of the rotary table and provide the structural support and basic mechanical movement units for the rotary table. The shape of the rotary table is shown in figure 2.

![Figure 2. Rotary table boundary diagram.](image)

The hydraulic rotary table adopts two or four hydraulic motors to drive the input shaft to rotate. The rotary table is locked by the way of directly driving the rotary table to rotate after the first gear transmission. The rotary table is locked by the way of locking the rotary table with two brake blocks, the control system adopts the way of electric control fluid, in which the hydraulic control system is closed control, and the electric control system adopts the way of PLC remote control. The rotary table bushing is assembled from the outside to the inside and from the big to the small. The bushing is installed or removed according to the required size of the rotary table opening.

2.3. hydraulic system
The hydraulic system mainly includes: hydraulic power source, Hydraulic Motor, Control Valve Group, hydraulic pipeline, pipeline joint, pressure gauge, hydraulic medium oil and so on. These components together constitute the hydraulic system of the rotary table and provide the hydraulic circulation channel and the Hydraulic Movement Unit for the rotary table.

2.4. electronic control system
The electronic control system mainly includes hardware system and software system. These two parts together constitute the electric control system of the rotary table, and provide the carrier of Control Logic and the operation mechanism of control logic for the rotary table. The details are as follows:

2.4.1. hardware system. The hardware system mainly includes\textsuperscript{[5]}: Control Unit (such as: PLC system\textsuperscript{[5, 6]}, proportional amplifier, relay, etc.) , executive unit (such as: Solenoid Valve, sensor, etc.) , man-machine interface (such as: Industrial Computer, physical switch, etc.).

2.4.2. software system. The software system mainly includes: executive layer control program (such as: PLC program\textsuperscript{[6, 7]}), Operation Layer Control Program (such as: WINCC program).

3. Research on control system of hydraulic rotary table

3.1. Analysis of input and output of electric control system for hydraulic rotary table
Through the analysis of the input and output of the electric control system of the hydraulic rotary table, the man-machine operation type and the measurable State Information of the system can be defined, and the type of the controlled object and its expected action can also be defined\textsuperscript{[8]}. 
3.1.1. Input Analysis of electronic control system

The input of electronic control system, I. E. The input of rotary table control unit, can be divided into two parts: man-machine interface input and sensor input. The details are as follows:

- **Man-machine interface input.** The input mode of physical switch is used for man-machine interface. The operation of rotary table forward, stop, reverse, rotary table torque release, stop operation, hydraulic motor select operation, emergency stop operation can be defined as input of switch quantity. The speed setting and torque setting operation of the rotary table can be defined as analog input. For the man-machine interface, the touch-screen input mode is adopted, and the operator input information will eventually be transmitted to the control unit of the electronic control system by means of communication protocol, which can be broadly defined as communication protocol input.

- **Sensor input.** The 4-20mA current input of the pressure sensor in a rotary table hydraulic system can be defined as analog input. The passive dry contact input of the pressure relay in a rotary table hydraulic system can be defined as the switch input. The rotary hydraulic motor speed encoder input can be defined as the communication protocol input. The passive dry contact input for rotary table rotation detection near switch can be defined as the switch quantity input.

3.1.2. Output analysis of electronic control system

The output of the electronic control system mainly refers to the output of the rotary table control unit, which is mainly used to control the specific movement of the rotary table execution unit. Among them, the speed proportional control and the torque proportional control can be defined as analog output, and the torque release and the selection of hydraulic motor can be defined as switch output.

In the case that the electronic control system has communication with other third-party equipment, the communication content sent by the control unit can also be defined as communication protocol output or hard-line signal output.

The output of the control unit can be defined as the output of the switch when the man-machine interface is equipped with a physical sound-light alarm device.

3.2. Hardware design of electronic control system for hydraulic rotary table

Under the condition that the input and output of the electronic control system have been determined, the rotary table control unit, executive unit and man-machine interface are designed according to the operational requirements and functional requirements of the system. The hardware frame of the electronic control system of the hydraulic rotary table is shown in Figure 3.
The design of the control unit generally includes: The design of the PLC system, the design of the proportional amplifier, the design of the relay, the design of the PNOZ (safety relays), the design of the safety grid, the design of the power module, the design of the circuit breaker, and the design of other parts. The details are as follows:

3.2.1. Design of Control Unit
• PLC system design
PLC system configuration of a CPU module, mainly for data processing and logical operation functions. Two groups of multi-channel input and output modules, mainly analog and digital input and output processing. Equipped with function module, mainly carries on the speed sensor input processing which has the communication protocol. One communication Module, which is used to communicate with driller integrated control system or other third-party equipment[9].

• Design of proportional amplifier
Equipped with two double-channel proportional amplifiers, the main purpose of which is to convert the control command signal from PLC system into the drive electric energy signal needed by proportional solenoid valve, and finally to ensure the operation accuracy of the solenoid valve to meet the design requirements.

• Relay Design
Equipped with five relays to isolate the solenoid valve from the PLC system and a proportional amplifier to enable control.
Configured with a PNOZ (safety relays) that, when the system has an emergency stop trigger, it can safely isolate the power of the output device or the enable of the driving device, ultimately ensuring the emergency stop of the sports device.

• Safety Grille Design
Equipped with two security grates to isolate the input signal of the sensor and ensure the explosion-proof requirement of the local safety equipment and the input safety of the PLC system.

• Design of power supply module
Equipped with two power modules to ensure the control unit power matching and power stability.

• Design of circuit breaker
Equipped with one circuit breaker is mainly for the control unit to provide short-circuit and overload protection, as well as the normal power division.

• The rest of the design
The system is equipped with an appropriate number of terminals, cables, Glans, connectors, electrical cabinet meeting the required explosion protection and protection requirements, and other electrical installation accessories to ensure the integrity of the system.

3.2.2. Design of execution unit
The design of the executive unit includes: The design of solenoid valve, the design of sensor, and the design of other parts. The details are as follows:

• Equipped with a rotary table positive speed control proportional solenoid valve, a rotary table reverse speed control proportional solenoid valve, a rotary table torque set proportional solenoid valve. And equipped with a rotary torque release switch solenoid valve, a hydraulic motor select switch solenoid valve,

• Equipped with 1 hydraulic motor working pressure sensor and 1 rotary speed sensor. In view of the low rotating speed of the rotary table, therefore, the accuracy of the sensor can only meet the accuracy requirements of the whole measurement system, do not have to choose too high. [10][11]

• The design content of the other part is consistent with that of the control unit.

3.2.3. Design of man-machine interface
The design of man-machine interface includes three parts: the design of industrial computer, the design of physical switch or device, and the design of other parts. The details are as follows:
• Industrial Control Computer design: Equipped with 1 industrial control computer, which is mainly used for the storage of man-machine interface program and the logical operation of Operation Layer, also can design the operation terminal or the display terminal of the man-machine interface.
  • Design of physical switches or devices: Equipped with 1 integrated rotary table forward, stop and reverse selector switch, rotary table torque release, stop selector switch, hydraulic motor selector switch, emergency stop button, rotary table speed setting potentiometer, rotary table torque setting potentiometer, operation box of physical sound and light alarm device. The operation box can be used in conjunction with a display integrated machine.
  • The design content of the other part is consistent with that of the control unit.

3.3. Software Design of electronic control system for hydraulic rotary table
When the hardware of the electronic control system has been determined, according to the need of operation and function of the control system, the executing layer control program and the operating layer control program of the rotary table are compiled and a complete software system is established. The software framework of the electric control system of the hydraulic rotary table is shown in Figure 4.

3.3.1. Design of Control Program of executive layer
The control program design of executive layer includes three parts: input processing, function processing and output processing[10]. The details are as follows:
  • Input Processing
    The system processes the input data from outside the CPU, including analog input, digital input, communication protocol input, and stores the processed data in the planned data block.
  • Functional Processing
    System-level functional processing, including operation mode processing (local emergency operation, driller operation), operation mode processing (initialization processing, non-start control output reset processing, normal operation processing, emergency stop processing), manual automatic test mode processing (manual and automatic test mode processing has detailed control function and protection function, test mode processing has no specific control function and protection function).
    Component-level processing is the logic operation between internal variable and external variable, which can realize the speed closed-loop control, torque closed-loop control and so on.
  • Output Processing
The system stores the data processed by function into the planned data block, including analog output, digital output, communication protocol data output.

3.3.2. Design of Operation Layer control program

When the man-machine interface hardware of the electronic control system has been determined, the operating environment of the operation layer control program can be determined. Operation Layer control program design includes: Landing Screen design, sub-screen design in two parts. The details are as follows:

- Login screen design
  - Login screen can include: User Account, clear screen, language selection, unit switching function.
- Sub-screen design
  - Sub-screen includes system screen (such as: Network Topology, variable list, Operation Record), alarm screen (such as: current alarm, history alarm), rotary table operation and status screen (such as: Rotary table forward, reverse, stop, rotary table speed setting, rotary table torque setting, rotary table torque release, rotary table motor selection, hydraulic system pressure, rotary table speed, emergency stop, etc.), data screen (such as: User Management, diagnostic list) and so on.

4. Conclusion

The following conclusions can be drawn from the above research contents. Firstly, the mechanical structure, hydraulic and Electronic Control System Scheme are obtained. Secondly, the man-machine operation type and measurable state information of the electronic control system are defined, the type of controlled object and its expected action are acquired, the design of hardware and software of the electronic control system are realized. Finally, a relatively perfect function, relatively reasonable configuration and electronic control system of the hydraulic rotary table are Formatted. It is a large diameter electro-hydraulic Rotary table with compact structure, high bearing capacity, large opening size and light weight is obtained. Which is especially suitable for the drilling system of a deep water floating drilling platform. It is of great significance to the integration of deepwater offshore drilling equipment.

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