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Hydraulic Motor Driving Variable-Pitch System for Wind Turbine

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Abstract

The present hydraulic variable-pitch mechanism of wind turbine uses three hydraulic cylinders to drive three crank and connecting rod mechanisms respectively; the blades are moved with the cranks. The hydraulic variable-pitch mechanism has complex structure, occupies a lot of space and its maintenance is trouble. In order to make up for the shortcomings of hydraulic cylinder variable-pitch system, the present hydraulic variable-pitch mechanism should be changed as follows: hydraulic motors are used to drive gears; gears drive blades; the electro-hydraulic proportional valves are used to control hydraulic motors. The hydraulic control part and electrical control part of variable-pitch system is redesigned. The new variable-pitch system is called hydraulic motor driving variable-pitch system. The new variable-pitch system meets the control requirements of blade pitch, makes the structure simple and its application effect is perfect.

***Keywords**: wind turbine, hydraulic variable pitch, electro-hydraulic proportional, control system*

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1. Introduction

The wind wheel and the blades are the important parts of wind turbine. The function that the blade pitch angle can be automatically adjusted is as follows: when the wind turbine starts a sufficient starting torque can be obtained by varying pitch; When wind is excessive, the blades can rotate around their longitudinal axles in order to change the attack angle of the airflow on the blades, the rotation of blades changes the aerodynamic torque obtained by the wind turbine, controls the energy absorption of the wind wheel, and maintains constant and smooth output power [1, 2, 6]. Variable-pitch system improves the operating efficiency of wind turbine, and allows the wind turbine to be operated reliably on the condition of different wind, different wind direction and different wind speed [7-9].

Variable-pitch control methods can generally be divided into two types, one is the electric servo control system in which electric motors are used to drive blades, the other is the hydraulic servo (or electro-hydraulic proportional) control system in which hydraulic cylinders are used to drive crank and connecting rod mechanisms respectively, the blades are moved with the cranks [3-5].

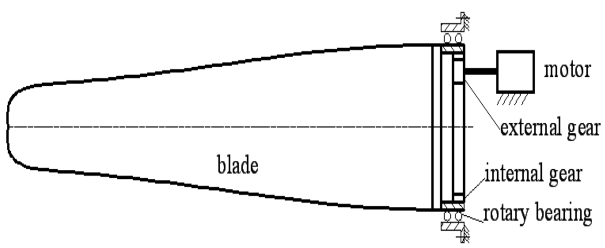

Figure 1. Variable-pitch Mechanical System

The hydraulic variable-pitch mechanism needs a big thrust and enough space. If a hydraulic motor is used to drive directly blade at the end of the blade as shown in Figure 1, the structure is more effort and compact.

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2. The Design of Hydraulic Motor Driving Variable-pitch Control System

Figure 2 is the hydraulic motor driving variable-pitch control system. There are three sets control valve blocks which are used to control the rotation of three hydraulic motors respectively. Motor 7 has overload protection and braking device. Number 6 is proportional directional valve. Wind wheel speed is measured by wind speed sensor and the signals from sensor are used as the input of the PLC, then PLC outputs analog proportional control signals which control the proportion direction valve 6 which adjusts and controls the speed and direction of hydraulic motor. On the fixed bearing there are two travel switches corresponding to the two limit angles (0^0 and 90^0) of each blade, totally there are six limit switches. If the contact on the blade touches the travel switch, hydraulic motor stops. Pressure relay 3 measures the hydraulic system pressure, when the hydraulic system pressure is more than allowable value (such as 22MPa), pump is unloaded. Relay 8 determines accumulator pressure, when pressure is less than 14MPa, pump starts, supplies oil to accumulator. In order to control the oil temperature, a temperature sensor is used; the electric heater is started when the temperature is below -20^0C, and stops heating when the temperature is above 10^0C.

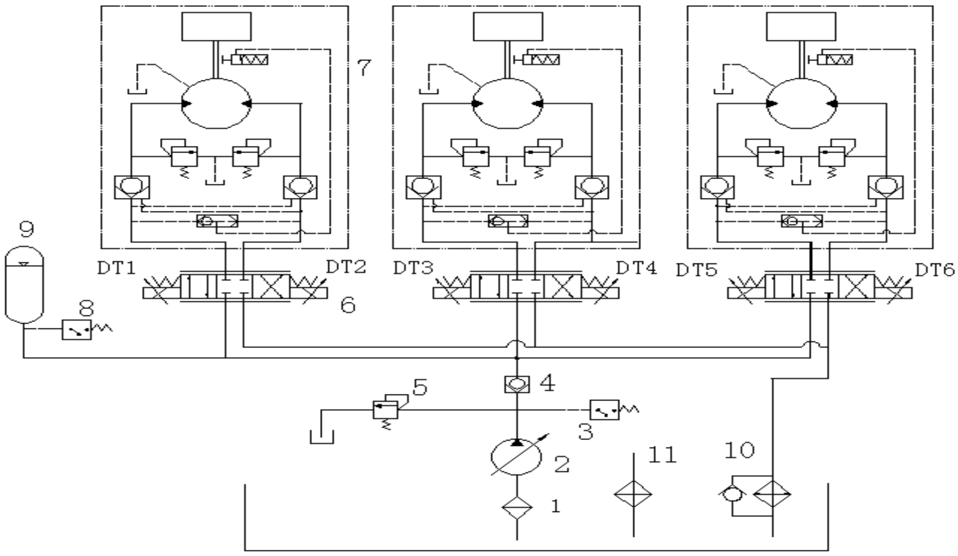

Figure 2. Hydraulic System
1- filter 2- variable pump 3,8- pressure relay 4- one-way valve 5- relief valve
6- electro-hydraulic proportional valve 7- hydraulic motor 9- accumulator
10- oil cooler 11- electric heater

The working process of hydraulic variable-pitch system is as follows:

1) When hydraulic system is at the normal working condition. When the hydraulic pump station is started completely, the proportional directional valve’s electromagnet DT1, DT3 and DT5 are charged ,pressure oil flows into motors from the left cavity of motors and the blades turn clockwise; Conversely, DT2, DT4 and DT6 are charged, pressure oil enters motors from the right cavity of motors, the blades rotate counterclockwise; if DT1, DT3, DT5, DT2, DT4, and DT6 are not charged, proportional valves work in the neutral position, the motors stop, the brake cylinders act. Pump stops under the control of the control system (electric motor stops).

2) When the power is cut-off, Uninterruptible Power Supply (UPS) is started, the accumulator supplies oil to motor, when DT1, DT3, DT5 are charged, motor rotates clockwise, completing feathering. When the pitch angle is adjusted in right position, the electro-hydraulic proportional valve goes back to the neutral position.

Figure 3 is a main control circuit chart of variable-pitch system, including the control circuit of the main pump electric motor M1 and relays. Figure 4 is the PLC control chart of variable-pitch. According to the above action requests, I/O terminals of PLC can be distributed as shown on Table 1 [10, 11].

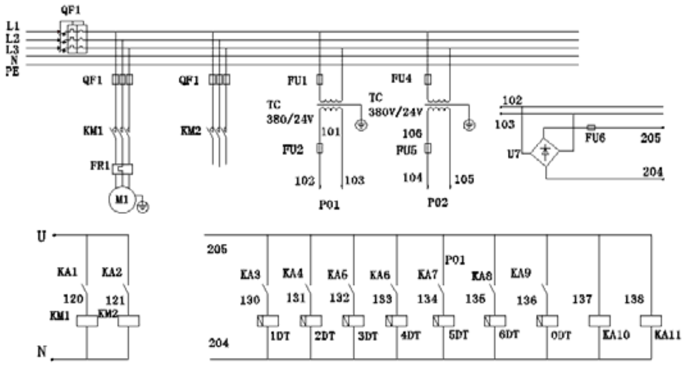

Figure 3. Main Circuit Control Part

Table 1. Input/output Terminal (I/O) and Function

I/O	function	I/O	function	I/O	Function	I/O	function
I0.0	Pump on	I1.0	ralay 3 switch close	I2.0	0^0limit switch close on shaft 3	Q0.6	KA7 on
I0.1	Pump off	I1.1	ralay 3 switch close	I2.1	90^0limit switch close on shaft 3	Q0.7	KA8 on
I0.2	blade 1 turn left	I1.2	Thermometer sensor on at low temperature	Q0.0	KA1 on	Q1.0	KA9 on，Pump unloading
I0.3	blade 1 turn right	I1.3	thermometer sensor on at high temperature	Q0.1	KA2 on	EM235（1）	proportional valve 1
I0.4	blade 2 turn left	I1.4	0^0limit switch close on shaft 1	Q0.2	KA3 on	EM235（2）	proportional valve 2
I0.5	blade 2 turn right	I1.5	90^0limit switch close on shaft 1	Q0.3	KA4 on	EM235（3）	proportional valve 3
I0.6	blade 3 turn left	I1.6	0^0limit switch close on shaft 2	Q0.4	KA5 on	EM235（4）	e-type thermocouple electrical signal
I0.7	Blade 3 turn right	I1.7	90^0limit switch close on shaft 2	Q0.5	KA6 on		

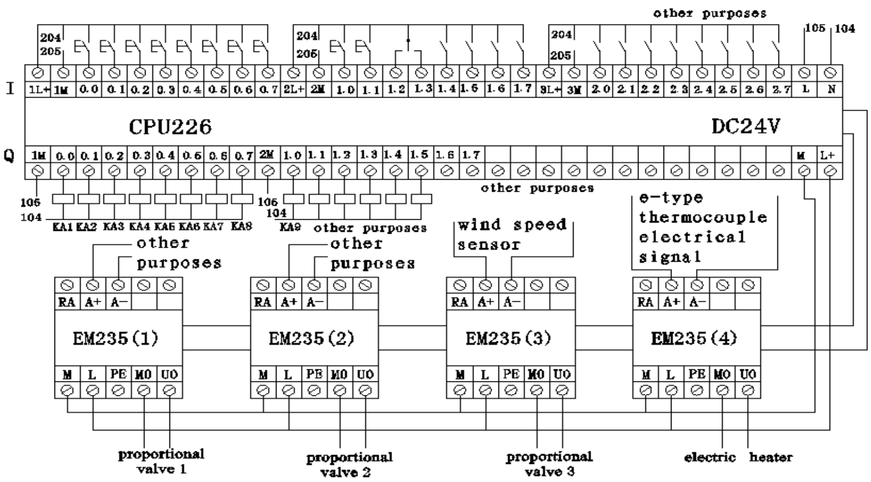

Figure 4. PLC Control Charts (variable-pitch part)

3. The Selection of Hydraulic Component for Variable-pitch Control System [12]

3.1. The Flow of Hydraulic Pump

According to requirements that the fluctuations of the output power is not greater than that of 15%-20% of rated value when the wind turbine works above the rated wind speed, referring to the parameters of the variable-pitch system of wind turbine relevant, The flow of hydraulic pump can be determined.

The maximum variable-pitch speed of 1rpm/min, transmission ratio i is 10, and efficiency η is 0.95, then motor maximum torque T_1 could be calculated according to the follow formula:

$$T_2 = T_1 \eta i \quad (1)$$

The calculated result is T_1=2105.26Nm.

Working pressure of the hydraulic motor P_1 is 16MPa, the oil return back pressure is 0.8 MPa, and then the pressure difference ΔP can be calculated according to the follow formula:

$$\Delta P = P_1 - 0.8 \quad (2)$$

The calculated result ΔP is 15.2 MPa.

The variable hydraulic motor displacement can be calculated according to the follow formula:

$$q_v = \frac{2\pi T_1}{\Delta P \eta_m} \quad (3)$$

The calculated result is 9.15584×10-4m3/r, that is 0.915584 L/r.

Hydraulic variable motor flow could be calculated according to the follow formula:

$$Q_1 = q_v n \quad (4)$$

The calculated result is 9.156 L/min.

The flow rate of the hydraulic pump is calculated by the follow formula:

$$Q = 3Q_1 \quad (5)$$

The calculated result is 27.467 L/min.

If the leak in the hydraulic circuit is estimated at 20% of the input flow of the motor, then the pump flow is calculated according to the follow formula:

$$Q = 27.467\times(1 + 20\%) = 32.96 \text{ L/min} \quad (6)$$

Therefore, the pump flow rate is selected as 34 L / min.

The pressure of the hydraulic pump is calculated according to the formula:

$$P = P_1 + \Sigma \Delta P \quad (7)$$

The hydraulic pump pressure P is selected as 20MPa considering the pressure loss of the piping and valves.

3.2. The Power Selection of Electric Motor

The power selection of electric motor depends on the hydraulic pump input power.

Hydraulic pump input power P_{in} could be calculated according to the follow formula:

$$P_{in} = \frac{PQ}{6\times10^{7}\eta} \quad (8)$$

Where P is the maximum working pressure of the hydraulic pump, unit is Pa; η is Total efficiency of the hydraulic pump.

The calculated result is P_{in} =14.167 Kw.

The rated power of electric motor is chosen as 15Kw considering the computation surplus above.

3.3. The Volume Selection of Oil Tank

The effective volume of the tank is V .According to the manual, V is calculated by formula V = (5~7) Q . The calculated result is 170~238 (L).

According to the actual situation, the choice of the tank volume is 250L.

3.4. Choice Feathering Accumulator's Volume in Emergency

According to the characteristics which the hydraulic system of the wind turbine is installed at the high-altitude, bladder accumulator is selected as the accumulator which has the characteristics of big ratio of volume to weight and good pressure response. The relevant parameters of accumulator are as follows:

P_0, P_1, P_2 are respectively refer to the inflation pressure, the minimum working pressure and maximum working pressure, their unit is MPa; V_0, V_1, V_2 are respectively refer to the total volume of the accumulator, the volume of gas when the pressure is P1, the volume of gas when the pressure is P_2,; ΔV is active schedule fuel, their unit is L.

According to the manual, the inflation pressure is as the follow formula:

$$P_0 = 25\% P_2 \sim 90\% P_1 \quad (9)$$

The minimum working pressure of system is 14MPa; the maximum working pressure of system is 20 MPa. So P_0 =5~12.6MPa, P_0 is selected as 10MPa.

According to the formula:

$$P_0V_0^{\,n} = P_1V_1^{\,n} = P_2V_2^{\,n} = C \quad (10)$$

Where C is constant, n is changeable index.

Due to the rapid expansion and compression process when the system is feathering, the polytrophic index n is selected as 1.4, that n =1.4. So V_0 is calculated by formula:

$$V_0 = \frac{\Delta V}{P_0^{\frac{1}{n}}\left[\left(\frac{1}{P_1}\right)^{\frac{1}{n}} - \left(\frac{1}{P_2}\right)^{\frac{1}{n}}\right]} \quad (11)$$

The maximum feathering speed is 1rpm/min, the rotational speed of the hydraulic motor is 10rpm/min, ΔV can be calculated according to the follow formula:

$$\Delta V = 3Q_1 n_1 \quad (12)$$

Where n_1 is the maximum turning laps of feathering, n_1=1/4=0.25.So ΔV =3×9.156×10-4×0.25=6.867×10-4m3=0.6867 L.

The calculated result is V_0 =3.88 L .

In the practical application, 10L is selected as the value of V_0, the volume is sufficient when considering all aspects of the working life of the accumulator.

4. Results and Analysis

In order to make up for the deficiencies of the hydraulic cylinder variable-pitch system, the hydraulic motor driving variable-pitch system is designed.

4.1. The Advantages of Hydraulic Motor Driving Variable-pitch System

The mechanism of hydraulic motor driving variable-pitch system uses hydraulic motors to drive gears directly, gears drive blades.So the system has simple and impact structure, small space occupation, and is convenient to control and repair, works steadily.

4.2. The Independence and Security of Variable-pitch System

The hydraulic control part of variable-pitch system uses three electro-hydraulic proportional valves to control hydraulic motors respectively. The electrical control part of variable-pitch system uses PLC to control electro-hydraulic proportional valves respectively. So the variable-pitch control system meets the independence and security requirements of the system: (1) In automatic control condition, the propeller pitch angles of three blades can be changed individually or altogether. (2) The wind turbine control system or security system can enable blades to come back to feathering position in the case of no external energy. When the power is cut-off, the accumulator supplies oil to motor by the proportional valve, and completes feathering. In normal working duration, the accumulator can not only supply oil to the system (when the pressure is reduced to a rated value, the pressure relay measures the value, and then pump restarts), but also absorbs fluctuations, accumulates energy.

5. Conclusion

The hydraulic motor driving variable-pitch system is designed to meet the independen-ce and security requirements of the power-generation system. The system has simple and imp-act structure, and is convenient to control and repair, works steadily. The hydraulic control part of variable-pitch system uses electro-hydraulic proportional valves to control hydraulic motors, and can be operated easily. The electrical control part of variable-pitch system uses PLC to control electro-hydraulic proportional valves, completes the adjusting actions of blades.

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