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Analysis of the Hydraulic Impact of the Wind Turbine Hydraulic Yaw Brake System

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Abstract

When the wind turbine hydraulic yaw system brake and pressure relief, hydraulic oil pressure in the hydraulic system is rapidly reduced, and its direction of flow has also undergone dramatic change. Hydraulic impact generated easily make equipment failure by mutations pressure in pipeline. For there is the larger hydraulic impact problem when hydraulic yaw brake system change direction, this paper has analyzed the reasons resulting hydraulic impact, and has established the mathematical model of the yaw brake system pressure relief oil passage, and then has proposed to the methods of reducing the hydraulic impact in the commutation process. The simulation results show that the methods of extend the hydraulic cylinder commutation time may well reduce the hydraulic impact when the wind turbine hydraulic yaw system brake and pressure relief. It has significantly changed its pressure curve. It can reduce the hydraulic impact damage to the equipment. Then it verify the feasibility of this method.

Keywords: *hydraulic yaw system brake system; hydraulic impact; commutation time*

1 Introduction

With wind power technology matures, wind turbine is developing towards the direction of large-scale. This requires its required power systems and regulating systems have high power output, reliable control accuracy and Small footprint, *etc.* Hydraulic system has a small volume, light weight, good dynamic response, larger torque and it do not required transmission mechanism. These characteristic features correspond with the above requirements. Hydraulic technology has been widely used in wind power generation [1]. At present, the hydraulic system almost complete the action of the final executive member of security control and power control and the main transmission system, in medium-sized wind turbines produced by Europe and USA [2].

The yaw system of the wind turbine is divided into two parts, which are the driving system and the braking system. Its main function is to make the wind wheel is always in the wind and provide necessary locking torque, to protect the safe operation of the wind turbine and ensure the maximum power generation capacity. The brake system of the wind turbine is one of the key parts, and is an important part of the safety and security of the unit [3]. Along with the increasing of wind speed, the speed of the wind turbine blade is also increasing. Therefore, if the brake device on the wind turbine is not reliable, it will cause the blade to rotate faster and faster. Eventually, it will lead to the occurrence of the speed accident and the occurrence of the wind turbine fire and damage of wind turbine. It is very important to choose a safe and reliable brake system. The hydraulic brake device has the advantages of small volume, light weight, small inertia, fast response, stable movement, small impact, simple structure, large bearing capacity, long service life, *etc.* It has been favored by the wind turbine manufacturers.

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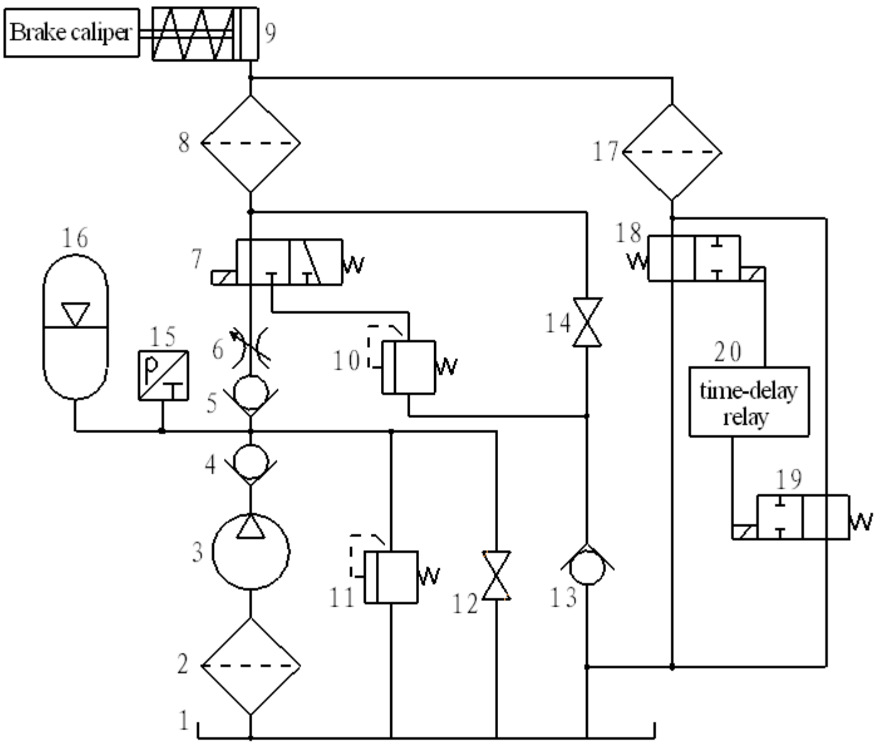
In the process of working, when the hydraulic system of the wind turbine is suddenly starting, stopping, transmission or reversing, the valve port of hydraulic valve suddenly will be closed or stopped. Because of the inertia of the fluid and moving parts in the hydraulic system, the kinetic energy of the hydraulic oil in the system pipeline can be changed to the pressure. It make the system instantaneous to form a high peak pressure. So as to produce hydraulic impact. Hydraulic impact may cause greater damage to the hydraulic system. Therefore, during the operation, to avoid the formation of hydraulic impact. The damage caused by the hydraulic impact are as follows: ①The peak pressure be produced by hydraulic impact can be up to 3-4 times the normal working pressure. This will cause the pipeline to rupture, or hydraulic components and measuring instrument to damage, or the instrument accuracy to be reduced. ②Reliability and stability of hydraulic system will be influenced. Such as, pressure relay fault signal due to hydraulic, interference with normal work of the hydraulic system, *etc.* ③ The hydraulic impact may lead to the hydraulic system oil temperature to rise, and lead to vibration and noise to produce, and lead to connecting parts to loosen, and lead to leakage and the pressure valve to adjust the pressure to change, *etc.*

The yaw brake system of the MW class wind turbine is driven by a hydraulic cylinder to complete the brake. When the yaw motor rotates, hydraulic brake system is in the release state. When the yaw motor stops to rotate, hydraulic brake system is in the brake state. When the yaw brake work , the hydraulic cylinder pressure will reach to 12.5 ~ 14.5Mpa, and reversing valve change direction and pressure relief. Because the pressure drop sharply in the oil circuit, it will have a greater damage to the pipeline and the hydraulic components. In practice, the failure phenomenon of frequent damage to pressure relief electromagnetic valve and violent vibration of the system are found. In this paper, the electromagnetic valve diameter, the use of a combination of time and delay the combination of electromagnetic valve and other ways to carry out theoretical analysis and simulation. Theoretical analysis and simulation are carried out in this paper by changing the electromagnetic valve diameter or using a combined electromagnetic valve with delay, to find the optimal solution, to provide theoretical support for system transformation.

Yaw system, also known as the wind device, is an essential part of horizontal axis wind turbine. Its role is to control the machine with the wind to the adjustment of the upwind side in order to achieve maximum efficiency. First, when the wind speed is in the range of available, it is matched with its control system, and keeps wind wheel swept surface and the wind direction is vertical by rotating the engine room. The wind wheel is always in the wind state, in order to ensure that the wind turbine has the largest power generation capacity. When the wind speed is out of rang, it use the 90 degrees of crosswind. Secondly, when it may cause cable winding in the continuous tracking of the wind, the yaw control system will automatically unmoor. Thirdly, when the engine room is in the correct position, it is necessary to provide the lock torque to ensure the safe operation of the wind turbine in the case of constant wind direction [4].

The main action of the yaw control system are as follows: automatic yaw of wind vane controlling, 90 degrees yaw vane of wind vane controlling, artificially yaw, automatic unmooring, damping brake control [5]. In order to prevent the engine room from the direction of the wind while stopping yaw, and ensure the stability of the braking process, the damping brake device for yaw system of wind power generator is symmetrically distributed. The damping brake device is composed of at least 6 groups of 2 brake discs. Its brake disc adopts hydraulic brake. The working principle of the damper is: When the wind turbine generator receives the yaw command, the brake mechanism moves. The size of the damping torque is determined According to the wind speed, the wind direction and the Speed of yaw system adjustment. The damping torque is adjusted by adjusting the size of the hydraulic flow and the size of the liquid pressure. The change of the size of the liquid pressure also changes the size of the brake torque. The change of the size of the brake torque t reflects the change of the damping torque. Damping brake controller is generally equipped with a pre pressure valve in the hydraulic drive line. In the condition of the valve to be opened, the brake hydraulic cylinder still maintains a very small pressure. There is still a certain resistance in the process of the yaw to ensure the stability of the yaw.

The yaw dynamics and braking force of the yaw system are provided mainly by the hydraulic system. As shown in Figure 1 is the 1.5MW wind turbine hydraulic yaw system schematic diagram. Electromagnetic valve 18 and 19 of the aperture is different and is controlled by the delayed relay 20. Delayed relay control two valves open at the same time or open respectively. It can adjust the pressure relief time of the system and form pressure relief passage of the yaw brake system. When the wind direction changes, the wind turbine automatically face the wind. The yaw brake valve 7 is electrified. The solenoid directional valve 18 is power off. Yaw brake clamps have half of residual pressure under the overflow valve 10. The yaw of the wind turbine is relatively stable. So as to make the wind turbine is relatively stable while yawing. When the wind turbine automatically unmoor or artificially yaw, the yaw brake valve 7 and the yaw relief pressure valve 18 at the same time is electrified, the yaw clamp completely release so as to reduce the wear of the yaw brake pads [6].



1. Oil Box 2, 8, 17. Fitter 3. Hydraulic Pump 4, 5, 13. One-Way Valve 6.Throttle Valve 7. Yaw Brake Valve 9. Hydraulic Cylinder 10, 11. Overflow Valve 12, 14. Globe Valve 15. Pressure sensor 16. Accumulator 18, 19. Yaw Relief Pressure Valve 20. Time-Delayed Relay

Figure 1. Wind Turbine Hydraulic Yaw System Schematic Diagram

The working process of the hydraulic yaw system circuit is as follows:

(1) Yaw brake circuit: Fitter 2 →Hydraulic pump 3 →One-way valve 4 and 5→Yaw brake valve 7 left (power off)→Fitter 8 →Hydraulic cylinder 9 (total pressure brake)

(2)Yaw circuit: Hydraulic cylinder 9 (half press brake)→Fitter 8→Yaw brake valve 7 right (power on)→Overflow valve 10→One-way valve 12→Oil box 1

(3) artificially yaw circuit or automatic unmooring circuit:

Hydraulic cylinder 9 (Brake release)→Fitter 17→the yaw relief pressure valve 18→Oil box 1

Hydraulic cylinder 9 (Brake release)→Fitter 17→the delayed relay 20→the yaw relief pressure valve 19 →Oil box 1

The characteristics of the hydraulic yaw system are the frequent action, the transmission power and motion inertia, and the complex hydraulic system. In particular, when the yaw brake hydraulic circuit is loaded, it will save a lot of hydraulic elastic potential energy. The hydraulic system pipeline interface, hydraulic parts and even the entire oil circuit in the unloading moment is greatly affected. Therefore, it is necessary to analyze the causes of the hydraulic impact in the system. Reasonable management means is given for the reasons.

2 Hydraulic Impact Analysis

In the process of equipment operation, when the reversing valve is quickly reversed or the circuit is closed. Due to sudden changes in motion, the kinetic energy of the hydraulic oil in the system pipeline is converted into pressure energy. At this time, the system will produce a hydraulic impact. In addition, some components of the hydraulic system is not flexible enough, it will produce a hydraulic impact. Such as, if the system pressure suddenly increased, the overflow valve cannot be quickly opened, it will produce a high pressure, resulting in a hydraulic impact. When the pressure of the hydraulic oil increases, limited pressure variable hydraulic pump cannot timely be reduced displacement. It caused pressure impact.

The essence of the hydraulic impact is the transformation of the kinetic energy of the liquid. It has a close relationship with the propagation velocity of impact wave C. Propagation velocity C determines the change in energy. Without consideration of the influence of hydraulic oil viscosity, the propagation velocity of shock wave is not considered. If we do not consider the impact of the change of hydraulic oil viscosity, the propagation velocity of impact wave C is as formula (1).

$$c = \sqrt{K'/\rho} = \frac{\sqrt{K/\rho}}{\sqrt{1 + dK/\delta E}} \qquad (1)$$

In formula (1): K is bulk modulus of liquid; d is Inner diameter of pipeline; δ is wall thickness of pipeline; E is elastic modulus of pipeline materials.

2.1 Hydraulic Impact Caused by Fluid Flow Velocity in the Pipeline

As shown in Figure 1,pipeline section area from the outlet of the hydraulic pump through the one-way valve 4, 5 and electromagnetic valve 7 is A. Its length is l. Assuming that the hydraulic pump outlet pressure constant. When the electromagnetic valve 7 is electrified, the valve is opened. The liquid flow rate is v in the pipeline. If the pressure loss in the pipeline is not considered, the oil pressure is p in the pipe and the hydraulic valve. When the electromagnetic valve 7 power off, the valve is closed. Because the kinetic energy of the liquid is immediately converted into pressure energy, impact pressure is produced. Then the followed liquid stop motion in turn, and the kinetic energy of the liquid is converted into pressure energy. Pressure shock wave is formed in pipeline. Pressure shock wave spread by velocity c from the hydraulic pump outlet to the electromagnetic valve 7. According to the law of conservation of energy, the kinetic energy of the liquid is converted into pressure energy. That is:

$$\frac{1}{2}\rho Al \cdot \Delta v = \frac{1}{2}\frac{Al}{K'}\Delta p_{1\max}^2 \qquad (2)$$

Then：
$$\Delta p_{1\max} = \rho\sqrt{\frac{K'}{\rho}}v = \rho c \cdot \Delta v = \rho c v\frac{2l}{t_1} \tag{3}$$

In formula (3): $\Delta p_{1\max}$ is the maximum pressure value of the hydraulic impact; K' is equivalent volume modulus of liquid; c is propagation velocity of pressure shock wave in pipeline; t_1 Commutation time; ρ Density of liquid.

The maximum pressure value of the hydraulic impact is proportional to liquid flow velocity. The transfer of hydraulic shock wave, reflection and fluid flow direction changes will be repeated. The impact phenomenon will not end until the energy that is caused by the shock is exhausted. Therefore, the sudden change in the flow rate of the pipeline is the external condition of the hydraulic impact. But the compressibility and inertia of the liquid are the intrinsic factor of the impact phenomenon.

2.2 Hydraulic Impact Caused by Load Brake

The movement speed of the load depends on the flow rate. The piston drive load m movement at speed v. The total mass of the piston and the load is M. When the electromagnetic valve 7 is power off and reversing, the electromagnetic valve outlet channel is off. The flow rate is suddenly changed. It makes the liquid to press in the rod cavity of the hydraulic cylinder because of inertia effect of the load component. It lead to the liquid pressure to sharp rise. The load component will be braked because the liquid pressure in the rod cavity of the hydraulic cylinder generate resistance. If we ignore the damping, leakage and other factors, according to the law of momentum, the impact pressure $\Delta p_{2\max}$ in the same side of the load can be obtained.

$$\Delta p_{2\max} = \frac{M \cdot \Delta v}{A_0 \cdot t_2} \tag{4}$$

In formula (4): A_0 is effective working area of the cavity without piston of the hydraulic cylinder; t_2 is load braking time; Δv is change value of load speed, $\Delta v = v - v'$; v is liquid flow velocity before the load is braked; v' is the load speed after time t_2.

In formula (4): The correlation calculation neglects the damping, leakage and other factors. The value is larger than the actual, and thus it is safe.

2.3 Total Increased Pressure of the Hydraulic Impact $\Delta p_{\max}$ in the Pipeline

$$\Delta p_{\max} = \Delta p_{1\max} + \Delta p_{2\max} = \rho c v\frac{2l}{t_1} + \frac{M \cdot \Delta v}{A_0 \cdot t_2} \tag{5}$$

By formula (5) can be known, total increased pressure of the hydraulic impact is decided by commutation time, liquid flow velocity, the piston velocity, the structure parameters of the pipeline, the structural parameters of the hydraulic components, *etc.* If the commutation time of the reversing valve is shorter, the value of $\Delta p_{\max}$ is bigger. The resulting vibration is greater. In order to reduce the hydraulic impact, the following measures can be taken from the hydraulic circuit:

(1)The electromagnetic valve of the longer commutation time or the reversing valve of the adjustable commutation time are used. Generally, the longer commutation time of AC electromagnetic valve is short, about 0.05s. the longer commutation time of DC electromagnetic valve is longer, generally 0.1 ~ 0.3s.

(2)As far as possible to shorten the length of tube or use to rubber hose, in order to reduce the propagation time of the pressure shock wave.

(3)The slide valve opening is designed to smooth change type so that the load component is uniform deceleration when braking.

(4)The rubber hose or accumulator are used in the positions of easily producing hydraulic impact to absorb impact pressure. Or install the safety valve in these positions to limit the pressure rise.

(5)Appropriate to increase the diameter of the pipe to limit the flow rate in the pipeline. In general, the speed is controlled in 4.5m/s in the hydraulic system. $\Delta p_{\max}$ is not more than 5MPa can be considered safe.

3 Mathematical Model Analysis of Pressure Relief Loop System

Hydraulic cylinders, oil tube and other components have been identified and is not easy to replace. So in order to prevent the hydraulic impact, more can be considered for the selection of appropriate commutation valve.

(1) Flow continuity equation of hydraulic cylinder without rod cavity is as follows:

$$Q_1 - Q_2 = A_1 \frac{dx}{dt} + \frac{V_1}{K'} \frac{dp_w}{dt} \tag{6}$$

In formula (6): Q_1 is the flow which flows into the cavity without piston rod of hydraulic cylinder; Q_2 is the flow which flows out the cavity with piston rod of hydraulic cylinder; A_1 is effective area of the cavity without piston of the hydraulic cylinder; x is displacement of piston; V_1 is volume of oil inlet chamber of hydraulic cylinder; p_w is pressure of the cavity without piston rod of hydraulic cylinder; K' is the liquid effective bulk modulus.

At the time of pressure relief, there is no inflow. The flow equation of the hydraulic cylinder without rod chamber is as follows:

$$-q_W = A_1 \frac{dx}{dt} + \frac{V_1}{K'} \frac{dp_w}{dt} \tag{7}$$

(2) Force balance equation hydraulic cylinder is as follows:

$$kx = M \frac{d^2 x}{dt^2} + A_1 p_w \approx A_1 p_w \tag{8}$$

(3) Flow-pressure characteristic of the solenoid commutation valve is as follows:

$$Q_F = C_q A_T \sqrt{\frac{2}{\rho}(p_1 - p_2)} \tag{9}$$

In formula (9): Q_F is flow through the commutation valve; C_q is flow coefficient of the commutation valve; A_T is flow cross section area of the valve port .

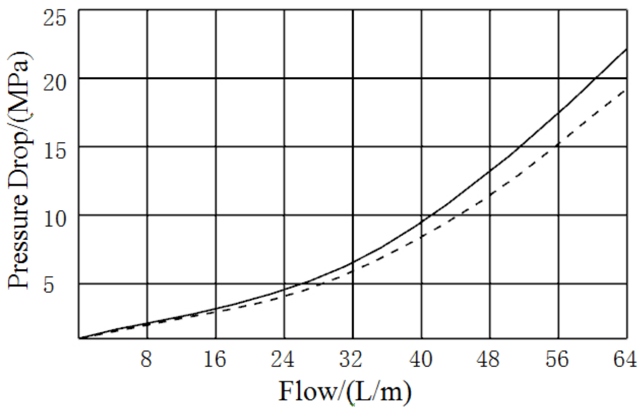


Figure 2. Pressure-Flow Curve of Electromagnetic Valve

According to the relevant information of the system, yaw relief pressure valve use Vickers DG4V series of two position two way electromagnetic valve. The pressure-flow curve is shown in Figure 2. Convenient for research, after the pressure-flow characteristics curve is linearized, flow equation is obtained as follows.

$$q_1 = \lambda p_1 \tag{10}$$

In formula (10): λ is flow-pressure coefficient of the relief pressure valve 18. It is proportional to the diameter of the electromagnetic valve. According to the connection of the system, there is the following: Simultaneous equations (6), (7), (8) and (10) are solved the differential equations of the system pressure changes. It is as follows:

$$\left(\frac{A_1^2}{\lambda k} + \frac{V_1}{\lambda K'}\right)\frac{dp_w}{dt} + p_w = 0 \tag{11}$$

The solution of the differential equation is obtained as formula (12).

$$\begin{cases} p_w = p_0 \cdot e^{-\frac{t}{\chi}} \\ \chi = \dfrac{A_1^2}{\lambda k} + \dfrac{V_1}{\lambda K'} \end{cases} \tag{12}$$

4 Simulation Result Analysis

4.1 Simulation Parameter Settings

The initial simulation parameters of the system are shown in Table 1.

Table 1. Main Parameters of System Simulation

Parameter name	Parameter symbol	Parameter Value
Piston diameter(mm)	ϕ_1	100
Piston rod diameter(mm)	ϕ_2	60
Piston stroke(mm)	L	400
The liquid effective bulk modulus(Pa)	K'	700×10^6
Electromagnetic valve spring coefficient(N/m)	k	0.94×10^6
System initial pressure(Pa)	p_0	2×10^7
Electromagnetic valve 18 pass diameter(mm)	ϕ_3	Respectively 0.5、1、1.2
Electromagnetic valve 19 pass diameter (mm)	ϕ_4	1.2

Electromagnetic valve spool axial(mm)	ζ	±2

4.2 MATLAB Simulation of Different Pressure Relief System

(1)Simulation of changing the path diameter of electromagnetic commutation valve

The pressure change of the system can be used to characterize the pressure strength of the hydraulic impact. The pressure drop is fiercer, the hydraulic impact is greater. Analysis of the simulation results can be found: with the throttle to become small, electromagnetic valve flow gain coefficient decreases and pressure relief time become longer. But the system pressure change also decreases [7-8]. It can be seen that the pressure relief time and pressure impact is a pair of contradictions, as shown in Figure 3.

(2)Structure simulation of combined electromagnetic valve

As shown in Figure 4, curve 1 is a single electromagnetic valve, the throttle diameter is 1.2 mm.

Curve 2 and 3 are the combination of electromagnetic valve 18 and 19. The throttle diameter of electromagnetic valve 18 is respectively 0.5mm, 1mm. The throttle diameter of electromagnetic valve 19 is respectively 1.2mm. The release of the pressure has continued 2S after the commutation valve is reversing.

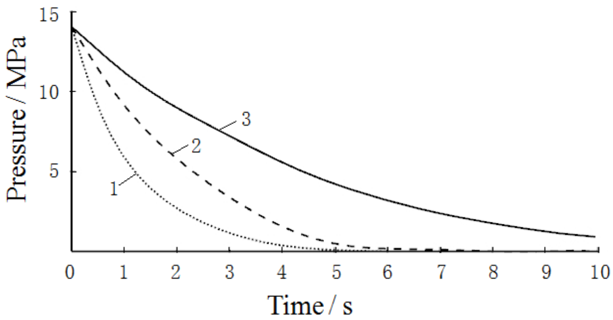


Figure 3. Relief Process Simulation Diagram of Valves

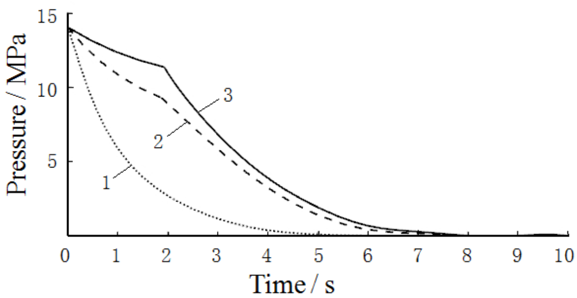


Figure 4. Relief Process Simulation Diagram of with Different Orifice Sizes Combination Electromagnetic Valve

1. $\phi = 1.2mm$ 2. $\phi = 1mm$ 3. $\phi = 0.5mm$

From the simulation curve 2and 3 in Figure 4 can be seen, when the electromagnetic valve group (18, 19) relax the pressure, the pressure relief curve is obviously slow, especially when the pressure is relatively large. This is in favor of slow down the hydraulic impact. This scheme can be arbitrarily set up the control time between 18 and 19 of the electromagnetic valve to adjust the pressure change curve.

5. Conclusion

This paper analyzes the causes of the hydraulic impact of the hydraulic yaw brake system of the wind turbine. A mathematical model of the discharge circuit of the yaw brake system is established. Through MATLAB simulation experiment, the pressure curve of the different pass diameter of the solenoid valve is analyzed. Then it proposed the use of combination of multiple electromagnetic commutation valve to replace a single valve for controlling pressure relief. Through simulation experiment: Under the condition of meeting the pressure relief time, small pass diameter of the slide valve is should tried to use. Combined electromagnetic commutation valve can effectively control the pressure drop rate of pressure relief, and reduce hydraulic impact while the hydraulic yaw system brake and pressure relief. And the pressure relief time will be not extend. Also it easy to install and more economical. Therefore, the combination of the electromagnetic valve to reduce the hydraulic impact is a more reasonable solution plan.

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