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Analysis On Common Hydraulic Balance Systems Used In Shield

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ABSTRACT:*This article introduces some common hydraulic balance systems used in shield. The characteristics of different systems which work under over-running load are analyzed, and their application ranges are pointed out. Several suggestions about the application of these hydraulic balance systems are proposed at last.*
KEYWORDS: *Hydraulic, Over-Running Load, Balance System.*

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I. INTRODUCTION

During shield construction, the hydraulic cylinders and hydro-motors of segment erector of shield drive segment to preset position when assembling segment. The difference between the gravity direction of segment and the movement direction of the hydraulic cylinders and the hydro-motors of segment erector has a great influence on the movement of segment. In serious cases, there will be security problems. So, that must be paid in attention to avoid any security problems.

Takes hydraulic cylinder as an example, the lifting hydraulic cylinder of segment erector is vertical installed to drive segment to move in a straight line. When the lifting hydraulic cylinder of segment erector drives segment to move upwards, the gravity direction of segment is opposite to the movement direction of the lifting hydraulic cylinder of segment erector, the gravity of segment is motion-resistance force, it is called positive load. When the lifting hydraulic cylinder of segment erector drives segment to move downwards, the gravity direction of segment is the same as the movement direction of the lifting hydraulic cylinder of segment erector, the gravity of segment is driving force, it is called over-running load (or negative load). The characteristic of segment's over-running load is that the gravity direction of segment is the same as its motion direction, and the gravity of segment will help the movement of the hydraulic cylinders and hydro-motors of segment erector[1].

The several common situations what segment's over-running load occurs when assembling segment are shown as the following figures.

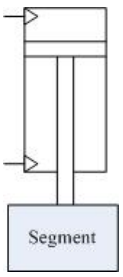

Figure1: Segment Moves Vertical Downwards

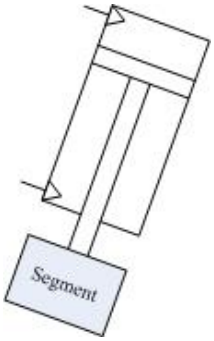

Figure2: Segment Moves Inclined Downwards

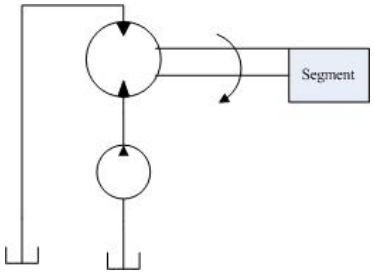

Figure3: Hydro-Motor Drives Segment to Downwards

When segment's over-running load occurs, if the hydraulic system of segment erector has no pressure in the back oil circuit, the moving segment will accelerate downward movement due to its own weight, thus it will cause exceed the movement speed of segment that be setted by the hydraulic system, this is easy to cause accident[2]. If a certain return oil pressure has been setted in the back oil circuit of the hydraulic system, that is use back pressure to balance segment's over-running load, it can effectively avoid self gliding of moving segment and moving segment's overspeeding that be caused by self gliding of moving segment. This hydraulic system can balance segment's over-running load by setting back pressure in the back oil circuit that be called hydraulic balance system[3]. The hydraulic balance system can not only balance segment's over-running load to ensure the safety of the hydraulic system of segment erector but also increase the damping of the hydraulic system of segment erector so as to improve the performance of the hydraulic system of segment erector.

II. HYDRAULIC BALANCE SYSTEMS

2.1 Hydraulic Balance System with One-Way Sequence Valve

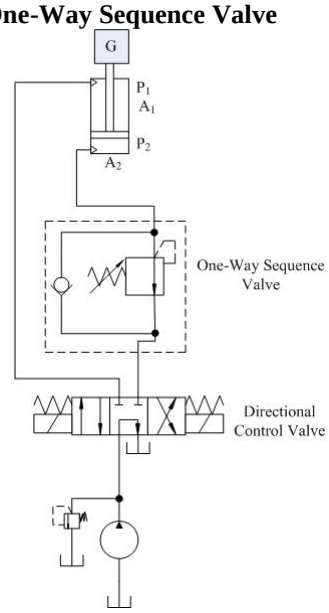

Figure4: Hydraulic Balance System with One-Way Sequence Valve

As the figure above shows, the oil inlet of one-way sequence valve is connected with the rodless chamber of hydraulic cylinder. Hydraulic oil flows out the rod less chamber of hydraulic cylinder and flows into the oil inlet of one-way sequence valve. The setting pressure of one-way sequence valve is slightly greater than the pressure that be caused from hydraulic cylinder's segment load as G in the rodless chamber of hydraulic cylinder, as follows:

The setting pressure of one-way sequence valve is: $p_x \geq \frac{G}{A_2}$.

G —Segment Load, A_2 —Area of Piston of the Rodless Chamber of Hydraulic Cylinder.

When directional control valve spool is in the middle, the pressure that be produced by segment's own weight where in the rodless chamber of hydraulic cylinder is less than the setting pressure of one-way sequence valve. At this time, one-way sequence valve closes and this back oil circuit closes, the oil outlet of the rodless chamber of hydraulic cylinder is blocked, segment holds still. So, one-way sequence valve prevents segment from sliding downwards because of its own weight. When directional control valve spool is in the left, hydraulic

oil that be pumped out from hydraulic pump flows into the rod chamber of hydraulic cylinder, that makes the piston of hydraulic cylinder drive segment to move downwards, now, the pressure in the rodless chamber of hydraulic cylinder is greater than the setting pressure of one-way sequence valve, and one-way sequence valve opens, and one-way sequence valve produces a certain back pressure in the rodless chamber of hydraulic cylinder. That can not only offset the over-running load that be produced by the gravity of segment but also increase the damping of this hydraulic balance system of segment erector so as to make the descent speed of segment not be overspeed.

The descent speed of segment is: $v = \frac{q_1}{A_1}$.

q_1—Oil Supply Flow of Hydraulic Pump, A_1—Area of Piston of the Rod Chamber of Hydraulic Cylinder.

The hydraulic balance system that is using this strategy, when the descent speed of segment is too fast, it will cause insufficient oil supply in the rod chamber of hydraulic cylinder so as to loss pressure. That makes the pressure in the rodless chamber of hydraulic cylinder is less than the setting pressure of one-way sequence valve, and one-way sequence valve closes, the segment temporary stops descent moving until insufficient oil supply in the rod chamber of hydraulic cylinder has been improved. Therefore, the hydraulic balance system that adopts this strategy makes the descent speed of segment not easy to be overspeed, and when segment is at a standstill, the locking performance of this hydraulic balance system is quite reliable. But after setting the opening pressure of one-way sequence valve, the back pressure as p_2 that be setted by hydraulic balance system is a fixed value, as ($p_2 = p_x$). Analyzing force balance of this hydraulic balance system and it will gain an equation, as follows:

$$p_1 A_1 + G = p_2 A_2,\ p_1 = \frac{p_2 A_2 - G}{A_1}.$$

p_1—Outlet Pressure of Hydraulic Pump, p_2—the Pressure in the Rodless Chamber of Hydraulic Cylinder.

When assembling segments, the weight of each segment is usually different. The setting pressure of one-way sequence valve must be setted according to the segment's over-running load that be produced by the heaviest segment. That can gain an equation, as follows:

$$p_1 A_1 + G_{\max} = p_2 A_2,\ p_2 = \frac{p_1 A_1 + G_{\max}}{A_2} = p_x.$$

When the weight of the heaviest segment as $G_{\max}$ changes smaller, it will make $p_2 \le p_x$, right now, this hydraulic balance system is in over balance state. This hydraulic balance system in order to open one-way sequence valve, this is $p_2 \ge p_x$, thus the hydraulic pump of this hydraulic balance system will increase it's own outlet pressure as p_1, this will increase the energy consumption of this hydraulic balance system. So, this hydraulic balance system is only applicable to the situation that each segment's weight is same.

2.2 Hydraulic Balance System with Liquid Controlled Balance Valve

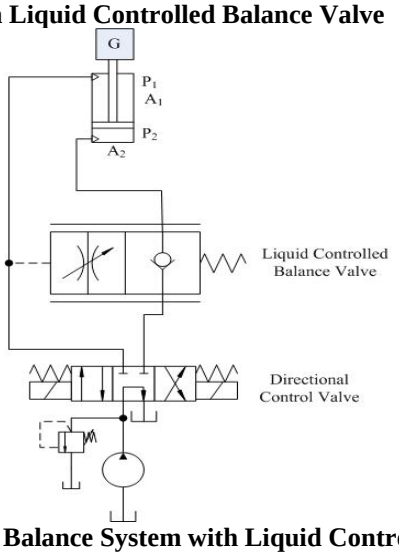

Figure5: Hydraulic Balance System with Liquid Controlled Balance Valve

As the figure above shows, this is an hydraulic balance system with liquid controlled balance valve[4]. When directional control valve spool is in the middle, pressure oil that be pumped out from hydraulic pump directly flows back to oil tank, the control pressure of liquid controlled balance valve and the oil inlet pressure of hydraulic cylinder are all zero. The liquid controlled balance valve is switched to the right position by its internal spring action. Right now, the liquid controlled balance valve is equivalent to a one-way valve. It closes the oil outlet of hydraulic cylinder, then the oil inlet and oil outlet of the two chambers of hydraulic cylinder are blocked, the segment holds still, so, the liquid controlled balance valve avoids segment's sliding downwards because of its own weight. When directional control valve spool is in the left, one part of hydraulic oil that be pumped out from hydraulic pump flows into the rod chamber of hydraulic cylinder, that makes the piston of hydraulic cylinder drive segment to move downwards. The other part of hydraulic oil that be pumped out from hydraulic pump acts as control pressure oil of liquid controlled balance valve to make liquid controlled balance valve switch to the left position. The size of the left orifice of liquid controlled balance valve varies with the pressure as p in the rod chamber of hydraulic cylinder（$p = \frac{p_1 A_1 + G}{A_1}$）, p becomes greater, the size of the orifice of liquid controlled balance valve becomes smaller, p becomes less, the size of the orifice of liquid controlled balance valve becomes larger. When p is zero, the condition of this hydraulic balance system is the same as the condition when directional control valve spool is in the middle, the liquid controlled balance valve of this hydraulic balance system is equivalent to a one-way valve.

This hydraulic balance system is applicable to the situation that the weight of each segment when being assembled is different. When the weight of segment that being assembled is heavy, the pressure as p in the rod chamber of hydraulic cylinder becomes greater, that makes the size of the orifice of liquid controlled balance valve become smaller, a great back pressure will be generated in the rodless chamber of hydraulic cylinder to balance a great over-running load that be produced by a heavy segment. When the weight of segment that being assembled is light, the pressure as p in the rod chamber of hydraulic cylinder becomes less, that makes the size of the orifice of liquid controlled balance valve become larger, a small back pressure will be generated in the rodless chamber of hydraulic cylinder to balance a small over-running load that be produced by a light segment, that can avoid the hydraulic balance system is in over balance stage in order to saving energy.

This hydraulic balance system can automatically balance the change of segment's over-running load that be produced from the different weight of segments, that makes the descend speed of segment be steady and not be overspeed. The performance of this hydraulic balance system is better than the hydraulic balance system that be analyzed above. The descent speed of segment only depends on the oil supply flow of hydraulic pump. During descending of segment, the back pressure be generated by this hydraulic balance system varies with segment load as G, it can automatically balance different over-running load be produced from different segment load as G to avoid this hydraulic balance system be in over balance state or in under balance state, so, the oil supply pressure of hydraulic pump is basically unchanged.

Due to liquid controlled balance valve is a hydraulic component that be designed to balance different over-running load that be produced from different load[5], so, this hydraulic balance system is more applicable for the situation that segment erector of shield assembles different weight segments.

2.3 Hydraulic Balance System with Speed Regulating Valve or Throttle Valve

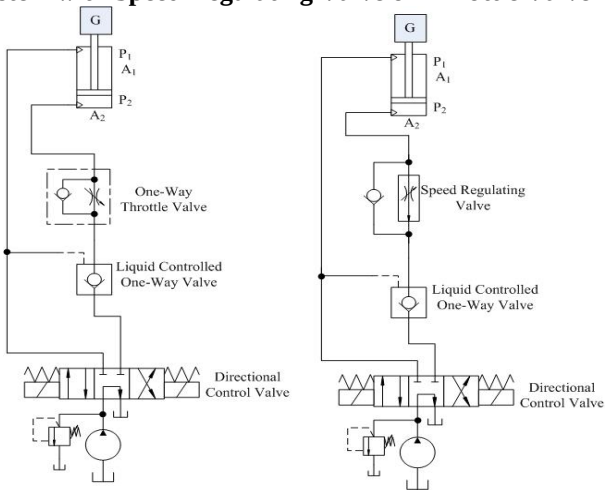

Figure6: Hydraulic Balance System with Speed Regulating Valve or Throttle Valve

As the figures above show, this is the hydraulic balance system with one-way throttle valve or speed regulating valve[6][7]. One-way throttle valve or speed regulating valve and liquid controlled one-way valve are connected in oil way of the rodless chamber of hydraulic cylinder. When directional control valve spool is in the middle or hydraulic pump stops working, no pressure oil of this hydraulic balance system flows into hydraulic cylinder and segment stops moving. At this time, liquid controlled one-way valve cuts off and block oil way of the rodless chamber of hydraulic cylinder to avoid segment's sliding downwards because of its own weight and ensure the safety of construction. When directional control valve spool is in the left, one part of hydraulic oil that be pumped out from hydraulic pump flows into the rod chamber of hydraulic cylinder, that makes the piston of hydraulic cylinder drive segment to move downwards. The other part of hydraulic oil that be pumped out from hydraulic pump acts as control pressure oil of liquid controlled one-way valve to make liquid controlled one-way valve open, and oil way of the rodless chamber of hydraulic cylinder is made into an oil access. Right now, one-way throttle valve or speed regulating valve produces a certain back pressure in the rodless chamber of hydraulic cylinder. That can not only offset the over-running load that be produced by the gravity of segment but also increase the damping of hydraulic balance system so as to make the descent speed of segment be steady and not be overspeed.

When using a one-way throttle valve, the descent speed of segment is:

$$v = \frac{q_{valve}}{A_2} = \frac{C_d A_x \sqrt{\Delta p}}{A_2} = \frac{C_d A_x \sqrt{p_2 - p_0}}{A_2} = \frac{C_d A_x \sqrt{\frac{p_1 A_1 + G}{A_2} - p_0}}{A_2}$$

q_{valve}—Flow Through the Throttle Valve, C_d—Flow Coefficient of the Orifice of Throttle Valve, A_x—Area of the Orifice of Throttle Valve, Δp—Pressure Difference between the Inlet and Outlet of Throttle Valve, p_0—Oil-Tank Pressure.

In the situation that the size of the orifice of throttle valve has been setted, when assembling segments, the different of segment load as G will cause the change of segment's over-running load, right now, that will cause the change of pressure difference between the inlet and outlet of throttle valve as Δp, and that will cause the change of the descent speed of segment as v, so one-way throttle valve is only applicable for the situation that segment load as G is unchanged.

If speed regulating valve is used, the formula of flow through the speed regulating valve as q_{valve} is basically the same as that of the throttle valve. But the pressure difference between the inlet and outlet of speed regulating valve as Δp is unchanged, the flow through the speed regulating valve as q_{valve} is only related to the area of the orifice of speed regulating valve as A_x. Thus, the change of segment's over-running load that be produced from the different weight of segments has little effect on the descent speed of segment, therefore, the speed regulating valve is more applicable for the situation that segment erector of shield assembles different weight segments than the throttle valve.

III. SOME SUGGESTIONS ON THE ESTABLISHMENT OF HYDRAULIC BALANCE SYSTEM

(1) When assembling segments, the hydro-motors need to drive segment erector of shield and hydraulic cylinder of segment erector moving. And the hydraulic cylinders of segment erector itself are expanding and contracting. So, the hydraulic components of hydraulic balance system can not all be connected with hard pipes, some need to be connected with hoses. To prevent falling of segments that be caused by loss pressure in the hydraulic balance system that be caused by hose explosion that be caused by excessive pressure of hydraulic balance system, it is recommended to use hard pipe or high pressure hose connecting the oil port of hydraulic cylinder with the oil port of balance control valve, and it can be also that directly connect the oil port of balance control valve with the oil port of hydraulic cylinder. See the following figure, an example of hydraulic balance system with liquid controlled balance valve.

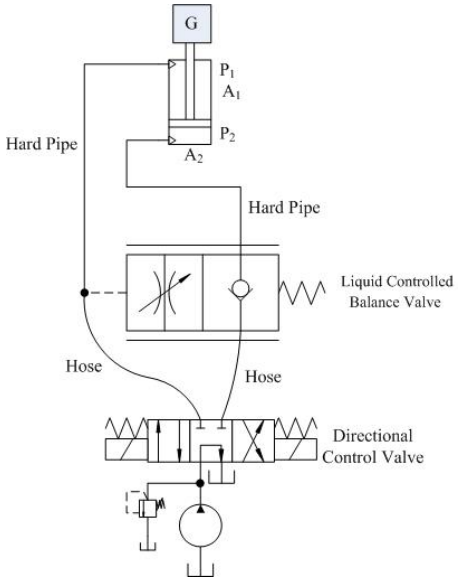

Figure7: Hydraulic Balance System with Hose Connection

(2) If the multiple hydraulic actuators of hydraulic balance system of segment erector of shield is rigid mechanically connected (This method is rarely used, and it is mostly used for hydraulic cylinders.), a balance valve can not be used to corresponding a hydraulic actuator to balance over-running load on each hydraulic actuator. This is because that though the control pressure of each balance valve is the same, but in fact, because of the manufacturing error, the spool of each balance valve has different opening sizes under the same control pressure, thereby increasing the motion asynchrony of hydraulic actuators of the hydraulic synchronous system, then it is possible damage to mechanical rigid connector. To avoid this kind of situation, a balance valve can be installed on the public line, uses this balance valve to balance the total segment's over-running load of hydraulic balance system, and installs an outlet type liquid controlled one-way valve on each hydraulic actuator to ensure the self locking of hydraulic balance system, takes the following figure as an example.

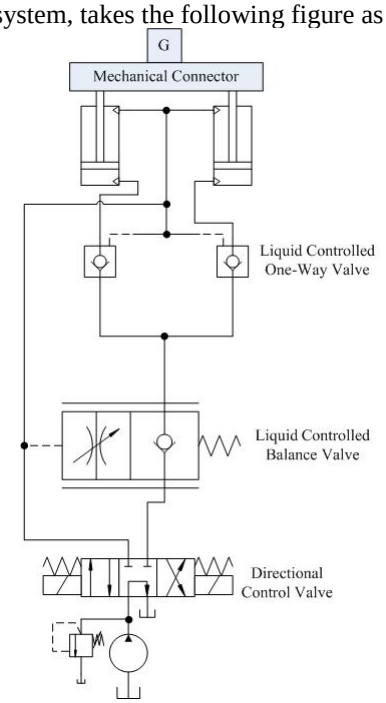

Figure8: Hydraulic Balance System with Hydraulic Cylinders Using Mechanical Force Synchronization

IV. CONCLUSIONS

The hydraulic actuators of the above systems that have been introduced are all hydraulic cylinders. But the hydraulic actuators of hydraulic balance system of segment erector of shield are also hydro-motor, it is basically the same as the hydraulic balance system whose hydraulic actuators are hydraulic cylinders except hydraulic actuators, so the previous suggestions can be applied.

These hydraulic balance systems that be introduced in foreword, the hydraulic balance systems that be most applicable for assembling segments are the hydraulic balance system with liquid controlled balance valve and the hydraulic balance system with speed regulating valve. The abilities what balance segment's over-running load of these two hydraulic balance systems are basically the same, these two hydraulic balance systems are all able to adapt to the change of segment's over-running load. But the hydraulic balance system of segment erector of shield is mostly hydraulic synchronous system with multiple hydraulic actuators. Therefore, the hydraulic balance system with speed regulating valve is more applicable for establishing hydraulic synchronous system. It is not only able to provide each hydraulic actuator with a speed regulating valve to balance segment load (including segment's over-running load) of each hydraulic actuator but also convenient to control the speed of each hydraulic actuator by adjusting the flow of valve port of speed regulating valve to make the synchronization of hydraulic balance system meet the requirements. Meanwhile, sets up a liquid controlled one-way valve in the oil circuit can ensure the self-locking of hydraulic balance system. So, in these hydraulic balance systems have been introduced in the foreword, the hydraulic balance system with speed regulating valve that be introduced by the 2.3 section is most applicable for assembling segments.

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