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Analysis On Common Hydraulic Speed-Limit And Locking Circuits Used In Construction Machinery

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Abstract: *This article introduces some common speed-limit and locking circuits of hydraulic cylinders. The reliability of a hydraulic cylinder which works under a negative load is also analyzed, and several improvement measures are put forward. Several attention points about the application of these speed-limit and locking circuits are proposed at last.*

Keywords- *Hydraulic, Speed-limit Circuit, Locking Circuit, Balance Circuit.*

I. INTRODUCTION

It is important for a hydraulic system of construction machinery which has vertical cylinders to contain speed-limit and locking circuits. If a hydraulic cylinder is used in luffing mechanism of construction machinery, an overrun drop will appear when it is on a negative load. Besides, the cylinder will drop gradually due to leakage and gravity when it is not operating in a stationary state [1].

A balance circuit is commonly used in a circuit with a vertical cylinder. The balance valve will prevent the ram from dropping rapidly duo to gravity when the system is not in operation and also improve the working stabilities during the load dropping. The hydraulic resistance should be set in the return oil chamber of the vertical cylinder to produce a balance force against it [2]. Owing to these advantages, balance circuits are widely used in construction machinery and hoisting machinery [3].

The function of a locking circuit is to lock the cylinder so that its piston can’t be moved due to external force which acts on the piston rod. According to the different locking elements, there are many types of circuits, such as a locking circuit with a directional valve, a locking circuit with a check throttle valve and a locking circuit with a hydraulic operated check valve [4].

II. HYDRAULIC SPEED-LIMIT AND LOCKING CIRCUITS

2.1 Speed-limit and locking circuit with a directional valve

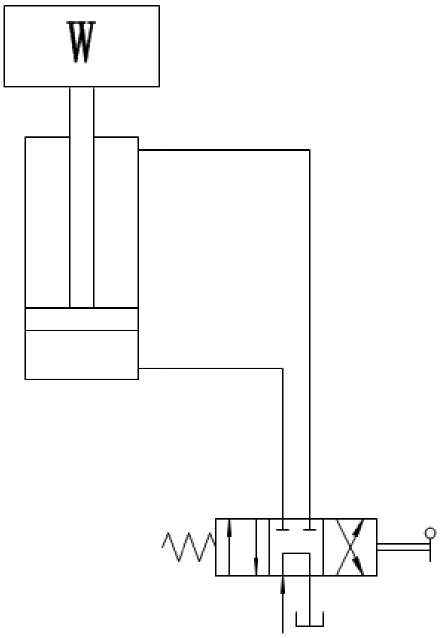

Fig.1. Speed-limit and locking circuit with a directional valve.

The Fig.1 shows a speed-limit and locking circuit with a directional valve. If the directional valve moves towards right, hydraulic oil can be controlled by manually adjusting the right orifice size of the directional valve and certain back pressure will be engendered. The balance force will prevent the ram from dropping rapidly and also improve the working stability when the load drops. When the piston of hydraulic cylinder locates at neutral of the directional valve, the cylinder can be locked. However, the locking reliability of the circuit is poor due to oil leakage from the directional valve. Thus, the circuit can only be used in construction machinery which is with low power and requires less in speed stability and locking [5].

2.2 Speed-limit and locking circuit with a check throttle valve

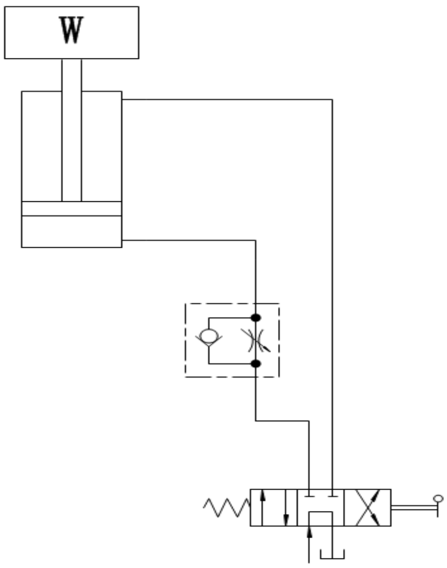

Fig.2. Speed-limit and locking circuit with a check throttle valve.

Referring to Fig.2, it is a speed-limit and locking circuit done by a check throttle valve. The main elements of the circuit are the following. When the directional valve works at the left position, hydraulic oil enters into the non-rod end chamber of the cylinder via a check valve and pushes the piston up; and when the directional valve locates at the right envelope, return oil in the rod end chamber flows via a throttle valve and produces certain back pressure to engender speed-limit protection. If back pressure is high enough, the load can avoid an overrun drop. The cylinder can be locked and the pump is unloaded when the directional valve is at neutral.

In this circuit, the stability when the load drops depends on the load weight changes. If the load is high, the cylinder will drop rapidly; otherwise slowly. Therefore, the more widely the weight of load varies, the poorer the stability of cylinder falling speed is. Because of oil leakage from the directional valve, the cylinder can't be locked for a long time when the valve is at neutral position. In order to lock the cylinder for a long time, a hydraulic operated check valve should be installed between the hydraulic cylinder and the throttle valve, as is shown in Fig. 3-a.

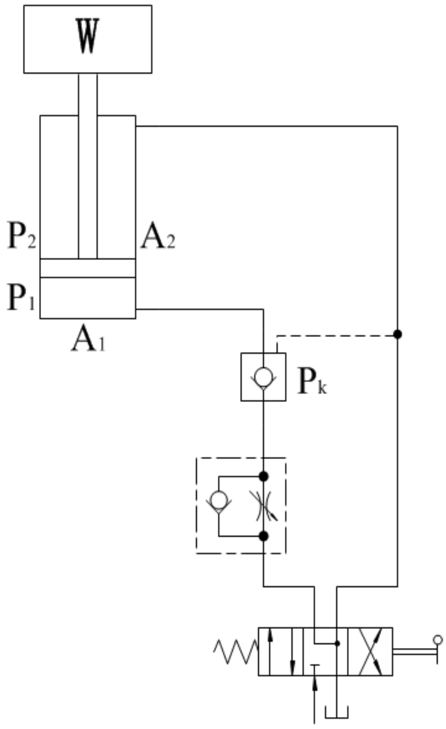

Fig. 3-a. A check throttle valve installed before the hydraulic operated check valve.

It must be emphasized that the check throttle valve should be installed before the hydraulic operated check valve, as is shown in Fig. 3-a.

The following calculation will explain the necessary of the arrange.

Referring to Fig. 3-a, the hydraulic oil pressure to open the hydraulic operated check valve is:

$$p_k = p_1 \tag{2.1}$$

where p_1 is the pressure in the non-rod end chamber.

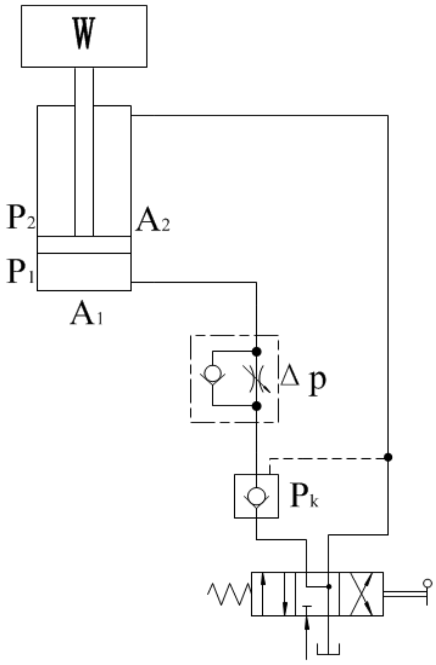

Fig.3-b. A check throttle valve installed after the hydraulic operated check valve.

Referring to Fig. 3-b, the check throttle valve is installed after the hydraulic operated check valve.
The pressure to open the hydraulic operated check valve is:

$$p_k = p_1 + \Delta p \tag{2.2}$$

where p_1 is the pressure in the non-rod end chamber , Δp is the pressure difference between the inlet and outlet orifice.

Visibly, if the check throttle valve is installed after the hydraulic operated check valve, it needs to overcome the pressure difference caused by the check throttle valve. Thus, in order to reduce the opening pressure of the hydraulic operated check valve, the check throttle valve should be installed before the hydraulic operated check valve.
The force balance equation in piston is:

$$p_1 = \frac{A_2}{A_1} p_2 + \frac{W}{A_1} \tag{2.3}$$

Meanwhile from formula (2.1) and (2.3),

$$p_k = \frac{A_2}{A_1} p_2 + \frac{W}{A_1} \tag{2.4}$$

From formula (2.4), it can be seen that the opening pressure of the hydraulic operated check valve p_k is determined by the pressure in the rod end chamber p_2 .

In Fig. 3-a, p_k aims to open the hydraulic operated check valve. Therefore, the system will generate a lot of heat because it consumes some energy. To maintain a very small value of p_2, two methods are demanded. On the one hand, a bigger hydraulic operated check valve will be chosen, while the valve size will be increased. On the other hand, a check throttle valve can be installed in the circuit, as is shown in Fig. 4. According to Fig.4, p_k is not determined by p_2, so p_2 can take a very small value, even zero [3].

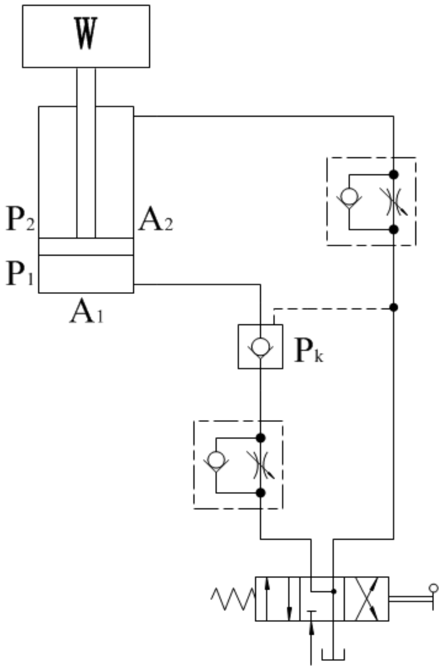

Fig.4. Speed-limit and locking circuit with two hydraulic operated check valves.

2.3 Speed-limit and locking circuit with a balance valve

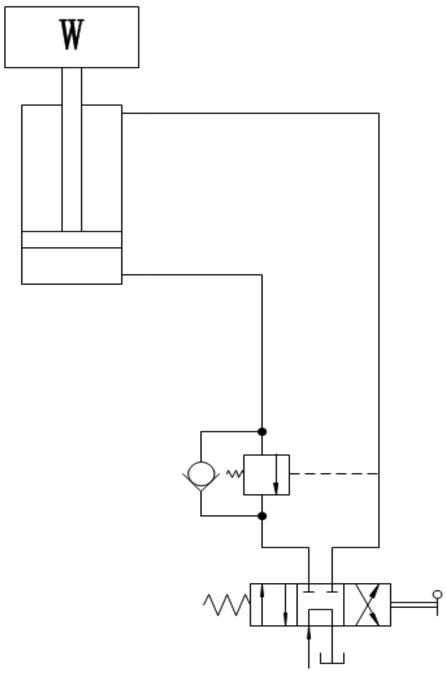

Fig. 5. Speed-limit and locking circuit with a balance valve.

Fig.5 shows a speed-limit and locking circuit with a balance valve. If the directional valve locates at the right envelope, the balance valve will open and back pressure in the non-rod end chamber is close to zero. Low pressure leads to an overrun drop of the cylinder, while the overrun drop causes the drop of pressure due to the shortage of hydraulic oil in the rod end chamber. Because of negative pressure, external control oil pressure of the balance valve is lower than response pressure. Thus, the balance valve closes and the cylinder stops immediately. However, pressure in the rod end chamber rises at once as the cylinder stops and the balance valve reopens. Meanwhile, the cylinder begins to fall, and the overrun drop occurs again. The above phenomenon, which is called cylinder 'nod' in this article, will recur and lead to serious impact, much noise, and security risks.

In order to mitigate and even eliminate the cylinder 'nod', a check throttle valve should be installed between the hydraulic cylinder and the balance valve, as is presented in Fig.6. The check throttle valve can engender certain back pressure in the non-rod end chamber to prevent the balance valve from being closed.

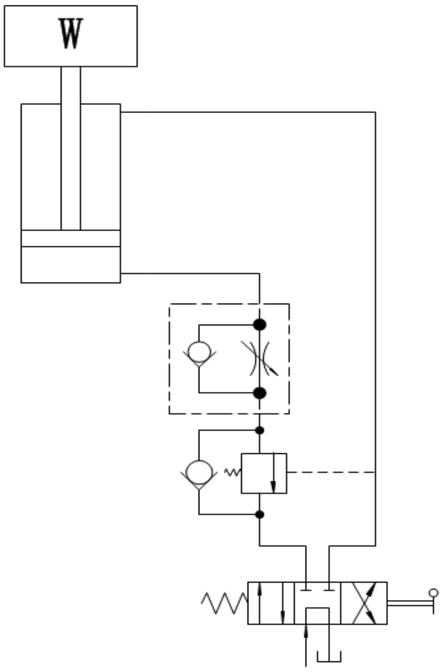

Fig.6. Speed-limit and locking circuit with a balance valve and a check throttle valve.

2.4 Speed-limit and locking circuit with a proportional directional valve and a hydraulic lock

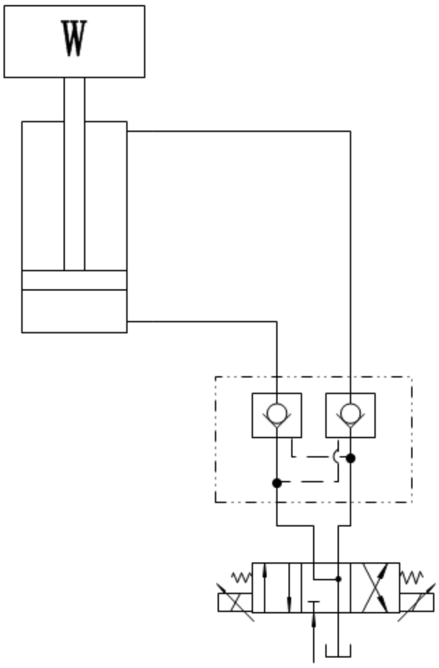

Fig.7. Speed-limit and locking circuit with a proportional directional valve and a hydraulic lock.

Fig.7 shows a speed-limit and locking circuit with a proportional directional valve and a hydraulic lock [6]. The speed of piston is controlled by adjusting the orifice size of the proportional directional valve and the cylinder can be locked rapidly and smoothly by the hydraulic lock for a long time. Though the hydraulic lock has a good locking feature, the cylinder 'nod' caused by 'negative pressure effect' can't be avoided when heavy loads fall. To solve this problem, a check throttle valve should be installed between return oil path of the cylinder and the hydraulic lock [7], as is presented in Fig.8.

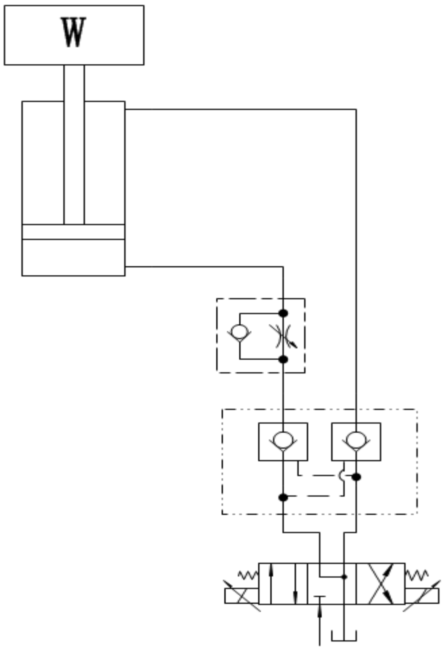

Fig.8. Speed-limit and locking circuit with a check throttle valve installed between a proportional directional valve and a hydraulic lock.

Referring to Fig.8, the orifice size of a throttle valve relies on the speed of piston travel and the requirement of stability. If it can be guaranteed that a hydraulic lock is always open and the cylinder 'nod' doesn't occur during the load dropping, the orifice size of throttle valve should be opened as widely as possible in order to minimize the power loss.

III. Several attention points

1. External control oil paths should be adopted for balance valves and hydraulic operated check valves to make sure that hydraulic oil flows concurrently into the inlet and outlet ports.
2. Tandem center valves or closed center valves should be used as the main directional valve when the hydraulic cylinder has positioning accuracy requirements.
3. External control oil paths of balance valves and hydraulic operated check valves should be installed closely to the main directional valve, so that balance valves and hydraulic operated check valves can be opened and closed rapidly.
4. Open center valves or float center valves should be adopted for locking circuits with hydraulic operated check valves and directional valves. The cylinder can be locked for a long time when hydraulic operated check valves connect with the tank directly.

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