Chapter 5. Applications

5.1. Introduction

Hydraulic circuits are composed of pumps, pressure control valves, directional valves, flow control valves, actuators and accessories, and change their compositions according to objectives and specifications. Many compositions are possible for a single objective. The most efficient circuit is:
(1) Safe and completely optimal to meet objective.
(2) Capable of smooth movement.
(3) Energy efficient.
(4) Effective for initial and running costs.
(5) Easy to maintain.
The followings are general circuit examples (8 types, 29 examples).

5.2. Unload Circuits

These circuits enhance the product life and efficiency, at the same time, keeping the power consumption and heat generation at a low level when the system is in waiting mode. Hydraulic power is expressed in the following equation.

$$L\ (\mathrm{kW}) = \frac{PQ}{60} \qquad \begin{array}{l} P : \text{Pressure (MPa)} \\ Q : \text{Flow Rate (L/min)} \end{array}$$

$$L\ (\mathrm{HP}) = \frac{PQ}{1\,714} \qquad \begin{array}{l} P : \text{Pressure (psi)} \\ Q : \text{Flow Rate (U.S.GPM)} \end{array}$$

As shown, hydraulic power is proportional to the product of pressure and flow rate. Reducing either exponent then leads to lessened hydraulic power.

a) Open Center Circuit (Fig. 5.1 (a) (b)) Figure 1.1 (a) shows a circuit in which output flow from the pump is by-passed to the reservoir with the spool of the PT connection valve at the center position. In the case of solenoid pilot operated directional valves, as shown in Fig. 5.1 (b), the check valve is required to maintain the minimum pilot pressure of the valve.

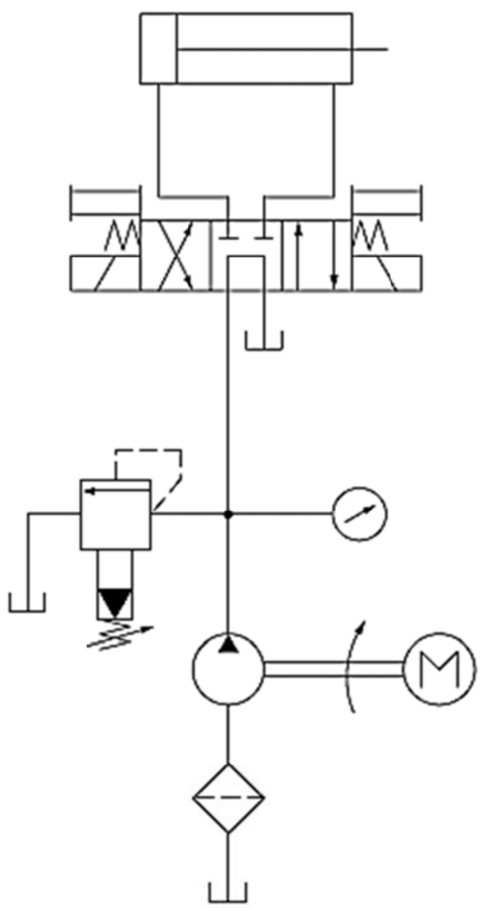
Fig. 5.1(a)

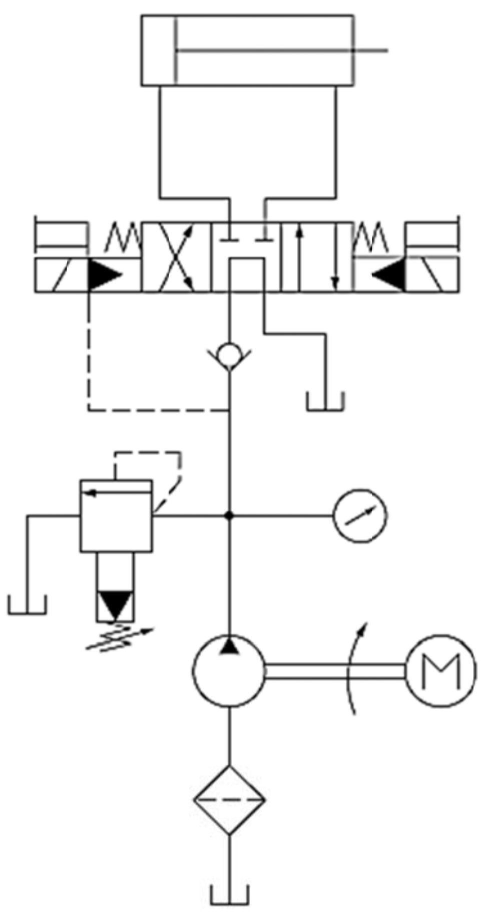
Fig. 5.1(b)

b) Circuit by Pressure Compensated Pump (Fig. 5.2) This circuit reduces the amount of output flow rate by using the variable displacement pump with pressure compensating function. The pressure of the system is raised to a set level even when it is in idle.

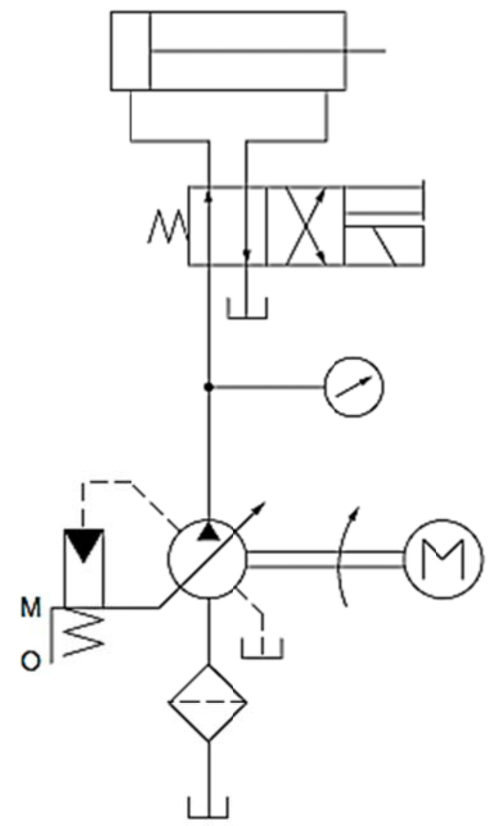

Fig. 5.2

c) Pump-Relief Unload Circuit (Fig. 5.3)

The circuit shown in Fig. 15.3 contains ① a low pressure and large volume pump and ② a high pressure and small volume pump. The circuit raises its efficiency by using ① and ②. In a case where the pressure in the circuit is lower than the pressure set at the unload valve, the output flow rate from ① and ② are gathered and provided to the circuit. In contrast, in a case where pressure in the circuit is higher than the pressure set at the unload valve, the output flow rate from ① is by-passed to the reservoir by the unload valve, and the pressure is unloaded. In this case, pressure within the circuit is kept at a certain level by the output flow rate from ② only. This circuit provides flow rate characteristics observed in a pressure vs. flow rate curve.

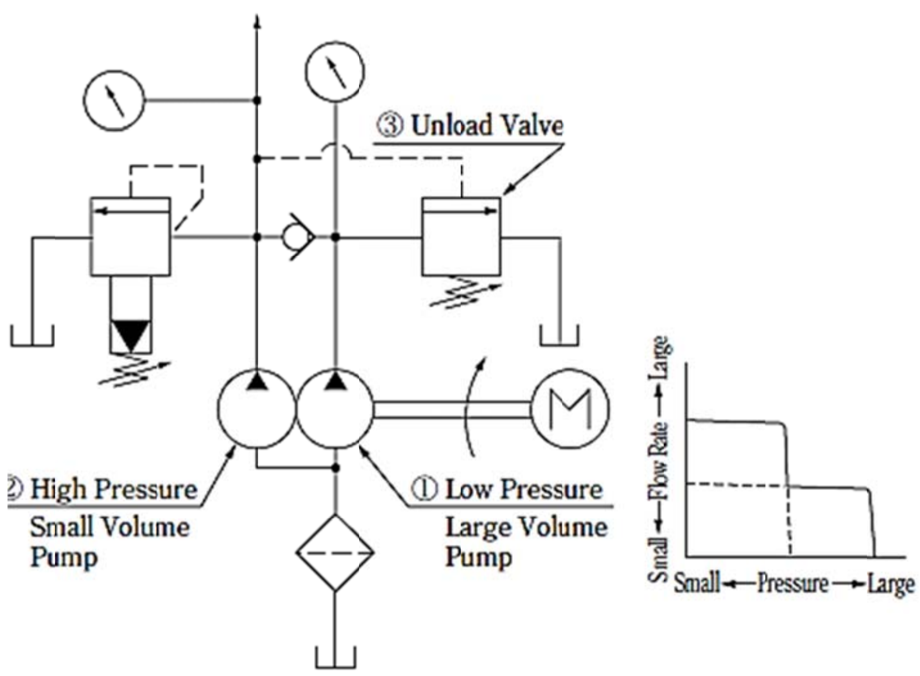

Fig. 5.3

d) Circuit with Accumulator (Fig. 5.4)

Pressure switch PS is correlated with the solenoid valve; when the circuit pressure equals the pressure set in the pressure switch PS, the solenoid valve is turned off, and output flow is by-passed to the reservoir, but the accumulator keeps the circuit pressure constant.

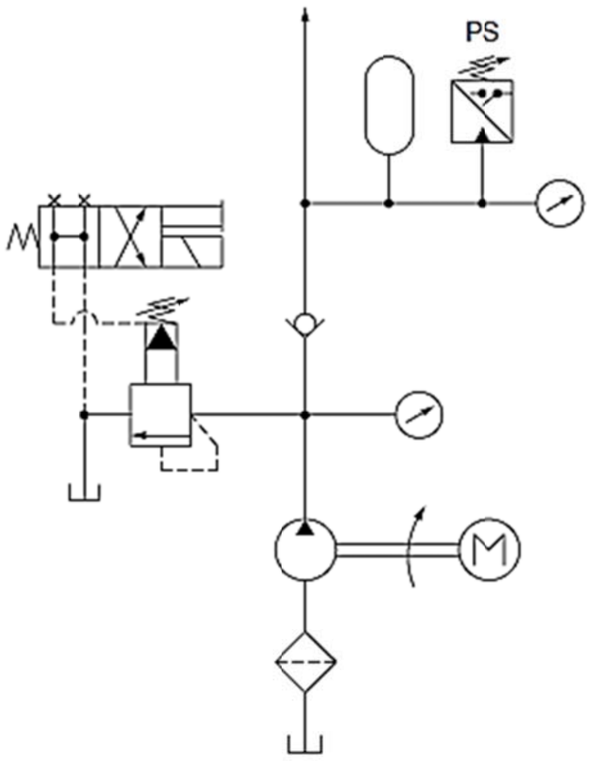

Fig. 5.4

e) Circuit with Two-Pressure Two-Control Type (Fig. 5.5)

When pump pressure is lower than PL, the angle of the swash plate becomes maximum, and the output flow reaches to the maximum (the flow rate goes to QH). In contrast, a pump pressure higher than PL causes a smaller swash plate angle and smaller output flow (QL). When the circuit pressure equals pump pressure, the swash plate angle falls close to zero, and output flow reduces to the amount of internal leakage. In this circuit, the power of the electric motor is kept small.

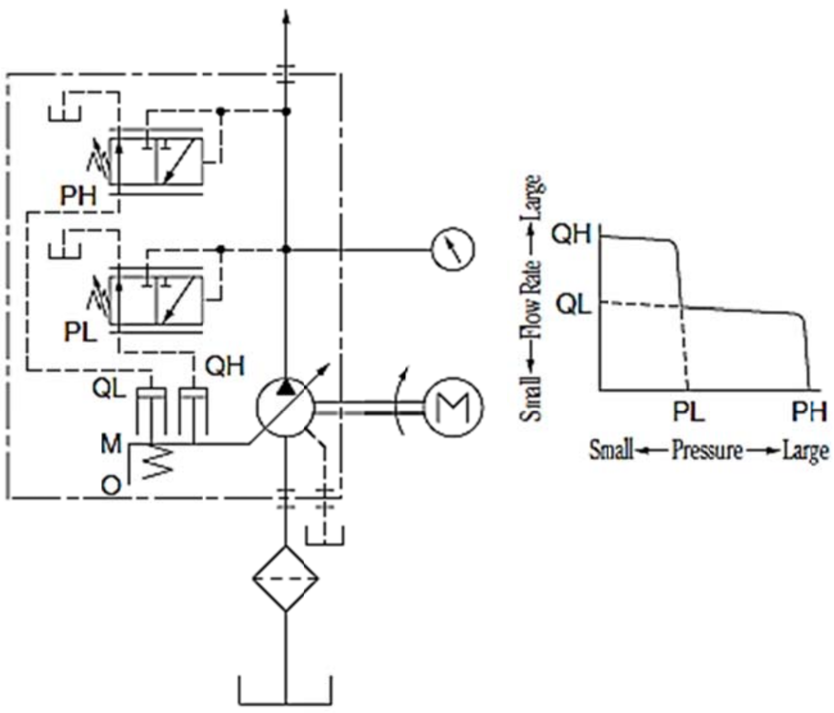

Fig. 5.5

5.3. Pressure Control Circuits

a) Two-Pressure Circuit with Decompression and Check Valves (Fig. 5.6)

In the cylinder-forwarding process (solenoid OFF), circuit pressure is kept at 10 MPa (1 450 psi). But, in the cylinder returning process (solenoid ON), circuit pressure is controlled at 7 MPa (1 015 psi) by the decompression valve.

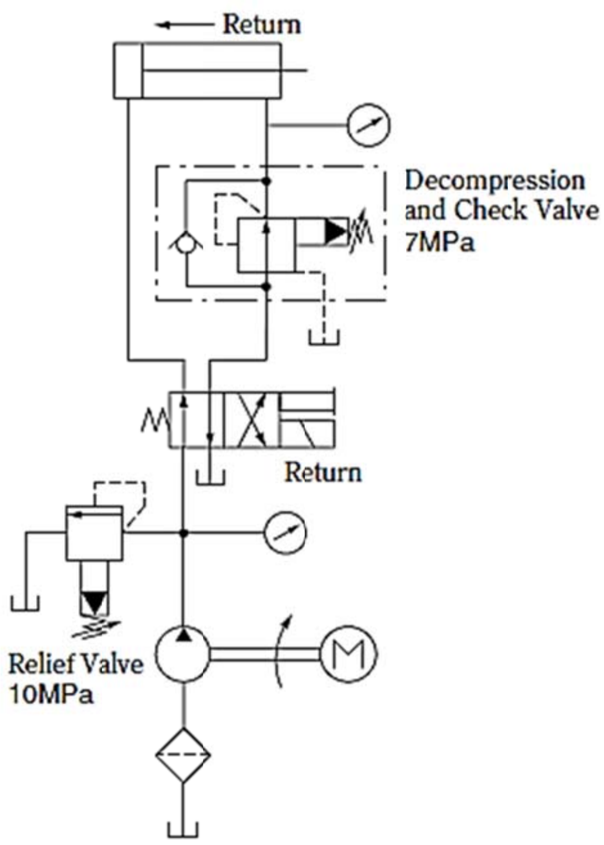

Fig. 5.6

b) Decompression Circuit ① (Fig. 5.7)

Releasing compressed working fluid instantly back to a reservoir generates shock waves. Compressed working fluid must be released gradually. In Fig. 5.7, compressed working fluid in the cylinder cap is released gradually through the flow control valve. This reduces circuit pressure slowly, thus preventing shock waves.

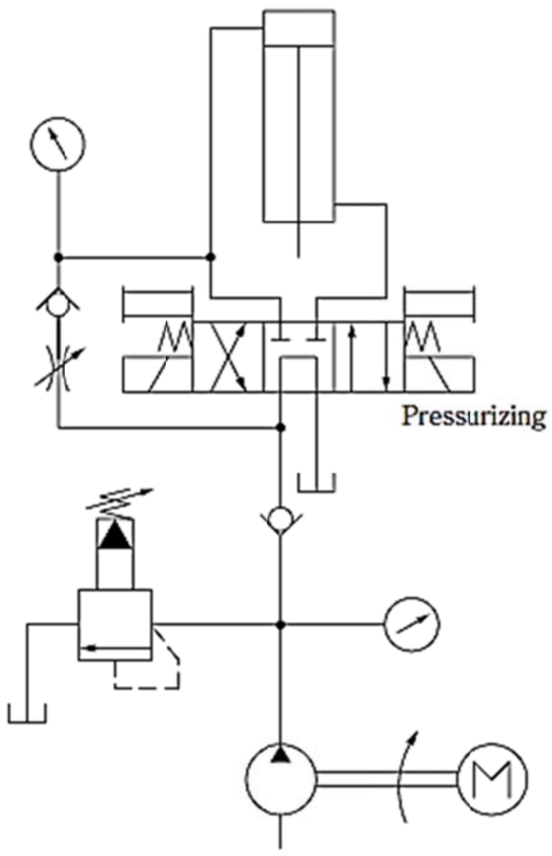

Fig. 5.7

c) Decompression Circuit ② (Fig. 5.8)

After completion of pressure release, this circuit achieves automatic lift of the cylinder by electric signals from the pressure switch. After compressing working fluid in the cylinder cap, the solenoid of the decompression valve is turned ON. Then, the compressed working fluid is released back to the reservoir through the flow control valve. Pressure in the circuit drops until it hits a certain point set in the switch PS. Then, the switch transmits signals out, and turns the solenoid valve ON to lift the cylinder. By this sequence, a smooth lift-up-and-down motion is achieved.

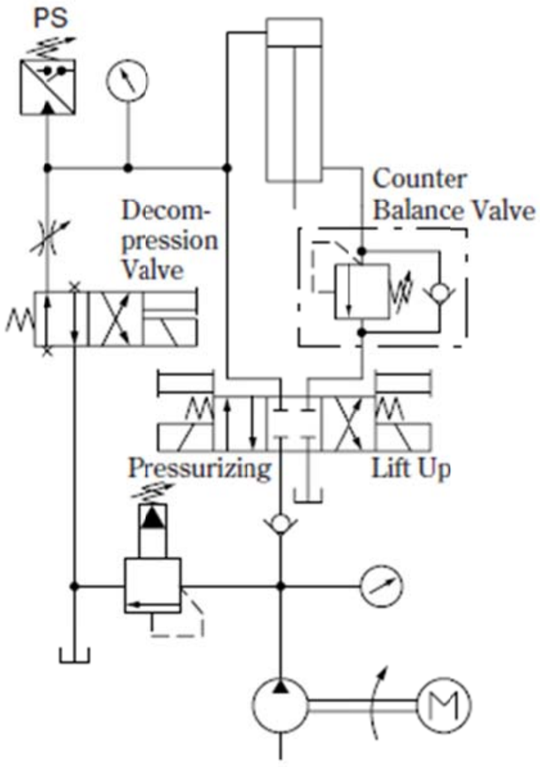

Fig. 5.8

d) Weight Balancing Circuit (Fig. 5.9)

This circuit balances (holds up) the weight by using the balancing valve. The balancing valve cannot hold up the weight if the pump does not work and does not generate enough energy or pressure to hold up the weight. Therefore, a pilot operated check valve is commonly used in the circuit.

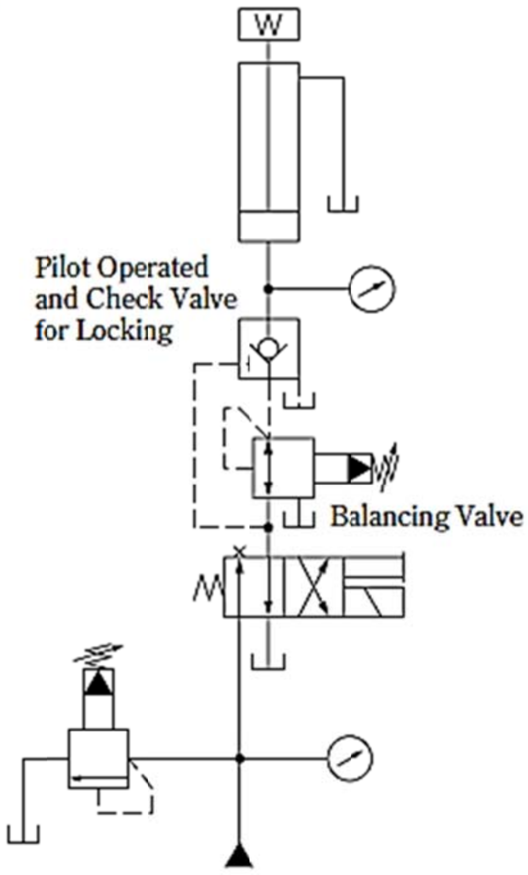

Fig. 5.9

5.4. Speed Control Circuits

a-1) Speed Change Circuit (Fig. 5.10)

This circuit changes the speed of the cylinder motion by employing two flow control valves. Shifting to high speed, change over the solenoid operated directional valve for low speed first then change over the solenoid valve for high speed so that shock is kept small as shown in Table 5.1.

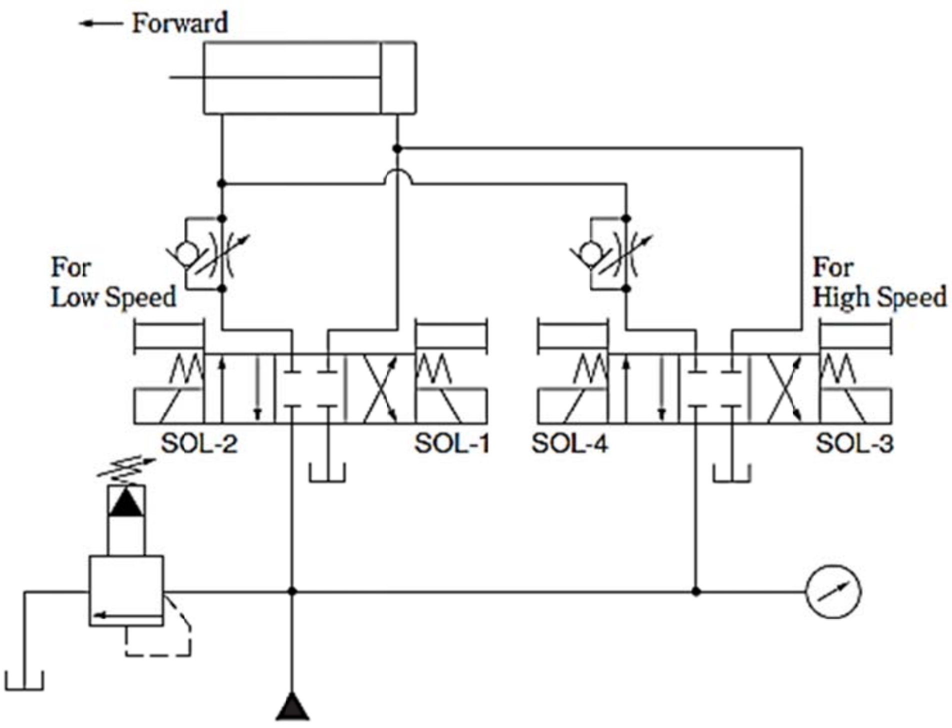

Fig. 5.10

Table 5.1 ON/OFF Change Pattern for Cylinder Forward Motion

Directional control valves	①	②
For Low Speed SOL-1	ON	ON
For High Speed SOL-3	OFF	ON

a-2) Speed Change Circuit (Fig. 5.11)

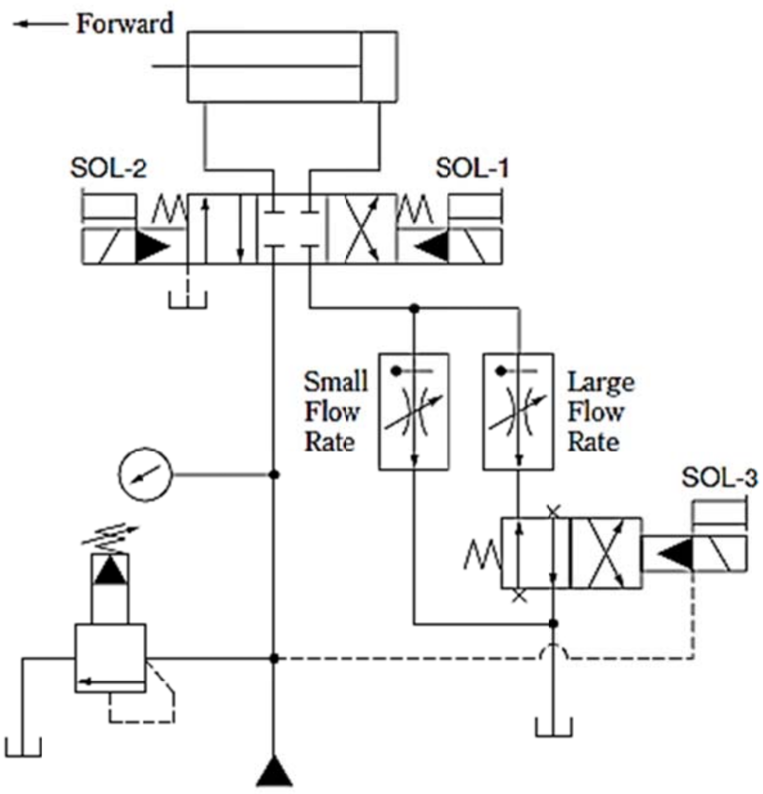

Fig. 15.11

b) Circuit with Proportional Electro-Hydraulic Directional and Flow Control Valve (Fig. 5.12)

Optimal flow rate (speed) is achieved by controlling the amount of the spool shifted in the proportional electrohydraulic valve; the spool is shifted proportional to the amount of electric signal received. The actuator is controlled smoothly with this valve, and the hydraulic circuit is simplified, as shown in Fig. 5.12.

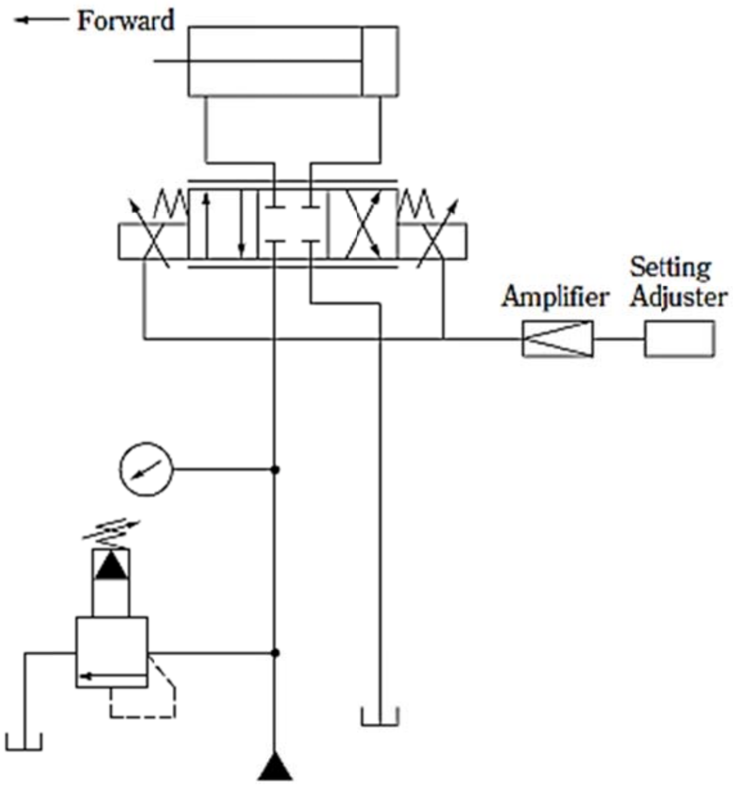

Fig. 5.12

c) Differential Circuit

When the cylinder is pushed forward, working fluid discharged from the cylinder head is added back to the cylinder cap because of the difference in surface area between the cap and the head of the cylinder. This achieves a faster-cylinder-forward motion, compared to a circuit with only one channel of incoming flow.

$$V = \frac{\text{Pump Output Flow Rate}}{\text{Rod Area}} \quad F = \text{Pressure Supplied} \times \text{Rod Area}$$

The relationship between forward speed V and the rod area, and between output force F and the rod area, are obtained as follows. V and F are functions of the rod area. The size of load pressure and pressure loss require due attention. as shown in Fig. 5.13.

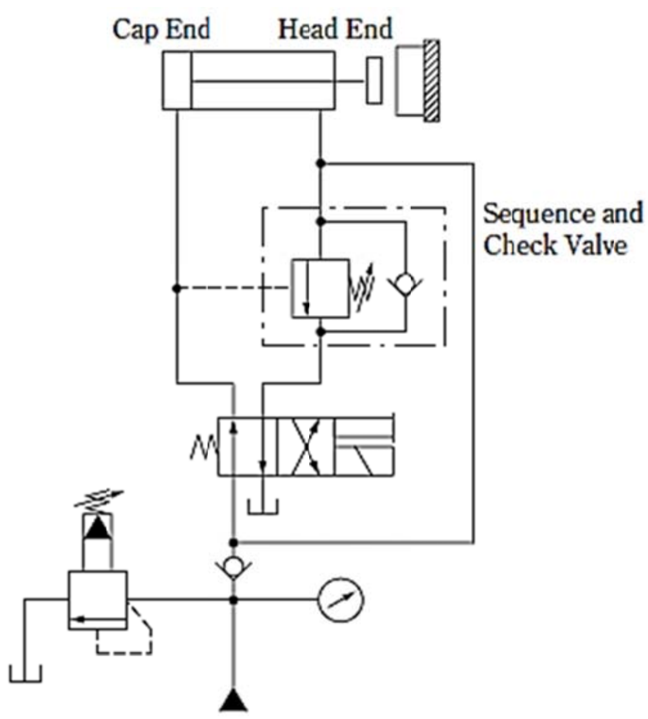

Fig. 5.13

d) Pre-Fill Valve Circuit (Fig. 5.14)

In this circuit, the subsidiary cylinders and the pre-fill valve help the main cylinder achieve pumping function. This circuit drastically reduces the pump-output volume required for the high-speed up-and-down cylinder motion of the press machine.

As the subsidiary cylinders move downward, the main cylinder is pulled down with them, sucking fluid from the reservoir through the pre-fill valve. At the end of the downward motion, the sequence valve is opened, and working fluid is directed to the main cylinder, which then generates a great pressure force on the press.

After the pressure is released, the solenoid valve is set for the high-speed upward motion. The main cylinder is pulled up again with the subsidiary cylinders, pushing fluid back to the reservoir through the pre-fill valve.

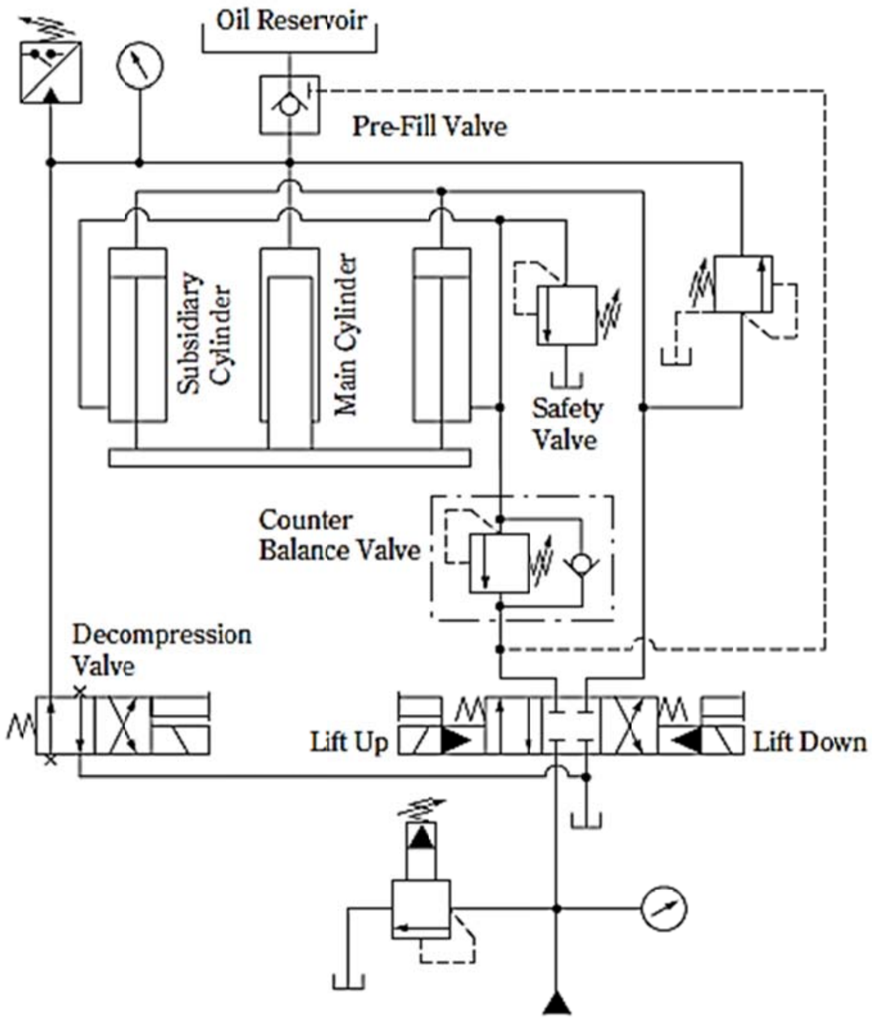

Fig. 15.14

5.5. Filter Circuits

Objectives of filtering and filtration rating change depending on where a filter is set in a circuit. One of the objectives, other than filtering contaminants is to let fluid flow at a certain rate. Another objective is to protect filter and provide a by-pass valve. Examples are shown in Fig. 5.15 to Fig.5. 17.

Figures 5.19 and 5.20 show circuits in which a clogged filter does not have an adverse impact. Also, filtration rating in these circuits can reach high class performance, (class 8 in the NAS Cleanliness Requirements with 1 pass quality,), when the ideal flow rate is applied to the filters.

a) Pump Filter Circuit (Fig. 5.15)

This circuit,s objective is to protect the hydraulic pump. This circuit has two types: in one type, a filter is set inside a reservoir on a pump suction port (sometimes it is called a strainer), and in the other, a filter is set outside a reservoir to aid in maintenance. The filtration rates of these circuit types are limited to around 100 µm because of the influence on pump suction resistance.

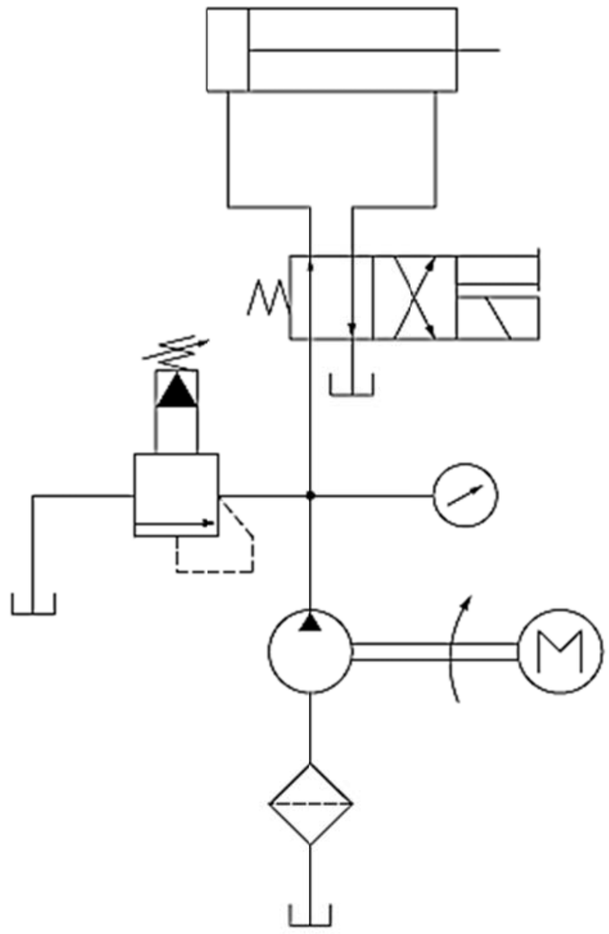

Fig. 5.15

b) Pressure Line Filter Circuit ① (Fig. 5.16)

This circuit protects the directional and other control valves in the line. Its filtration rate ranges from about 10µm (solenoid/proportional valve) to 3µm (servo valve, etc.).

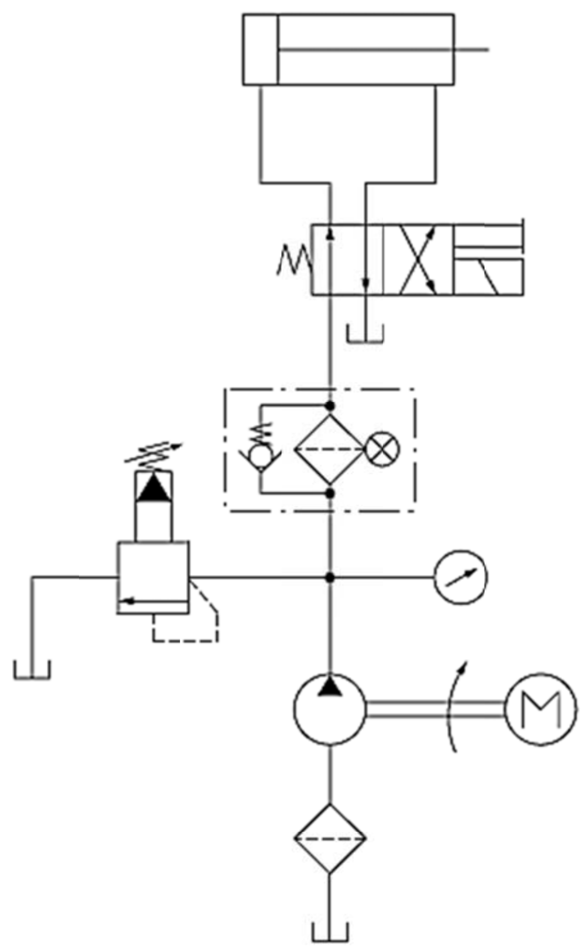

Fig. 5.16

c) Pressure Line Filter Circuit ② (Fig. 5.17)

This circuit has an objective similar to that of Fig. 5.16, but it filters out contaminants from the cylinder. It is better to filter out contaminants from only one direction with the anti-reverse-flow valve.

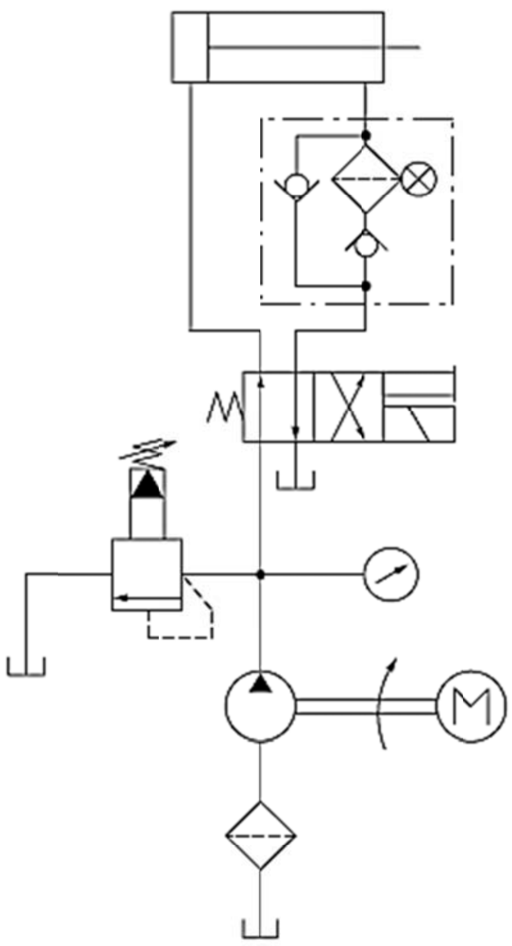

Fig. 15.17

d) Return Line Filter Circuit (Fig. 5.18)

This circuit filters working fluid going back to the reservoir. The filtration rate is approximately 10µm to 20 µm.

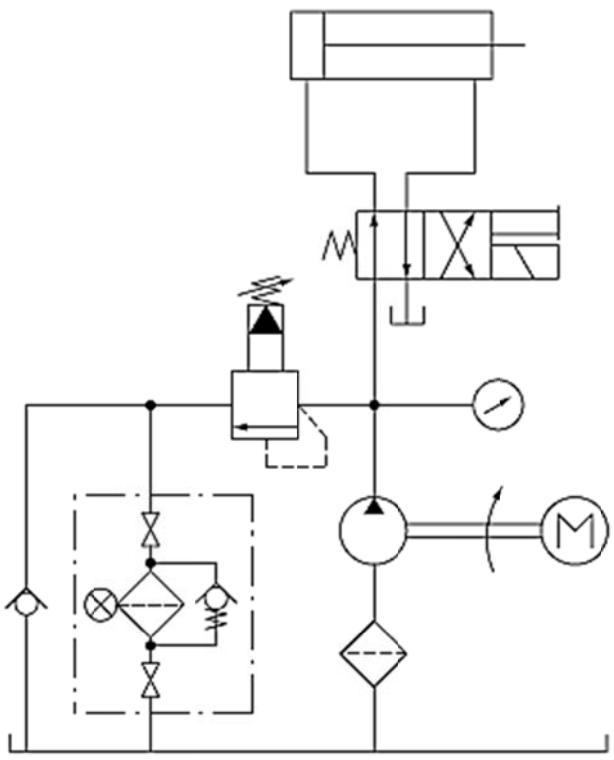

Fig. 5.18

e) Pressure Line Bleed-Off Filter Circuit (Fig. 5.19)

This circuit filters a small amount of the by-passed outlet flow from the pump (about 1 to 2 L/min (0.26～0.53 U.S.GPM)).

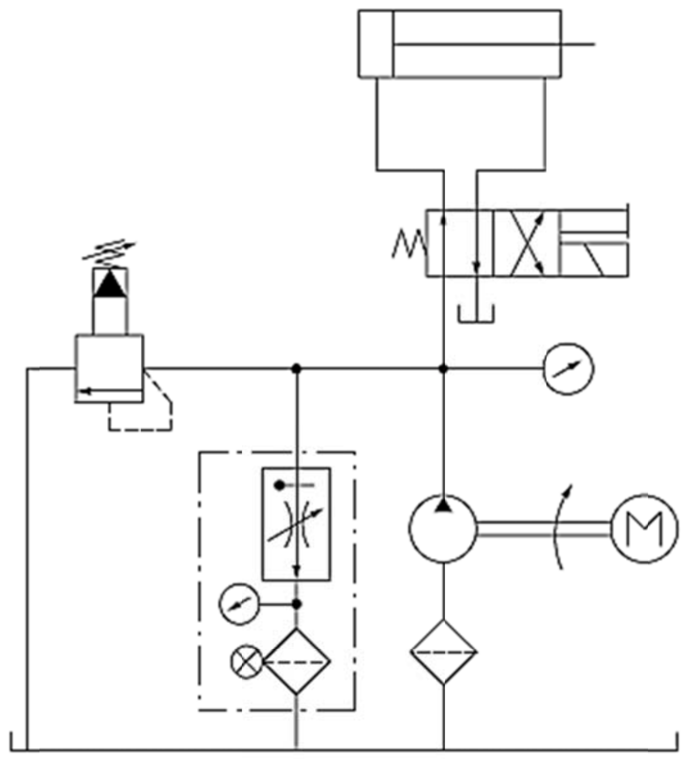

Fig. 5.19

f) Off-Line Filter Circuit (Fig. 5.20)

By using a pump and an electric motor specialized for filtration, this circuit filters contaminants even when the main hydraulic pump is not turned on. This circuit has the best filtration of all the filtration circuits.

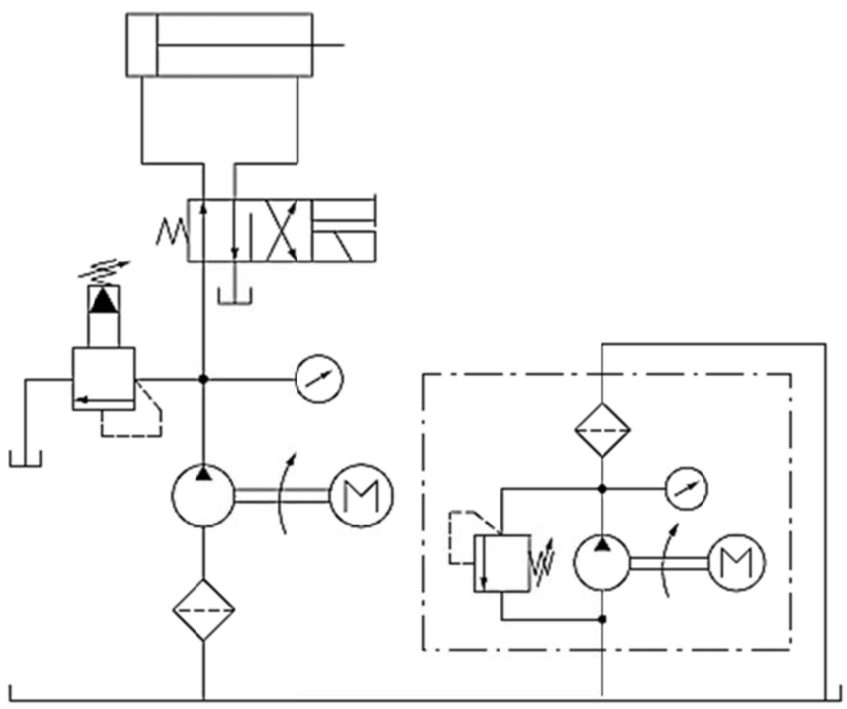

Fig. 5.20

5.6. Synchronizing Circuits

This circuit synchronizes movements of multiple actuators. Minimal error should never be overlooked, however, to avoid the accumulation of synchronization errors, it is always recommended that the circuit be set in such a way that the error is corrected at the end of an operation with one, full cylinder stroke, instead of the repeated, half-way cylinder motion.

a) Synchronizing Circuit with Mechanical Combination (Fig. 5.21)

This circuit realizes a synchronized motion by mechanically combined cylinder rods. In the following figure, the relationship between the two main cylinders and two other auxiliary cylinders is also a mechanical combination. This circuit does not necessitate a control valve for synchronization. Synchronization errors would be happened by production accuracy and rigid of mechanism.

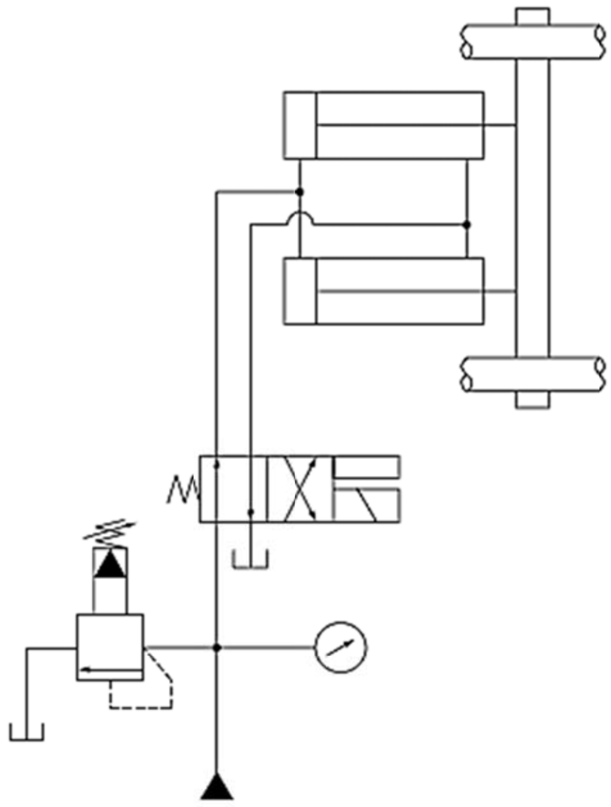

Fig. 5.21

b) Synchronizing Circuit with Flow Control Valves (Fig. 5.22)

In this circuit, the flow control valve controls fluid flowing in and out of the cylinders. Generally, a high accuracy valve is employed.

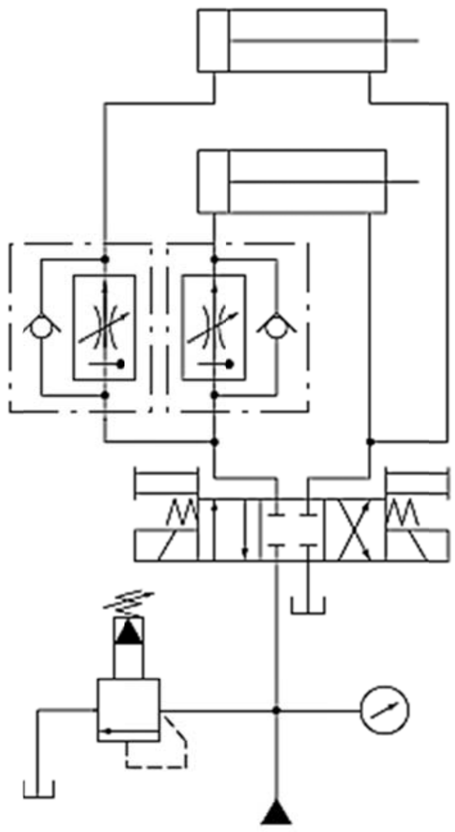

Fig. 5.22

c) Circuit with Flow Divider (Fig. 5.23)

This circuit utilizes the flow divider specialized for synchronization.

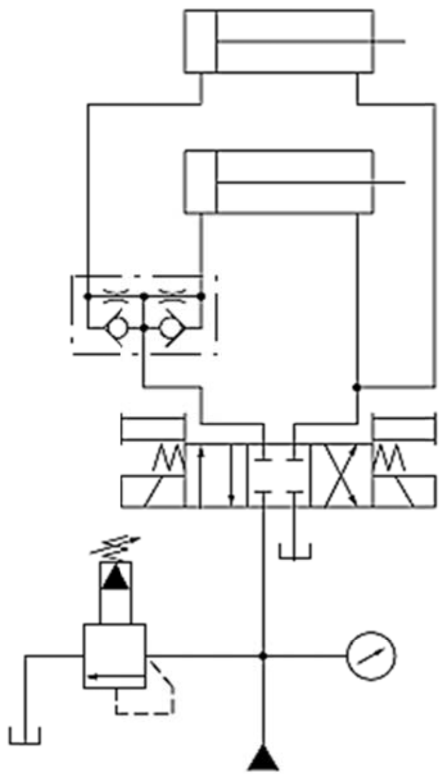

Fig. 5.23

d) Circuit with Synchronized Hydraulic Motors (Fig. 5.24)

With the shafts combined, these motors can displace the same amount of working fluid to and from each cylinder. The accuracy of the amount of displacement controls the accuracy of synchronization. Therefore, if the volumetric efficiency is the same, setting the circuit with high speed motors reduces synchronization errors.

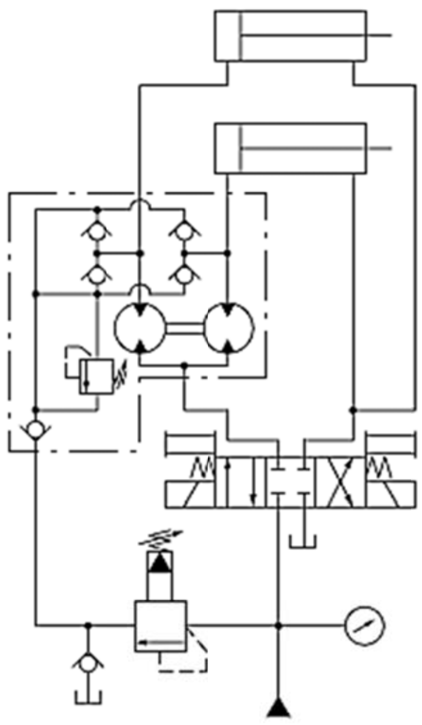

Fig. 5.24

e) Circuit with Synchronized Cylinders (Fig. 5.25)

This circuit realizes a very accurate synchronized motion via combined synchronizing cylinders. But, sometimes, spacing becomes an issue because it requires the volume of all the cylinders to be the same.

f) Circuit with Servo Valve (Fig. 5.26)

This circuit detects the position of two cylinders and uses two servo valves to control the amount of working fluid required to adjust synchronization errors. The following figure is an example of such feedback-synchronization control. Rather than detecting the position of one cylinder, and giving the feedback to the other cylinder for synchronization, it is better and more accurate with less time lag if each cylinder works separately and their positions are controlled by different servo valves.

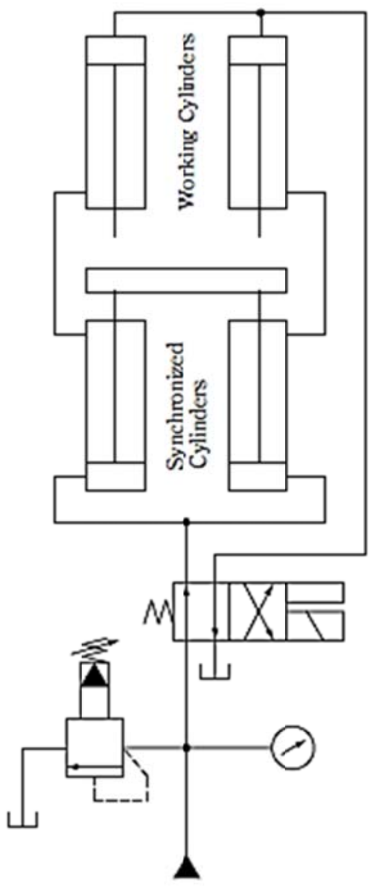

Fig. 5.25

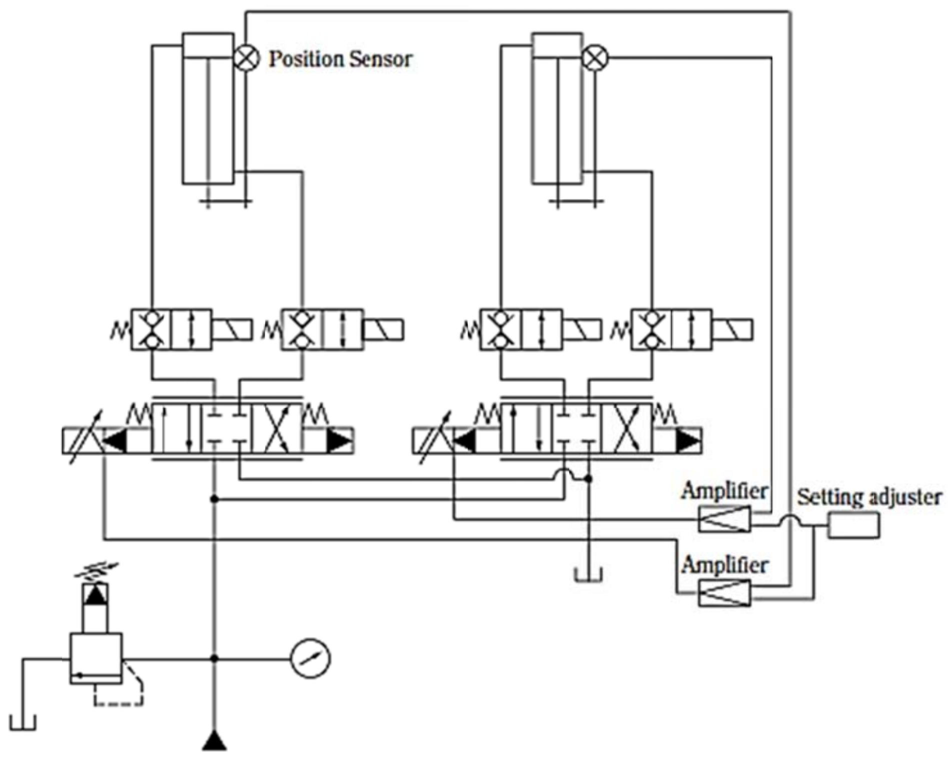

Fig. 5.26

5.7. Intensifying Circuits

Circuit with a Cylinder as Intensifier (Fig. 5.27)

This circuit intensifies pressure by using the difference between cap and head area in cylinders. In the following figure, the solenoid valve for adding pressure is turned ON. Working fluid channeled through the sequence valve ① pushes the working cylinder head forward until it hits an object. The contact between the cylinder head and the object eventually increases the pressure inside the line. Then, the circuit delivers the pressurized working fluid to the intensifying cylinder in which the fluid is pressurized yet further. The highly pressurized working fluid in the intensifying cylinder is then supplied back to the working cylinder. The decompression valve on the primary side of the intensifying cylinder adjusts the output power. Also, in the process of returning the cylinders, it is important to note that the intensifying cylinder is returned by the sequence valve ② (using the counter balance valve as the sequence valve).

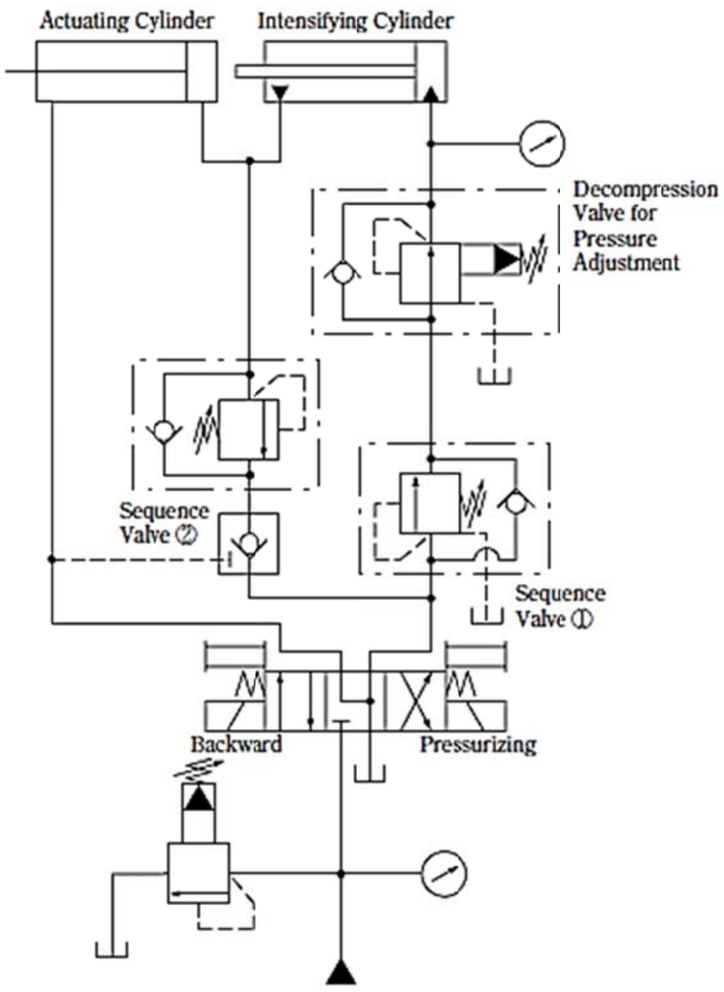

Fig. 5.27 Circuit with Intensifying Cylinders

5.8. Brake Circuits

Brake Circuit with Hydraulic Motor (Fig. 5.28)

This figure is an example of a motor that turns both directions. With the solenoid valve in position ①, the hydraulic motor turns right. After that, the solenoid valve is in the middle position, but the hydraulic motor keeps working as a pump because of inertia. Discharged working fluid runs through the check valve ④, and returns to the reservoir with back pressure given by the relief valve. The primary side of the motor becomes low pressure, thus working fluid through the check valve ③ is supplied into the line. In the case of a left turn, the check valve ② and ⑤ are used.

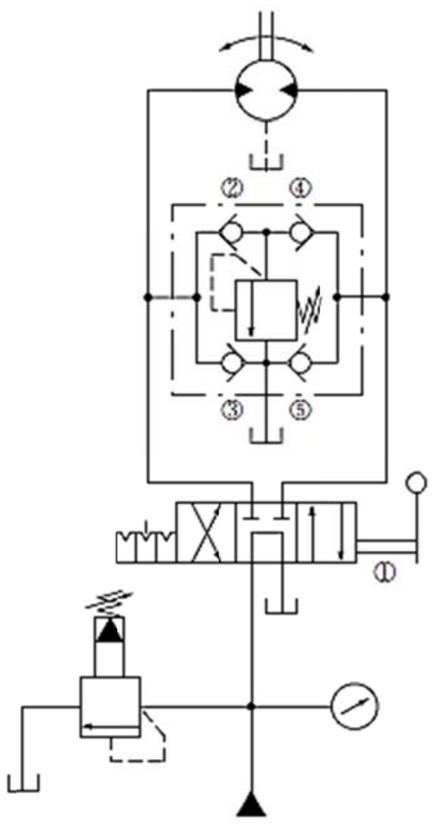

Fig. 15.28

5.9. Closed Circuits

Closed Circuit for Vehicle (Fig. 5.29)

Closed circuits are widely employed in vehicles performing running, circling or HST (Hydro Static Transmission: no shift change for speed change) functions. One of the characteristics of this circuit is to use a pump as a hydraulic motor to absorb the power: this is a reverse use of the pumping function of a motor found in the previous section on brake circuits. In addition, pressure inside the line is low because the hydraulic pump controls the speed of the vehicle. This system is more efficient, and achieves less heat generation when compared to valve control systems. The feed pump fills and replaces working fluid internally, and it supplies clean fluid through a filter. The circuit must be made in such a way that safety valve ① has a higher pressure than that of safety valve ②, and that working fluid from the feed pump is discharged to the reservoir via the flushing valve.

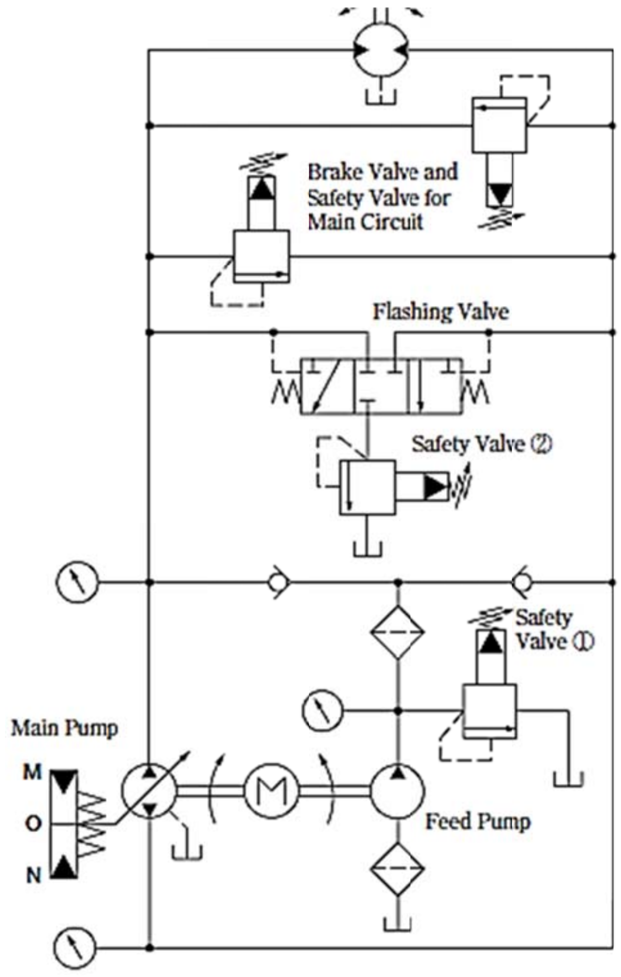

Fig. 5.29