Technical education document

Oil Hydraulics – Basic Technology Textbook

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Training Dept.

CONTENTS

Chapter 1

Basis of Oil Hydraulics

1. Overview of oil hydraulics

“Oil hydraulics” is a term for power-converting or power-transmitting systems and devices that actuate hydraulic cylinders, hydraulic motors and such by controlling three elements (i.e. pressure, flow rate and direction) of oil discharged from a hydraulic pump while the systems and devices provide turning force to the hydraulic pump. Making a good use of the oil characteristics in such a manner that the functions required for a task are fully exploited collectively means utilization of hydraulics. The hydraulics application field has been greatly expanding as the demands for automation and labor-saving have increased. The hydraulic technologies have made remarkable progress and development.

(1) Applications of oil hydraulics

Typical applications include tasks that require linear motion, rotary motion, loading power, speed adjustment, and such.

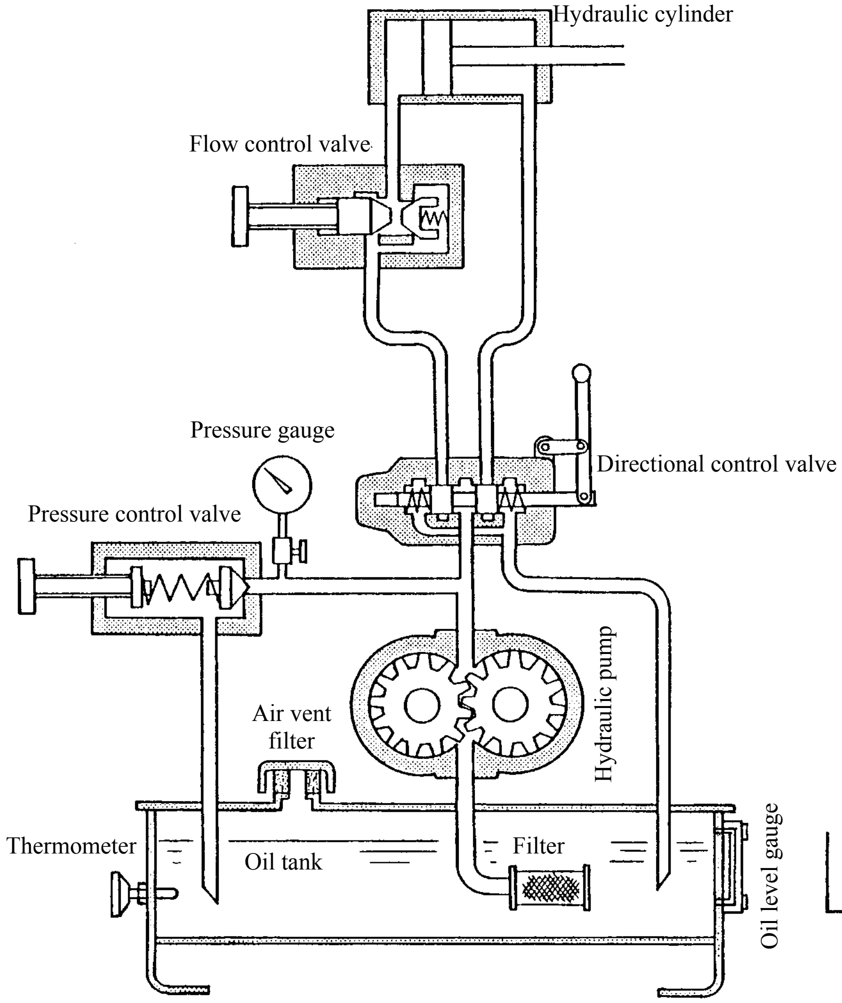
Construction equipment: Bulldozer, Excavator, truck crane
Transporting equipment: Forklift, dump truck, cement mixer truck
Vessel deck machinery: Winch, steering engine
Machine tool: Lathe, miller, driller, machining center
Steel machinery: Shearing machine, coil winding/rewinding machine
Metal machinery: Casting machine
Synthetic resin: machines for injection molding, extrusion molding and foam molding
Wood working machinery: Hot press, wood transporting vehicle
Bookbinding and printing: Cutting machine, offset printing machine, rotary press
Others: Incinerator, amusement facility, industrial robot

(2) Features of oil hydraulics

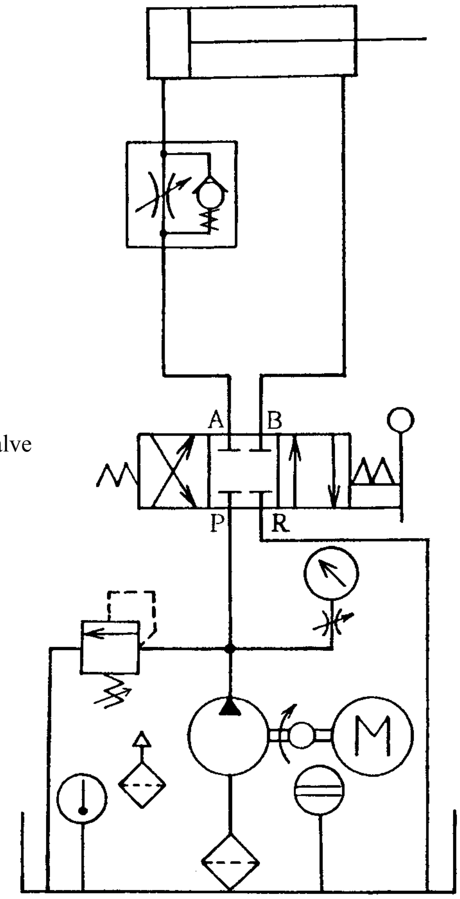
[1] Compact in size, big output power
[2] Linear power adjustment is available
[3] Linear speed adjustment is available
[4] Easy to control the direction of motion
[5] Simple overload safety device is applicable
[6] Accumulating of energy is available
[7] Lubricative and rust-preventive working oil prevents moving parts from wearing

2. Basic structure of oil hydraulic device and JIS symbols

(1) JIS symbols and circuit diagram



Cross section circuit diagram



Circuit diagram using JIS symbols

(2) Sub-assembly of oil hydraulic device

[1] Oil tank
[2] Hydraulic pump
[3] Pressure control valve
[4] Directional control valve
[5] Flow control valve
[6] Actuators (hydraulic cylinder, hydraulic motor)
[7] Others (pressure gauge, filter, air vent filter, thermometer, oil level gauge, etc.)

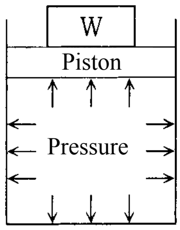
3. Basic equations of oil hydraulics

(1) Pascal's principle

See the illustration to the right. A vertical force W applied on the top of the closed vessel compresses the fluid confined in the vessel, and the fluid produces a counter-force against the compressive force since a fluid never changes its cubic volume by nature under compressive pressure.

The counter-force of a fluid is called **"pressure"**.

Such pressure produced in a fluid has **three features** as follows.



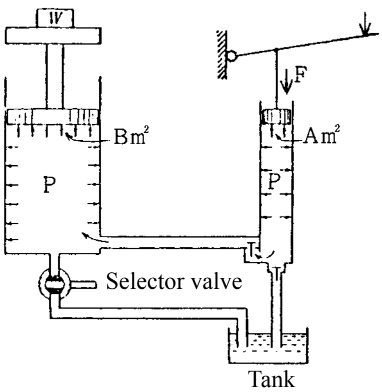
[1] Where a fluid is in a static state and contacting surfaces, the pressure of the fluid **acts perpendicular to each surface.**

[2] The pressure at a point in a static fluid **acts in every direction with equal force.**

[3] A pressure applied on any part of a static fluid confined in a closed vessel is **transmitted undiminished everywhere at the same time.**
(The above features are called **"Pascal's law"**.)

(2) Relationship between pressure and force

The term "pressure" used in oil hydraulics is defined as "a magnitude of force (N: Newton) applied on a unit area of an object (1 m^2) and is written as N/m^2, which is substituted by Pa (Pascal) as the unit of pressure."



In the illustration to the left, F (N) is a force pushing the right-side piston downward and A (m^2) is the cross-sectional area of the piston. Consequently, the pressure P produced in the fluid is expressed as P (Pa) = F (N) / A (m^2).

On the Pascal's principle, the pressure is transmitted through the piping up to the bottom of the left-side piston with a cross-sectional area of B (m^2). Where the pressure and the load W are balanced, it is expressed as W (N) = P (Pa) × B (m^2).

The relationship between pressure and force is expressed as follows.

Pressure (MPa), Force (N), Area (mm^2):

$$P = \frac{F}{A}$$

⇒

Pressure (MPa), Force (N), Area (cm^2):

$$P = \frac{F}{A \times 10^2}$$

[Conversion of pressure]

1Pa = 1 N/m^2 = 1 MPa × 10^{-6} (MPa ⇒ Megapascal)

1 MPa = 1 N/mm^2 = 1000000 Pa (MPa and N/mm^2 are different in expression but same in magnitude.)

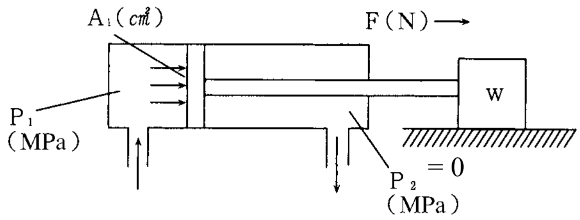
[Conversion between conventional unit and International System of Units (SI)]

1 kgf/cm^2 = 0.0980665 MPa = 0.1 MPa approx.

1 MPa = 10.1972 kgf/cm^2 = 10 kgf/cm^2 approx.

(3) Hydraulic cylinder output force (Difference between forces acting on piston area)

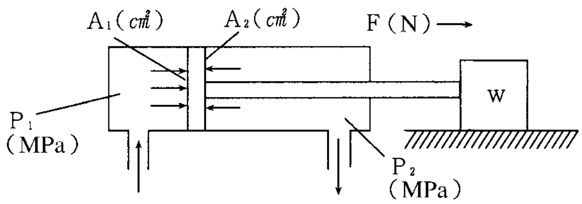
When the pressure receiving area of the hydraulic cylinder piston is A_1 and P_1 is the pressure of the oil sent into the cylinder for pushing and moving the load rightward, the cylinder output force F is expressed as follows (<u>where $P_2 = 0$, on the assumption that there is no back pressure</u>).



Output force (N) — Pressure (MPa) — Pressure receiving area (cm²)

$$F = P_1 \times A_1 \times 10^2$$

If there is another force (back pressure) acting on the other side of the piston (A_2 area) caused by resistance in the piping or so, the back pressure P_2 acts and makes the work of P_1 less effective. Consequently, the amount of the back pressure force has to be subtracted from that of the P_1 force. In this regard, <u>the cylinder output force where a back pressure exists</u> shall be expressed as follows.



Output force (N) — Pressure (MPa) — Pressure receiving area (cm²)

$$F = P_1 \times A_1 \times 10^2 - P_2 \times A_2 \times 10^2$$

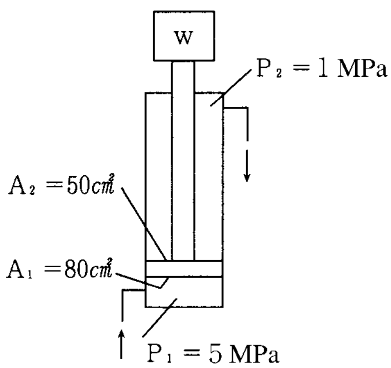
Pressure receiving area (cm²) — Pressure (MPa)

Therefore, P_1 is given by

$$P_1 = \frac{F + P_2 \times A_2 \times 10^2}{A_1 \times 10^2}$$

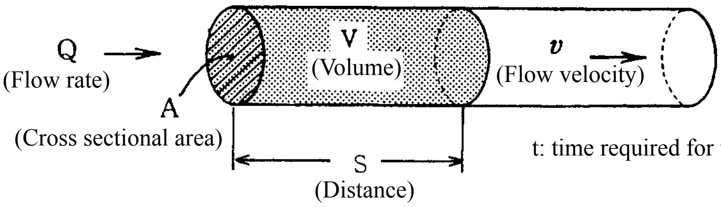
[Exercise 1] In the illustration to the right, the hydraulic cylinder (A_1 = 80 cm^2, A_2 = 50 cm^2) lifts up the load W while P_1 = 5 MPa and P_2 = 1 MPa are produced. Find the force F (N) to lift the load W up.

[Solution]



(4) Pipe flow rate and velocity

The term flow rate means the volume of a fluid traveling in a unit of time and is expressed as the product of a cross sectional area and a flow velocity.



t: time required for the fluid traveling a distance S

$$\underset{\text{(Flow rate)}}{Q} = \frac{V\ \text{(Volume)}}{t\ \text{(Time)}} = \frac{A\ \text{(Cross sectional area)} \times S\ \text{(Distance)}}{t\ \text{(Time)}} = A \times \upsilon$$

Flow rate (cm^3/s)	$Q = A \times \upsilon$	Cross sectional area (cm^2); Flow velocity (cm/s)

* Flow rate Q is expressed in a unit of L/min.
* Flow velocity υ is expressed in a unit of m/s or mm/s.

[Conversion of unit: L/min to cm^3/s]

$$Q\ (\text{L/min}) \times \frac{1000}{60} = Q\ (cm^3/s)$$

[Conversion of unit: cm^3/s to L/min]

$$Q\ (cm^3/s) \times \frac{60}{1000} = Q\ (\text{L/min})$$

[Exercise 2] Find the flow rate (cm^3/s) of oil flowing at a velocity of 3 m/s in a pipe whose cross sectional area is 3 cm^2.

[Solution]

[Exercise 3] Find the flow velocity (m/s) of oil being sent at a rate of 30 L/min in a pipe whose cross sectional area is 10 cm^2.

[Solution]

[Exercise 4] Determine the inner diameter (mm) of the suction side pipe of a pump with a capacity of 42 L/min where the flow velocity is 0.7 m/s.

[Solution]

In planning of a oil hydraulic system, the first thing to do is selection of devices and tanks that meet the system capacity, and what's coming next is selection of connecting piping. A frequent guideline for pipe size determination is flow velocity.

In general, the range of practical flow velocities of each piping is as follows.

Pump suction line: 0.5 to 1.5 m/s

Pressure line: 1.5 to 5 m/s

Return line: 1.5 to 3 m/s

Reference

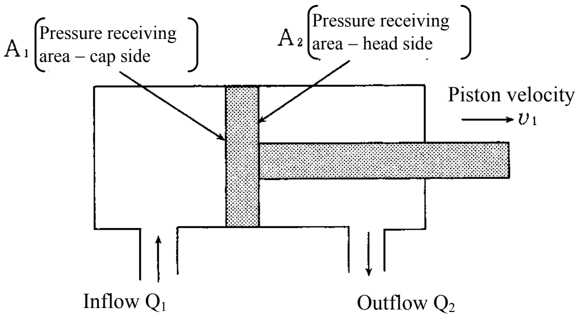
Equation to find the pipe inner diameter

Diameter *d* can be found if area of a circle A is known.

$$A = \frac{\pi d^2}{4} \qquad \pi d^2 = 4A \qquad \boxed{d = \sqrt{\frac{4A}{\pi}}}$$

(5) Inflow required for ensuring piston velocity

As with the case in "(4) Pipe flow rate and velocity", the equation $Q = A \times \upsilon$ is used to find the "inflow" that enables the piston to move at a velocity υ_1. The equation to find "inflow" is provided below.



$$Q_1 = A_1 \times \upsilon_1$$

- Inflow (cm^3/s)
- Pressure receiving area – cap side (cm^2)
- Piston velocity (cm/s)

In the above diagram, the outflow Q_2 forced out by the A_2 area of the piston is also found by the equation $Q = A \times \upsilon$, and the equation to find Q_2 is provided to the right.

$$Q_2 = A_2 \times \upsilon_1$$

- Outflow (cm^3/s)
- Pressure receiving area – head side (cm^2)
- Piston velocity (cm/s)

(6) How to find piston velocity

When Q_1 and A_1 in the equation $Q_1 = A_1 \times \upsilon_1$ are known, υ_1 can be found by the equation to the right.

$$\upsilon_1 = \frac{Q_1}{A_1}$$

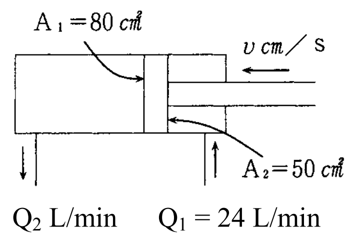
- Piston velocity (cm/s)
- Inflow (cm^3/s)
- Pressure receiving area – cap side (cm^2)

[Exercise 5] Find the piston velocity υ_1 (cm/s) and outflow Q_2 (L/min) where $A_1 = 80\ cm^2$, $A_2 = 50\ cm^2$ and $Q_1 = 24$ L/min in the above diagram.

[Solution]

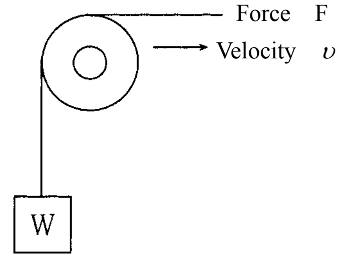
[Exercise 6] See the diagram below. Find the piston velocity υ (cm/s) and outflow Q_2 (L/min) when the piston travels backward, using the values provided.

[Solution]



(7) Fluid power

[1] Power is the product of force and velocity.

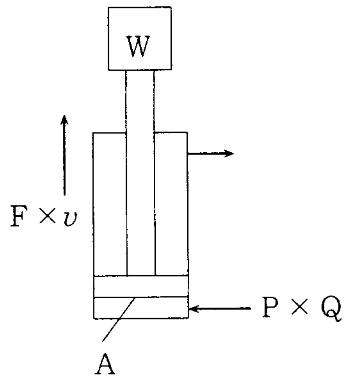


In the diagram to the left, the equation (in basic unit [N·m/s]) to express the power L needed for lifting the load upward by pulling the rope is as follows.

$$L = F \times \upsilon$$

Power (N·m/s) — L; Force (N) — F; Velocity (m/s) — υ

[2] Case of hydraulic system



As with the above, F is the lifting force and υ is the velocity. Then, where P is the cylinder pressure and Q is the feeding flow rate, the fluid power L_O is expressed as follows.

$$L_O = F \times \upsilon = P \times A \times \frac{Q}{A} = \boxed{P \times Q}$$

In other words, <u>fluid power is expressed as a product of pressure and flow rate.</u>

[3] Expressing fluid power in practical units, kW or PS gives following equations.

Where P in MPa and Q in L/min.

$$L_O\,(\text{kW}) = \frac{P \times Q}{60}$$

P: Pressure (MPa); Q: Flow rate (L/min)

$$L_O\,(\text{PS}) = \frac{P \times Q}{44.1}$$

P: Pressure (MPa); Q: Flow rate (L/min)

[Exercise 7] A pressure of 10 MPa and a flow rate of 20 L/min are needed when a hydraulic cylinder moves a load. Find the fluid power in kW in this case.

[Solution]

(8) Torque and number of revolutions of hydraulic motor

T: Output torque	(N·m)
N: Actual number of revolutions	(min^{-1}) … rpm
p: Difference in pressure between inlet and outlet (available pressure difference)	(MPa)
q: Theoretical volume required for one motor revolution (displacement of motor)	(cm^3)
Q: Supply oil quantity	(cm^3/min)
η_T: Mechanical efficiency of motor	
η_V: Volumetric efficiency of motor	

[1] Motor output torque … Torque is proportional to available pressure difference and displacement

$$T = \frac{p \times q}{2\pi} \eta_T$$

Equation to find q ⇨

$$q = \frac{2\pi \times T}{p \times \eta_T}$$

[2] Actual number of revolutions of motor … Number of revolutions is proportional to supply oil quantity and inversely proportional to displacement.

$$N = \frac{Q}{q} \eta_V$$

Equation to find Q ⇨

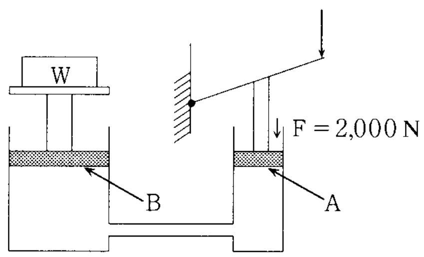
$$Q = \frac{N \times q}{\eta_V}$$

[Exercise 8] Determine the displacement of a hydraulic motor when the required output torque is 100 N·m and the available pressure difference p of the hydraulic motor is 10 MPa.
Then, determine the supply oil quantity needed to run the hydraulic motor up to 1000 min^{-1}.
(where η_T = 90% and η_V = 94%)

[Solution]

Exercises

Exercise 1.



In the diagram to the left, F = 2,000 N, A = 20 cm^2, and B = 100 cm^2.

Find the force that lifts up Piston B.

(10,000 N)

Exercise 2. The pipe inner diameter is 21 mm, and the flow rate is 30 L/min. Find the flow velocity (m/s).

(1.45 m/s)

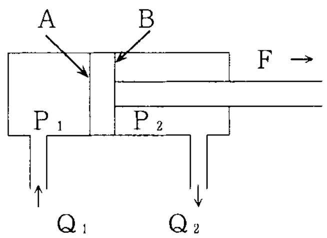
Exercise 3. Determine the pipe diameter associated with a flow rate of 120 L/min and a flow velocity of 1 m/s.

(50 mm)

Exercise 4. In the hydraulic cylinder diagram below, find the output force F using the values provided.

A = 50 cm^2 B = 40 cm^2

P_1 = 5 MPa P_2 = 0.5 MPa (23,000 N)



Exercise 5. In the Exercise-4 diagram, find the outflow Q_2 when the inflow Q_1 is 30 L/min.

Then, find the piston forward speed as well.

[Q_2 = 24 L/min
Piston speed = 10 cm/s]

Exercise 6. When the pump discharge pressure is 7 MPa and the discharge quantity is 31 L/min, the shaft power is 4.9 kW.

Find the overall efficiency of the pump. (74%)

[Work on this exercise after learning about hydraulic pumps in Chapter 2.]

Exercise 7. Find the output torque when running a hydraulic motor with displacement q = 150 cm^3 at available pressure difference p = 20 MPa. Where mechanical efficiency η_T = 0.92. (439 N·m)

Exercise 8. Determine the pump discharge quantity when running the hydraulic pump given in Exercise 7 at a speed of 1,200 min^{-1}. Where volumetric efficiency η_V = 0.96. (187.5 L/min)

Chapter 2

Oil Hydraulic Equipment

1. Actuator

An actuator, in general, is such equipment that provides linear, oscillating or rotary motion by converting fluid power from a hydraulic pump into mechanical power.

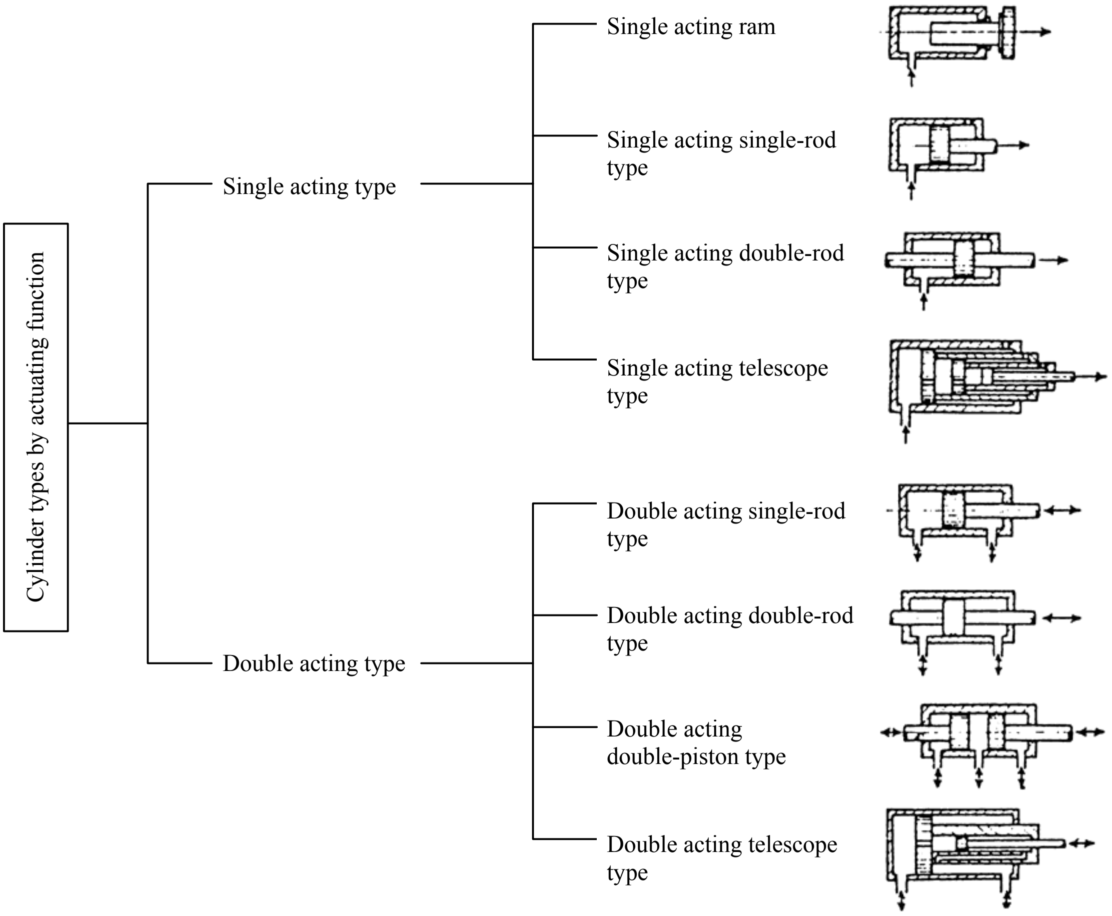
(1) Types

- Hydraulic cylinder
  - Single acting type
  - Double acting type
- Oscillating hydraulic actuator
- Hydraulic motor
  - Gear type
  - Vane type
  - Piston type

(2) Hydraulic cylinder

An actuator that uses hydraulic oil pressure to move an operating part in a straight line is called a hydraulic cylinder.

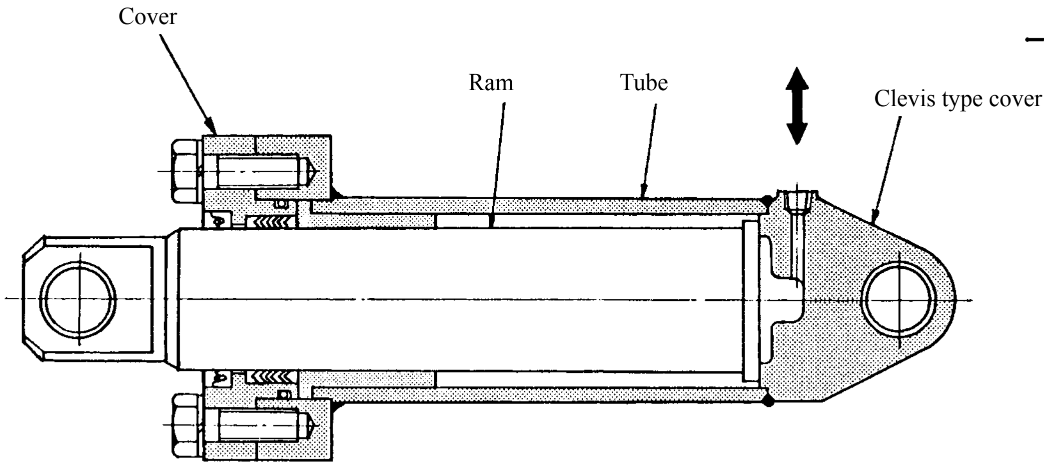
[1] Types of Hydraulic cylinder



[2] Single acting cylinder

Single acting cylinder is such that hydraulic oil pressure controls the cylinder motion in one single direction only while applying a hydraulic oil pressure on one side of the piston. It uses gravity for the return stroke, which offers an advantage of saving power. In some cases, a spring is used in the return stroke instead of gravity. There are two types of single acting cylinders: piston type and ram type.

JIS symbol

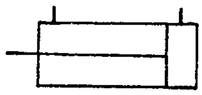


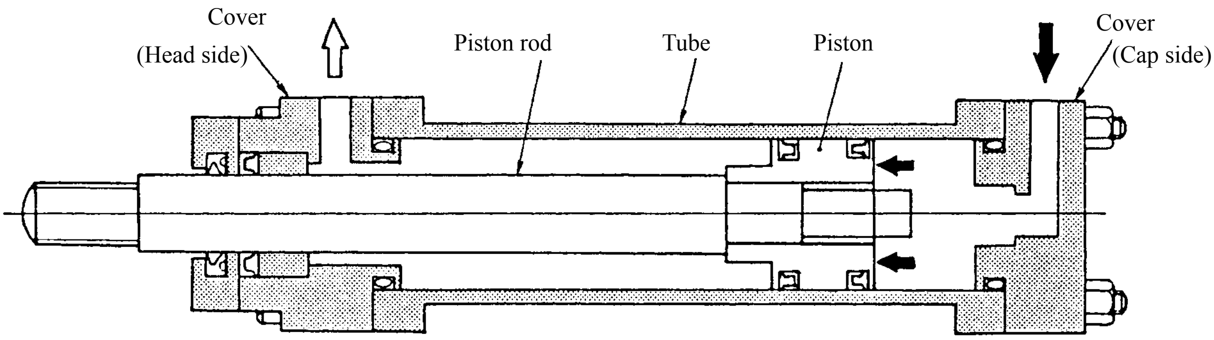
[Single acting ram type cylinder]

[3] Double acting cylinder

Double acting cylinder is such that hydraulic oil pressure controls the cylinder motion in both forward and return strokes while applying a hydraulic oil pressure on both sides of the piston alternately. There are two types of double acting cylinders: single-rod type and double-rod type.

JIS symbol



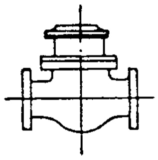


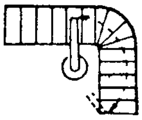
[Double acting single-rod type cylinder]

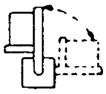
(3) Oscillating hydraulic actuator

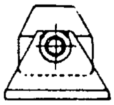
Oscillating hydraulic actuator is such that it uses hydraulic oil pressure to rotate its output shaft within a predetermined range of angle.

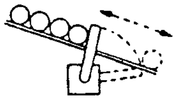
[1] Application examples of oscillating hydraulic actuator


Valve switching device


Conveyor turn device

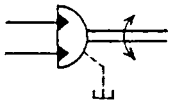

Load elevating equipment


Rolling equipment

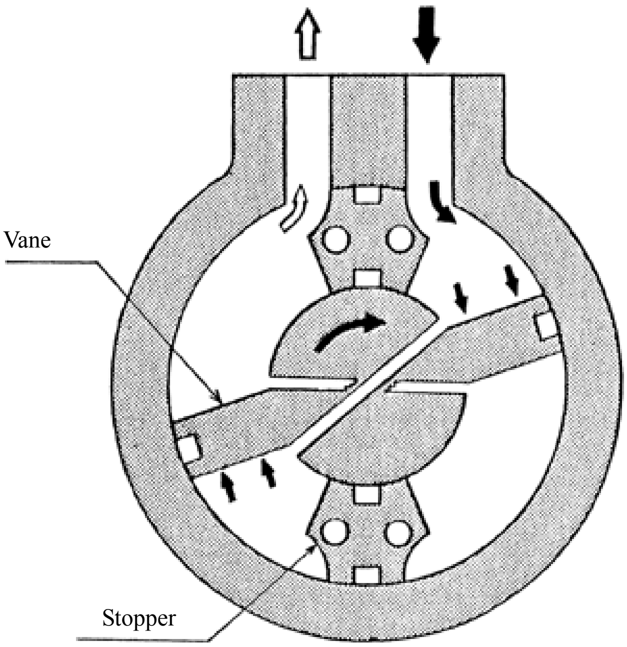

Intermittent feeding equipment

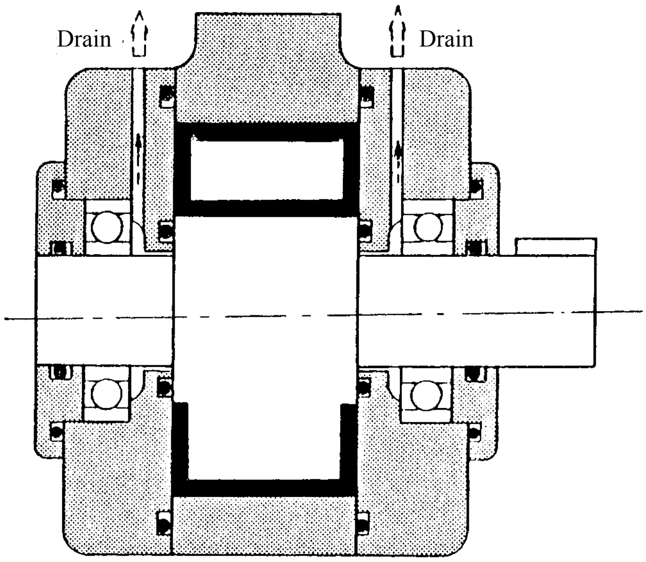
[2] Vane type oscillating hydraulic actuator

JIS symbol



There are one-vane type, two-vane type and three-vane type. The oscillating angle ranges from 60 to 280 degrees depending on the number of vanes. The illustration to the left shows a two-vane 100-degree actuator. It is relatively compact and less expensive in cost. Valve switching mechanism is one of the typical applications.





[Double vane type]

(4) Hydraulic motor

A hydraulic motor is such an actuator that it uses hydraulic oil pressure to continuously rotate its output shaft. The mechanism of hydraulic motor is similar to that of hydraulic pump but slightly different in structure.

A hydraulic motor, featuring easy control of the revolving speed and revolution direction, is small in size and weight but high in output power. Though variable displacement motors are available, fixed displacement motors are frequently used in many applications and the pump flow rate control method is commonly employed to control the revolving speed.

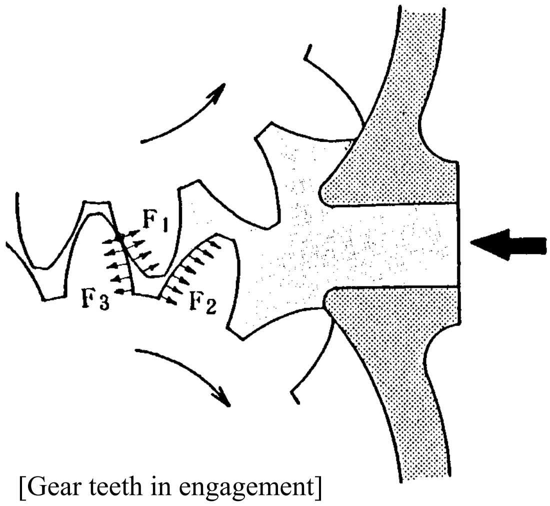
[1] Types

- Hydraulic motor
  - Gear motor
  - Vane motor
  - Piston motor
    - Axial type
    - Radial type

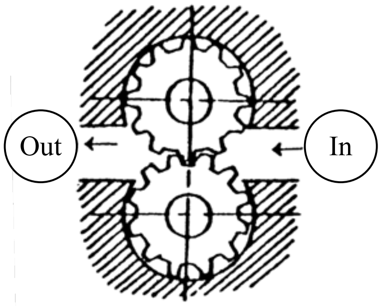
[2] Application example of hydraulic motor

Table feed, winch drive, concrete mixer, winding equipment, dividing table drive, construction vehicle traveling

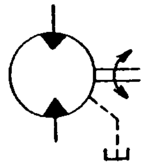
[3] Gear motor

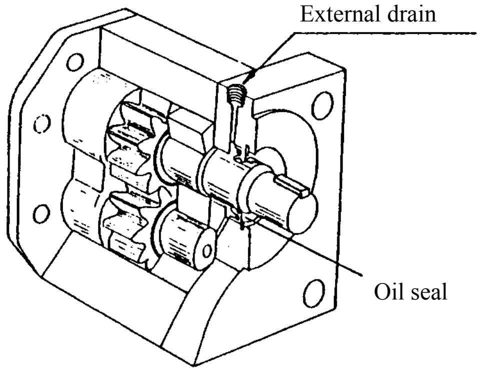


[Gear teeth in engagement]



JIS symbol





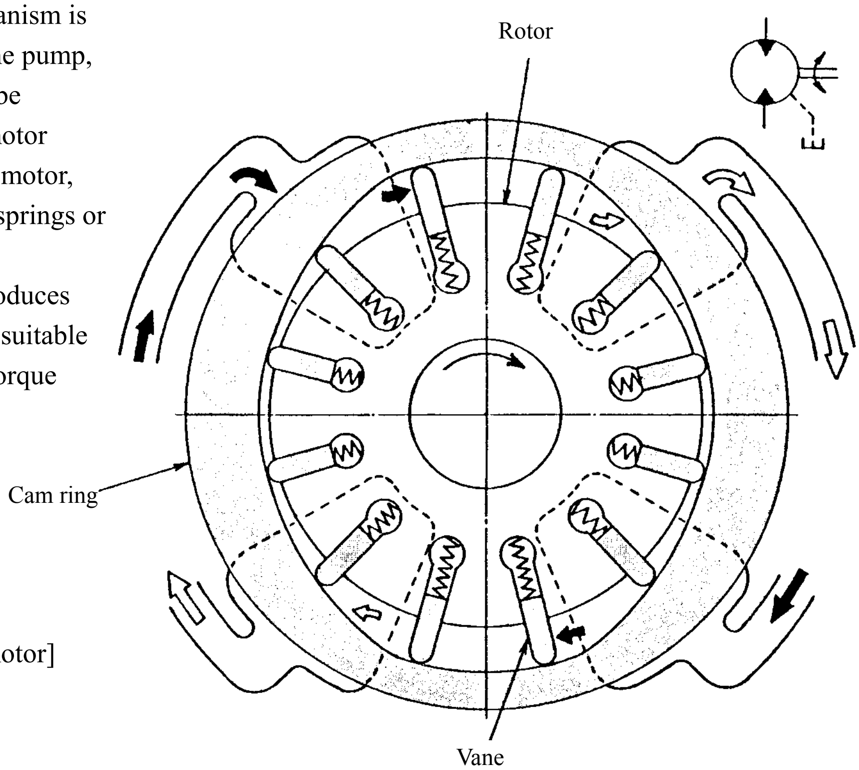
[Gear motor]

Simple in structure and small in size and weight.
Suitable for high-speed low-torque motor.
The basic mechanism is similar to that of gear pump, but every hydraulic motor is equipped with an external drain.
The illustration above explains that the flank area difference among the teeth on which pressure oil is acting produces torque.

[4] Vane motor

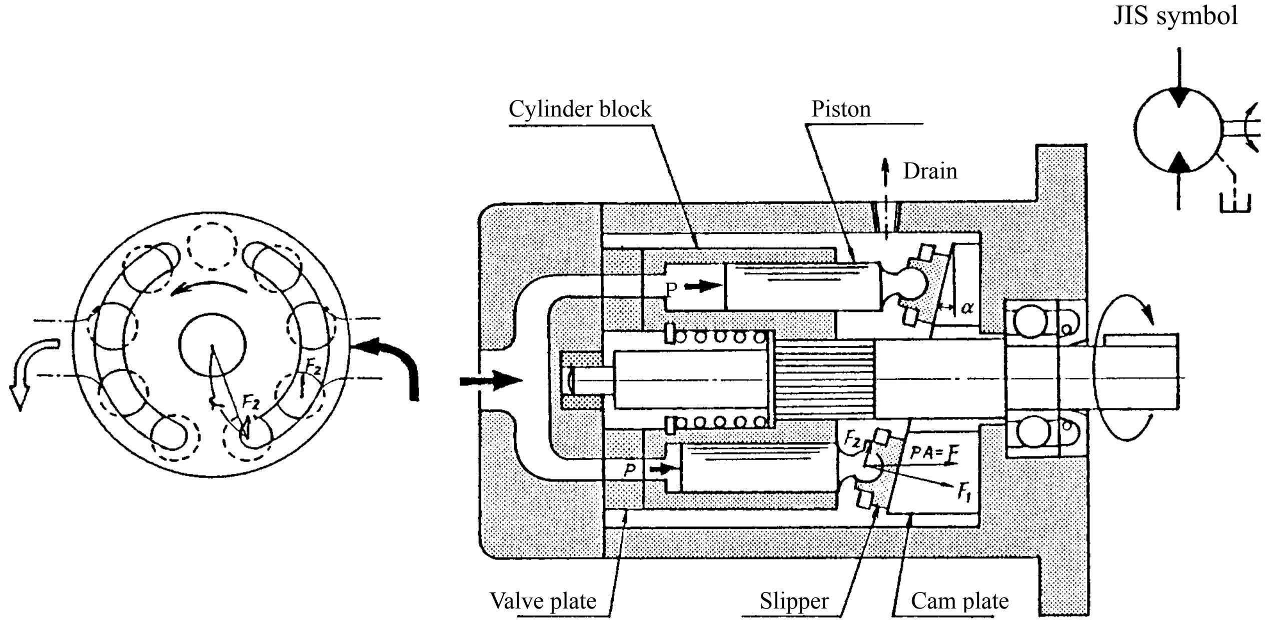
The vane motor mechanism is similar to that of a vane pump, but every vane has to be projected before the motor starts running. A vane motor, for this purpose, uses springs or hydraulic oil pressure.
Since a vane pump produces torque uniformly, it is suitable for a mid-speed mid-torque application.

JIS symbol



[Vane motor]

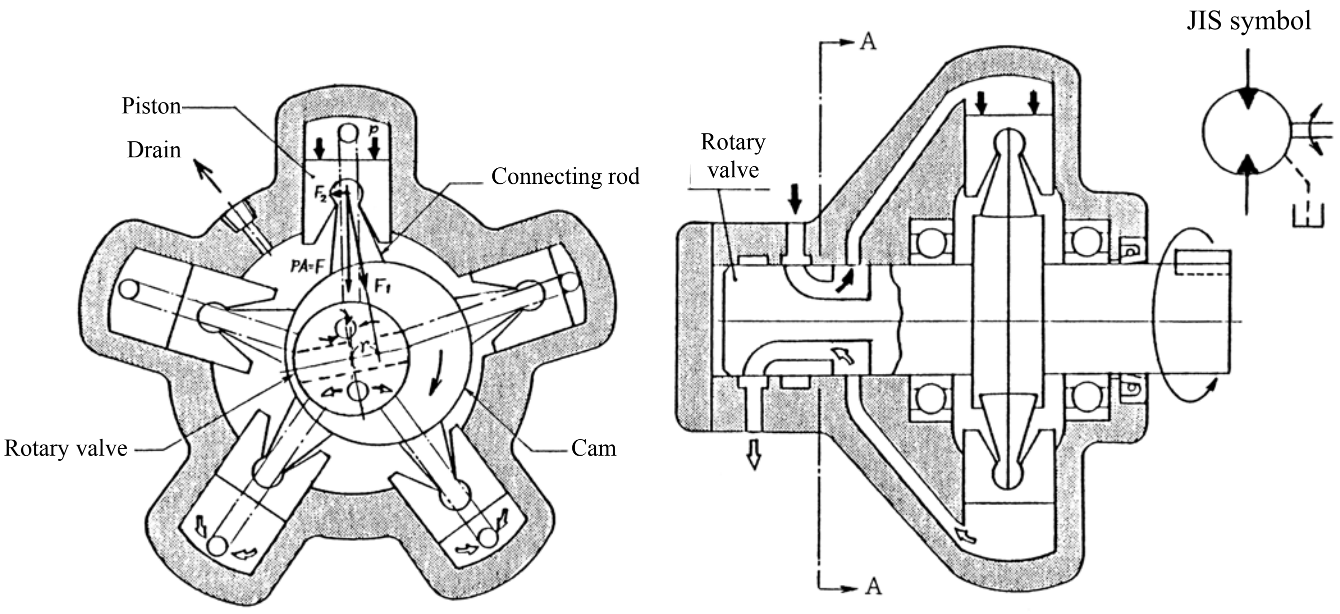
[5] Axial piston motor



It is complicate in structure and expensive in cost, but high in efficiency and significant in power output. Variable displacement type is available as well.

[Axial piston motor]

[6] Radial piston motor



[Radial piston motor]

The hydraulic oil pressure, entering the inlet, comes into the cylinder through the rotary valve and thrusts the pistons.
Then, the pistons thrust the eccentric cam with the connecting rods, resulting in rotation of the shaft.
While a piston travels its outward stroke, the outlet port of the rotary valve opens to send oil out.
Switching the oil inlet and outlet from one to another reverses the rotation direction.
Commonly used in low-speed high-torque applications.

2. Hydraulic pump

A hydraulic pump is a power source of hydraulic equipment that actuates hydraulic motors and cylinders by providing fluid power (i.e. pressure and flow rate) to oil while receiving mechanical power produced by an electric motor or an engine.
For hydraulic applications, positive displacement pumps are employed.
A positive displacement pump is such that it sucks and discharges oil in line with the volumetric change in the closed oil chamber. Since its suction side and discharge side are isolated, its discharge rate remains almost constant even when a varying load fluctuates the discharge pressure. It is, therefore, suitable for hydraulic equipment.

(1) Types of pump

[1] Classification by discharge rate

- Fixed displacement pump: The theoretical discharge rate (cm^3) per revolution is constant.
- Variable displacement pump: The theoretical discharge rate (cm^3) per revolution is adjustable.

[2] Classification by structure

- Gear pump
  - External gear pump
  - Internal gear pump
- Vane pump
  - Balanced vane pump
  - Unbalance vane pump
- Piston pump
  - Axial piston pump
    - Swash plate type
    - Bent axis type
  - Radial piston pump

(2) Features and descriptions of pumps

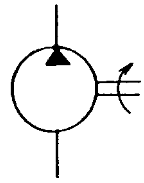
[1] Features of gear pump

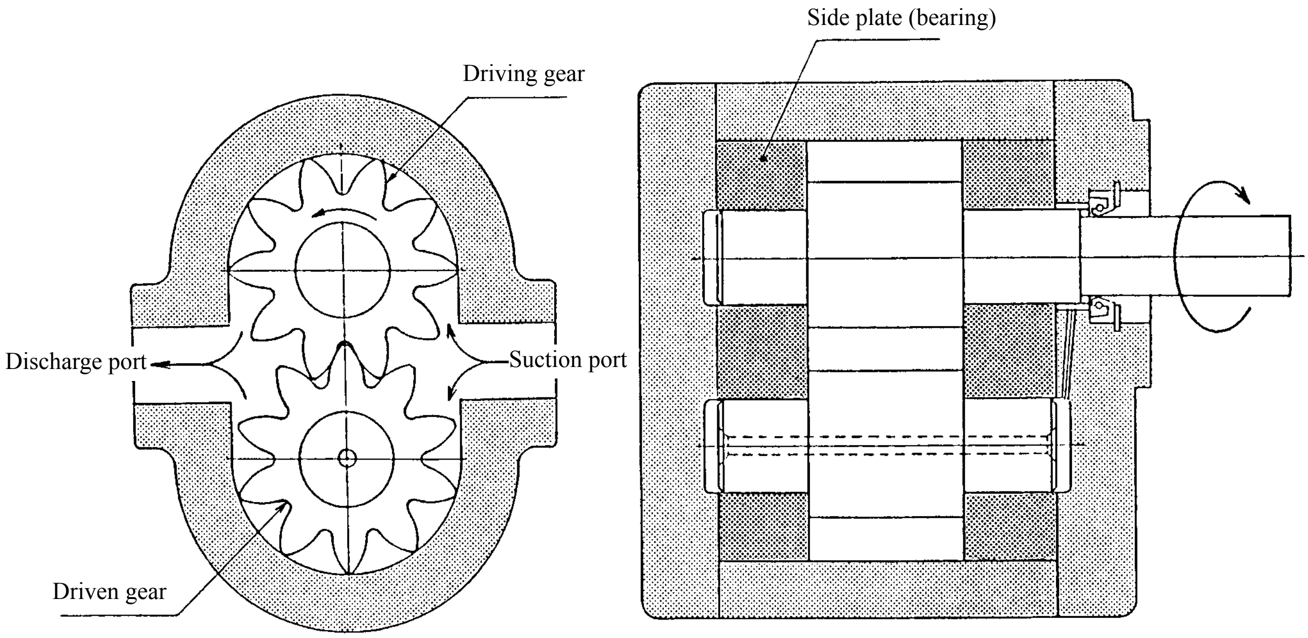
- Simple in structure
- Compact in size
- Variable displacement type not available.
- Highest in suction capacity among pumps

[2] External gear pump

Two gears engage with each other in the casing. As the gears rotate and come out of engagement, they create empty space, which sucks oil. The oil filling up the space between the gears is delivered along the inner wall of the casing toward the discharge side.
The gear teeth in engagement isolate the suction side and discharge side from one another.

JIS symbol

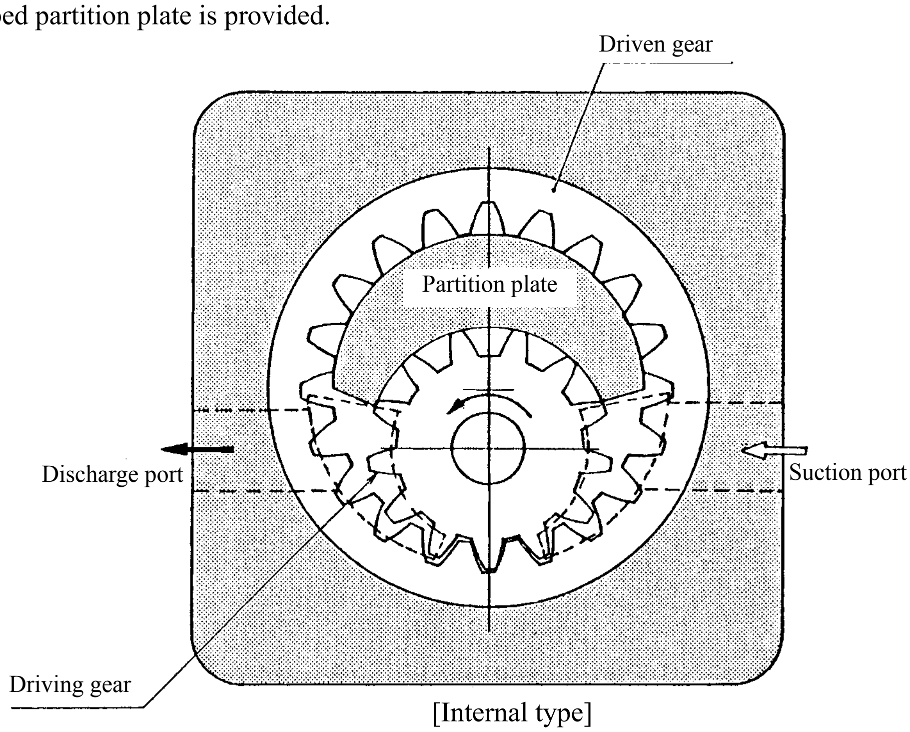




[External type]

[3] Internal gear pump

The principle is identical to that of the external type. On the other hand, the gears engage internally and a crescent-shaped partition plate is provided.



[Internal type]

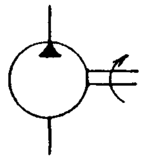
[4] Features of vane pump

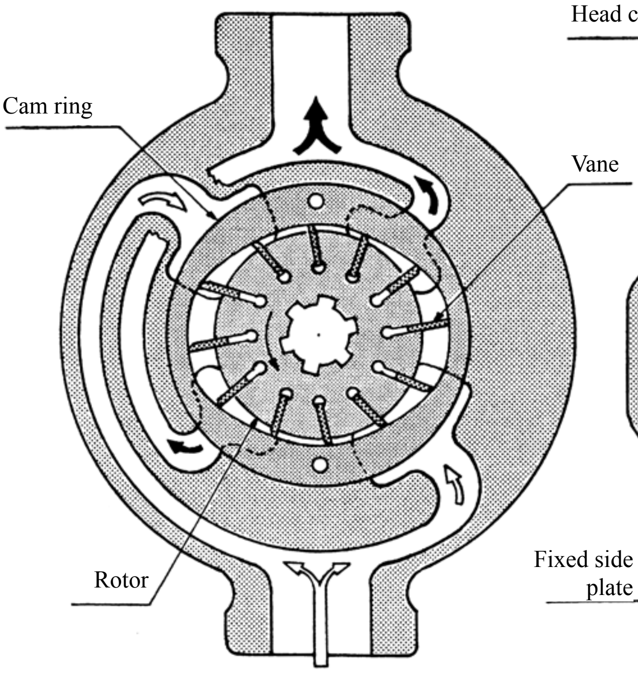
- Long life, and stable in performance for long periods
- Low in pulsation and noise
- Easy to maintain

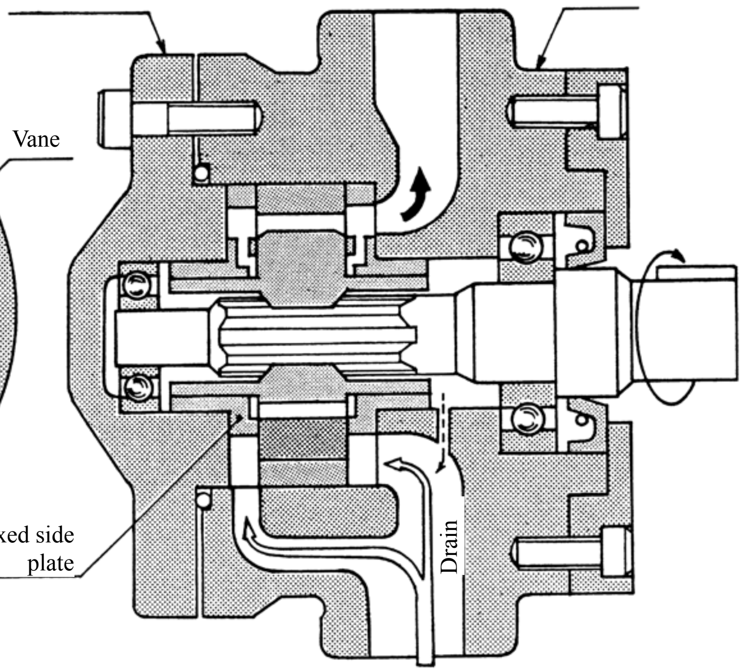
[5] Balanced vane pump

As the rotor rotates, vanes project because of the centrifugal force and hydraulic oil pressure. They contact and slide on the inner surface of the cam ring.
The volume of an oil chamber formed between vanes varies in line with the curve of the cam ring.
The suction port is provided in the area where the oil chamber enlarges so that oil is sucked.
The discharge port is provided in the area where the oil chamber diminishes so that oil is forcedly discharged. With regard to the cartridge, the clamping force of the head cover fastening bolts maintains the side clearance appropriately. Since the hydraulic oil pressure acting on the perimeter of the rotor is in balance, it is called pressure-balanced type.

JIS symbol







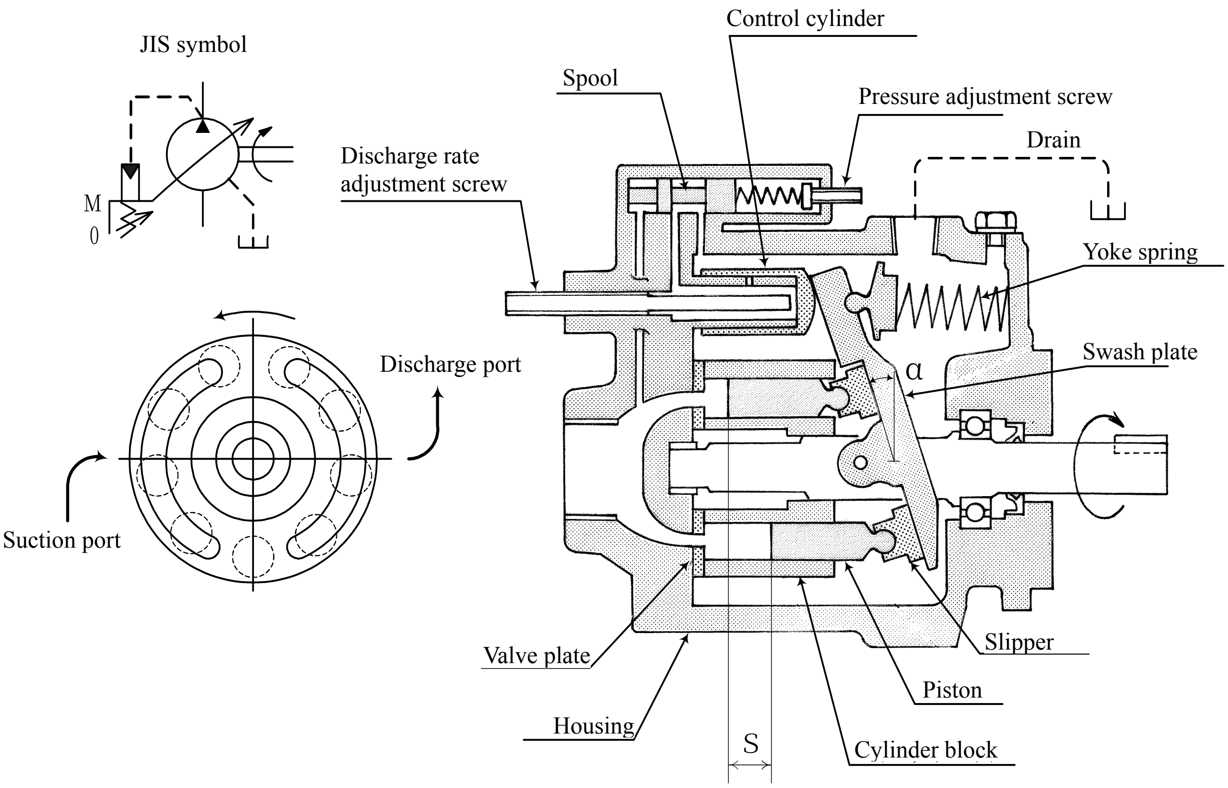
[6] Features of Piston pump

- Suitable for high pressure, and highest in pump efficiency among pumps
- Various control options can be added (Axial type).
- Complicated in structure
- Sensitive to oil contamination
- Lowest in suction capacity

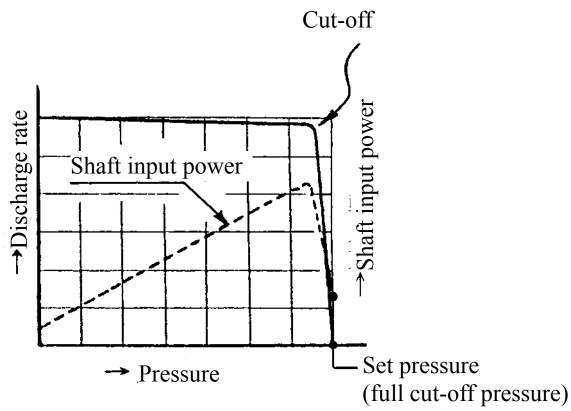
Overall pump efficiency… $\eta_p = \dfrac{\text{Lo (Fluid power)}}{\text{Ls (Shaft input power)}}$

Shaft input power……….Ls (kW) $= \dfrac{P \times Q}{60 \times \eta_p}$

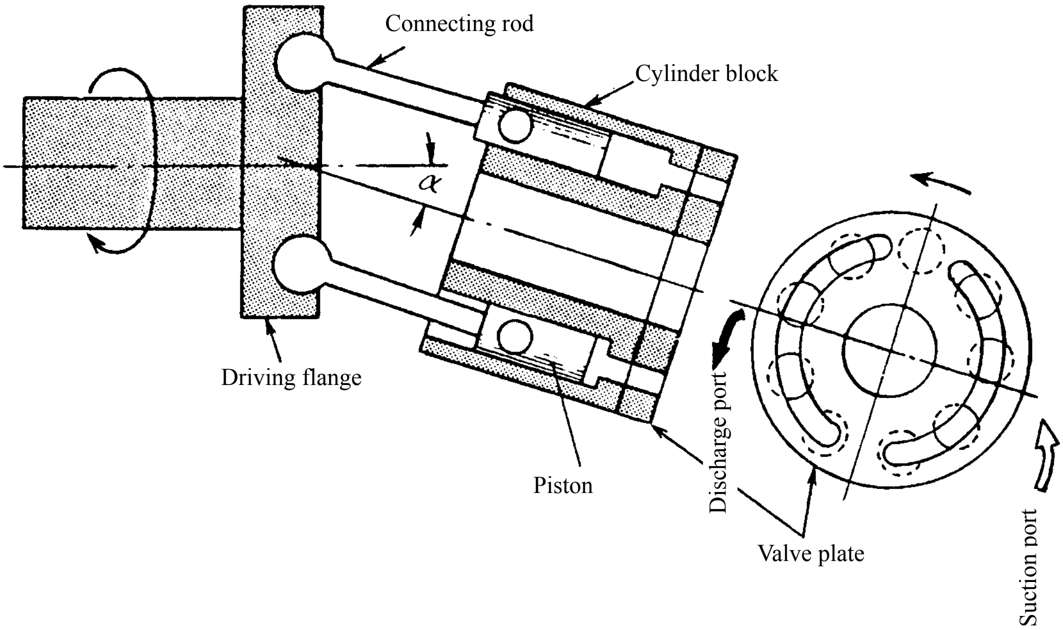
[7] Variable displacement type axial piston pump (Swash plate type)

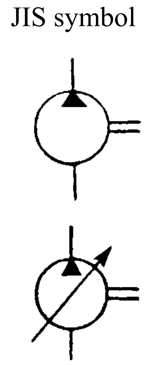


The shaft and cylinder block rotate simultaneously because they are connected through splines. Since the top of a piston rotates always in contact with the swash plate through a slipper, the piston travels the stroke and produces pumping action proportional to the inclination α of the swash plate while it turns. The discharge rate can be controlled with the discharge rate adjustment screw.
The maximum pump pressure is set with the pressure adjustment screw provided on the pump. When the pump discharge pressure comes close to the set value, the discharge rate starts decreasing. When the actuator stops, the swash plate becomes almost vertical and the discharge rate is almost zero. In this manner, the discharge pressure is maintained at the set pressure. At the same time, the shaft input power rapidly decreases.



[8] Axial piston pump (bent axis type)

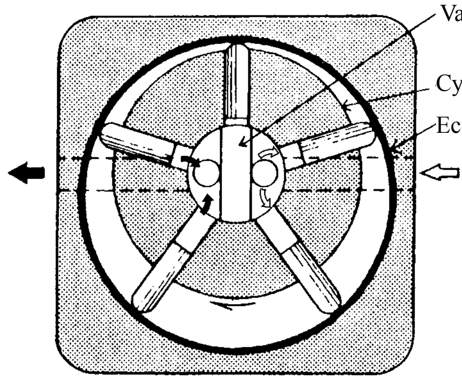


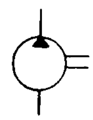


Since the driving flange on the shaft end is connected with the cylinder block with pistons and ball joints of the connecting rod, the cylinder block rotates as the shaft rotates.
The inclination α causes stroke motion of pistons. While pistons repeat the motion, oil enters the cylinder block through the suction port of the fixed valve plate, and then, is discharged through the discharge port.

[9] Radial piston pump (rotating cylinder/fixed valve type)

While the cylinder block rotates, the piston heads run on the inner surface of the eccentric ring and pistons repeat stroke motion.
In the area where pistons travel outward, oil enters below the piston bottom through the hole of the valve stem. In the area where pistons travel inward, oil is discharged through another hole of the valve stem.





3. Pressure control valve

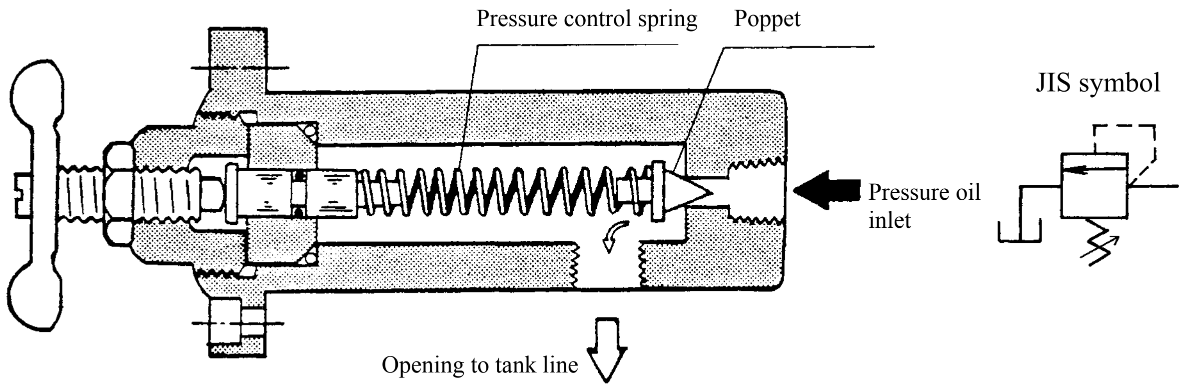
A pressure control valve is used to limit the maximum pressure of the main circuit (e.g. relief valve); reduce and regulate pressure in certain portions of the circuit; and switch the connection of a circuit (line) when pressure in the circuit has reached the set value.

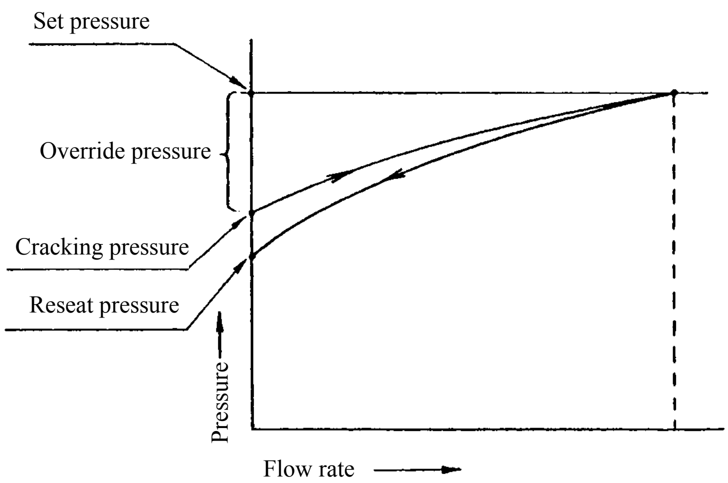
(1) Types

- Relief valve (direct-operated type and pilot-operated type)
- Pressure reducing valve
- Sequence valve
- Counter balance valve

(2) Direct operated relief valve

A simple valve composed of a conically-shaped valve (poppet valve) and a pressure control spring. When pressure exceeds the set value, the poppet valve opens to let pressure oil go out in a tank line. Since the valve is prone to vibrate (chatter) in high-pressure high-flow applications, it is frequently used as a relief valve in low-flow applications as well as a pilot valve of a pilot-operated relief valve.



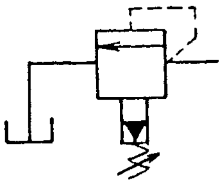


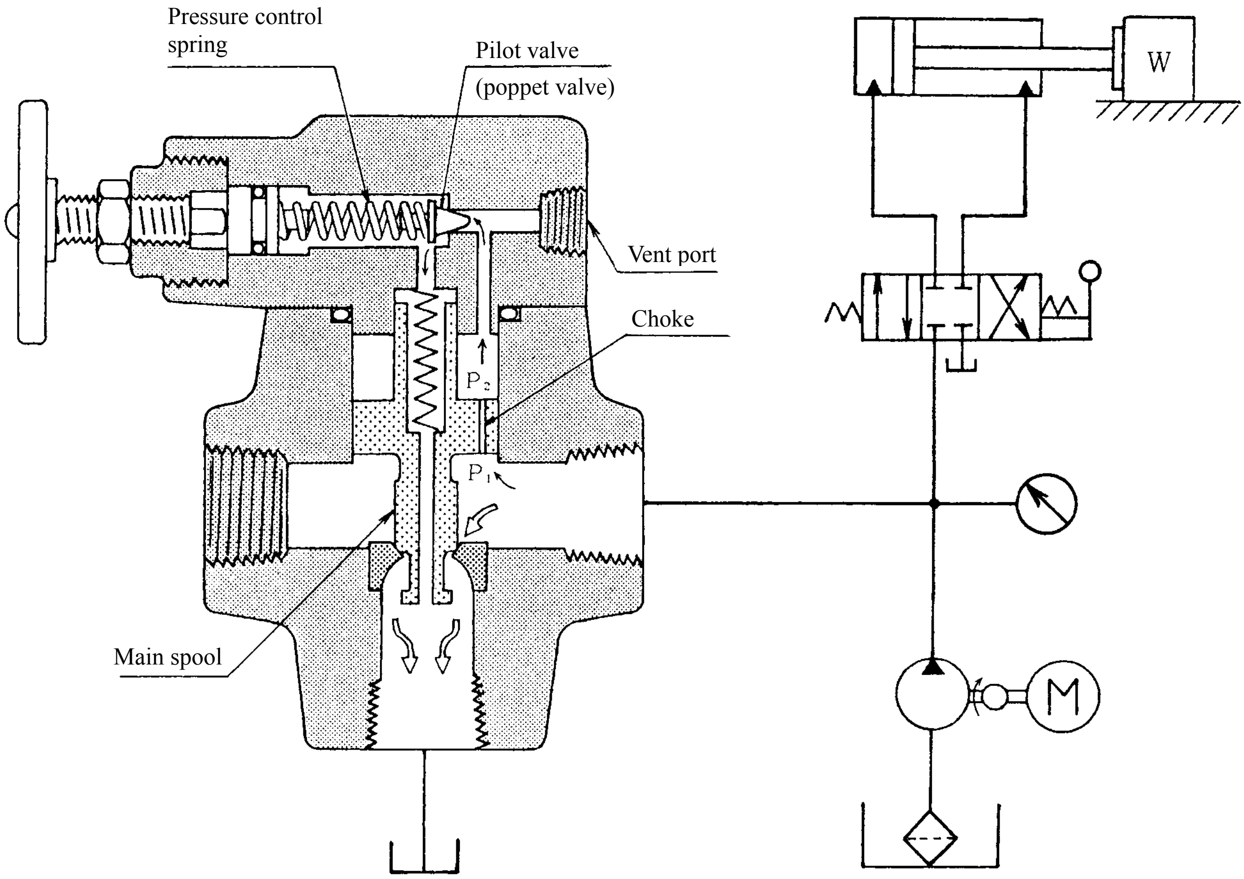
Pressure – Flow rate characteristics

(3) Pilot-operated relief valve

The advantages of a pilot-operated relief valve are as such: It is less prone to chatter because of the pressure balancing structure of its main valve; its override pressure is small; it can be remotely controlled using the vent port.

JIS symbol



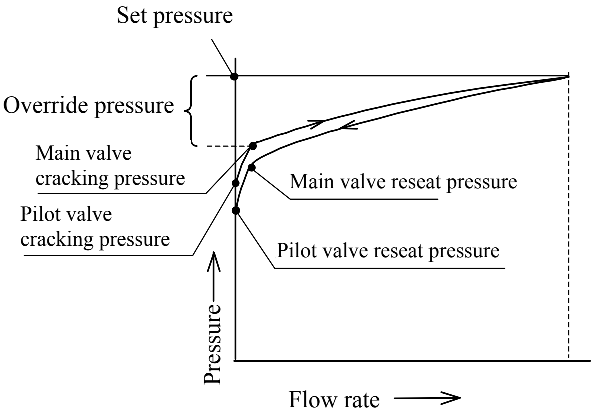


[1] Operation

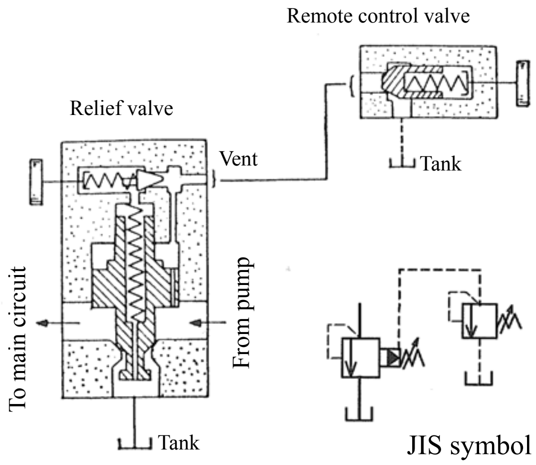
The pilot valve, being pushed by the pressure control spring, is closed until pressure reaches the cracking pressure. Since the choke of the main valve transmits only static pressure, no flow is produced. There is, therefore, no differential pressure ($P_1 = P_2$), and the spring force keeps the main valve closed.

When pressure P_1 has reached the cracking pressure of the pilot valve, the pilot valve opens. Then, pressure oil passes through the choke of the main valve and the pilot valve and comes out into a tank line. At this time, flow rate passing through the choke produces a pressure difference ($P_1 - P_2$). When it exceeds the spring force that keep pushing the main valve, the main valve opens. This suppresses the increase of the primary pressure P_1 and whole or part of discharge from a pump is released into the tank line.

[2] Pressure – Flow rate characteristics



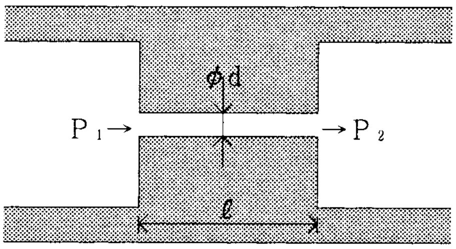
[3] Remote control using vent port



[4] Choke

When a narrowed passage is relatively long in comparison with section size as illustrated below, the throttle of flow is called a choke.

The choke is used to actuate a relief valve and a pressure reducing valve.



$$P_1 - P_2 = \frac{128Q\rho\nu\ell}{10000\pi d^4}$$

Q: Flow rate	cm^3/s
d: Hole diameter	cm
$P_1 - P_2$: Differential pressure	MPa
ρ: Fluid density	kg/cm^3
ν: Coefficient of kinematic viscosity	cm^2/s
($1\ cm^2/s = 1\ St = 100\ cSt$)	
ℓ: Hole length	cm

(4) Pressure reducing valve (pilot-operated pressure reducing valve with check valve)

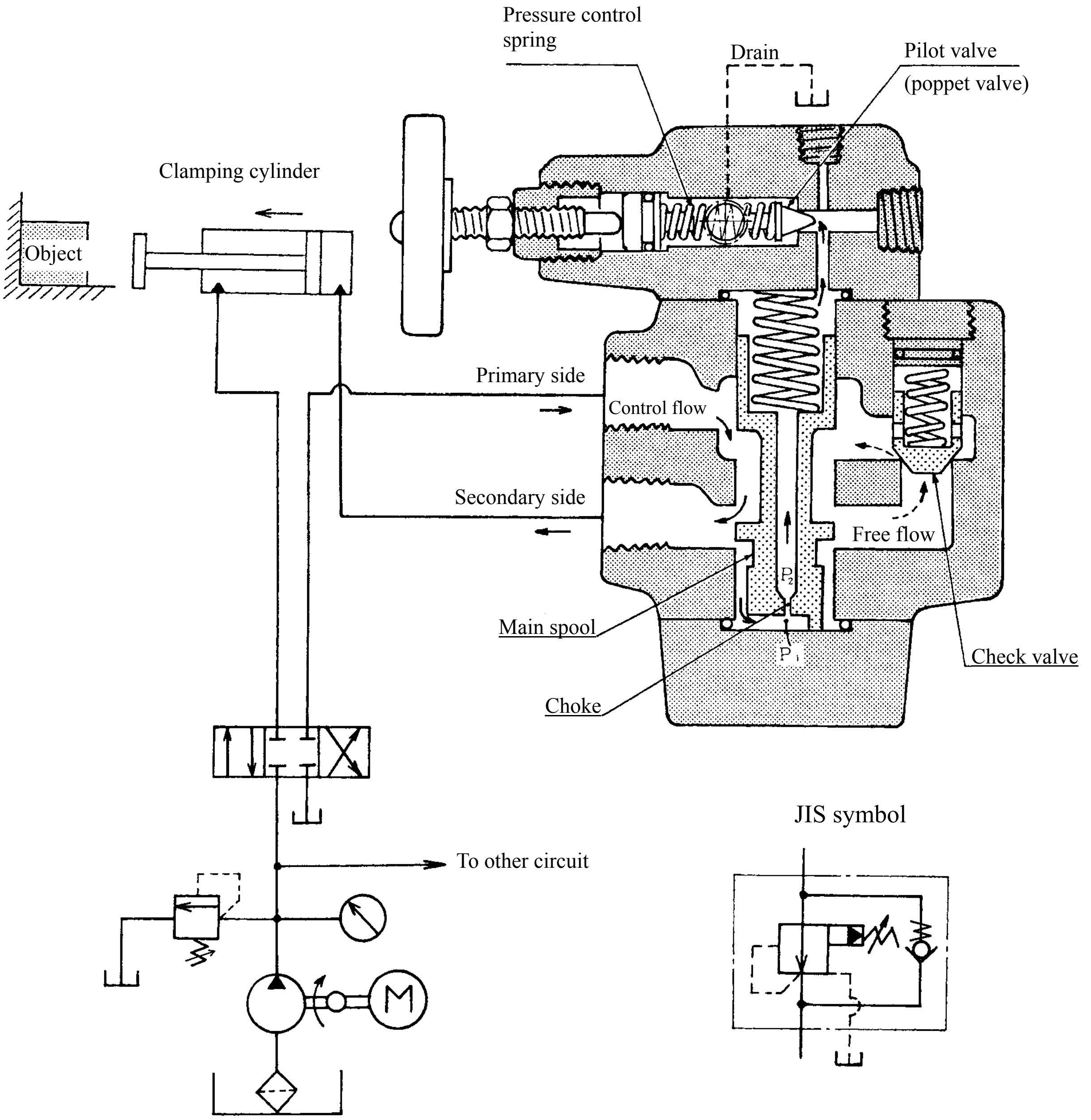
A pressure reducing valve is such a pressure control valve that is used where necessary to reduce and maintain pressure in certain portions of the circuit lower than that of the main circuit.

Operation

Switching the directional control valve to the right (⊠) starts the clamping cylinder piston moving leftward. The secondary pressure, passing through the choke of the main valve, reaches the head end of the pilot valve. Since the pilot valve remains closed while the secondary pressure is lower than the set value, the pressure above and below the main valve are identical because of the choke, and the spring force maintains the main valve fully open.

When the piston reaches the forward-stroke end, the secondary pressure rises to the set pressure of the pilot valve and the pilot valve opens, resulting in a pressure difference ($P_1 - P_2$) because of flow passing through the choke, which overcomes the spring force and raises the main valve to close. If the primary pressure further increases, the pressure reducing mechanism starts working in the secondary side to maintain the secondary pressure constant at the set pressure.

The main valve opens to such an extent that it allows a limited flow amount to meet the drain amount that enables the valve to work.

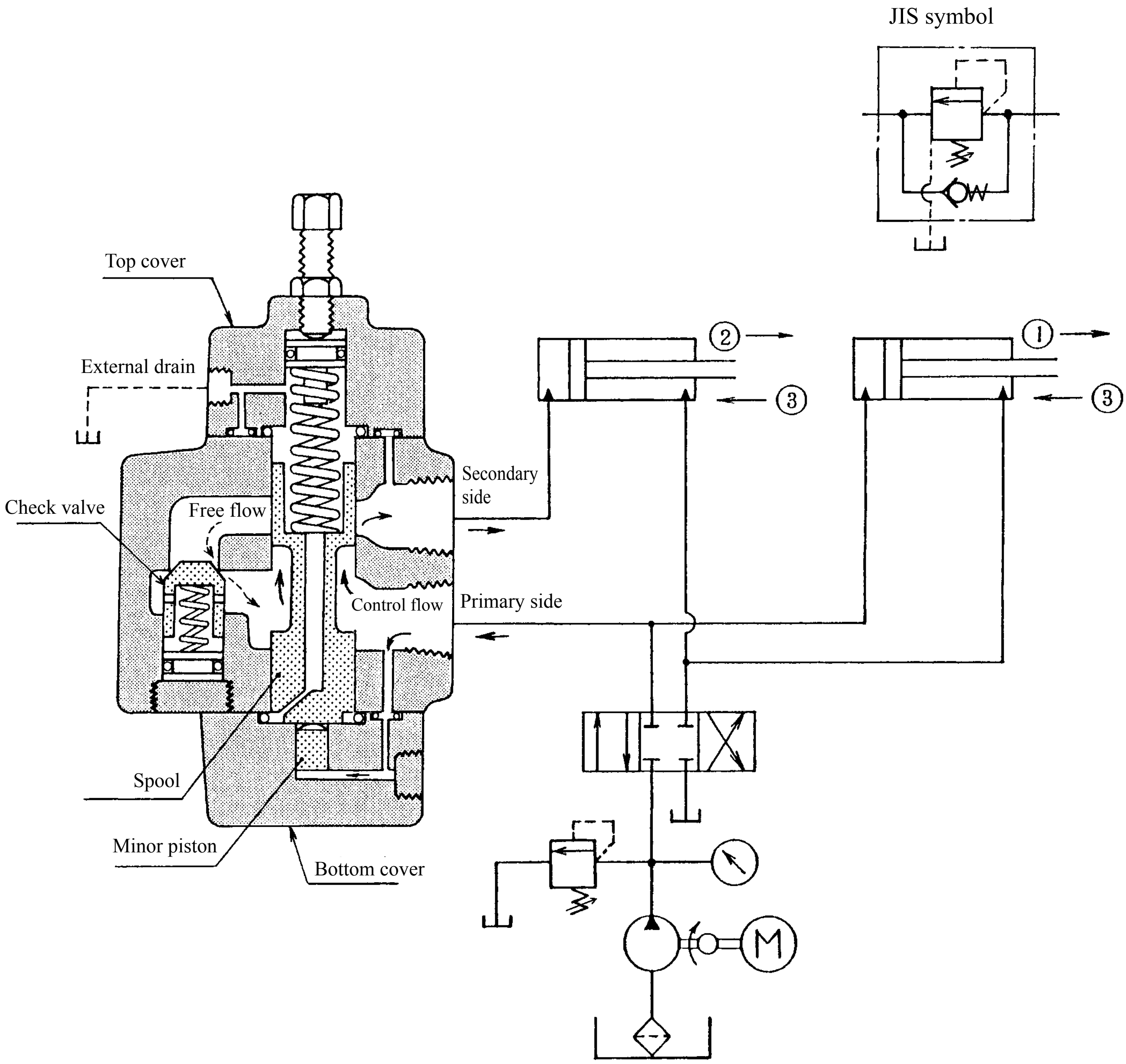


(5) Sequence valve with check valve

A sequence valve controls the sequential operation of a cylinder.

The sequence valve shown below is a direct-operated type that actuates the spool in rivalry with the spring force.

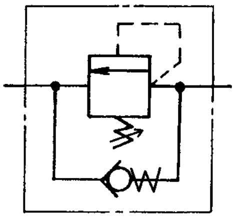
When the primary pressure rises and reaches the set pressure, it actuates the spool. As a result, the port between the primary and secondary sides is opened to traffic and pressure oil enters the secondary side.

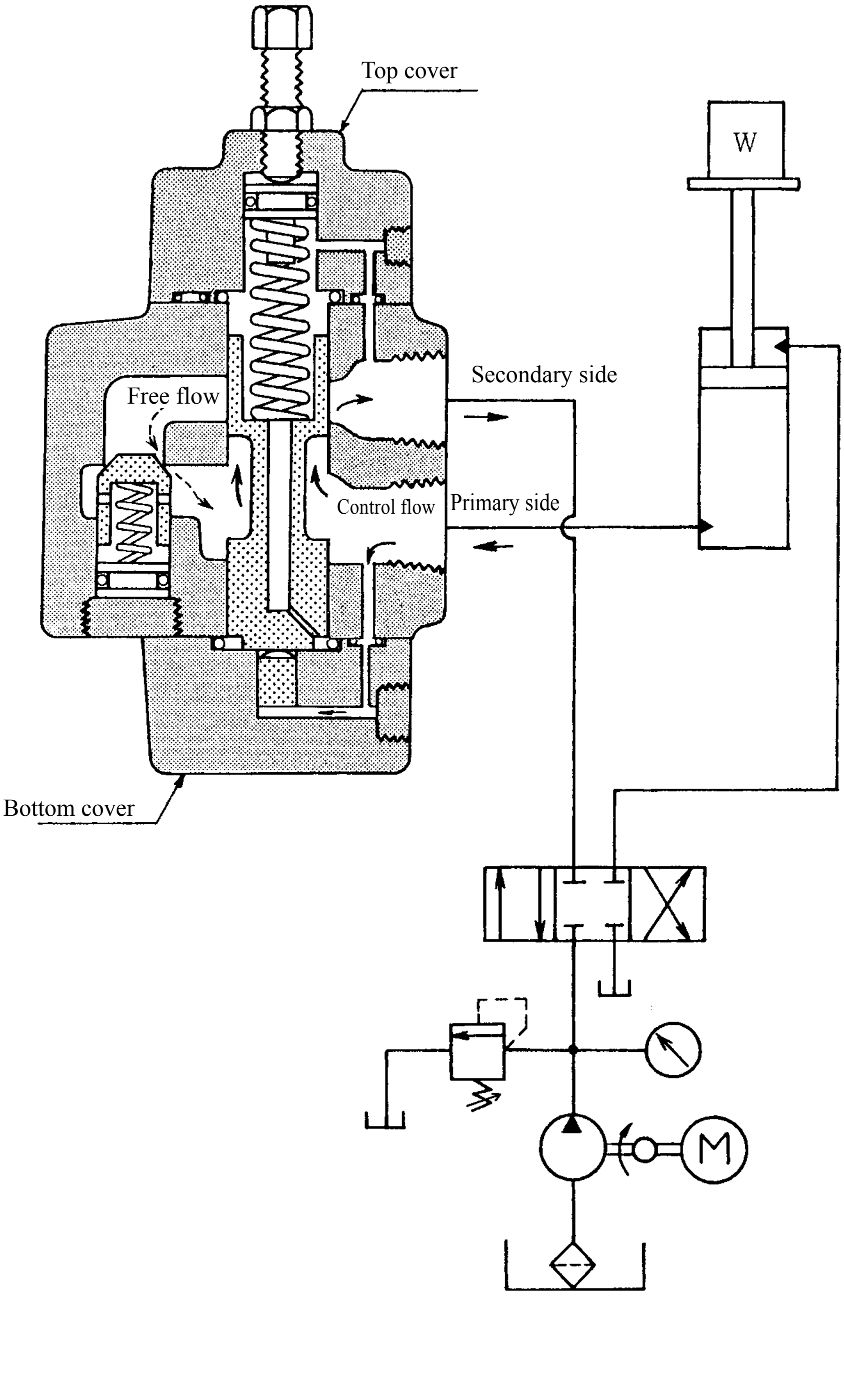


(6) Counter balance valve (back pressure control valve)

Lifting down a heavy load requires a pressure (back pressure) produced in the outflow side of a hydraulic cylinder in order to prevent the load from falling. A counter balance valve is used to control the pressure in line with the amount of supply oil.

JIS symbol





4. Flow control valve

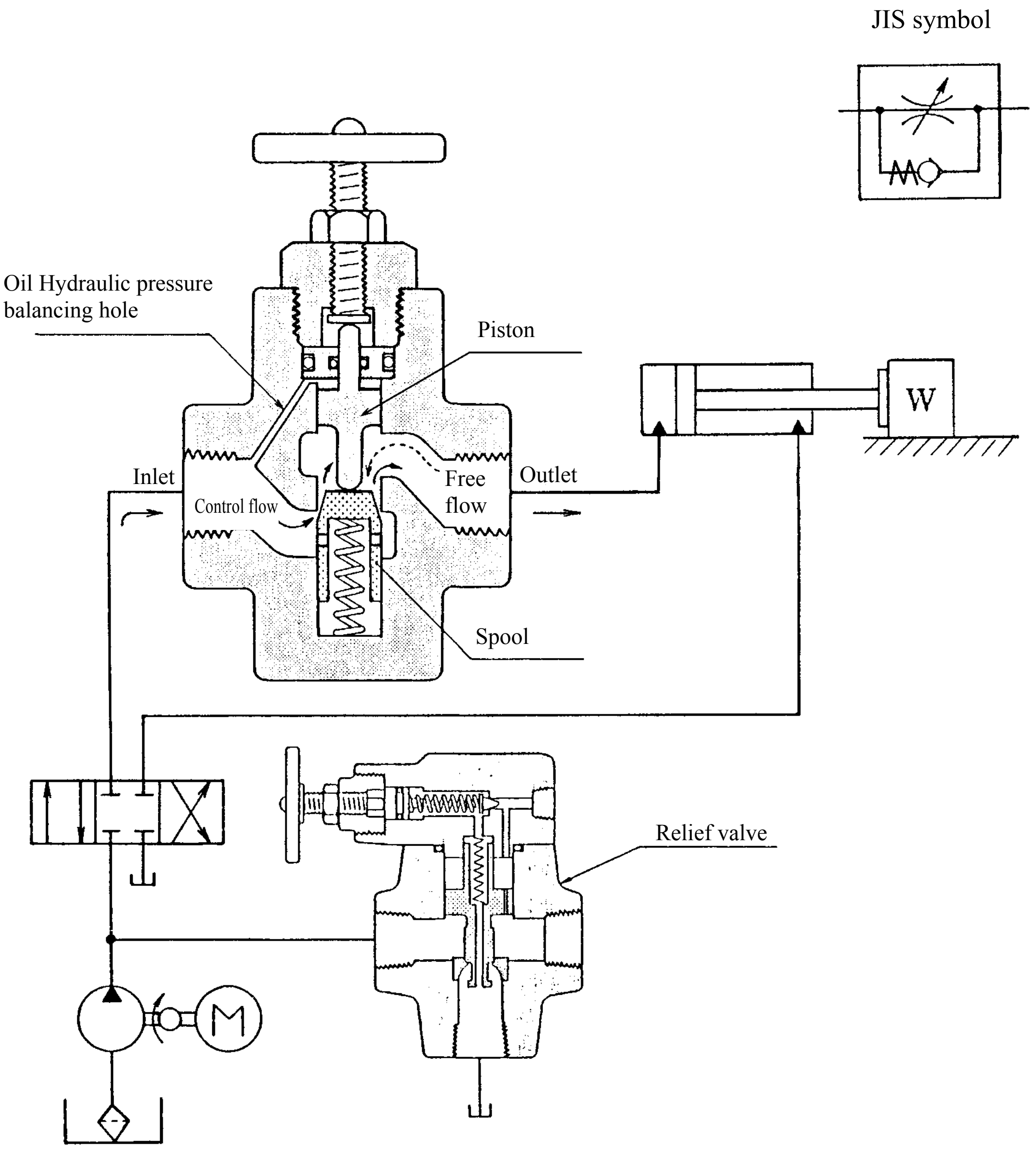
A flow control valve controls the flow rate in order to control the motion speed of an actuator, such as a hydraulic cylinder and hydraulic motor.

(1) Types

There are two basic types provided below. They are available either with or without a built-in check valve.

- Throttle valve
- Pressure compensated flow control valve

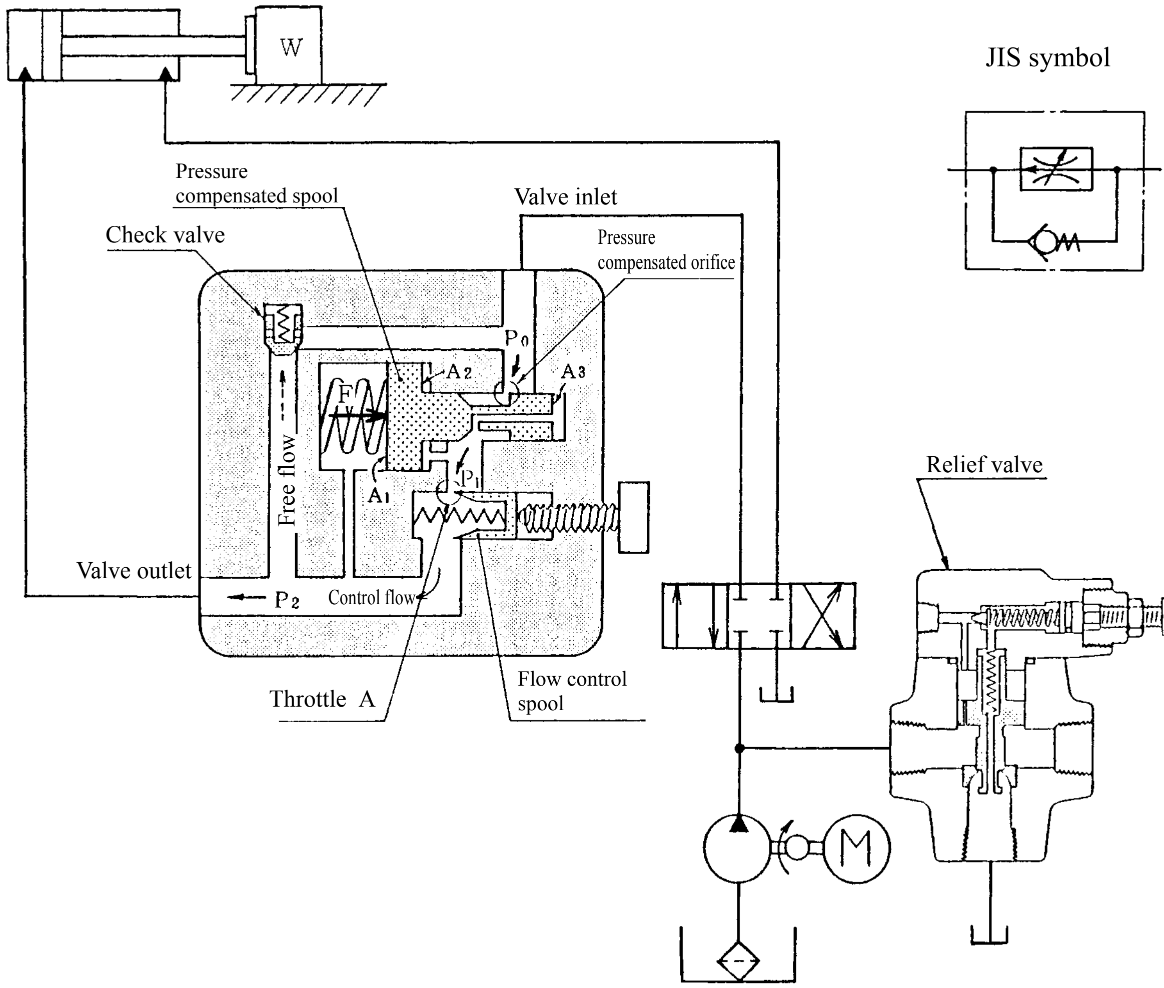
(2) One-way throttle valve



The structure is simple. The flow rate slightly varies as the load pressure changes.
It is not possible to totally shut the flow down to zero.

(3) Pressure compensated flow control valve (with check valve)

A mechanism to compensate a constant pressure difference between before and after the throttle is additionally built in the valve so that the through flow rate remains constant even when load pressure varies.



[1] Operation

Pressure P_1 right before the throttle A acts on areas A_2 and A_3 of the pressure compensated spool. Acting on area A_1 are outlet pressure P_2 and spring force F.

Pressure P_1 is maintained in such a manner that a force acting on area A_1 of the pressure compensated spool and another on area $A_2 + A_3$ are balanced (the pressure compensated orifice reduces inlet pressure P_0).

$F + P_2 \times A_1 = P_1 \times (A_2 + A_3)$ $\rightarrow$ Where $A_1 = A_2 + A_3$:

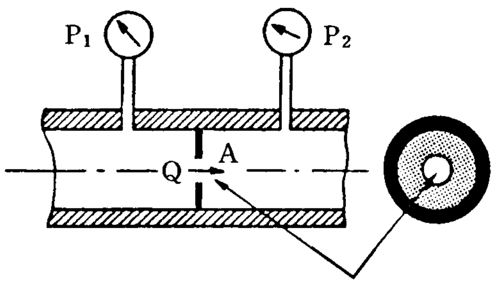
$F + P_2 \times A_1 = P_1 \times A_1$ $\rightarrow$ $F = A_1 (P_1 - P_2)$

$$\boxed{\frac{F}{A_1} = P_1 - P_2}$$

As explained above, the pressure compensated spool operates accordingly so that the pressure difference $P_1 - P_2$ over the throttle A is equal to $\frac{F}{A_1}$, the hydraulic equivalent of spring force.

[2] Orifice

When a narrowed passage is relatively short in comparison with section size as illustrated below, the throttle is called an orifice. The orifice is used as a flow rate controlling throttle.



$$Q = 100CA\sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

Q: Flow rate	cm^3/s
C: Flow rate coefficient	
A: Orifice cross section	cm^2
ρ: Fluid density	kg/cm^3
$P_1 - P_2$: Pressure difference between before and after orifice	MPa

5. Directional control valve

A directional control valve conducts open/close operation and blocks a back flow in an oil line. It is used to control the oil flow for the purpose of starting/stopping an actuator, converting a motion direction, and such.

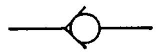
(1) Types

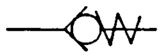
- Check valve
- Pilot-operated check valve
- Directional control valve
  - Manually-operated valve
  - Cam-operated valve
  - Solenoid-operated valve
  - Pilot-operated directional control valve
  - Solenoid-controlled pilot-operated directional control valve

(2) Check valve

A check valve allows a free flow of fluid in only one direction and blocks a flow in the opposite direction. There are two types available: in-line check valves and angle check valves.
Selection of a spring used in a check valve depends upon an application. A back-flow check application (simply as a check valve) requires a spring with a force equivalent to more or less the cracking pressure 0.05 MPa. A spring of more or less 0.45 MPa is used in a back-pressure valve (resistance valve) application.

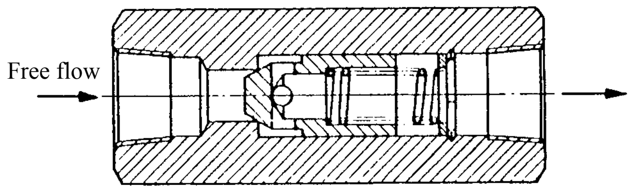
JIS symbol



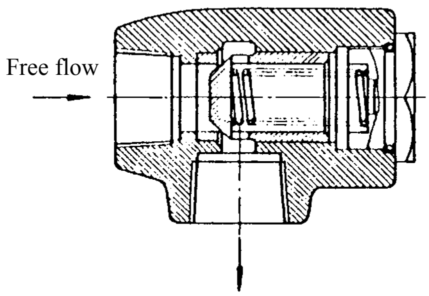


(with spring)

(a) In-line check valve

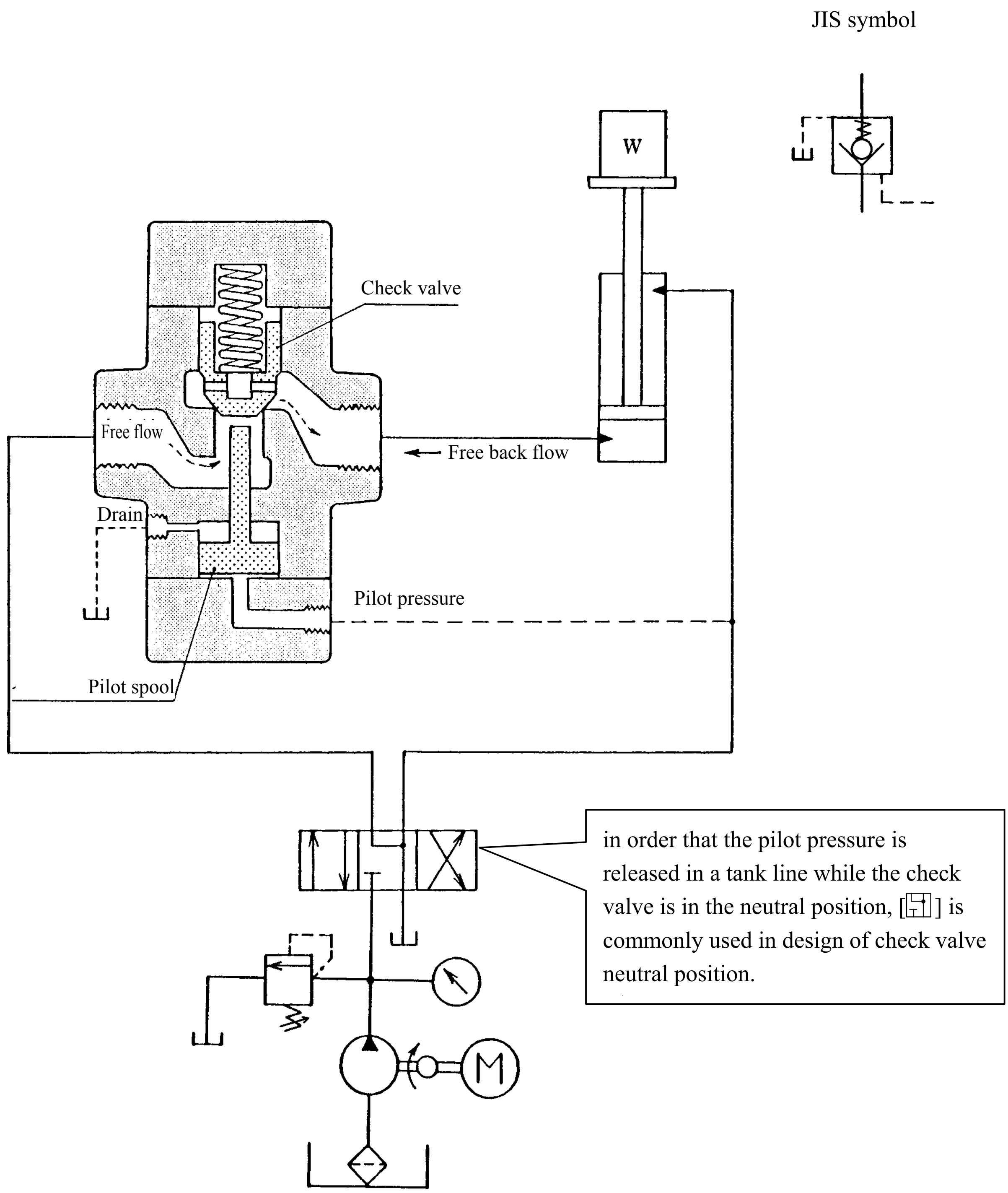


(b) Angle check valve



(3) Pilot-operated check valve

A pilot-operated check valve is used to keep a cylinder load in a position for a long period of time. The operation of a pilot-operated check valve is such that it takes in the pump discharge pressure as a pilot pressure as needed by switching a directional control valve to [⊠] side so that the pilot spool, being pushed on its bottom, rises to forcibly open the check valve in order to allow a free back flow. The space above the pilot spool is furnished with a drain hole so that it is kept not enclosed.



(4) Directional control valve

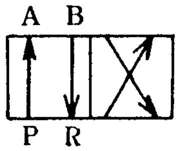
[1] Outline of functions of directional control valve

Number of ports, number of positions, spool type, return type, spool operation type and such, as provided in following items (A) to (E), have to be indicated in order to specify the functions of a directional control valve.

(A) Number of ports: Number of line ports to be provided to a directional control valve.
A 4-port type (having ports P, R, A and B) is most frequently used.

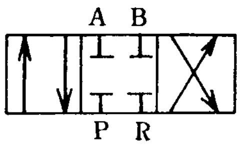
(B) Number of positions:

2-position valve



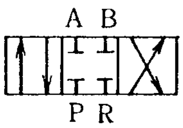
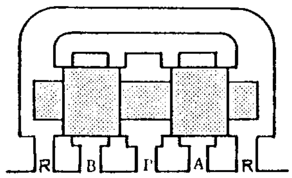
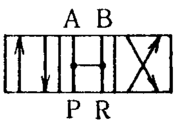
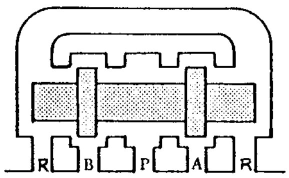
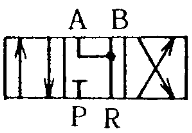
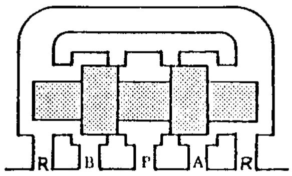
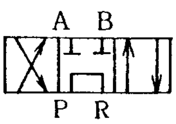
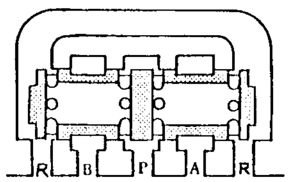
Only two positions – actuator "forward" and "backward"

3-position valve

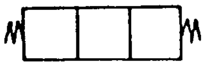
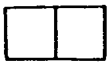


Actuator "neutral stop position" is included as well.

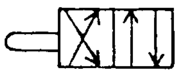
(C) Spool type: It specifies the connecting status among ports when a 3-position valve is in neutral position.

Spool types	Symbols	Spool structures	Descriptions
All port block			Valve in neutral position, with all the ports and the oil lines closed and shut off respectively
All port open			Contrary to all port block, all the ports are connected, and both the pressure oil supply side and the load side communicate with a tank.
Pressure port block (ABR connection)			Only port P is closed, while ports A and B are connected with port R.
Center bypass (PR connection)			Ports P and R are connected, while ports A and B are closed.

(D) Return type (how the operated spool returns)

Names	Symbols	Function descriptions
Spring center		Applicable to 3-position valve. Upon receipt of an external signal, the position shifts to either the left or the right. It automatically returns to the neutral when the signal is off.
No spring		Applicable to 2-position valve. The position remains unchanged when the signal is off. NOTE: There is such a manually-operated valve that has three positions and detent mechanism.
Spring offset		Applicable to 2-position valve. Upon receipt of an external signal, the position shifts from the normal to another. It automatically returns to the original when the signal is off.

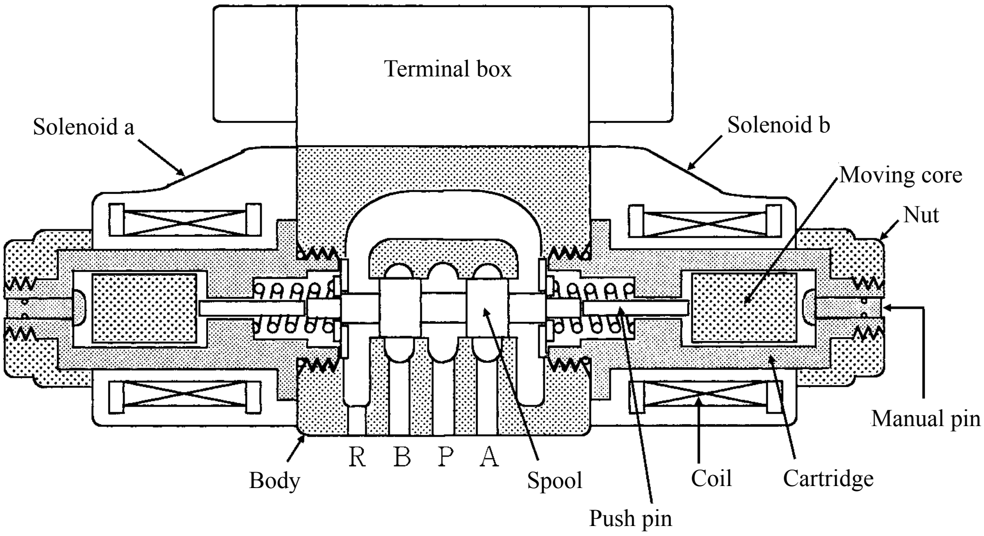
(E) Spool operation type

Operation method	Manually-operated		A valve operated by hand
	Mechanically-operated		A valve operated by a mechanism, such as a cam, a roller, etc.
	Pilot-operated		A valve operated by pilot hydraulic pressure
	Solenoid-controlled		A valve operated by electromagnetic force
	Solenoid-controlled pilot-operated		A valve (operated by electromagnetic force) that actuates the main spool valve using hydraulic pressure from a pilot valve

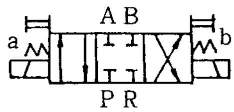
[2] Solenoid-operated valve

Since a solenoid-operated valve is operated using electric signals, automatic operation, remote control, emergency shutoff and such are easily realized. The solenoid includes a cartridge filled with oil. A moving core in the oil moves and switches the spool when externally excited.

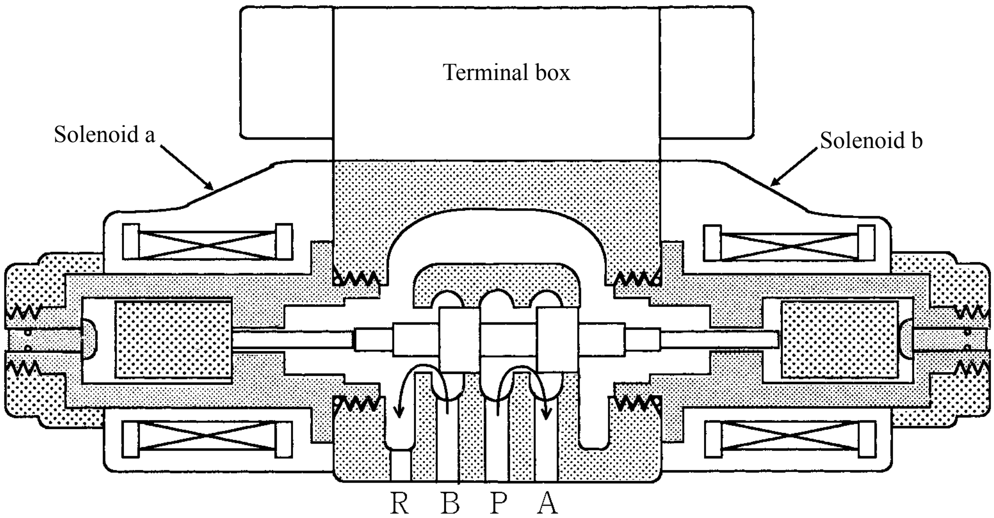
Spring center type



JIS symbol

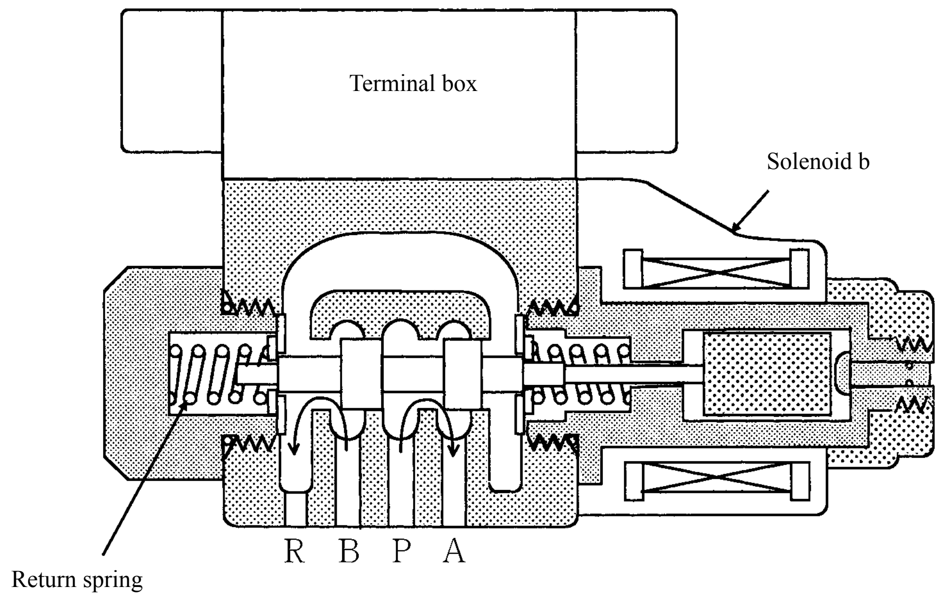


No spring type

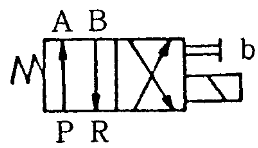


JIS symbol

Spring offset type

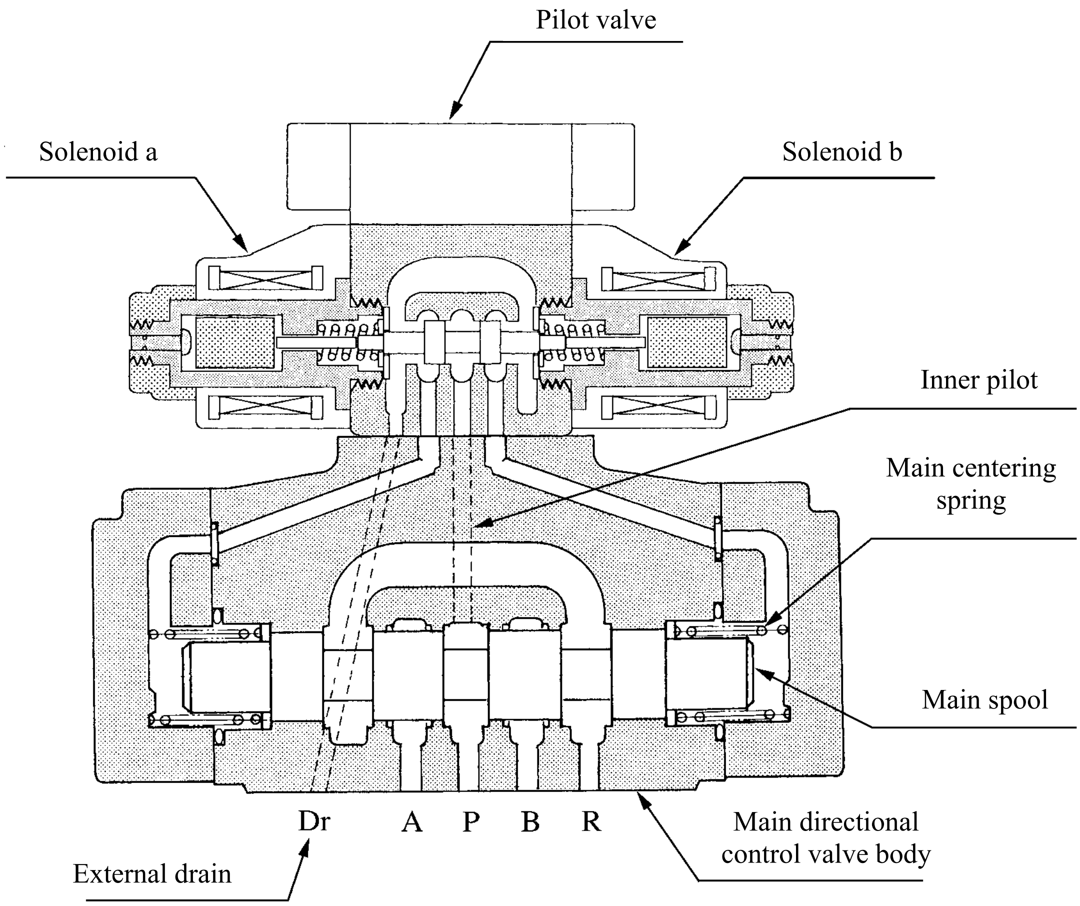


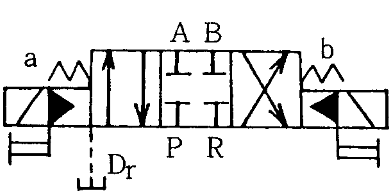
JIS symbol

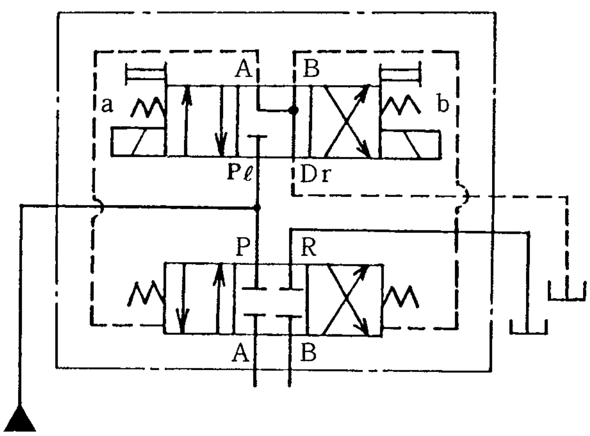


[3] Solenoid-controlled pilot-operated directional control valve

The flow rate that a solenoid-controlled valve is capable of handling is limited because of electromagnetic force, hydrodynamic shock, durability and such. A solenoid-controlled pilot-operated directional control valve is used in a high-flow application or for the purpose of ensuring shockless effect in switching operation. Though the indication of spool type is same with that of solenoid-controlled valve, there is a regulation in combining a pilot valve (solenoid-controlled valve) and a main valve.







Chapter 3

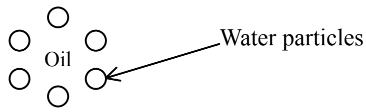
Hydraulic fluid

Hydraulic Fluid

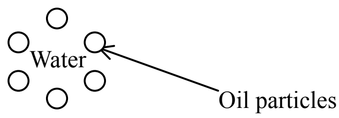
The role of hydraulic fluid is very important in energy transfer. There are various types of hydraulic fluids in use depending on the machine type and operation requirements. The knowledge of hydraulic fluid, as with hydraulic equipment, is essential in design, manufacturing, operation and control of hydraulic systems.

1. Hydraulic fluid types

- Hydraulic fluid
  - Mineral fluids
    - General hydraulic fluid (R&O) …… Turbine oil-based fluid with rust and oxidation prevention agents added (frequently called R&O, short for “rust and oxidation”).
    - Anti-wearing hydraulic fluid …… Fluid made of R&O and additional Anti-wearing agents (e.g. zinc), mostly used where pressure exceeds 14 MPa.
    - High viscosity index hydraulic fluid …… Fluid with viscosity index improver added, used in an application that needs to diminish temperature-viscosity changes.
  - Synthetic fluids
    - Phosphate hydraulic fluid …… Fluid with lubricity equivalent to mineral fluids, excellent in fire resistance. You need to pay attention to paint and sealing material before use (nitrile-butadiene rubber not applicable).
    - Polyol ester (fatty acid) hydraulic fluid …… Fluid with fire resistance less than phosphate hydraulic fluids, but tolerates epoxy resin paint and nitrile-butadiene rubber sealing material.
  - Aqueous fluids
    - Water + glycolic hydraulic fluid …… Etylene glycol + water (37 to 40%)
    - Water-in-oil type hydraulic fluid (W/O emulsions) …… Water: 40% approx.



    - Oil-in-water type hydraulic fluid (O/W emulsions) …… Water: 90 to 95%



2. Viscosity of hydraulic fluid

Kinematic viscosity is used to express the viscosity of hydraulic fluid.
Using a capillary viscometer, kinematic viscosity is found by measuring the efflux time of a specified amount of oil in a capillary tube under forces of gravity.
The unit of kinematic viscosity is “mm^2/s = cSt (centistoke)”. Kinematic viscosity of a hydraulic fluid is expressed using a kinematic viscosity (mm^2/s) when the fluid temperature is 40°C.

3. Viscosity index (VI)

In the case of oil, the higher its temperature, the lower the viscosity, and the lower its temperature, the higher the viscosity. VI is used to express such viscosity – temperature characteristics.
Oil with a high VI value produces relatively less viscosity changes due to temperature changes.
(The VI values of petroleum hydraulic fluids refined from high-VI paraffin-base crude range between 100 and 115 in general except for special types.)

4. Appropriate working range of hydraulic fluid

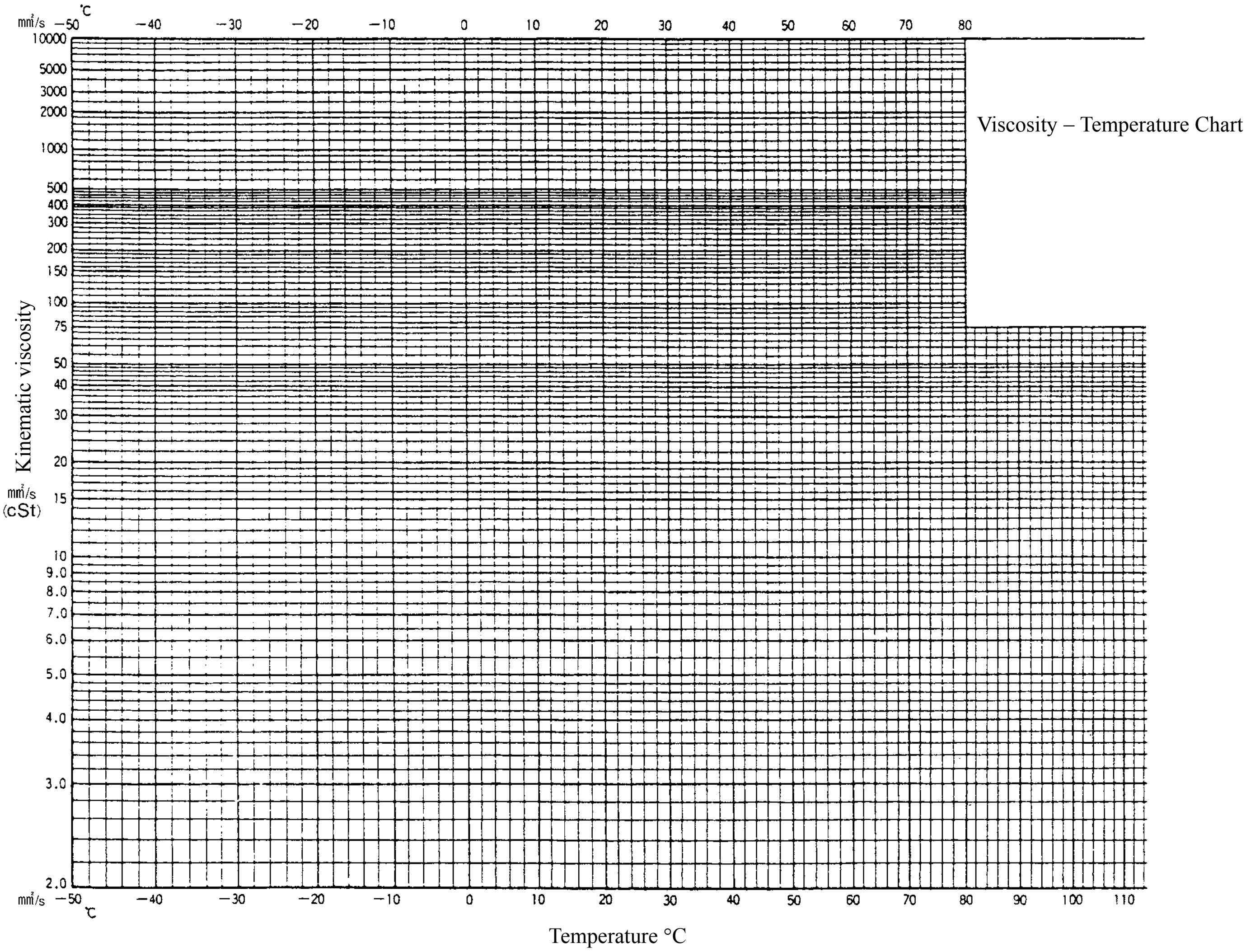
Hydraulic equipment is designed to properly work when the hydraulic fluid viscosity is appropriate.

Too low viscosity → increased leak → lowered efficiency of pumps and motors
→ shortage of oil film → progress of wearing → Lock-up

Too high viscosity → diminished fluidity → increase line pressure loss
Increased power loss
Impaired responsiveness
→ Pump suction failure

The desirable working temperature, therefore, ranges from 15 to 55°C.
(Using oil at a temperature over 60°C accelerates oil deterioration.)
Water + glycolic hydraulic fluids prefer temperatures between 15 and 50°C.

Viscosity – Temperature Chart



Example:

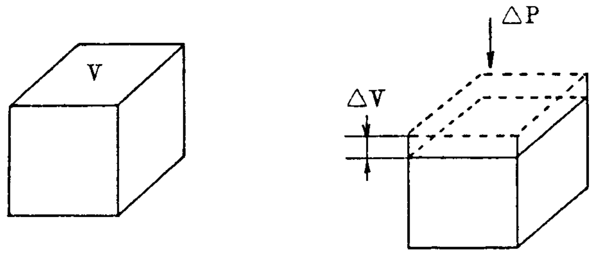
40°C………… 32 mm^2/s	at 15°C______________ mm^2/s
100°C……… 5.8 mm^2/s	at 60°C______________ mm^2/s

40°C………… 68 mm^2/s	at 30°C______________ mm^2/s
100°C……… 8.7 mm^2/s	at 50°C______________ mm^2/s

5. Compressibility

In line with the development in utilization of high pressure, compressibility of hydraulic fluid has become recognized these days.
Compressibility β is expressed as follows.

$$\beta = \frac{1}{\underset{(cm^3)}{V}} \cdot \frac{\Delta V\,(cm^3)}{\Delta P\,(MPa)}$$



To find the reduced volume by compression, use an equivalent to the above equation.
<u>$\Delta V = \beta \cdot V \cdot \Delta P$</u>

V: volume before compression
ΔV: volume reduced by compression pressure ΔP

Types of hydraulic fluid	B (1/MPa)
Mineral hydraulic fluid	6×10^{-4}
Phosphate hydraulic fluid	3.3×10^{-4}
Water + glycolic hydraulic fluid	2.87×10^{-4}

6. Aeration and influence

Air mixed in a hydraulic fluid destabilizes piston motions of a hydraulic cylinder and may cause breathing. The more air is mixed, the more frequently fluid produces cavities in it when passing through the low pressure areas before and after a pump and valve, which is called cavitation. Cavitation causes decline in the volumetric efficiency, noise and erosion.

7. Water incorporation and influence

Water mixed in a hydraulic fluid causes deterioration in the lubricity of the fluid, malfunction of hydraulic equipment and wearing as well as reducing rust resistance and accelerating oxidization of the fluid resulting in rusty metal and shortened life respectively.

8. Hydraulic fluid contamination and its effects

A hydraulic fluid includes various types of and plenty of foreign particles that have entered through many routes of entry. The contaminant particles not only accelerate wearing of bearing and sliding surfaces but also lead to hydraulic equipment failures.
There are two methods for measuring contaminant particles: counting method and weighing method. The counting method has been frequently used.

9. Hydraulic fluid and Fire Defense Law

A hydraulic fluid with flashing point is designated as a hazardous material under the Fire Defense Law. Aqueous fluids do not have flashing point in normal condition and are not designated so. On the contrary, Mineral and synthetic fluids have flashing point of mostly 200°C or higher and are designated as 4th Group, 4th Class Petroleum, which will be subject to regulation when 6,000 liters or over are stored. (in Japanese law)

* Small-scaled hazardous materials

Even when the quantity of stored fluid is less than 6,000 liters, a quantity not less than 1/5 of stored fluid (i.e. 1,200 liters or over) shall be subject to the fire prevention ordinance of a local authority and designated as Small-scaled hazardous materials.

4th-Group hazardous materials: Types and specified quantities

Classifications		Flashing points	States	Hazardous quantities (L)	Typical products
4th Group (inflammable fluid)	1st class Petroleum	Under 21°C	Water-insoluble fluid	200	Gasoline, acetone
			Water-soluble fluid	400	
	Alcohol			400	Ethyl and methyl alcohol
	2nd class Petroleum	Not less than 21°C and not more than 70°C	Water-insoluble fluid	1000	Kerosene, light oil
			Water-soluble fluid	2000	
	3rd class Petroleum	Not less than 70°C and not more than 200°C	Water-insoluble fluid	2000	Heavy oil (some hydraulic fluids fall into this category)
			Water-soluble fluid	4000	
	4th class Petroleum	200°C and over		6000	Gear oil, cylinder oil, general hydraulic fluid
	Animal and plant oil			10000	

Notes (1) Water-insoluble fluid means any fluid other than water-soluble fluid.
(2) Water-soluble fluid is such that when it is mixed with a same quantity of purified water by being stirred gently at 20°C under 1 atmospheric pressure, the mixed solution presents and maintains homogeneous appearance even after the mixing flow has stopped.

* Things to do in conformance with the Fire Defense Law

Application for construction permit, oil tank leak test by filling water, complete examination, use of explosion-proof electric devices, etc.

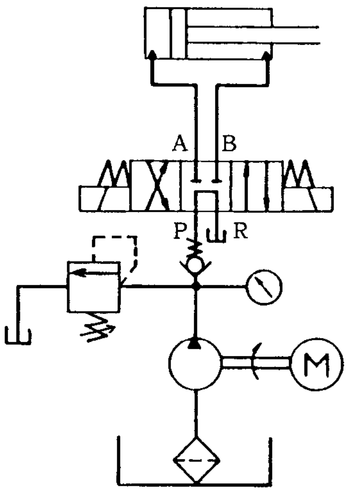
Chapter 4

Basic Circuit

1. Unload circuit

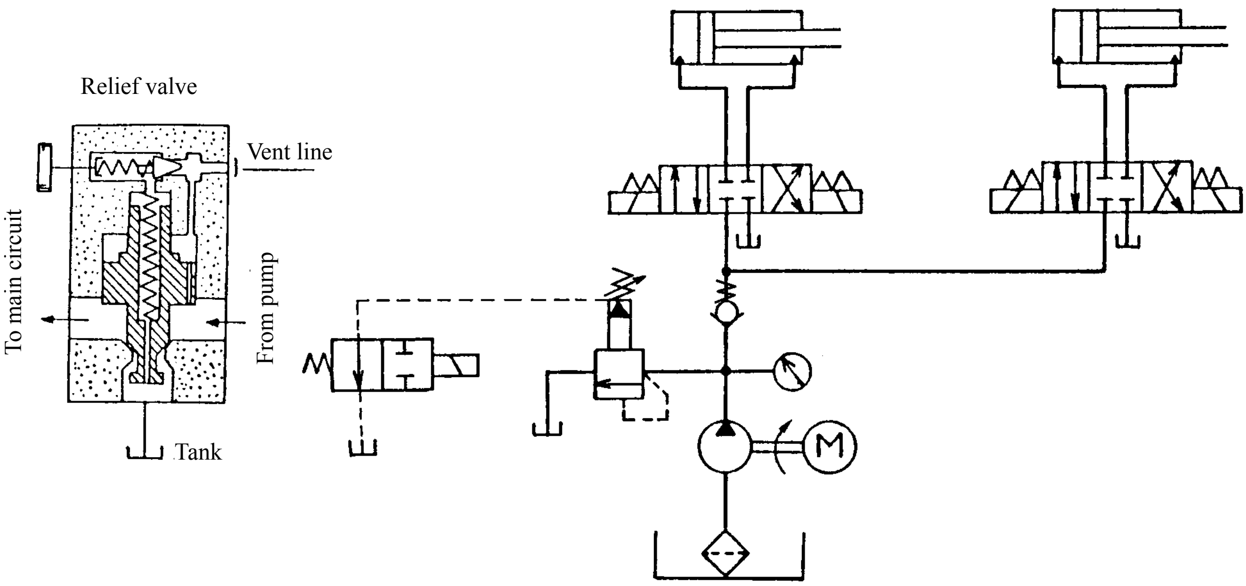
In a circuit using a fixed displacement pump, all the discharge from a pump returns into a tank through a relief valve when a cylinder stops.
Pressure rises to open the relief valve, and the fluid power, turning into heat without working, is lost.
What is useful to reduce the power loss is a system that applies low pressure to release the pump discharge into a tank.

(1) Circuit using center bypass valve



To be used where one single hydraulic drive is involved.

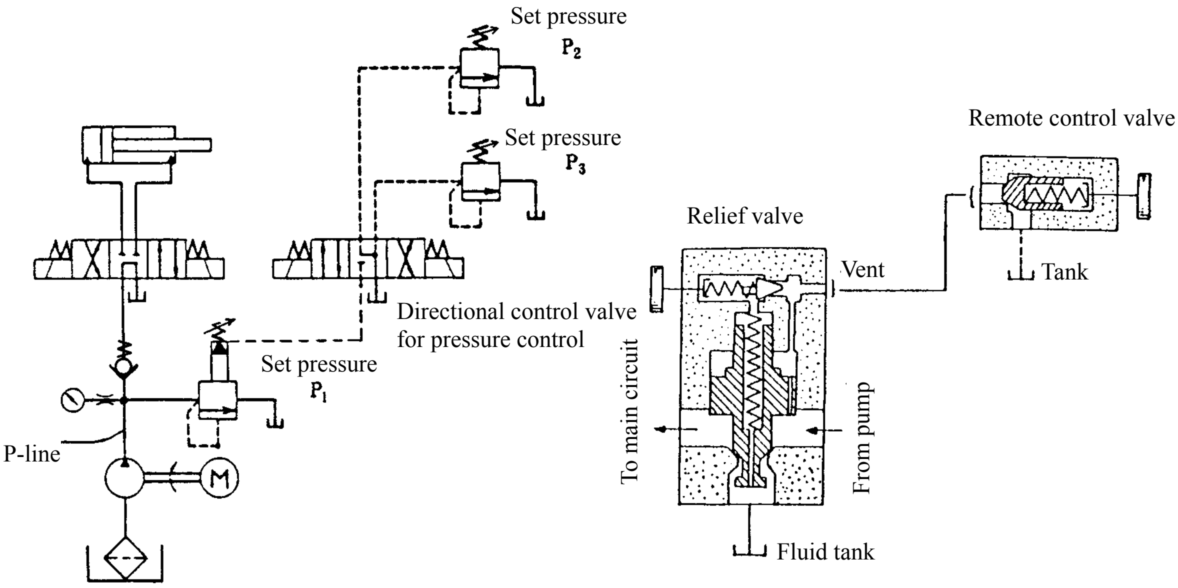
(2) Vent unload circuit



Since the flow rate in a vent line is small, a small size solenoid-controlled valve can be used for control regardless of the pump capacity.

2. Circuit to control pressure required for hydraulic drive

(1) Circuit for switching P-line pressure

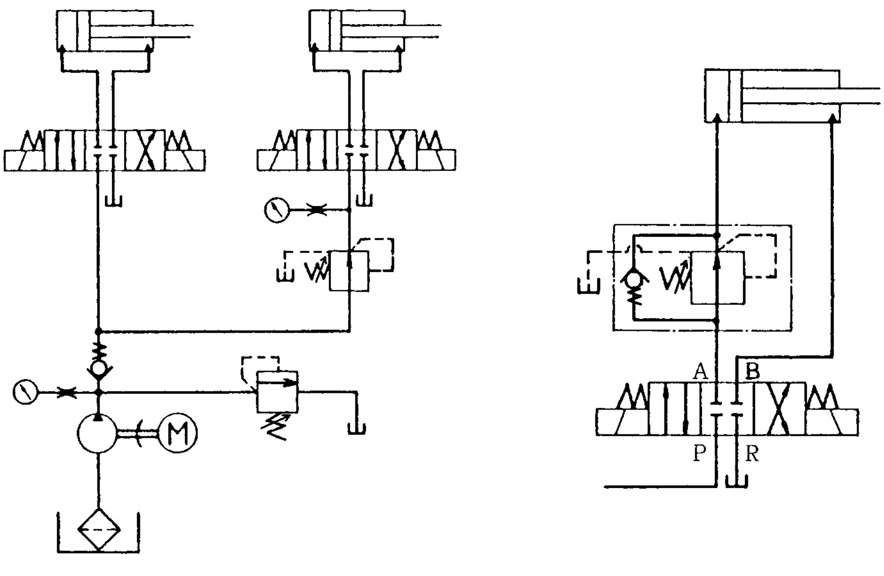


It is used where the hydraulic cylinder output has to be controlled in line with load changes.

The diagram provided above shows a 3-step pressure-switching circuit. In the circuit, with the main relief valve set at the highest pressure P_1 and two pilot relief valves set at mid pressure P_2 and low pressure P_3 respectively, P-line pressure can be switched over using a small size solenoid-controlled valve for vent-line control.

(The above method controls pressure across the entire circuit. It is, therefore, not applicable where a circuit includes multiple driving units and a reduced pressure works against one or more of the driving units.)

(2) Circuit for controlling pressure by series



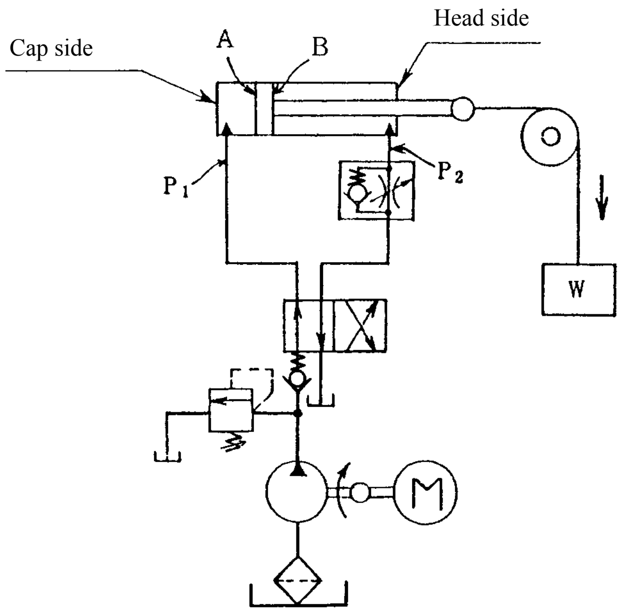
It is used where more than one series system is involved and pressure of one or more of the series systems have to be controlled below the set pressure of a relief valve.

Where a line (A or B) of a directional control valve is used to reduce pressure in only one side of a cylinder, a pressure reducing valve with check valve has to be installed in the line.

3. Control method of flow control valve

There are two methods for controlling the actuator speed: a method that changes the discharge rate using a variable displacement pump, and another that uses a combination of a metering pump and a flow control valve. There are three methods to control a flow control valve: meter-out, meter-in and bleed-off methods.

(1) Meter-out method



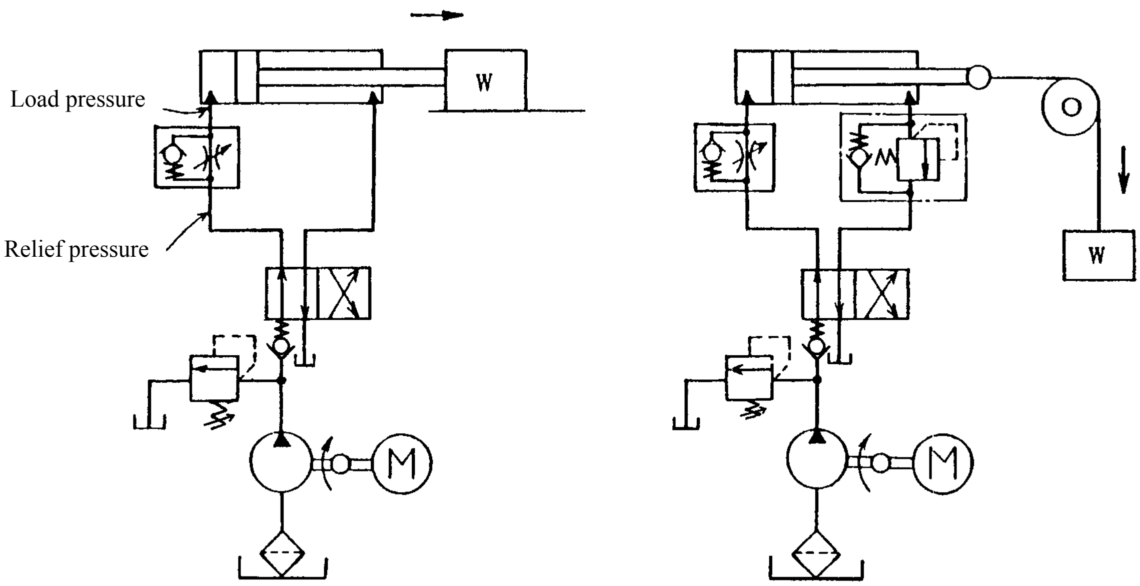
$$P_2 = \frac{P_1 \times A \times 10^2 + W}{B \times 10^2}$$

This method controls the inflow from a pump by throttling down the outflow from an actuator and releases excess flow into a fluid tank through a relief valve.

This is applicable when load is either positive or negative. The pressure P_2 right before the throttle (i.e. head side of stroke in the above diagram) varies depending on the direction and size of load.

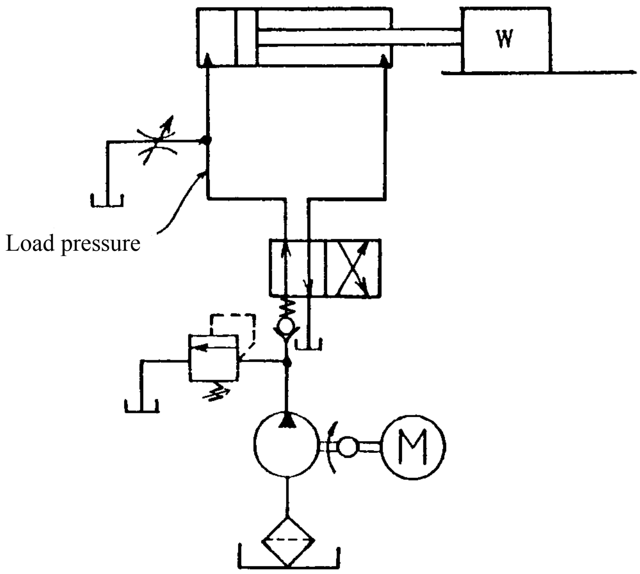
With such load direction as shown in the diagram, in particular, P_2 exceeds the set pressure of the relief valve. If P_2 goes beyond the allowable pressure of the actuator, it can not be used without treatment. It is necessary to keep P_2 pressure down by reducing cap-side pressure (with an additional relief valve or pressure reducing valve).

(2) Meter-in method



This method throttles down the inflow of an actuator and releases excess flow into a fluid tank through a relief valve.
It is applicable when load is positive.
Since the actuator is liable to work self-assertively when load is negative, a counterbalance valve has to be added and used together with the meter-in control method.

(3) Bleed-off method



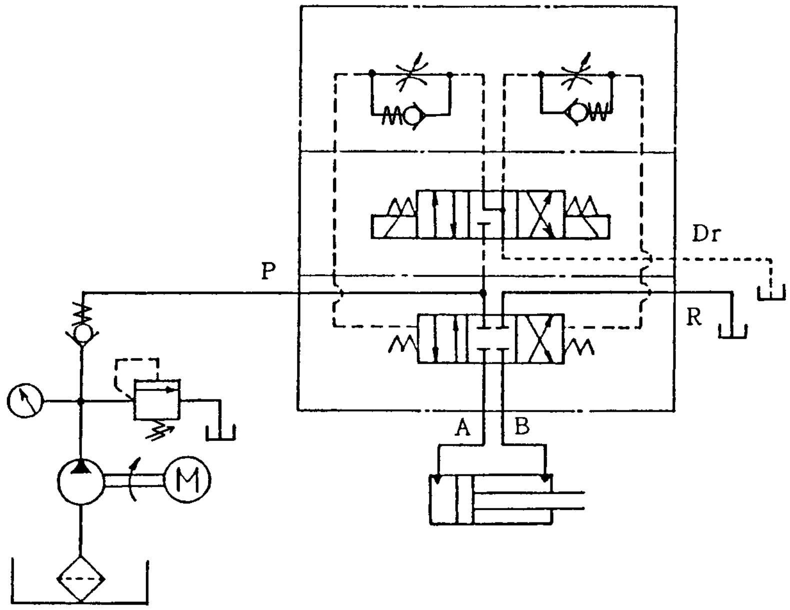
This method bypasses part of inflow to an actuator into a fluid tank.
This is better for efficiency since pump pressure variation corresponding to load changes is always below the set pressure of a relief valve unlike the meter-in and meter-out methods.
This is applicable where just one hydraulic drive unit is involved.
On the other hand, this is not applicable where precise speed control is required since pump discharge rate varies somewhat when load pressure fluctuates widely or fluid temperature changes.

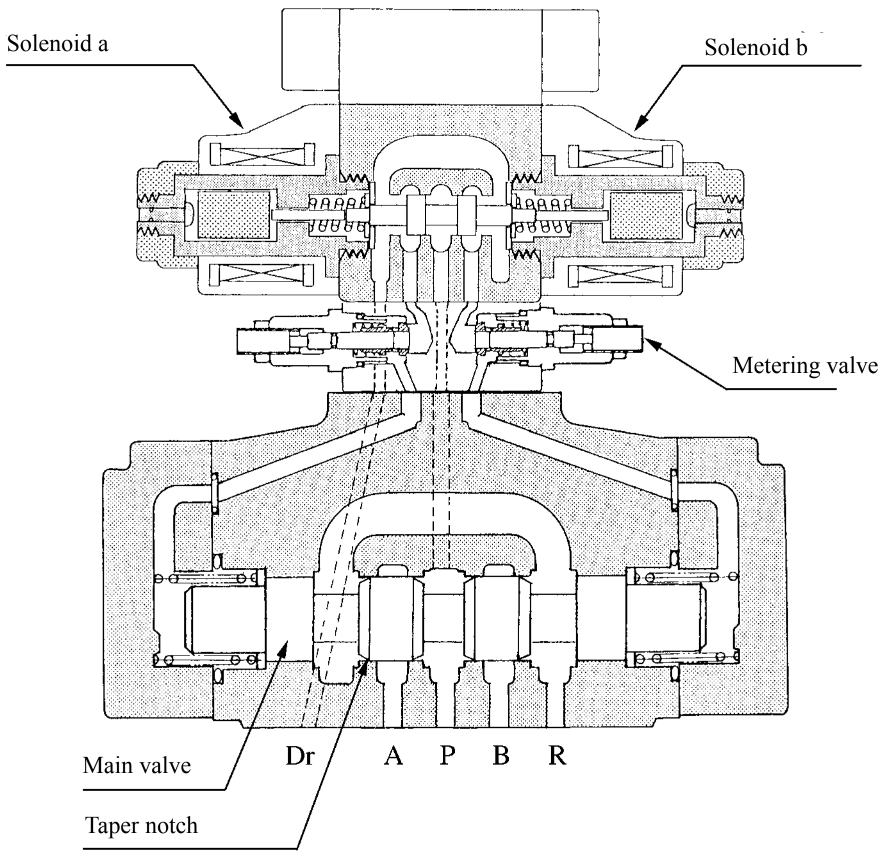
4. Circuit for controlling high load

High load operation requires use of high pressure and high flow. Abruptly switching such fluid produces surge pressure. Following methods are employed to mitigate the problem.

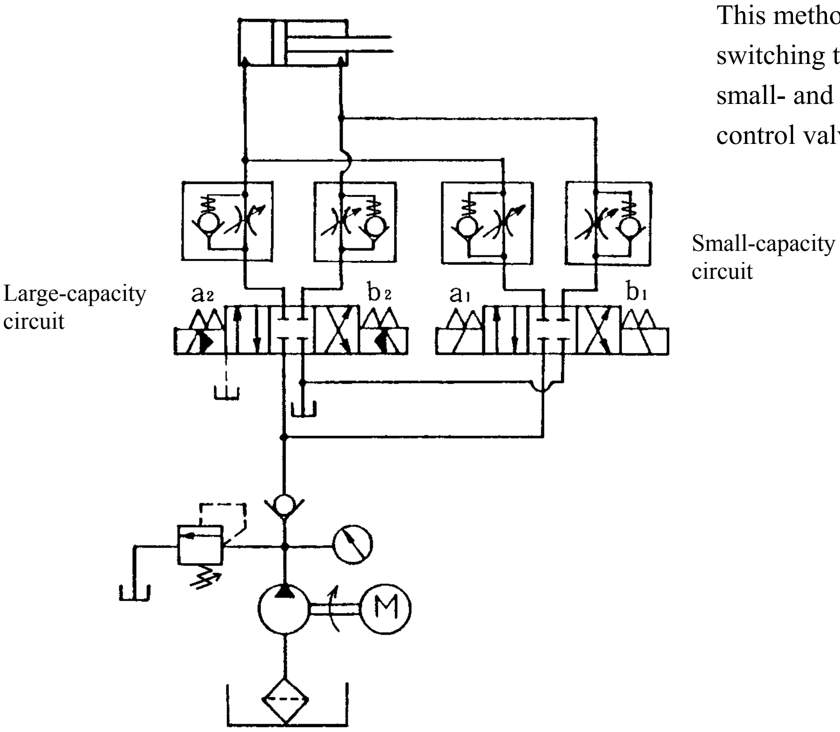
(1) Circuit using solenoid-controlled pilot-operated directional control valve

In the circuit with a solenoid-controlled pilot-operated directional control valve, the shock produced in switching is mitigated by controlling the taper notch effect and switching time using a metering valve.

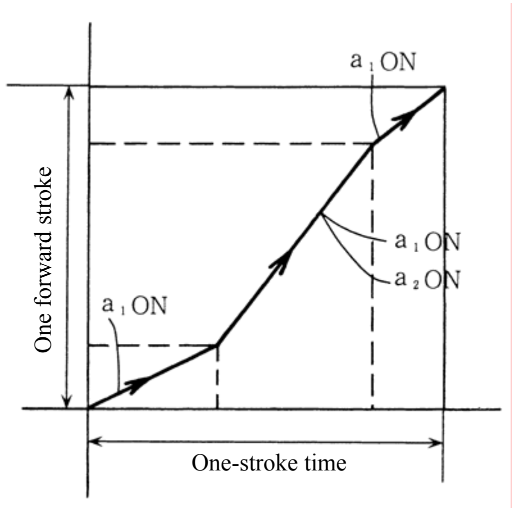




(2) 2-speed control circuit



This method conducts a 2-speed control by alternately switching two circuits by a solenoid-controlled valve, small- and large-capacity circuits including a flow control valve respectively, arranged in parallel.

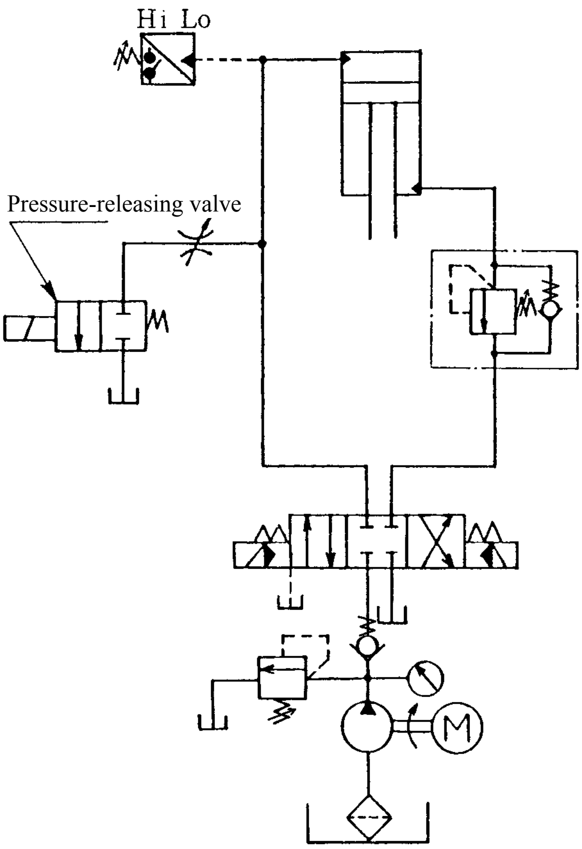


In starting a cylinder, the small-capacity circuit feeds fluid so that the cylinder piston begins traveling slowly. When the piston has traveled a certain distance, the large-capacity circuit starts feeding to increase the speed.
In stopping a cylinder, the large-capacity circuit stops feeding to decelerate the speed, and then, the small-capacity circuit stops feeding to stop the cylinder. (A sequence control is used to control the On/Off sequence and timing of each solenoid for start/stop operation.)

(3) Decompression circuit

When a cylinder piston is at the end of down stroke and pressure in press process reaches the upper limit “Hi” (value set in a pressure switch), a signal is sent out. Upon receipt of the signal, the main directional control valve returns to the neutral position and a pressure-releasing valve opens to slowly release pressure.

When pressure comes down to the lower limit “Lo” (value set in a pressure switch), a signal is sent out. The signal allows the main directional control valve to shift the position for lifting operation.

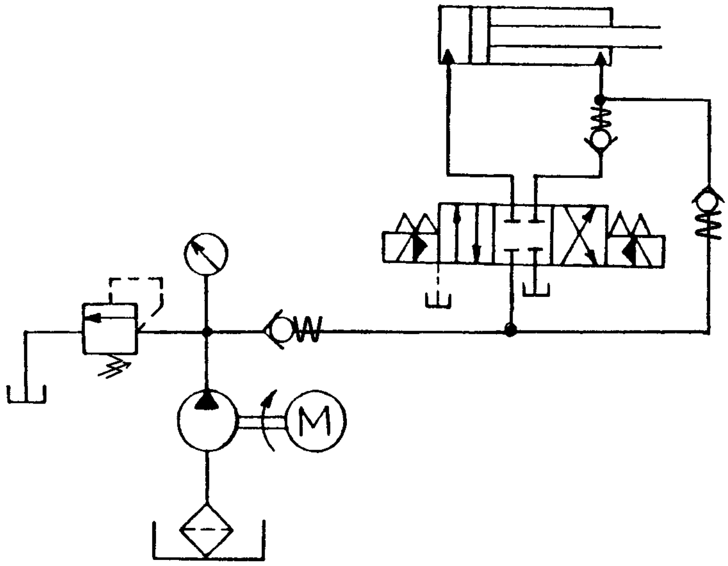


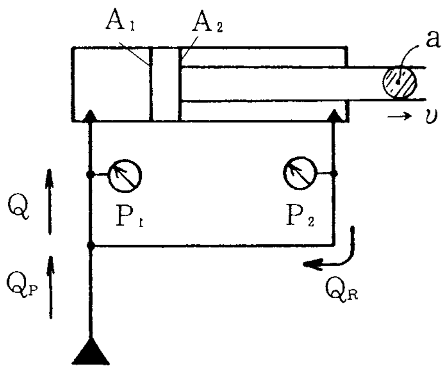
5. Accelerating circuit (to produce a speed faster than that available by pump discharge rate)

(1) Differential circuit

This is applicable where high cylinder output is not needed and the cylinder piston needs to travel fast in its forward stroke.

The piston travels forward at an accelerated speed when the directional control valve is in the left position and returns when the valve is in the right position.





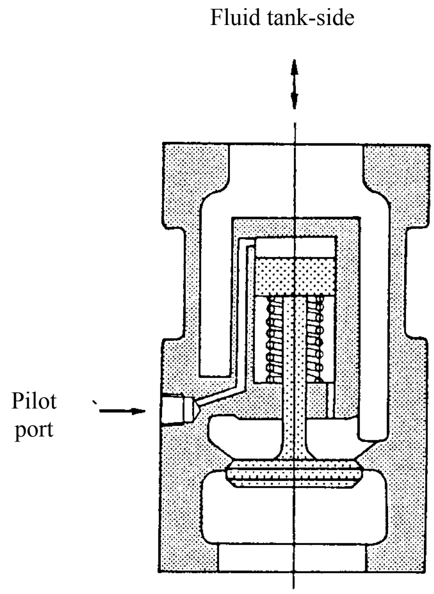
A_1 … Cylinder cap-side cross-sectional area (cm^2)
A_2 … Cylinder head-side cross-sectional area (cm^2)
a … Piston rod cross-sectional area (cm^2)
υ … Piston speed (cm/s)
Q_P … Pump discharge rate (cm^3/s)
Q_R … Outflow (cm^3/s)
Q … Confluent flow rate (cm^3/s)
F … Output (N)
P_1 … Pressure acting on A_1 (cap-side) (MPa)
P_2 … Pressure acting on A_2 (head-side) (MPa)

$Q = Q_P + Q_R$
$A_1 \times \upsilon = Q_P + A_2 \times \upsilon$
$Q_P = A_1 \times \upsilon - A_2 \times \upsilon$
$Q_P = (A_1 - A_2) \times \upsilon$

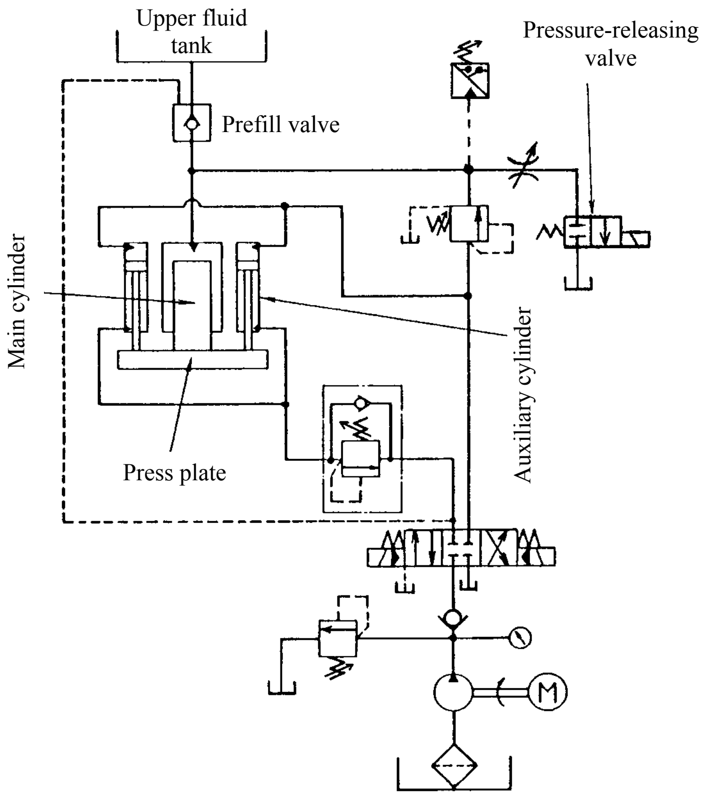
$$\therefore \upsilon = \frac{Q_P}{A_1 - A_2} = \frac{Q_P}{a}$$

(Output)
$F = P_1 \times A_1 \times 10^2 - P_2 \times A_2 \times 10^2$

(2) Accelerating circuit using auxiliary cylinder



[Prefill valve]



This circuit is frequently used where a large-diameter cylinder is employed for a hydraulic press. To increase working efficiency, processes other than press process employ rapid-run. Using a small-diameter auxiliary cylinder for this purpose enables rapid-run with a small pump.

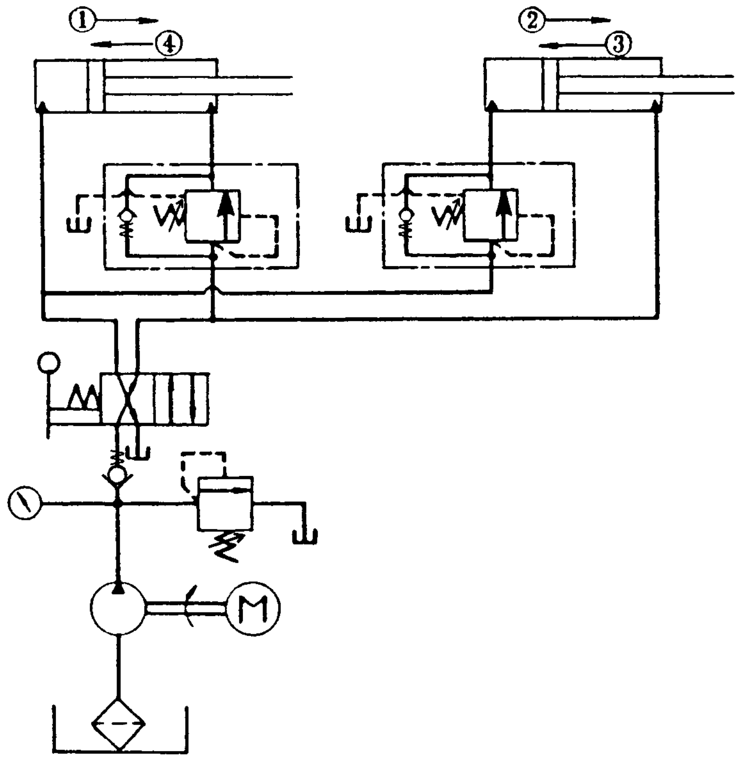
[Downward stroke] Pump discharge drives the auxiliary cylinder piston downward while the main cylinder indraws fluid by itself from the upper fluid tank. When pressure starts rising and reaches the set pressure of the sequence valve after the press plate contacts a workpiece, the valve opens and pump discharge enters the main cylinder so that pump discharge pressure is used for pressing. After pressing is complete, the pressure releasing valve opens to slowly release pressure.

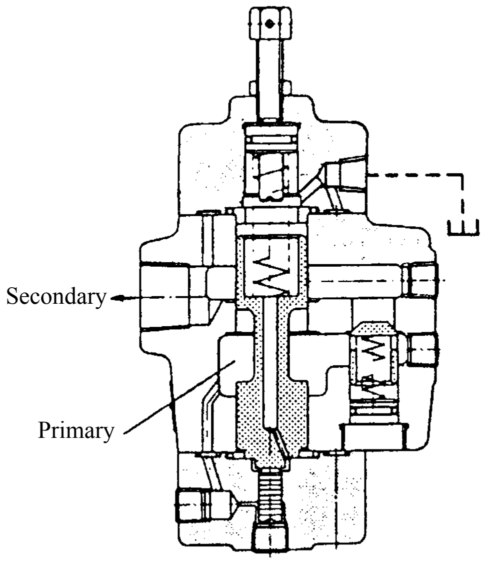
[Upward stroke] While pressure lifts up the auxiliary cylinder piston, part of the pressure opens the upper prefill valve in order to send fluid from the main cylinder back to the upper fluid tank.

6. Circuit for sequential operation of cylinder

This circuit operates more than one cylinder in accordance with the specified sequence.
There are two methods to implement the sequence: one by cylinder pressure detection (using a sequence valve) and another by cylinder position detection.
Using limit switches to detect positions is common.

(1) Circuit using sequence valve

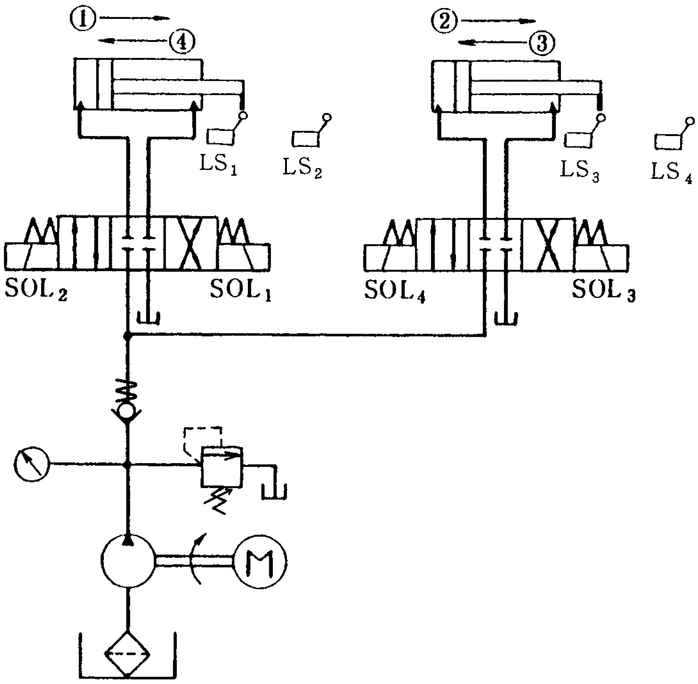




[Sequence valve]

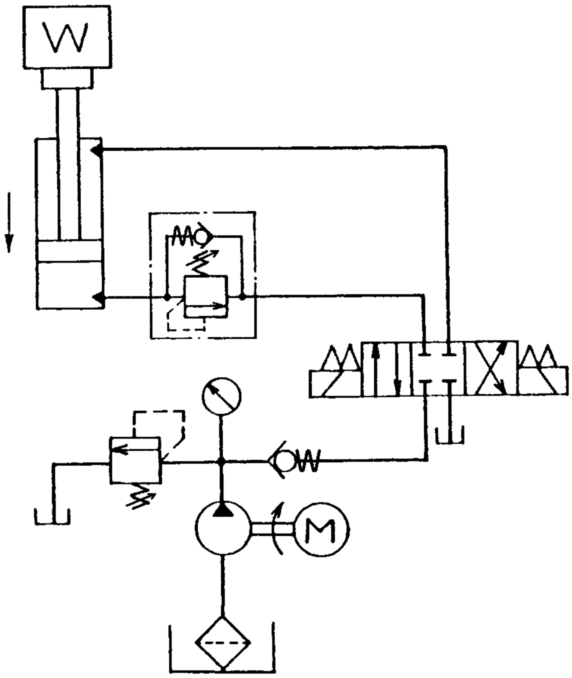
This circuit, capable of controlling up to two or three cylinders, is used in a line of manually-operated valve.

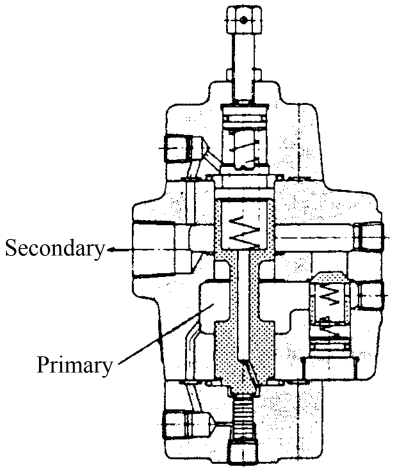
(2) Circuit using limit switch and solenoid-controlled valve



The circuit turns solenoid of a solenoid-controlled valve on and off while detecting the position of a cylinder piston with limit switches.
It is capable of handling complicated motions and wide-ranging control.

7. Circuit to maintain back pressure (negative load)

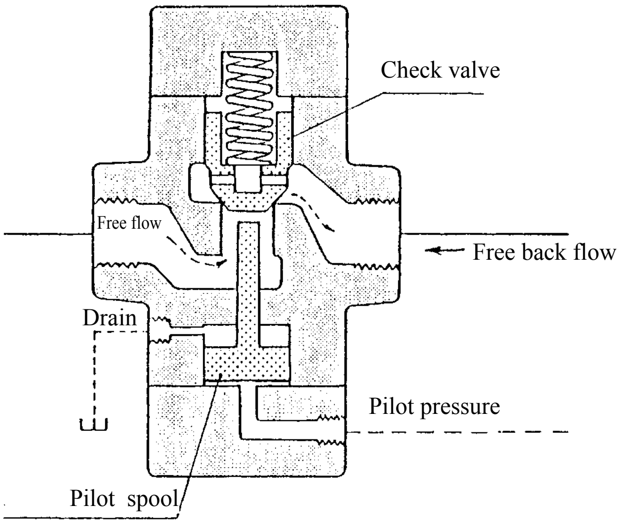




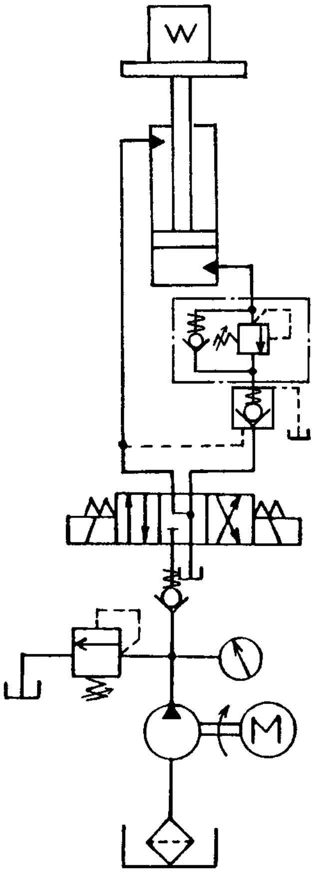
[Counterbalance valve]

The circuit employs a counterbalance valve to maintain back pressure that is produced by load W.

8. Position-keeping circuit

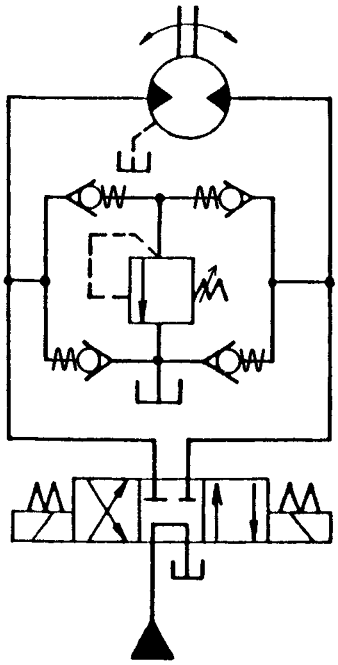


[Pilot-operated check valve]



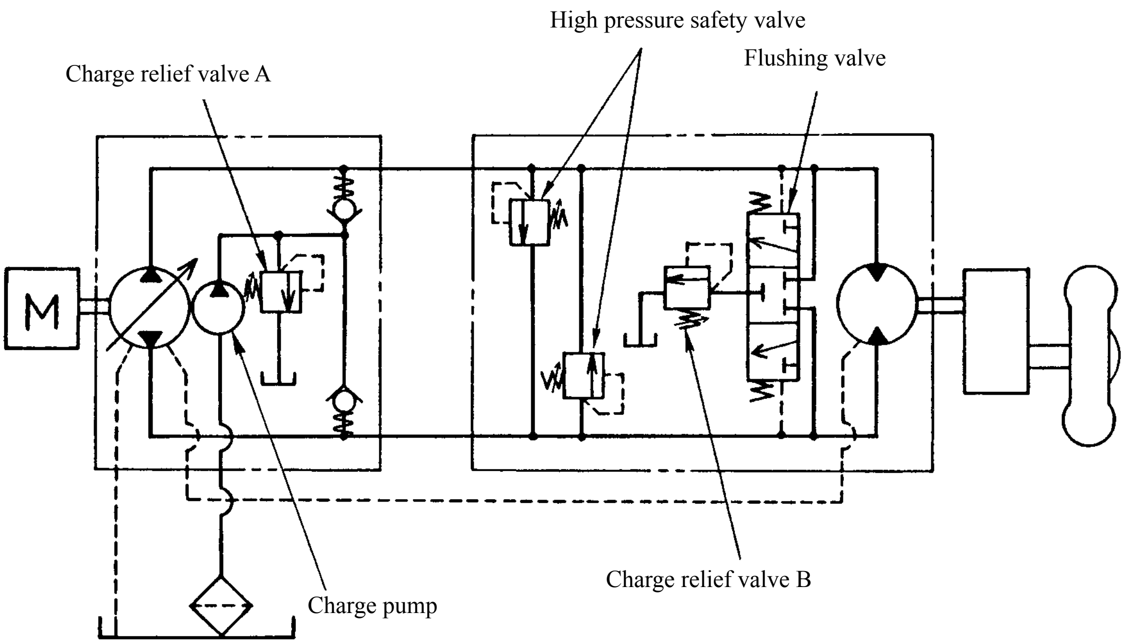
The circuit employs a pilot-operated check valve in it to hold a cylinder piston in any position with reliability.

9. Brake circuit



While a relief valve absorbs inertial force, a lower check valve secures supply so that pressure of the opposite line is not negative.

10. Closed circuit



In a closed circuit, a pump produces a pressure and flow rate only in line with a load. No other circuits can compete with closed circuit in efficiency.
Alternating the pump discharge direction switches the motor rotation between forward and reverse, and changing the pump discharge rate controls the number of revolutions of a motor.
In order to prevent negative pressure in the low pressure line when a leak takes place in the high pressure line (on the pump discharge side), a charge pump is employed to supply pressure into the low pressure line. The relief valve B determines the pressure.
Pressure of the high pressure line opens the flushing valve and pressure runs from the low pressure line to the charge relief valve B. At that time, the charge relief valve has to remain closed, and for this purpose, the pressure of A is higher than that of B.
Fluid discharged from the charge relief valve B returns into the fluid tank after cooling and lubricating the motor and pump. Then, the fluid enters the low pressure line after being filtered with a filter. This chain flow forms the flushing circuit.
When the motor stops, the flushing valve shifts to the neutral position. At the same time, the charge relief valve B closes and the charge relief valve A opens.
(The filter of the charge pump is installed on the discharge side in some cases.)

11. Filter circuit for hydraulic fluid

The most essential practice in using hydraulic equipment is to maintain hydraulic fluid cleanliness.
Utilization of high pressure is more common today. The higher the pressure, the smaller the clearance in pumps and valves, resulting in increased problems caused by contaminations in fluid.
Filter circuit weight has been increasing so as to prevent troubles of and extend the life of hydraulic equipment.

(1) Circuit in return side

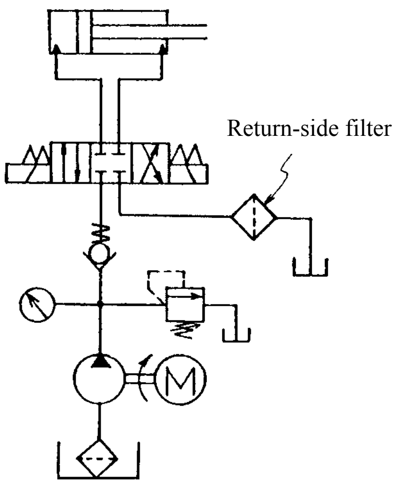
The most simple circuit, frequently used in small-size equipment.
Large-size equipment needs a large flow rate in the return line, resulting in a large-capacity filter.

(2) Circuit in discharge side

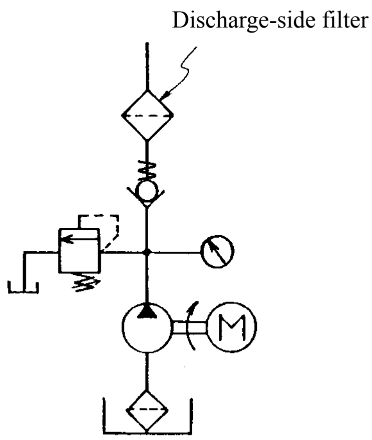
It is employed in a circuit that uses valves (e.g. servo valve) that require a high fluid cleanliness.
A high-pressure filter meeting the pump capacity is used.

(3) Circuit dedicated to filtering purpose

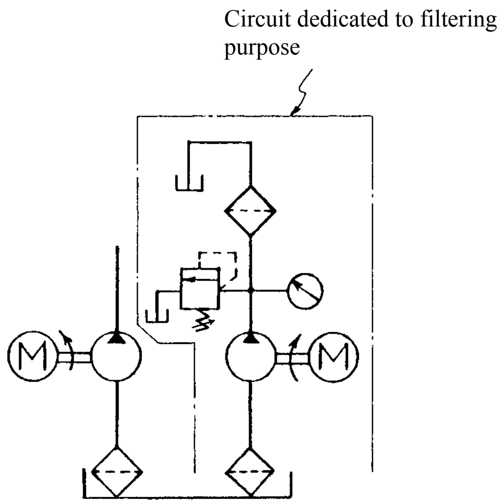
The circuit uses a small-size pump and filter, but is capable of filtering fluid in a large-capacity tank. It is used in large-size equipment.



(1) Circuit in return side



(2) Circuit in discharge side



(3) Circuit dedicated to filtering purpose

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