PDHonline Course M523 (8 PDH)

Hydraulics & Oil Power Systems – Automation Guidebook, Part 2

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2020

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HYDRAULICS & OIL POWER SYSTEMS
AUTOMATION GUIDEBOOK – PART 2

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OBS.: This is a didactic and professional handbook. It´s highly recommended to downloading and printing the course content for your study, before answering the quiz questions.

INTRODUCTION:

The word hydraulics is a derivative of the Greek words **hydro** (meaning water) and **aulis** (meaning tube or pipe). Originally, the science of hydraulics only covered the physical behavior of water at rest and in motion. The use has broadened its meaning, to include compressed air or gases and oil compounds and other confined liquids commonly used under controlled pressure to do some work.

Hydraulics can be defined as the engineering science that pertains to liquid pressure and flow. This study includes the manner in which liquids act in tanks, cylinders, hoses, valves and pipes, dealing with their properties and the common ways of utilizing these properties to create motion. It includes the laws of floating bodies and the behavior of fluids under various conditions, and ways of directing this flow to useful ends, as well as many other related subjects and applications.

The fundamental concepts of fluid power include both pneumatic (gas) and hydraulic (liquid) systems, and contain four basic components: reservoir/receiver, pump/compressor, valve, and cylinder. These systems include everyday applications, such as bulldozers, front-end loaders, excavators, height lever adjustors, door closer dampers, dental drills, vehicle brakes, and related equipment.

Fluid power defines the generation, control, and application of smooth, effective power of pumped or compressed fluids, gas, or liquid, when this power is used to provide force and motion to mechanisms. If the compressed fluid is a gas, it is called **pneumatics**, while if the compressed fluid is a liquid, it is called **hydraulics**. This motion may be in the form of pushing, pulling, rotating, regulating, or driving.

The original hydraulic fluid, dating back to the time of ancient Egypt, was water. Beginning in the 1920s, mineral oil began to be used more than water as a base stock due to its inherent lubrication properties and ability to be used at temperatures above the boiling point of water. Today most hydraulic fluids are based on mineral oil, synthetic oil, and compounds.

Natural oils such as rapeseed (also called canola oil) are used as base stocks for fluids where biodegradability and renewable sources are considered important. Other base stocks are used for specialty applications, such as, for fire resistance and extreme temperature applications.

Some include a wide range of chemical compounds as, glycol, esters (e.g. phthalates, adipates and organophosphates), polyalphaolefin, propylene glycols, silicone oils, butanol, polyalkylene glycols, tributylphosphate, alkylalated aromatic hydrocarbons, polyalphaolefins (e.g. polyisobutenes), corrosion inhibitors (acid scavengers), anti-erosion additives, etc.

BASIC PRINCIPLES OF HYDRAULICS:

Basic principles of fluid flow: Include **three concepts**, the **first** is equations of fluid forces, the **second** is the conservation of energy (First Law of Thermodynamics) and the **third** is the conservation of mass. Since the main subject here is hydraulics, the pressure at different levels in the tank varies and also varies velocities. The force is due to the weight of the water above the point where the pressure is being determined, as shown below:

1. **Pressure**: Pressure (P) is the force per unit area applied in a direction perpendicular to the surface of an object. Mathematically it is **P = F/A**, where F is Force and A is Area. Then, atmospheric pressure is the total weight of the air above unit area at the point where the pressure is measured. The air pressure varies with location and weather. The main basic pressure units are: **101300 Pa** (Pascal) = **101.3 kPa** (Kilopascals) = **0.1013 mPa** (Megapascal) = **1.013 bar** = **1.033 kg/cm² abs** = **760 mmHg (torr)** = **14.7 psia** = **29.92 inches of mercury** (Hg).

There are three standards available:

- 1. API Standard: 14.7 psia, 60°F, 0% relative humidity;
- 2. ASME Standard: 14.7 psia, 68°F, 36% relative humidity;
- 3. CAGI Standard: 14.7 psia, 60°F, 36% relative humidity;

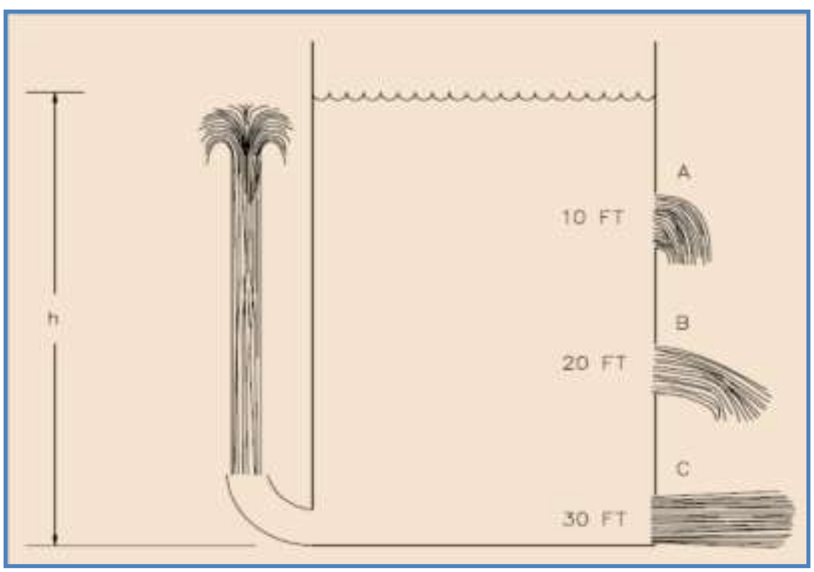
Then, **pressure** is defined to be **force per unit area**, as shown by the following equations:

$$\textbf{Pressure} = \frac{\textbf{Force}}{\textbf{Area}} = \frac{\textbf{Weight}}{\textbf{Area}}$$

$$P = \frac{m.g}{A.g_c} = \frac{\rho.V.g}{A.\ g_c}$$

Where:

m = Mass, in lbm;
g = Acceleration (earth´s gravity), 32.17 ft/s²;
g_c = 32.17 lbm-ft/lbf.s²;
A = Area, in ft²;
V = Volume, in ft³;
P = Density, in lbm/ft³.



Since the **volume** is equal to the **cross-sectional area (A)** multiplied by the **height (h**) of liquid, then:

$$P = \frac{\rho . h . g}{g_c}$$

Example 1: If the tank in figure above is filled with water that has a density of 62.4 lbm/ft³, calculate the pressures at depths of 10, 20, and 30 feet.

Solution:

$$P = \frac{\rho . h . g}{gc}$$

$P = \frac{62.4 \times 10 \times 32.17}{32.17 \text{ lbm-ft/lbf-s}^2}$ = **624 lbf/ft² = 4.33 psi** (divided by 144 in² to psi)

$P = \frac{62.4 \times 20 \times 32.17}{32.17 \text{ lbm-ft/lbf-s}^2}$ = **1248 lbf/ft² = 8.67 psi** (divided by 144 in² to psi)

$P = \frac{62.4 \times 30 \times 32.17}{32.17 \text{ lbm-ft/lbf-s}^2}$ = **1872 lbf/ft² = 13.00 psi** (divided by 144 in² to psi)

Example 2: A cylindrical water tank 40 ft high and 20 ft in diameter is filled with water with a density of 61.9 lbm/ft³.

(a) What is the water pressure on the bottom of the tank?
(b) What is the average force on the bottom?

a) $P = \frac{\rho . h . g}{gc}$

$P = \frac{62.4 \times 40 \times 32.17}{32.17 \text{ lbm-ft/lbf-s}^2}$ = **2496 lbf/ft² = 17.3 psi** (divided by 144 in² to psi).

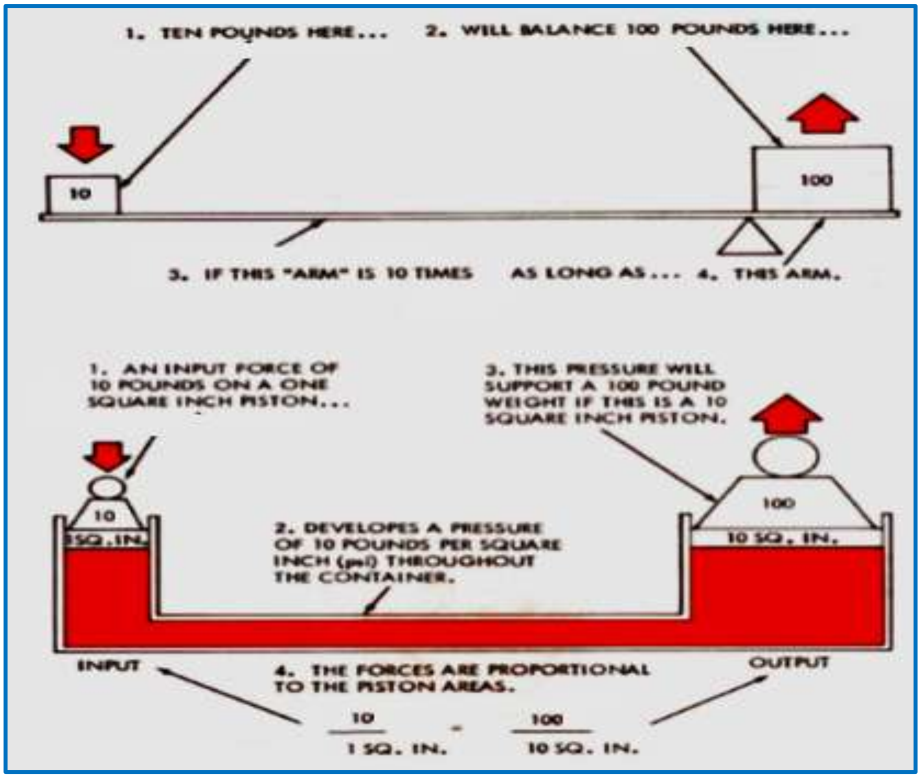
b) Pressure = $\frac{\textbf{Force}}{\textbf{Area}}$ **=**

Force = (Pressure x Area) =

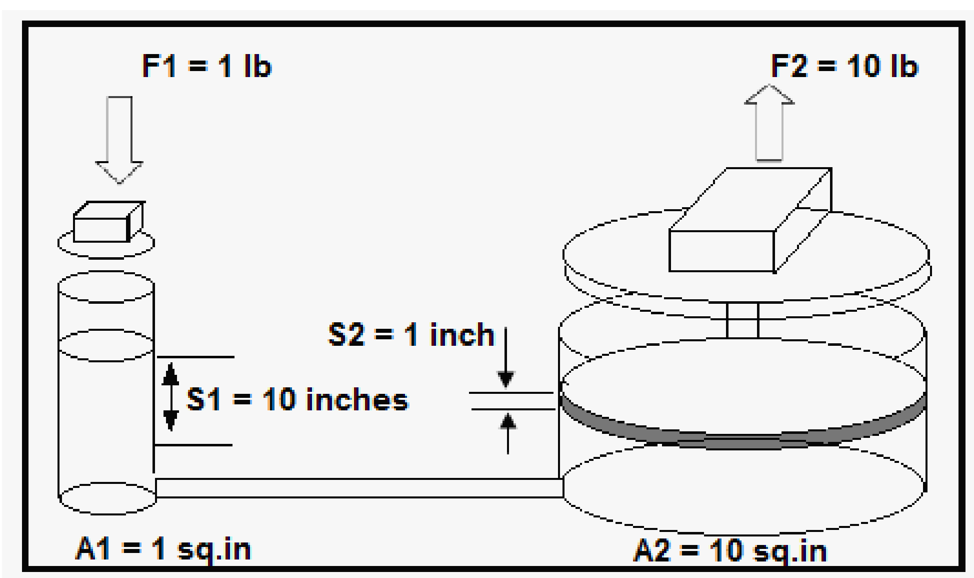
Force = 2496 lb/ft² x (π.R²) = 17.3 x (π.10²) = **5435 lbf**.

2. **Pascal's Law**: Or the principle of transmission of fluid-pressure, states that a certain pressure exerted any-where in a confined incompressible fluid, is transmitted equally in all directions throughout the container, the way that the pressure variations remain the same.

Many years ago, in the 1600s, a French scientist and mathematician named Blaise Pascal stated a physical law that describes the effect of applying pressure on a fluid (whether gas or liquid) in a closed container. Pascal's law states that pressure applied to an enclosed fluid is transmitted with equal force throughout the container.



The cylinder on the left shows a **cross-section area of 1 sq. inch**, while the cylinder on the right shows a **cross-section area of 10 sq. inches**. The cylinder on the left has a weight (force) of **1 lb** acting downward on the piston, which **lowers the fluid in 10 inches**. Because of this force, the piston on the right **lifts a 10-pound weight** a **distance of 1 inch**.



The **1 lb** load on the **1 sq. inch area** causes an increase in pressure on the fluid. This pressure is distributed equally on every square inch area of the large piston. As a result, the larger piston lifts up a **10-pound** weight. The bigger the cross-section area of the second piston, more weight it lifts.

Since pressure equals force per unit area, then it follows that:

F1 / A1 = F2 / A2

1 lb / 1 sq. inch = 10 lb / 10 sq. inches

The Volume formula is:

V1 = V2

Then,

A1.S1 = A2.S2

Or,

A1 / A2 = S2 / S1

It is a simple lever machine since force is multiplied. The mechanical advantage is:

MA = [S1 / S2 = A2 / A1]; can also be = [S1 / S2 = (π. r^2) / (π.R^2)]; or = [S1 /S2 = r^2 / R^2]

Where:

A = Cross sectional area, $inches^2$;
S = Distance of the moved piston, inches;

For the sample problem above, the **MA is 10:1** (10 inches / 1 inch or 10 square inches / 1 square inch).

Example 1: A hydraulic press, similar the above sketch, has an input cylinder 1 inch in diameter and an output cylinder 6 inches in diameter.

a. Find the estimated force F2 exerted on the output piston, when a force F1 of 10 pounds is applied on the input piston.
b. If the input piston moved 4 inches, how far the output piston should move, with force F2?

a. Solution:

F1 / A1 = F2 / A2
A1 = 0.7854.d^2 = 0.7854.1^2 = **0.7854 sq. in**;
A2 = 0.7854.D^2 = 0.7854.6^2 = 28.274 sq. in. Then, F1 / A1 = F2 / A2 = 10 / 0.7854 = **F2** / 28.274 =

F2 = 360 lb.

b. Solution:

S1 / S2 = A2 / A1 = 4 / **S2** = 28.274 / 0.7854 = **4 / 36**

S2 = 1/9 (0.11 inch).

Example 2: A hydraulic system has a mechanical advantage of 40 (MA). MA is F2 / F1. If the input piston, with 12 inches radius has a force of 65 pounds pushing downward a distance of 20 inches, find:

a. the upward force on the output piston;
b. the radius of the output piston;
c. the distance the output piston moves;
d. the volume of fluid that has been displaced;

a. Solution:

MA = F2 / F1 =
40 = F2 / 65 =

F2 = 2600 lb - (Upward force);

b. Solution:

Piston radius = 12 inches, then, **A1** $=\pi.r^2 = \pi.(12^2)$ = **452.4 in²**

F1 / A1 = F2 / A2
65 / 452.4 = 2600 / A2

A2 = 18096 in²

R^2 = $A2 / \pi = 18096 / \pi$ **= 5760**

R = ~76 inches - (the radius of the output piston);

c. Solution:

The input piston displaces **20 inches** of fluid, then:

A1 / A2 = S2 / S1
452.4 / 18096 = S2 / 20

S2 = 0.5 inch – (the distance the output piston moves);

d. Solution:

Volume = A2 x S2 = 18096 in² x 0.5 inch **= 9048 in³** - (the volume of fluid that has been displaced).

Obs.: As defined above, both pneumatics and hydraulics are applications of **fluid power**. Pneumatics uses an easily compressible gas such as air or a suitable pure gas, while hydraulics uses relatively incompressible liquid media such as oil. **Pneumatic** applications usually use pressures of about **80** to **100 psi** (550 to 690 kPa). **Hydraulics** applications commonly use from **1,000** to **5,000 psi** (6.9 to 34.5 mPa), but specialized applications may exceed **10,000 psi** (69 mPa).

3. **Air Properties**: In hydraulics it is also important to know air properties and what means dew point, relative humidity and altitude, in both English and Metric units. The International Standard Atmosphere standard conditions for **zero density** altitude are:

- ✓ Altitude 0 meters (0 ft), Air Temperature 15°C (59°F), Air Pressure 1013.25 mPa (29.92 in Hg) and Relative Humidity 0 % (0 absolute dew point). The **Standard Sea** Level Air Density is **1.225 kg/m^3 (0.002378 slugs/ft^3).** At **20 °C** and **1.0 bar** (101.325 kPa), dry air has a density of **1.2041 kg/m^3**. At **70 °F** and **14.696** psi, dry air has a density of **0.074887 lbm/ft^3**.

- ✓ The 1976 International Standard Atmosphere is mostly described in metric SI units.

Fluid density is greatly affected by **pressure, temperature, and altitude**. The density of fluids and its compounds can be altered by pressure, temperature, or altitude. Reduction in fluid density may modify engine horsepower, aerodynamic lift, reduces drag and so on.

Density and Altitude: The density of air at sea level is about **1.2 kg/m^3 (0.002378 slugs/ft^3)**. Density is not measured directly but is calculated from measurements of temperature, pressure, and humidity using the equation of state for air (a form of the ideal gas law). The atmospheric **density decreases** as the **altitude increases**.

Air Density: To begin to understand air density, consider the ideal gas law. The specific gas constant for dry air is **287.058 J/(kg·K)** in SI units, and **53.35 (ft·lbf)/(lbm·°R)** in United States customary and Imperial units.

P x V = n x R x T

Where:

P = pressure
V = volume
n = number of moles
R = gas constant
T = temperature

Example 3: Calculate the air density using the ISA standard sea level conditions below. (Use metric units and find the conversion in imperial units):

P = 101,325 Pa (14.7 psia)
T = 15°C (59°F)

The **air density at sea level**, may be calculated as:

D = (101325) / [287.05 x (15 + 273.15)] = **1.225 kg/m^3** = **0.002378 slugs/ft^3**.

4. **Density (ρ) and Specific Gravity (Sg):** The difference between density and specific gravity is that one is a ratio of the other. Thus, specific gravity is the ratio of the density of a substance to the density (mass of the same unit volume) of a reference substance. The reference substance is nearly always **water** for liquids and **air** for gases.

Specific gravity is commonly used in industry for obtaining information about the concentration of solutions of various materials such as brines, hydrocarbons, sugar solutions (syrups, juices, honeys, brewers, etc.) and acids.

a) **Density (ρ)** of a material is defined as **mass divided by volume**:

$$\mathbf{P = \frac{m\ (lb)}{V\ (ft^3)} =}$$

Where:

ρ = Density, in lb/ft³;
m = Mass, in lb;
V = Volume, in ft³.

Density of water = **1 ft³** of water at 32°F equals **62.4 lb**.

Then, $\boldsymbol{\rho_{water}}$ **= 62.4 lb/ft³ = 1000 Kg/m³**

b) **Specific Gravity** is the substance density compared to water. The density of water at standard temperature is:

$\boldsymbol{\rho_{water}}$ **= 1000 Kg/m³ = 1.0 g/cm³ = 1.0 g/liter**

So, the **Specific Gravity (Sg)** of water **is 1.0**.

Example 4: Knowing that the Density of iron is 7850 kg/m³*,* what is the Specific Gravity?

Sg = 7850 kg/m³ / 1000 kg/m³ = **7.85**

5. **Viscosity**: describes a fluids resistance to flow. The viscosity of a fluid is a measure of its resistance to gradual deformation by shear stress or tensile stress. For liquids, it corresponds to the informal notion of "thickness". For example, honey has a much higher viscosity than water. Viscosity is divided in dynamic and kinematics, described below.

. Dynamic Viscosity: Also known as Absolute Viscosity is obtained by dividing the shear stress by the rate of shear strain. The units of Dynamic Viscosity are Force / area x time. **Centipoise (cP)** is commonly used to describe **Dynamic Viscosity,** referenced by the Greek letter**, *μ*,** and the **Pascal** unit **(Pa)** is used to describe pressure = force / area.

***μ* = Pa** = 1.00 Pa = 10 Poise = 1000 Centipoise.

Water temperature of **20°C has a viscosity of 1.002 cP** must be converted to **1.002 x** $\mathbf{10^{-3}}$ **Pa**.

. Kinematic Viscosity: Is measured by timing the flow of a known volume of fluid from a viscosity measuring cup, whose value is in **Centistokes (cSt)**, referenced by the letter**, *v*.** The unit of the Kinematic Viscosity as area / time is:

***v* = m²/s** = 1.0 m²/s = 10,000 Stokes = 1,000,000 Centistokes.

Water at a temperature of **20°C has a viscosity of 1.004 x** $\mathbf{10^{-6}}$ **m²/s** or 1.004000 Centistokes. This value must be converted back to **1.004 x** $\mathbf{10^{-6}}$ **m²/s** for use in calculations.

Kinematic Viscosity and Dynamic Viscosity Relationship: Kinematic Viscosity can also be determined by dividing the Dynamic Viscosity by the fluid density. Centistokes = Centipoise / Density

$\boldsymbol{v = \mu / \rho}$

- **Metric units:** In this system of units the **kilogram (kg)** is the standard unit of mass, a **cubic meter** is the standard unit of volume and the **second** is the standard unit of time. To understand viscosity involved in this relationship is necessary to use an example:

Dynamic viscosity μ = Pa. Substitute for Pa = N/m² and N = kg.m/s²

Therefore, dynamic viscosity μ = Pa.s = kg/(m.s) - *Density* ρ = kg/m³

Kinematic Viscosity = $v = \mu / \rho$ = (kg/(m.s) x 10^{-3}) / (kg/m³) = m²/s x 10^{-6}

Density ρ: As defined above, the density of a fluid is obtained by dividing the mass of the fluid by the volume of the fluid, normally expressed as kg / cubic meter.

ρ = kg/m³ - Water at a temperature of **20°C has a density of 998 kg/m³.**

Relative Density: Sometimes this term is also used to describe the density of a fluid. Relative density is the fluid density divided by 1000 kg/m³. Thus, water at a temperature of **20°C has a Relative density of 0.998.**

- **Imperial Units:** In this system of units the **pound (lb)** is the standard unit of weight**,** a **cubic foot** is the standard unit of volume and the **second** is the standard **unit of time**. The standard unit of mass is the **slug**. This mass will accelerate by **1.0 ft /s** when a force of one pound (lbf) is applied to the mass. The **acceleration** due to gravity **(g) is 32.17 ft per second per second**.

Then, to obtain the **mass of a fluid the weight (lb)** must be **divided by 32.17**.

Density ρ: As defined above density is normally expressed as mass **(slug) per cubic foot**. The weight of a fluid can be expressed as pounds per cubic foot.

ρ = slugs/ft³

Water at a temperature of **70°F** has a **density** of **1.936 slug/ft³ - (62.286 lb/ft³)**

Dynamic Viscosity μ: As defined above the units of dynamic viscosity are Force / area x time, ***μ*** = lb.s/ft². Thus, water at a temperature of **70°F has a viscosity of 2.04 x 10^{-5} lb.s/ft².**

1.0 lb.s/ft² = 47880.26 Centipoise

Kinematic Viscosity v: The units of Kinematic Viscosity are area / time. Then, v = ft²/s.

1.0 ft²/s = 929.034116 Stokes = 92903.4116 Centistokes. Water at a temperature of **70°F has a viscosity of 10.5900 x 10^{-6} ft²/s (0.98384713 Centistokes)**

Kinematic Viscosity and Dynamic Viscosity Relationship: As defined, the imperial unit of Kinematic Viscosity is ft²/s. To understand the Imperial units involved in this relationship it will be necessary to use an example: Kinematic Viscosity = Dynamic Viscosity / Density.

$\boldsymbol{v = \mu / \rho}$

Dynamic viscosity μ = lb.s/ft². Density ρ = slug/ft³.

Substitute for slug = lb/32.17 ft.s². **Density ρ = (lb/32.174 ft•s²)/ft³ = (lb/32.17•s²)/ft^4**

Kinematic Viscosity v = (lb.s/ft²)/(slug/ft³), substitute lb•s²/ ft^4 for slug/ft³ = (lb.s/ft²) / (lb.s²/ ft^4) = ft²/s

Conversions: It is possible to **convert** between the **Imperial system** and the **Metric system** by substituting the equivalent of each dimension with the appropriate value.

1 slug/ft³ = 515.36 kg/m³. The **density of water is 1.94 slug/ft³** or **1000 kg/m³ (1 gr/cm³)**.

Fluid	T (°F)	Density (slug/ft^3)	*v* (ft^2/s)	T (°C)	Density (kg/m^3)	*v* (m^2/s)
Water	70	1.936	1.05 x 10^5	20	998.2	1.00 x 10^6
Water	40	1.94	1.66 x 10^5	5	1000	1.52 x 10^6
Seawater	60	1.99	1.26 x 10^5	16	1030	1.17 x 10^6

6. **Volumetric Flow Rate:** Is the volume of fluid, which passes through a given surface per unit of time. The **SI** unit is **m³/s** (cubic meters per second). In **US** Customary Units, volumetric flow rate is often expressed as **ft³/s** (cubic feet per second. The volumetric flow rate **(Q, ft³/s)** can be calculated by the cross sectional area **(A, ft²)** and the average flow velocity **(v, ft/s)**.

Q = A x v

Example 4: A pipe with an inner diameter of 4 inches contains water that flows at an average velocity of 14 ft/s. Calculate the volumetric flow rate of water in the pipe.

Q = (π.r²).v =

Q = (π x 0.16² ft) x 14 ft/s = **1.22 ft³/s**

Mass Flow Rate: The **mass flow rate** is also related to the **volumetric flow rate**, as shown using the equation below:

m = ρ x V. Replacing with the appropriate terms allows the calculation of direct mass flow rate:

m = ρ x (A x v)

Example 5: The water in the pipe, (previous example) had a **density of 62.44 lb/ft³** and a velocity of **1.22 ft/s**. Calculate the **mass flow rate**.

m = ρ x V =

m = 62.44 lb/ft³ x 1.22 ft/s =
m = 76.2 lb/s

7. **Continuity Equation:** The continuity equation is simply a mathematical expression of the principle of conservation of mass. The continuity equation is:

m (inlet) = m (outlet)

$(\rho_1 \times A_1 \times v_1)$ **inlet** $= (\rho_2 \times A_2 \times v_2)$ **outlet**

$(\rho_1 \times (R_1)^2 \times v_1)$ **inlet** $= (\rho_2 \times (R_2)^2 \times v_2)$ **outlet**

Example 6: In a piping process undergoes a gradual expansion from a **diameter of 6 in.** to a **diameter of 8 in.** The **density** of the fluid in the pipe is constant at **60.8 lb/ft³**. If the flow **velocity** is **22.4 ft/s** in the **6 in.** section, what is the **flow velocity** in the **8 in**. section?

m (inlet) = m (outlet) =

$(\rho_1 \times (R_1)^2 \times v_1)$ **inlet** $= (\rho_2 \times (R_2)^2 \times v_2)$ **outlet =**

$$v_2 \text{ (outlet)} = v_1 \times \frac{\rho_1}{\rho_2} \times \frac{(R_1)^2}{(R_2)^2} =$$

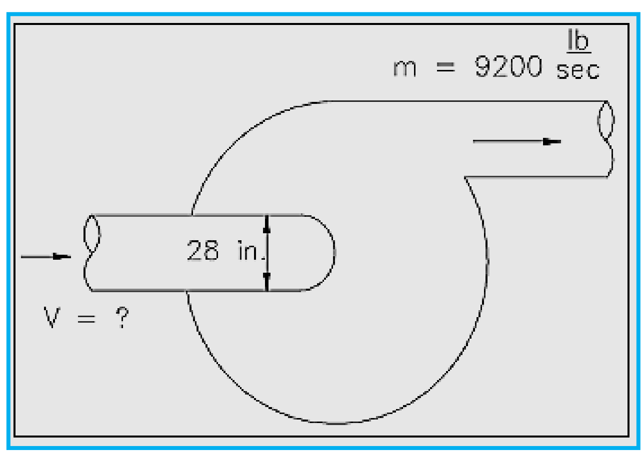
$\rho = \rho_1 = \rho_2$

$$v_2 \text{ (outlet)} = v_1 \times \frac{\rho_1}{\rho_2} \times \frac{(R_1)^2}{(R_2)} =$$

$$v_2 \text{ (outlet)} = 22.4 \text{ ft/s} \times \frac{60.8 \text{ lb/ft}^3}{60.8 \text{ lb/ft}^3} \times \frac{(3)^2}{(4)^2} =$$

v_2 **(outlet) = 12.6 ft/s** (decrease in flow velocity in the 8 in. section).

Example 7: The inlet diameter of the centrifugal pump, shown in figure below, is **28 in.** and the outlet flow through the pump is **9200 lb/s**. The density of the water is **49 lb/ft³**. What is the **velocity** at the pump inlet?



A $= \pi . r^2 = \pi \times (14 / 12)^2 =$ **4.28 ft²**

m = ρ.A.v = 9200 lb/s

$$v = \frac{9200 \text{ lb/s}}{A.\ \rho} = \frac{9200 \text{ lb/s}\ldots\ldots}{4.28 \text{ ft}^2 \times 49 \text{ lb/ft}^3} =$$

v = 43.9 ft/s

8. **Reynolds Number:** The **Reynolds Number**, based on studies of **Osborn Reynolds**, is a dimensionless number comprised of the physical characteristics of the flow. The flow regime, called commonly **laminar or turbulent**, is determined by evaluating the Reynolds Number of the flow.

If the Reynolds number is less than **2000, the flow is laminar**. Reynolds numbers **between 2000 and 3500** are sometimes referred to as **transitional flows**. If it is **greater than 3500**, **the flow is turbulent**. Most fluid systems in plant facilities operate with turbulent flow. The equation used to calculate the **Reynolds Number** for fluid flow is:

$$\mathbf{Re} = \frac{\rho\, v\, D}{\mu\, g_c} \quad \text{or,} \quad \mathbf{Re} = \frac{\rho\, v\, D}{\mu} =$$

Where:

Re = Reynolds Number (unitless)
v = Velocity (ft/sec)
D = Diameter of pipe (ft)
μ = Absolute Viscosity of fluid (lbf.s/ft²)
ρ = Fluid Density (lb/ft³)
g_c = Gravitational constant (32.17 ft-lbm/lbf-s²)

Obs.: Reynolds numbers can also be conveniently determined using the Moody Chart.

Example 8: A hydraulic hose with internal diameter of 1.0 in. is carrying oil with kinematic viscosity 50 cSt at a flow rate of 20 gpm. Calculate the Reynolds number and determine if the flow is laminar or turbulent.

Solution: Convert to SI units:

Q = 10 gpm = 0.00126 m³/s
D = 1:0 in. = 0.0254 m
v = 50 cSt = 5.0×10^{-5} m²/s

Find the average velocity:

$$V = \frac{4Q}{\pi D^2} = \frac{(4)(.00126)}{(3.142)(.0254)^2} = 2.49\ \mathrm{m/s}$$

Calculate the Reynolds number:

$$\mathrm{Re} = \frac{\mathrm{VD}}{\nu} = \frac{(2.49)(.0254)}{5.0 \times 10^{-5}} = 1265$$

Because Re is below 2000, the flow is laminar.

9. **Simplified Bernoulli Equation:** Is a result from the application of the **first Law of Thermodynamics** to a flow system in which no work is done by the fluid, no heat is transferred to, or from the fluid, and no temperature change occurs in the internal energy. So, the general energy equation is simplified to equation below:

$$\frac{mgz_1}{g_c} + \frac{mv_1^2}{2g_c} + P_1 v_1 = \frac{mgz_2}{g_c} + \frac{mv_2^2}{2g_c} + P_2 v_2$$

Where:

m = Mass of the fluid (lbm)
z = Height above reference (ft)
v = Velocity (ft/s)
g = Acceleration due gravity **(32.17 ft/s²)**
g_c = Gravitational constant, **(32.17 ft-lbm/lbf-s²)**

Note: The **factor g_c** is only required when the **English System** of measurement is used and mass is measured in pound mass. It is **essentially a conversion factor** needed to allow the units to come out directly. If mass is **measured in slugs or if the metric system** of measurement is used.

Multiplying all terms of the above equation, by the factor g_c / m.g, the form of Bernoulli's equation is:

$$z_1 + \frac{v_1^2}{2g} + P_1 v_1 \frac{g_c}{g} = z_2 + \frac{v_2^2}{2g} + P_2 v_2 \frac{g_c}{g} =$$

Extended Bernoulli Equation: The Bernoulli equation can be modified to take into account **gains and losses of head**. The head loss due to fluid friction **(Hf)** represents the energy used in overcoming friction caused by the walls of the pipe.

Then, the applied extended Bernoulli equation is very useful in solving most fluid flow problems, as shown below:

$$z_1 + \frac{v_1^2}{2g} + P_1 v_1 \frac{g_c}{g} + H_p = z_2 + \frac{v_2^2}{2g} + P_2 v_2 \frac{g_c}{g} + H_f =$$

Where:

z = Height above reference level (ft)
v = Velocity of fluid (ft/s)
P = Pressure of fluid (lbf/ft²)
n = Volume of fluid (ft³/lbm)
Hp = Head added by pump (ft)
H_f = Head loss due to fluid friction (ft)
g = Acceleration due to gravity (ft/s²)

Example 9: Water is pumped from a large reservoir to a point **65 ft** higher. How many **feet of head** must be added by the pump, if **8000 lb/h** flows through a **6 inch pipe** and the **frictional head loss (Hf) is 2.0 ft**? The density of the fluid is **62.4 lb/ft³**, and the **cross-sectional area** of the pipe is **0.2006 ft²**.

$$\mathbf{m = \rho.A.v}$$

$$\mathbf{v = \frac{m}{\rho.A}}$$

$$v = \frac{8000\ \text{lb/h}.............}{(62.4\ \text{lb/ft}^3)\ (0.2006\ \text{ft}^2}$$

$$\mathbf{v = 639\ ft/h = 0.178\ ft/s}$$

Using the Extended Bernoulli equation to determine the required pump head:

$$z_1 + \frac{v_1^2}{2g} + P_1\, v_1 \frac{g_c}{g} + H_p = z_2 + \frac{v_2^2}{2g} + P_2\, v_2 \frac{g_c}{g} + H_f =$$

$$H_p = (z_2 - z_1) + \frac{v_1^2 - v_2^2}{2\,g} + (P_2 - P_1)\, v \frac{g_c}{g} + H_f =$$

Considering that, $(z_2 - z_1) = 65ft$; $(P_2 - P_1)\, v \frac{g_c}{g} = 0$; $v_1 = 0.178$ ft/s; and $H_f = 2.0$ ft

$$H_p = 65\ \text{ft} + \frac{(0.178\ \text{ft/s})^2 - (0\ \text{ft/s})^2}{2\ (32.17\ \text{ft-lbm/lbf-s}^2)} + 0 + 2\ \text{ft} =$$

$$\mathbf{H_p = 67\ ft.}$$

Boyle's law: Sometimes referred to as the Boyle–Mariotte law is an experimental gas law, which describes how the pressure of a gas tends to decrease as the volume of a gas increases. “The absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system”.

$$\mathbf{P_1.V_1 = P_2.V_2}$$

V = volume (in^3 or m^3);
P = pressure (lb or N).

Charles' law: Also known as, the law of volumes is an experimental gas law, which describes how gases tend to expand when heated. “When the pressure on a sample of a dry gas is held constant, the Kelvin temperature and the volume will be directly related”.

$$\mathbf{V_1 / T_1 = V_2 / T_2}$$

Where:

V = volume (in^3 or m^3);
T = *absolute* temperature (°R).

Gay-Lussac's law: The absolute pressure of a gas increases or decreases as the temperature increases or decreases, provided the amount of gas and the volume remain constant.

$$\mathbf{P_1 / T_1 = P_2 / T_2}$$

p = *absolute* pressure (lb/in^2 or N/m^2);
T = *absolute* temperature (°R)

Torque, Horsepower: The twisting force found by multiplying the force times the distance is designated as torque, (Force x Radius) measured in kg.meter or foot.pounds. Horsepower, a unit measurement of energy, is a common term used to measure power. Given a specific motor torque and motor rotation (RPM), it specifies energy usage or horsepower requirement.

Head: The term **head** is used in **reference to pressure**. It is a reference to the **height** (typically in feet), of a **column of water** that a given **pressure** will support. The **pressure head** represents the flow energy of a column of fluid **whose weight** is equivalent to the pressure of the fluid. The sum of the **elevation head, velocity head, and pressure head** of a fluid is called the **total head**. As defined above, the Bernoulli's equation states that the **total head** of the fluid is **constant**.

Example 10: Assume frictionless flow in a long, horizontal, conical pipe. The diameter is **2.0 ft** at one end and **4.0 ft** at the other. The **pressure head** at the smaller end is **16.0 ft of water**. If water flows through this cone at a rate of **125.6 ft³/s,** find the **velocities at the two ends** and the **pressure head** at the larger end.

$$\mathbf{v_1 = \frac{Q_1}{A_1} \qquad v_2 = \frac{Q_2}{A_2}}$$

$$v_1 = \frac{125.6}{\pi\,(1)^2} \qquad v_2 = \frac{125.6}{\pi\,(2)^2}$$

$$\mathbf{v_1 = 40\ ft/s \qquad v_2 = 10\ ft/s}$$

$$z_1 + \frac{v_1^2}{2g} + P_1\, v_1\, \frac{g_c}{g} = z_2 + \frac{v_2^2}{2g} + P_2\, v_2\, \frac{g_c}{g} =$$

$$P_2\, v_2\, \frac{g_c}{g} = P_1\, v_1\, \frac{g_c}{g} + (z_1 - z_2) + \frac{v_1^2 - v_2^2}{2\,g} =$$

Considering that, $P_1\, v_1\, \frac{g_c}{g} = \mathbf{P_{h1} = 16\ ft;}$ $P_2\, v_2\, \frac{g_c}{g} = \mathbf{P_{h2}}$; and $\mathbf{(z_1 - z_2) = 0}$

$$P_{h2} = 16 \text{ ft} + 0 + \frac{(40 \text{ ft/s})^2 - (10 \text{ ft/s})^2}{2.\ (32.17 \text{ ft-lbm/lbf-s}^2)} =$$

$$P_{h2} = 16 \text{ ft} + 0 + \frac{(1600) - (100)}{64.34} =$$

$$\mathbf{P_{h2} = 39.3\ ft.}$$

10. **Head Loss, Darcy-Weisbach & Hazen-Williams:** Head loss is a measure of the reduction in the total head (sum of elevation head, velocity head and pressure head) of the fluid as it moves through a fluid system. The **head loss** is directly proportional to the **length of pipe**, the **square of the velocity**, and a term for fluid friction called the **friction factor**.

Darcy-Weisbach Head Loss, $\mathbf{H_f = f.\ \frac{L\ v^2}{D\ 2g} =}$

Where:

f = Friction Factor (see Moody Chart)
L = Length of pipe, ft
v = Velocity of fluid, ft/s
D = Diameter of pipe, ft
g = Acceleration due gravity (ft/s²)

As a rule of thumb, for transition flow with Reynolds numbers **between 4,000 and 100,000**, **SI** friction factors will be of the order suggested by **equation 1**, whilst **Imperial** friction factors will be of the order suggested by **equation 2**. Consider the equations below only for an estimating calculation.

$$\mathbf{f = \sim \frac{0.55}{Re^{0.25}}} \quad \mathbf{(1)} \qquad \mathbf{f = \sim \frac{0.3}{Re^{0.25}}} \quad \mathbf{(2)}$$

Example 14 (above): $\mathbf{f =} \frac{\sim 0.55}{40{,}000^{0.25}} = \mathbf{0.039}$

Darcy-Weisbach Equations: The **Darcy-Weisbach equation** can be calculated using a relationship known as **frictional head loss**. The calculation takes **two distinct forms**. The **first form** is associated with the **piping length** and the **second form** is associated with the **piping fittings and accessories**, with a **coefficient "K"**.

Darcy-Weisbach equation associated with piping length:

$$\mathbf{H_f = f\ \frac{L\ v^2}{D\ 2g} =}$$

Where:

f = Friction factor (unitless)
L = Length of pipe (ft)
D = Diameter of pipe (ft)

v = Velocity of fluid (ft/s)
g = Acceleration due gravity (ft/s²)

Example 10: A pipe **100 ft long and 20 inches in diameter** contains water at **200°F** flowing at a mass flow rate of **700 lb/s**. The water has a **density of 60 lb/ft³** and a **viscosity of 1.978 x 10^{-7} lbf-s/ft²**. The **relative roughness** of the pipe is **0.00008**. Calculate the **head loss** for the pipe.

$$m = \rho . A . v$$

$$v = \frac{m}{\rho . A}$$

$$v = \frac{700 \text{ lb/s}}{(60 \text{ lb/ft}^3)\ \pi\ \frac{(10 \text{ in})^2}{144}} =$$

$$v = 5.35 \text{ ft/s}$$

The **Reynolds Number** is:

$$R_n = \frac{\rho\ v\ D}{\mu\ g_c}$$

$$R_n = \frac{60 \times 5.35 \times \frac{(20)}{12}}{(1.978 \times 10^{-7})(32.17)} = 8.4 \times 10^7$$

The Moody Chart for a Reynolds Number of **8.4 x 10^7** and a relative roughness of **0.00008, f = 0.012.**

$$H_f = f.\ \frac{L\ v^2}{D\ 2g} =$$

$$H_f = (0.012)\ \frac{100.}{\frac{20}{12}}\ \frac{(5.35)^2}{2 \times 32.17} =$$

$$H_f = 0.32 \text{ ft}$$

Hazen-Williams Equation: Since the approach does not require so efficient trial and error, an **alternative empirical piping head loss** calculation, like **Hazen-Williams** equation, may be preferred, as indicated below:

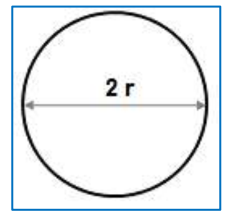
$$H_f = \frac{0.2083\ (100 / C)^{1.85} \times Q^{1.85}}{D^{4.8655}} = \text{(in feet)}; \qquad H_f = \frac{10.64 \times Q^{1.85}}{C^{1.85}\ D^{4.8655}} = \text{(in meters)}$$

Where:

f = Friction head loss in feet of water (per 100 ft of pipe);
C = Hazen-Williams roughness constant (see table below);
Q = Volume flow (gpm);
D = Inside pipe diameter (inches);
L = Length of pipe, (in. or m).

Hydraulic Diameter: The hydraulic diameter uses the perimeter and the area of the conduit to provide the diameter of a pipe which has proportions such that conservation of momentum is maintained.

The hydraulic diameter of a Circular Tube or Duct can be expressed as:

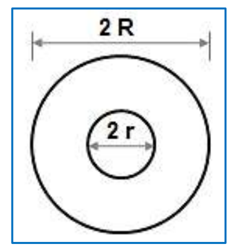


$D_h = 2r$

Where:

r = Pipe or Duct radius (ft)

The hydraulic diameter of a Circular Tube with an inside Circular Tube can be expressed as:

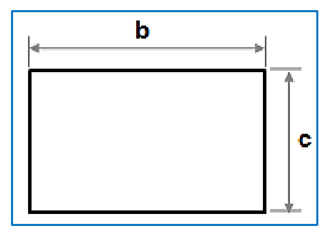


$D_h = 2(R - r)$

Where:

r = Inside radius of the outside tube (ft)
R = Outside radius of the inside tube (ft)

The hydraulic diameter of Rectangular Tubes or Ducts can be expressed as:



$D_h = 2\,b\,c\,/\,(b + c)$

Where:

b = width/height of the duct (ft)
c = height/width of the duct (ft)

Pipe Roughness Ratio: The relative piping roughness is the ratio of the **surface roughness** (**ε – see table below**), divided by the **diameter (D)** of the pipe or duct, as a result of equation **ε / D.**

Simplified Pressure Drop: The equation for calculating the simplified pressure drop is:

$\Delta p = \rho . g . H_f =$

Where:

ρ = Density of fluid, in slugs/ft^3;
g = Acceleration due gravity, 32.17 ft/s^2;
H_f = Frictional head loss.

Example 11: Using the same **example in problem 16** (page 13), calculate the **simplified pressure drop** (in psi), knowing that the frictional head loss is **H_f = 0.58** and fluid density is **1.94 slugs/ft^3.**

Solution: The simplified **pressure drop** is:

$\Delta p = \rho.g.H_f$ =

Δp = 1.94 x 32.17 x 0.58 = **36 lb/ft²**

Δp = 36/144 psi = **0.25 psi**

Converting Head to Pressure: Converting head in **feet to pressure,** in psi:

p = 0.433 h SG

p = Pressure (psi)
h = Head (ft)
SG = Specific Gravity

Converting head in **meter to pressure,** in bar:

p = 0.0981 h SG

h = Head (m)
p = Pressure (bar)

Converting pressure in **psi to head,** in feet:

h = p 2.31 / SG

Where:
h = Head (ft)
p = Pressure (psi)

Converting pressure in **bar to head,** in meter:

h = p 10.197 / SG

h = Head (m)
p = Pressure (bar)

Example 12: The **pressure – psi**, of a hydraulic pump (oil = 0.8) with a **head of 50 ft** is expressed as:

p = (50 ft) x 0.8 / 2.31 =

p = 17.3 psi

Temperature: Temperature **decreases** with **altitude** starting at **sea level**. Above 11 km, the temperature stabilizes through a large vertical distance through the rest of the troposphere. The main temperature units are:

- ✓ **Celsius** scale (also known as centigrade) at **0°C** is defined as the freezing point of water, and the temperature at **100 °C** is defined as the boiling point of water.

- ✓ **Fahrenheit** scale at **32°F** is defined as the freezing point of water, and the temperature at **212°F** is defined as the boiling point of water.

The relation between Celsius and Fahrenheit becomes:

F° = 1.8 C° + 32

C° = $\frac{F-32}{1.8}$

OBS.: The average temperature of the atmosphere at the surface of Earth is 14 °C (57 °F; 287 K) or 15 °C (59 °F; 288 K) depending on the reference.

Vapor Pressure or Saturated Vapor Pressure: Vapor pressure can be defined as the pressure exerted by a vapor in thermo-dynamic equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system. Vapor pressure measures the pressure exerted by a vapor in thermodynamic equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system.

The atmospheric pressure boiling point of a liquid (also known as the normal boiling point) is the temperature at which the vapor pressure equals the ambient atmospheric pressure. The vapor pressure of a single component in a mixture that contributes to the total pressure in the system is called partial pressure. For example, **air** at sea level, and saturated with water vapor at **21 °C**, has partial pressures of about **0.025 bar** of water, as can be seen below:

A fluid's **vapor pressure** is the **force per unit area** that a fluid exerts as an effort to change phase from a **liquid to a vapor**, and depends on the fluid's chemical and physical properties. **At 60°F**, the **vapor pressure of water** is approximately **0.25 psia;** at **212°F** (boiling point of water) the **vapor pressure** is **14.7 psia** (atmospheric pressure).

Imperial and Metric Relations:

1 foot of head = 0.433 psi = **~0.030 kg/cm²**
1.0 psi = 0.0703 kg/cm² = **2.31 feet**

Water Vapor Pressure - Suction Head:

Temperature		**Abs. Water Vapor Pressure**		**Max. Elevation**	
C°	***F°***	*psi/psia*	*bar*	*(m)*	(ft)
0	**32**	0.0886	0.0061	0.062	0.2044
5	**40**	0.1217	0.0084	0.085	0.2807
10	**50**	0.1781	0.0122	0.125	0.4108
15	**60**	0.2563	0.0176	0.180	0.5912
21	**70**	0.3631	0.0250	0.255	0.8376
25	**77**	0.4593	0.0316	0.322	1.0594
30	**86**	0.6152	0.0424	0.432	1.4190

35	**95**	0.8153	0.0562	0.573	1.8806
40	**104**	1.069	0.0737	0.751	2.4658
45	**113**	1.389	0.0957	0.976	3.2040
50	**122**	1.789	0.1233	1.258	4.1267
55	**131**	2.282	0.1573	1.604	5.2639
60	**140**	2.888	0.1991	2.030	6.6618
65	**149**	3.635	0.2506	2.555	8.3849
70	**158**	4.519	0.3115	3.177	10.424
75	**167**	5.601	0.3861	3.938	12.9199
80	**176**	6.866	0.4733	4.827	15.8379
85	**185**	8.398	0.5790	5.904	19.3718
90	**194**	10.167	0.7010	7.148	23.4524
95	**203**	12.257	0.8450	8.618	28.2735
100	**212**	14.695	1.0132	10.332	33.8973

Note: In Imperial system, the unit used for mass is the slug and not the lb.mass**.** 1 slug **=** 32.174 lbm**.**
- International System **-** 1 Newton (N) = 1 kg m/s^2 - Imperial **-** 1 lbf = 1 slug ft/s^2

Water: ρ_w = 62.4 lb/ft^3 - **do not use this value** - instead, use ρ_w = **1.94 slug/ft^3**.

Manometry **ρ . g . h** (kg/m^3) * (m/s^2)* (m) = **(kg m/s^2) / m^2 = N/m^2**
(slug/ft^3) * (ft/s^2) * (ft) = **(slug ft/s^2) / ft^2 = lbf/ft^2**

Imperial Units References:

- **CFM (Cubic Feet per Minute):** is the imperial method of describing the volume flow rate of compressed air. It must be defined further to take account of pressure, temperature, and relative humidity.
- **SCFM (Standard CFM):** is the flow in CFM measured at some reference point but converted back to standard or normal air conditions (Standard Reference Atmosphere) 14.7 psia, 60°F and 0% relative humidity.
- **ICFM (Inlet CFM):** rating is used to measure air flow in CFM (ft^3/min) as it enters the air compressor intake.
- **ACFM (Actual CFM):** rating is used to measure air flow in CFM at some reference point at local conditions. This is the actual volume flow rate in the pipework after the compressor.

Europe Units References:

- **ANR** (Atmosphere Normale de Reference) is quantity of air at conditions **1.013 bar absolute** (1.033 kg/cm^2 abs), 20^o C and 65% RH (Relative Humidity).

- **Nl/min** (Normal liter/min) is the flow in l/min measured at some reference point but converted to standard or normal air conditions **1.013 bar absolute** (1.033 kg/cm² abs), 0°C, and 0% RH (Relative Humidity).
- **ISO 1217** Standard reference for ambient conditions - temperature 20°C, pressure 1.0 bar abs, relative humidity 0%, cooling air/water 20°C and working pressure at outlet 7.0 bar absolute.

The Barometer: Evangelista Torricelli was born in 1608 in Faenza, Italy and died in 1647 in Florence, Italy and became the first scientist to discover the principle of a barometer, in 1643. Galileo suggested to use mercury in his vacuum experiments. It works because the air applies pressure with its weight.

Torricelli noted that the opening of a glass tube filled with mercury, the atmospheric pressure would affect the weight of the column of mercury in the tube. The higher the air pressure, the longer is the column of mercury. Thus, the pressure can be calculated by multiplying the height of the column of mercury by mercury density and the acceleration of gravity.

At sea level, atmospheric pressure is about 15 psi, 29.9 in.Hg (inches of mercury) or 760 mmHg. This is equivalent to 101.3 kPa, the unit of pressure used by meteorologists, in addition to millibars. There are two types of barometers in current use: the **mercury** barometers and the **aneroid** barometers, invented the French scientist Lucien Vidie, in 1843.

The aneroid barometer "registers the change in the shape of an evacuated metal cell to measure variations on the atmospheric pressure. “Aneroid means fluidless, no liquids are used, the metal cell is usually made of phosphor bronze or beryllium copper”.

An **altimeter** is an aneroid barometer that measures altitude. Meteorologists, geologists, and land surveyors use altimeters that measure the altitude with respect to sea level pressure. A **barograph** is an aneroid barometer that gives a continuous reading of atmospheric pressures on a graph paper.

Definition for Cv: Literally, Cv means coefficient of velocity, generally used to compare flows of hydraulic or pneumatic valves. The higher the Cv, the greater the flow. It is sometimes helpful to convert Cv into SCFM (Standard Cubic Feet per Minute) and conversely, SCFM into Cv. (SCFM means Standard Cubic Feet per Minute. “Standard” is air at sea level and at 70° F). Although Cv represents flow capacity at all pressures, SCFM represents flow at a specific air pressure. The following chart relates Cv to SCFM at a group of pressures, as shown below:

Cv to SCFM Conversion Factor Table

PSI of Air Pressure	40	50	60	70	80	90	100
Factor	.0370	.0312	.0270	.0238	.0212	.0192	.0177

Example 13: What is the output in SCFM of a value with a Cv of 0.48 when operated at 100 PSI?

$$\textbf{SCFM} = \frac{0.48..}{0.0177} = \textbf{27 (scfm)}$$

Obs.: To convert SCFM into Cv, reverse the process, and multiply the SCFM times the factor.

HYDRAULIC OIL PROPERTIES:

In hydraulic fluid power systems, the fluid is commonly oil or water, ideal for high speed, and high power applications, capable of generating extremely high forces with relatively lightweight cylinder actuators. However, oil power is not all-good news. The hydraulic systems can leak oil at connections and seals, oil flow is not as easy to generate as electric power and requires a heavy, noisy pump.

Oil fluids can cavitate and retain air resulting from a spongy performance and loss of precision. However, other practical considerations dictate the specific fluids used in oil flow systems. The fluids must cool the system by dissipation of heat in piping, radiators, or reservoirs, must lubricate sliding and rotating surfaces such as those in motors and cylinders, must avoid to corrode components and process equipment must have a long life without a chemical breakdown.

Modern hydraulic systems use petroleum-based oils, with additives to inhibit foaming and corrosion, since petroleum oils are inexpensive, provide good lubrication, and with additives, have long life. The brake and automatic transmission fluids in your car are examples.

Organic oils: Organic oils are produced by plants, animals, and other organisms through natural metabolic processes. Lipid is the scientific term for fatty acids, steroids, and similar chemicals often found in the oils produced by living things, while oil refers to an overall mixture of chemicals, including proteins, waxes, and alkaloids.

Mineral oils: Crude oil, or petroleum, and its refined components, collectively termed as petrochemicals, are crucial resources in the modern economy. Crude oil originates from ancient fossilized organic materials, such as zooplankton and algae, which geochemical processes convert into oil. Mineral oil is also organic, classified as "mineral oil" instead of as "organic oil" because of its organic remote origin and because it is obtained near rocks, underground traps, and sands. The mineral oil also reference to several specific distillates of petroleum crude oil.

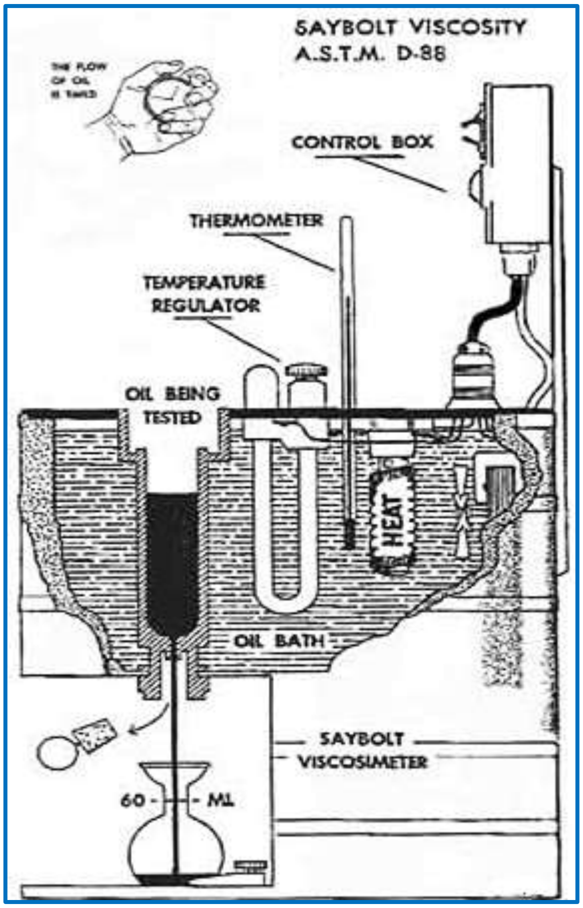
Viscosity: As defined before, viscosity is a measure of a fluid's resistance to flow. A liquid, such as gasoline, which flows easily has a low viscosity, and a liquid, such as tar, which flows slowly has a high viscosity. The viscosity of a liquid is affected by changes in temperature and pressure, and as the temperature of a liquid increases, its viscosity decreases.

On the other hand, if the liquid is too thick (viscosity is too high), the internal friction of the liquid will cause an increase in the liquid's flow resistance through clearances of closely fitted parts, lines, and internal passages. This results in pressure drops throughout the system, sluggish operation of the equipment, and consequently an increase in power consumption.

Saybolt Universal Seconds (SSU): Several types of viscometers are in use today. The Saybolt viscometer, shown below, measures the time required, in seconds, for 60 milliliters of the tested fluid at 100°F to pass through a standard orifice. The time measured is used to express the fluid's viscosity, in Saybolt Universal Seconds (SSU) or Saybolt- Furol Seconds (SFS).

The Saybolt viscometer, measures the time in seconds required for the tested fluid to flow through the capillary. This time is multiplied by the temperature constant of the viscometer in use to provide the viscosity, expressed in centistokes. The following formulas may be used to convert centistokes (cSt units) to approximate Saybolt universal seconds (SUS units). The following formulas may be used to convert centistokes to approximate Saybolt universal seconds (SUS units).

- ✓ SFS = SSU / 10.
- ✓ For SUS values between **32 and 100**: cSt = 0.226 x SUS – 195 / SUS.
- ✓ For SUS values **greater than 100**: cSt = 0.220 x SUS – 135 / SUS.



The petroleum industry relied on measuring kinematic viscosity by means of the Saybolt viscometer, and expressing kinematic viscosity in units of Saybolt Universal Seconds (SUS) and Saybolt Furol Seconds (SFS), however, this practice is **now obsolete** in the petroleum industry. This practice establishes the official equations relating SUS and SFS to the SI kinematic viscosity units, mm²/s (cSt).

The ASTM D2161 - 10 (Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity), covers the conversion tables and equations converting kinematic viscosity in mm²/s at 122°F and 210°F (50°C and 98.9°C) to Saybolt Furol viscosity and Saybolt Furol seconds (SFS), based on water being 1.0034 mm²/s (cSt) at 68°F (20°C).

Dynamic Viscosity: Is a measurement of a lubricant's internal friction and it is usually reported in units called poise (P) or centipoise (1 P = 0.01 cP). Force is required to make the plates move, or overcome the fluid's film friction thus, this force is known as dynamic viscosity. A common tool used to measure dynamic viscosity is the Brookfield viscometer, which employs a rotating spindle that experiences torque as it rotate against fluid friction.

Kinematic Viscosity: As defined above, the fluid density as a quotient of the fluid's dynamic viscosity is usually reported in stokes (St) or centistokes (1 St = 0.01 cSt). The kinematic viscosity is determined by using a capillary viscometer in which a fixed volume of fluid is passed through a small orifice at a controlled temperature under the influence of gravity.

Fluid Oil Viscosity Classification: The Society of Automotive Engineers (SAE) has created two viscosity standards for automotive lubricants. The SAE J300 is a viscosity classification for engine oils, summarized in Table 1. The SAE J306 is for axle and manual transmission lubricants, shown in Table 2. For both these classifications, the grades are denoted with the letter "W", intended for use in applications operating in low-temperature conditions, or lubricants considered "winter grade". Nowadays, the "W" products are formally called multigrade lubricants, and the grades without the "W" are recognized as monograde, or straight grade lubricants.

SAE Grade	Viscosity, cP Max.	cP Max - no yield stress	Kinematic Viscosity (cSt) at 100°C Max.	Kinematic Viscosity (cSt) at 40°C Max.	Viscosity (cP) at 150°C Min.
0W	3250 @ -30	60,000 @ -40	3.8	-	-
5W	3500 @ -25	60,000 @ -35	3.8	-	-
10W	3500 @ -20	60,000 @ -30	4.1	-	-
15W	3500 @ -15	60,000 @ -25	5.6	-	-
20W	4500 @ -10	60,000 @ -20	5.6	-	-
25W	6000 @ -5	60,000 @ -15	9.3	-	-
20	-	-	5.6	<9.3	2.6
30	-	-	9.3	<12.5	2.9
40	-	-	12.5	<16.3	2.9*
40	-	-	12.5	<16.3	3.7**
50	-	-	16.3	<21.9	3.7
60	-	-	21.9	<26.1	3.7

Notes: * For 0W-40, 5W-40 and 10W-40 Grades.
** For 15W-40, 20W-40, 25W-40 and 40 Grades.

SAE Viscosity Grade	Maximum Temp. for Viscosity of 150,000 cP, °C	Viscosity at 100°C - cSt Minimum	Viscosity at 100°C - cSt Maximum
70W	-55	4.1	-
75W	-40	4.1	-
80W	-26	7.0	-
85W	-12	11.0	-
80	-	7.0	<11.0
85	-	11.0	<13.5
90	-	13.5	<18.5
110	-	18.5	<24.0
140	-	24.0	<32.5
190	-	32.5	<41.0
250	-	41.0	-

Industrial Hydraulic Oils: Are also specified according to various viscosity classifications, most frequently used in industrial viscosity classification jointly developed by ASTM and STLE (Society of Tribologists and Lubrication Engineers), and recognized as ASTM D2422. This method originally standardized 18 different viscosity oil grades measured at 100°F in Saybolt Universal Seconds (SUS), later converted to the more universally accepted metric system values measured at 40°C. These ranges denoted in Table 3, are recognized as “ISO Viscosity Grade Numbers”, or “ISO VG numbers”.

ISO Grade	Kinematic Viscosity at 40°C, Min. cSt	Kinematic Viscosity at 40°C, Max. cSt
2	1.98	2.42
3	2.88	3.52
5	4.14	5.06
7	6.12	7.48
10	9.00	11.0
15	13.5	16.5
22	19.8	24.2
32	28.8	35.2

ISO Grade	Kinematic Viscosity at 40°C, Min. cSt	Kinematic Viscosity at 40°C, Max. cSt
46	41.4	50.6
68	61.2	74.8
100	90.0	110
150	135	165
220	198	242
320	288	352
460	414	506
680	612	748
1000	900	1100
1500	1350	1650

Degree Engler: Is commonly used in Great Britain as a scale to measure the kinematic viscosity. Unlike the Saybolt and Redwood scales, the Engler scale is based on comparing a flow of the substance being tested to the flow of another substance - water. Viscosity in Engler degrees is the ratio of the time of a flow of 200 cm^3 of the fluid whose viscosity is being measured - to the time of flow of 200 cm^3 of water at the same temperature (usually20ºC but sometimes 50ºC or 100ºC) always tested in a standardized Engler viscosity meter, according to the following formula:

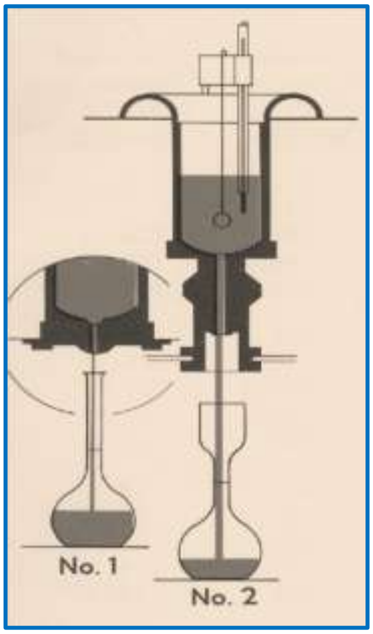
$$E^o = \frac{\text{Drain time - 200 cm}^3\text{ of oil + C}^o\text{ temperature}}{\text{Drain time - 200 cm}^3\text{ of distilled water at 20ºC}}$$

Redwood Viscometer N. 1: Consist of vertical cylindrical oil cup that holds the test sample, surrounded by the water bath. The oil is heated by heating the water by means of an immersed electric heater in the water bath. The cylinder is approximately 50 mm in diameter and 90 mm deep and the orifice is 1.62 mm in diameter. The time for a sample of 50 ml to flow through the orifice is measured, with a calibrated receiving flask.

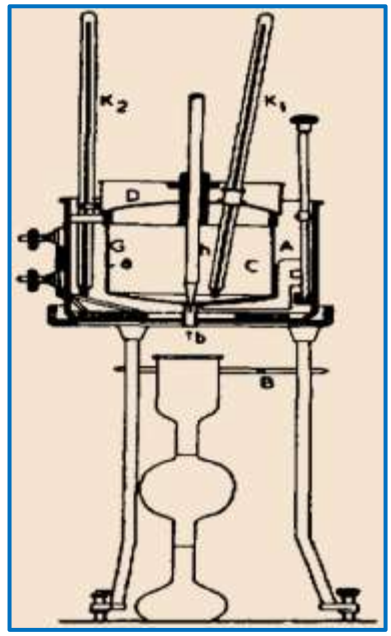
Redwood Viscometer N. 2: Has the same principle except that the cylindrical oil cup is designed with a larger discharge tube, that is, 3.80 mm diameter. The receiving flask is similar, but designed with a larger orifice diameter. The results are reported in seconds, for example, 140ºF, 350 seconds.

Reyn and Pascal-second: Are used for such large units that microreyn (μreyn) and millipascal second (mPa·s) are more commonly used. The former standard metric unit of viscosity was the poise. One centipoise, cp, is equal to one millipascal-second: 1 cp = 1 mPa·s.

1 reyn =1 lb·s/in² = 6890N·s/m² = 6890 Pa·s.



Redwood Test



Engler Test

Temperature Application: During summer the ambient temperatures are high and the oil tends to be thinner, so a more viscous oil should be used. The SAE 10W-20 is thinner oil than the SAE 10W-30 or SAE 15W-30 at high temperatures as indicated by the second number (20 < 30). Therefore in warm temperatures, a thicker oil (SAE 10W-30 or SAE 15W-30) could offer better engine protection than SAE 10W-20. In summer SAE 10W type oil is not required which is why the SAE 15W-40 is favored.

Viscosity of Some Common Liquids:

Centistokes *(cSt)*	Saybolt Second Universal *(SSU)*	Typical liquid
1.0	31	Water (20^{o}C)
4.3	40	SAE 20 Crankcase Oil SAE 75 Gear Oil
15.7	80	No. 4 fuel oil
20.6	100	Cream
43.2	200	Vegetable oil
110	500	SAE 30 Crankcase Oil SAE 85 Gear Oil
220	1000	SAE 50 Crankcase Oil SAE 90 Gear Oil
440	2000	SAE 140 Gear Oil
1100	5000	Glycerine (20^{o}C) SAE 250 Gear Oil

Mineral Oils X Synthetic Oils: The synthetic oils offer certain advantages over mineral oils in terms of low temperature performance and high temperature oxidation stability. Synthetic oils can be formulated from mineral oils and are more than suitable for most engine applications. A hydraulic synthetic oil are considered for very cold temperatures, or for applications that may need a high level of oxidation protection. The manufacturer's recommendations should be followed.

Flash Point: Refers to flammable liquids or combustible liquids. There are various standards for definition of each term. Liquids with a flash point less than 60.5 or 37.8 °C (140.9 or 100.0 °F) - depending upon the standard being applied - are considered flammable, while liquids with a flash point above those temperatures are considered combustible. For example, testing by the Pensky-Martens closed cup method is detailed in ASTM D93 and ISO 2719. Determination of flash point by the Small Scale closed cup method is detailed in ASTM D3828, D3278, and EN ISO 3679.

Pour Point: Is the temperature at which a fluid becomes semi solid and loses its flow characteristics. In crude oil, a high pour point is generally associated with high paraffin content. Within a temperature range, the sample may appear liquid or solid. The ASTM D5949, Standard Test Method for Pour Point of Petroleum Products (Automatic Pressure Pulsing Method) is an alternative to the manual test procedure. It uses automatic apparatus and yields pour point results in a format similar to the manual method (ASTM D97) when reporting at a 3°C.

Viscosity index (VI): Measures the variation in viscosity with temperature. The viscosity index, on the Dean and Davis scale, of Pennsylvania oils is **VI=100**. The viscosity index, on the same scale, of Gulf Coast oils is **VI=0**. Other oils are rated intermediately. Nonpetroleum-base lubricants have widely varying viscosity indices. Silicone oils have relatively little variation of viscosity with temperature. The viscosity index improvers (additives) can increase viscosity index of petroleum oils.

American Petroleum Institute Gravity: Also called API gravity, is a measure of how heavy or light petroleum liquid is compared to water. When API gravity is greater than 10, it is lighter and floats on water; if less than 10, it is heavier and sinks. API gravity is thus an inverse measure of the relative density of a petroleum liquid and the density of water, but it is used to compare the relative densities of petroleum liquids. For example, if one petroleum liquid floats on another and is therefore less dense, it has a greater API gravity.

When converting between density and relative density, it is important to use the correct density of water. The official density of water at 60°F according to the 2008 edition of ASTM D1250 is 999.016 kg/m³. The 1980 value is 999.012 kg/m³. In some cases the standard conditions may be 15°C (59°F) and not 60°F (15.56°C). Thus, oil with an API gravity between 40 and 45 commands the highest prices and above 45º the molecular chains become shorter and less valuable to refineries.

Crude oil is classified as **light**, **medium**, or **heavy**, according to its measured API gravity. Crude oil with API gravity less than 10° API is referred to as extra heavy oil or bitumen. The classification is:

- Light crude oil defined as having an API gravity higher than 31.1° API (less than 870 kg/m^3).
- Medium oil defined as having an API gravity between 22.3° API and 31.1° API (870 to 920 kg/m^3).
- Heavy crude oil defined as having an API gravity below 22.3° API (920 to 1000 kg/m^3).
- Extra heavy oil defined with API gravity below 10.0° API (greater than 1000 kg/m^3).

Density of some common fluids:

Fluid	Temperature - t - (^oC)	Density - ρ - (kg/m^3)
Automobile oils	15	880 - 940
Crude oil, 48^o API	60^{o}F	790
Crude oil, 40^o API	60^{o}F	825
Crude oil, 35.6^o API	60^{o}F	847
Crude oil, 32.6^o API	60^{o}F	862
Crude oil, california	60^{o}F	915
Crude oil, Mexican	60^{o}F	973
Crude oil, Texas	60^{o}F	873
Gasoline, natural	60^{o}F	711
Heating oil	20	920
Kerosene	60^{o}F	820.1
Methanol	20	791
Oil of resin	20	940
Oil of turpentine	20	870
Oil, lubricating	20	900
Sea water	25	1025
Silicone oil	20	760
Turpentine	25	868.2
Water, heavy	11.6	1105
Water - pure	4	1000

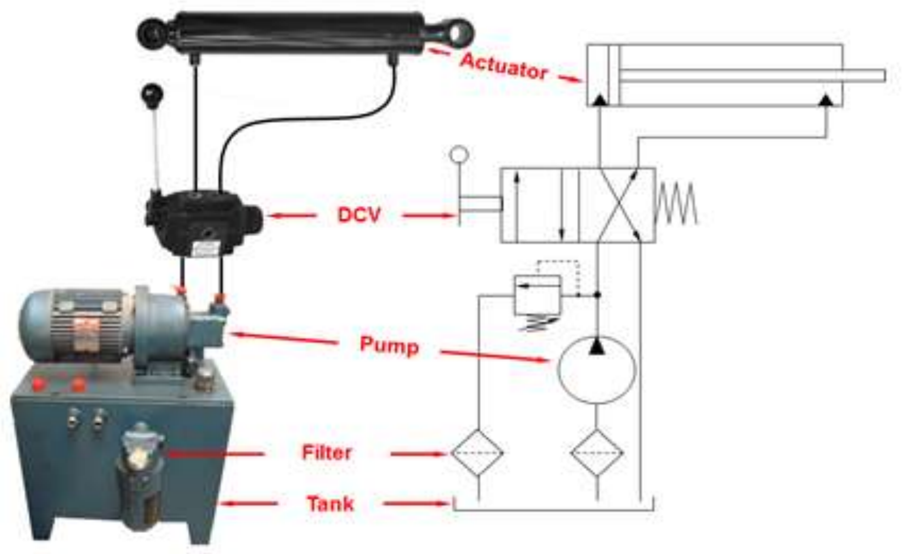
Obs.: 1 kg/m^3 = 0.001 g/cm^3 = 0.0624 lb/ft^3 = 0.000036127 lb/in^3 = 0.008345 lb/gal (U.S).

Hydraulic Oils Application: Hydraulic fluids are used to transfer power to drive, control and motion, based on mineral oils, such as synthetic fluids and fire-resistant fluids. Modern hydraulic systems can be divided into three principle areas: stationary, mobile and aviation. The performance of hydraulic systems has increased significantly, reflected in higher pressures, higher system temperatures and lower system volumes. The table below shows the most used hydraulic oils for several applications.

ISO Grade	Equivalent SAE Grade	Viscosity				Density	
		Centistokes		*10^{-6} reyns ($lb\ s/in^2$)*		*kg/m^3*	*lb/in^3*
		40^{o}C	*100^{o}C*	*104^{o}F*	*212^{o}F*		
32	10W	32	5.4	4	0.6	857	0.0310
46	20	46	6.8	5.7	0.8	861	0.0311
68	20W	68	8.7	8.5	1.1	865	0.0313
100	30	100	11.4	12.6	1.4	869	0.0314
150	40	150	15	19	1.8	872	0.0315
220	50	220	19.4	27.7	2.4	875	0.0316

HYDRAULIC DRIVE SISTEMS:

A hydraulic drive system is a transmission system that uses pressurized hydraulic fluids, pumped to drive valves and actuate cylinders or hydraulic machinery. Circuit diagrams using symbols represent the function and sequence of individual components within a system. The basic hydraulic drive system generally consists of five main parts, as can be seen below:



Example - Hydraulic Drive System - Simple Application

Basic Flow Circuit: Basically, for the hydraulic fluid to do work, it must flow from a motor-driven hydraulic motor installed over an oil tank (or a reservoir), actuate the directional control valve (DCV), drive a cylinder (or a machinery), and then return to a reservoir, all connected by pressure hydraulic hoses and fittings. In an open circuit there is a continuous flow, the fluid is then filtered and re-pumped back to drive an actuator (or machinery). In a closed circuit, the valves may be actuated or not. The path taken by hydraulic fluids is called a hydraulic circuit.

Hydraulic Reservoir: Sometimes is referred to as a sump tank, service tank, operating tank, supply tank, or base tank. A hydraulic system uses a fluid tank commonly constructed with carbon steel plates as a reserve, generally hydraulic oil. Beyond providing storage, the reservoir acts as a radiator to dissipate heat from the fluid. The reservoir also serves as a settling tank where heavy particles of contamination may settle out of the fluid and remain harmlessly on the bottom until removed by cleaning or flushing off the reservoir. It also allows entrained air to separate from the fluid.

Hydraulic reservoirs are of two general types - non-pressurized and pressurized, operating up to 5 psi, however, most systems are normally designed for equipment operating at normal atmospheric pressure. As a rule of thumb, the **quantity of fluid** in the ideal reservoir, will hold about **2.5 times** the pump output per minute, indicated by a direct reading sight gauge, a clear tube, or a float/dial gauge. The minimum reservoir must be large enough to accommodate thermal expansion of the fluid and changes in fluid level due to system operation.

Hydraulic Pumps: Supply fluid to the components of the system. Hydraulic pumps have a power efficiency about ten times greater than an electric motor (by volume), powered by an electric motor or a diesel engine, connected by gears, belts, or a flexible elastomeric coupling to reduce vibration. Hence, a pump rated for 5,000 psi is capable of maintaining its flow against a required load.

Classification of Pumps: Many different methods are used to classify pumps. Terms such as nonpositive displacement, positive displacement, fixed displacement, variable displacement, fixed delivery, variable delivery, constant volume, and others are used to describe pumps.

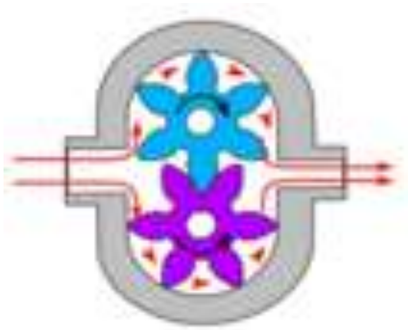
- Nonpositive & Positive Displacement Pumps: Basically, pumps that discharge liquid in a continuous flow are referred to as nonpositive displacement, and those that discharge volumes separated by a period of no discharge, are referred to as positive displacement.

- Fixed-displacement & Variable-displacement Pumps: Delivers the same amount of fluid on each cycle, then, the output volume can be changed only by changing the speed of the pump. When a pump of this type is used in a hydraulic system, a pressure regulator (unloading valve) must be incorporated in the system. The variable-displacement pump is constructed so that the displacement per cycle can be varied, using an internal controlling device.

- Fixed delivery, Constant Delivery, and Constant Volume Pumps: These terms are all used to identify the fixed-displacement type pumps. The most common types of hydraulic pumps to hydraulic machinery applications are:

1. **Gear Pumps**: Are cheap, durable (especially the g-rotor form), simple, less efficient, because are constant (fixed) displacement, and mainly suitable for pressures below 20 MPa (3000 psi). There are two main variations; *external,* which use two external spur gears, and *internal,* which use an external and an internal spur gear.

   External precision gear pumps are usually limited to a maximum working pressure of 210 bar and a maximum speed of 3,000 rev/min. Some manufacturers produce gear pumps with higher working pressures and speeds but these types of pumps tend to be noisy. Positive displacement (or fixed displacement) pumps, means they pump a constant amount of fluid for each revolution. Gear pumps may be **spur gears, helical gears, gerotor, and off-centered gears**.

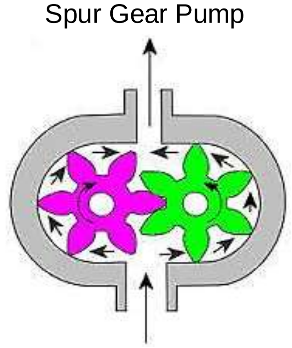
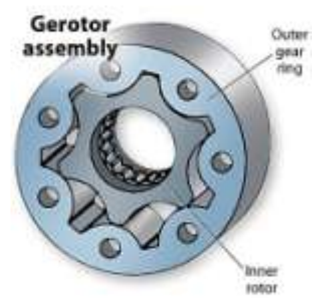
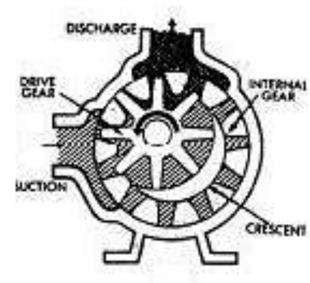
External gear pumps design for hydraulic power applications.	Gerotor: Internal gear pump design for automotive oil pumps.	Gerotor: Internal gear pump design for high viscosity fluids.
		

Spur Gear Pumps: The spur gear pump, as shown in the pictures below, consists of two meshed gears that revolve in a housing. The clearances between the gear teeth as they mesh and between the teeth and the pump housing are very small. The inlet port is connected to the fluid supply line, and the outlet port is connected to the pressure line.

Helical Gear Pumps: Are other modifications of the spur gear pump. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth is even greater than it is in the herringbone gear pump; therefore, the discharge flow is smoother. Since the discharge flow is smooth in the helical pump, the gears can be designed with a small number of large teeth, thus allowing increased capacity of flow.

Gerotors: The name is derived from "Generated Rotor". A gerotor unit consists of an inner and outer rotor, as shown in the pictures below. The inner rotor is located off-center and both rotors rotate. During the assembly's rotation cycle, fluid volumes change continuously; first increases, and then decreases. The increasing fluid creates a vacuum, that creates suction, and as the volume decreases compression occurs. During this compression period fluids can be pumped, or compressed (if gas fluids).

Off-centered Internal Gear Pump: This pump, as illustrated below, the drive gear is attached directly to the drive shaft of the pump and is placed off-center in relation to the internal gear. The two gears mesh on one side of the pump, between the suction (inlet) and discharge ports. On the opposite side of the chamber, a crescent-shaped form fitted to a close tolerance fills the space between the two gears.

Spur Gear Pump	Helical Gear Pump	Gerotor	Off-centered Gear Pump
			

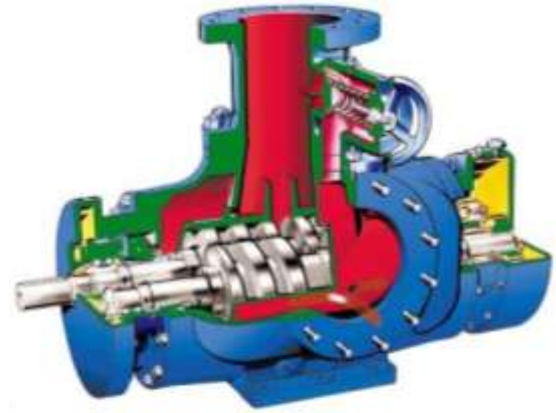
2. **Lobe Pumps**: The lobe operation as pump uses the same principle of the external gear pump described before, as illustrated below. The lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor. The two elements are rotated, one directly driven by the source of power, and the other through timing gears. As the elements rotate, the fluid is trapped between two lobes of each rotor and the walls of the pump chamber, and carried from the suction side to the discharge side of the pump. When the fluid leaves the suction chamber, the pressure is lowered, as soon additional liquid is forced to be pumped.

3. **Screw Pumps**: Suitable for high pressures (up to 3000 psi), and delivers fluid with little noise or pressure pulsation, but has a very low efficiency and is very expensive. Screw pumps are available in several different designs; however, all operate in a similar manner. In a fixed-displacement rotary-type screw pump, as shown below, fluid is propelled axially in a constant, uniform flow through the action of just three moving parts: a power rotor and two idler rotors.

The power rotor is the only driven element, extending outside the pump casing for power connections to an electrical motor. The fluid pumped between the meshing helical threads and power rotors provides a protective film to prevent metal-to-metal contact.

Lobe Pumps:

Screw Pumps:

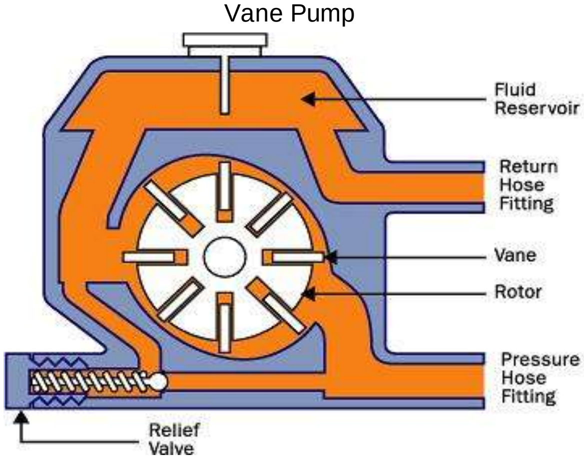


4. **Vane Pumps**: Generally have circularly or elliptically internal shaped flat end plates, and a slotted rotor fixed to a shaft that enters the housing cavity through one of the end plates. A number of small rectangular plates or vanes are set into the slots of the rotor. When the rotor turns, the centrifugal force causes the outer edge of each vane to slide along the surface of the housing cavity as the vanes slide in and out of the rotor slots.

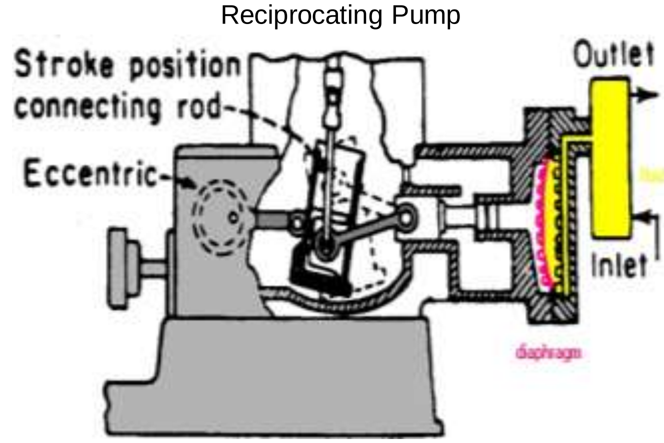
   Usually vane pumps are fixed-displacement; however, there are some designs of vane pumps that provide variable flow. Vane pumps are generally restricted to service, since pressure demand must not exceed 2000 psi, due wear rates, vibration, and high noise levels.

5. **Reciprocating Pumps:** The term *reciprocating* is defined as back-and-forth motion, as the motion of pistons inside of cylinders, provides the flow of fluid. These pumps, as rotary pumps operate on the positive displacement, that is, each stroke delivers a definite volume of liquid to the system. Radial and axial piston pumps are also classified as reciprocating pumps, and rotary pumps, because the rotary motion is imparted to these pumps by the source of power.

Vane Pump



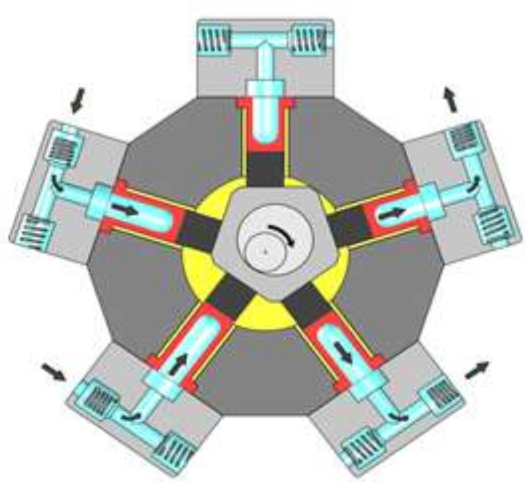
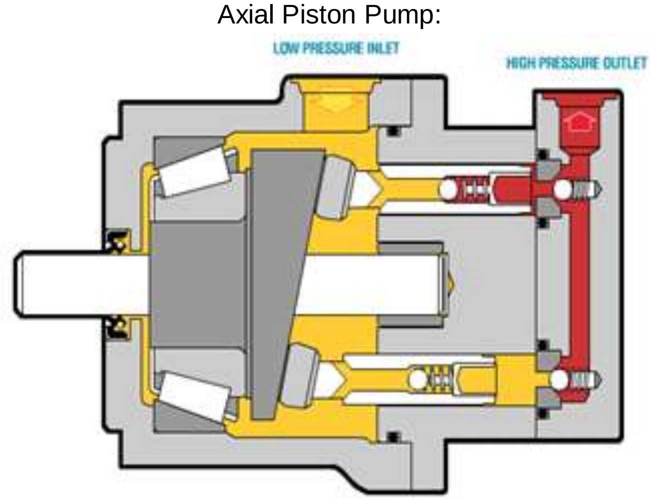
Reciprocating Pump



6. **Piston Pumps**: Are constructed in a variety of types and configurations, commonly axial and radial pumps. The **axial piston** pump has the cylinders parallel to each other and the drive shaft. The **radial piston** design has the cylinders extending radially outward from the drive shaft like the spokes of a wheel. The most important distinction is between pumps that provide a fixed delivery volume and those pumps that are able to vary the flow of the fluid. Then, the variable delivery pumps can also be divided into those able to pump fluid, from zero to full delivery in **one direction**, and those able to pump from zero, to full delivery in both **directions**.

Radial Piston Pumps: Contain pistons arranged as wheel spokes around a cylindrical block. A drive shaft rotates this cylindrical block, which pushes or slings the pistons, causing compression and expansion. The eccentricity between the piston housing and cylinder block centerlines determines the piston stroke. There is a rotor, which lodges the reaction ring, and a slide block used to control the length of the piston strokes. The slide block does not revolve but supports the rotor that revolves due to the friction set up by the sliding action between the piston heads and the reaction ring.

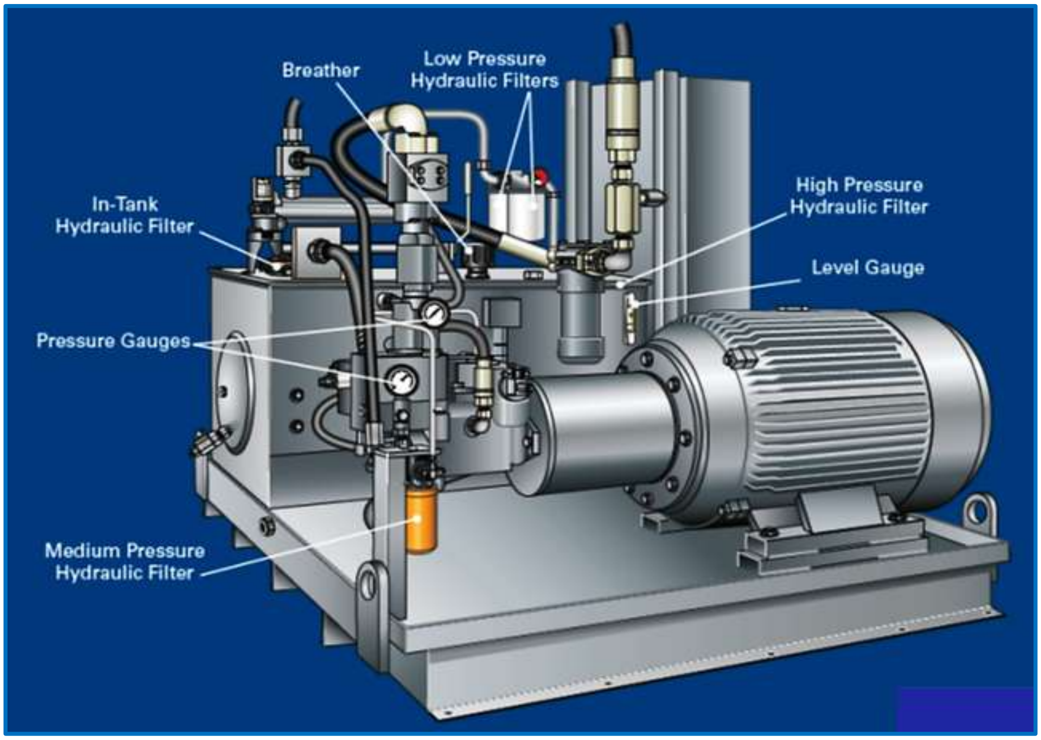
Axial Piston Pumps: Contain a number of pistons attached to a cylindrical block, which move in the same direction as the block's centerline (axially). The reciprocating motion is created by a cam plate, also known as a wobble plate, tilting plate, or swash plate that lies in a plane, which cuts across the centerline of the drive shaft doing the cylinder barrel does not rotate. These pumps may be fixed-displacement types, when the cam plate is mounted in a position that intersects the centerline of the cylinder barrel at an angle approximately 25 degrees from perpendicular. On the other hand, these pumps may be variable-delivery types, when the angle of the cam plate may be varied from zero to 20 or 25 degrees to one or both sides.

Radial Piston Pump:	Axial Piston Pump:
	

Hydraulic Filters: Are elements for oil filtering and cleanliness levels of the components in a hydraulic fluid system. Generally, come with multiple inlet and outlet port sizes and with various by-pass valve settings to meet specific requirements of fluid power, also available for water-base fluid compatibility.

Metal particles are continually produced by mechanical components and need to be removed along with other contaminants. Abrasive particles enter the system and, if unfiltered, damage sensitive components like pumps, valves, and actuators. The hydraulic filter is commonly installed to remove these particles from the oil flow to help prevent premature component wear and system failure.

Filters may be **positioned** in many locations of the hydraulic system, as can be seen below. The filter may be located between the reservoir and the pump intake. Blockage of the filter may cause cavitation and a possible failure of the pump. Sometimes the filter is located between the pump and the control valves. The third common filter location is just before the return line enters the reservoir, and does not require a pressurized housing, but contaminants that enter the reservoir from external sources are not filtered until passing through the system at least once.



Filtration Efficiency: As the sophistication of hydraulic systems increases, the need for reliable filtration protection becomes ever more critical. The ISO (International Organization for Standardization), NFPA (National Fluid Power Association), and ANSI (American National Standards Institute) use the beta ratio (β) to qualify the filtration efficiency of filters.

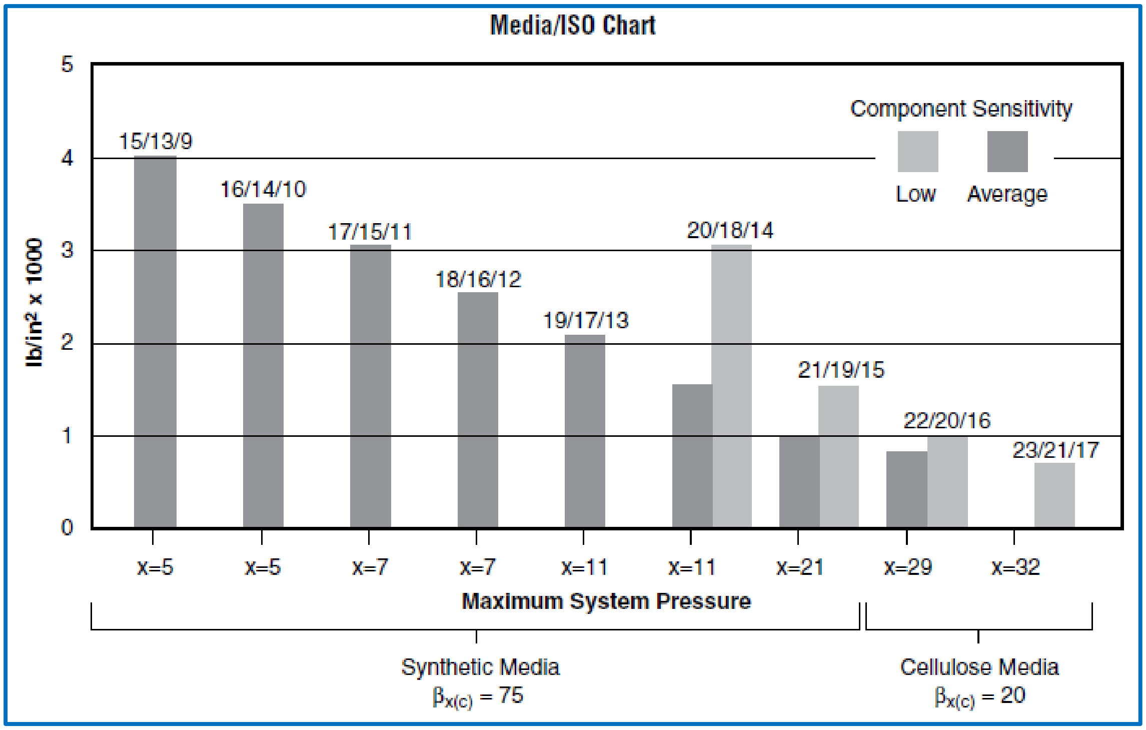
The beta ratio (β) is a hydraulic filtration qualification standard, used to determine the number of particles over a given size upstream of the oil filter. The beta ratio (β) is formulated dividing the upstream particles by the number of particles downstream of the filter. **Example**: If a filter has 1000 particles 10 microns and larger upstream and 50 particles downstream, the β is 20, using the formula below:

$$\beta 10 = \frac{1000 \text{ Particles Upstream}}{50 \text{ Particles Downstream}} = 20$$

The standard for evaluating filter contaminant holding capacity and filtration efficiency is ISO 16889-1999, "Hydraulic Fluid Power Filters – Multi-Pass Method for Evaluating Filtration Performance of a

Filter Element." and is the international standard to determine the efficiency (beta rating or beta ratio) and the dirt-holding capacity of hydraulic filters (ISO 16889 replaced the ISO 4572 test standard).

ISO Chart: Reading the chart below, the high-pressure synthetic media with higher capacity characteristics shows the ISO code in the range of 15/13/9 to 21/19/15. The letter "x" underneath the bars represents the media code. For **example**, if the target pressure is 3000 lb/in² and the application is "Construction Equipment," the ISO code is 17/15/11 and the recommended media is x=7. Synthetic media or cellulose media refer to the filtering elements.



Oil is usually contaminated to a level above what is acceptable for most hydraulic systems: typically, new fluid has a cleanliness level about the same as ISO Code 23/21/19, and water content is typically 200 to 300 ppm. It is not recommended assume that oil is clean until it has been filtered. The major source of contamination is the pump and actuators, the hydraulic cylinder, or the hydraulic motor.

Example: The code "20/18/14" means that the smaller these three numbers, the cleaner the hydraulic system and/or the more demanding the system is for cleanliness. Component manufacturers specify the desired ISO code for the component parts and systems they build.

The first number is an indication of the number of contaminant particles that are 4 micron(c) and larger that can be contained in a volume of hydraulic fluid. The second number indicates the number of contaminant particles that are 6 micron (c) and larger that can be contained in the same volume. The third number indicates the number of contaminant particles that are 14 micron (c) and larger that can be contained in the same volume.

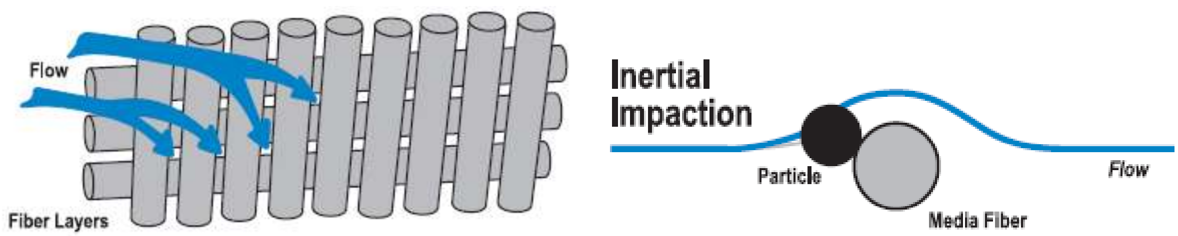
Rating Efficiency: The ISO 16889 recommends reporting beta (β) ratings at:

2........................50%; 10......................90%; 75......................98.7%; 100....................99%; 200...................99.5%; 1000.................99.9%.

Example, ß4(c) = 200: Signifies that there are 200 times as many particles that are 4 µm and larger upstream as downstream. This is 99.5% efficiency.

Example, ß5(c) = 1000: Indicates that there are 1000 times as many particles that are 5 µm and larger upstream as downstream. This is 99.9% efficiency.

How to Apply the Media: Media is a term used to describe any material used to filter particles out of a fluid flow stream. The job of the media is to capture particles and allow the fluid to flow through. For fluid to pass through, the media must have holes or channels to direct the fluid flow and allow it to pass. The filter media is a porous material that alters the fluid flow stream by causing fluid to twist, turn, and accelerate during passage, as shown below.



Cellulose fibers: Are defined as wood fibers, microscopic in size and held together by resin. The fibers are irregular in both shape and size. The cellulose filter types often have lower beta (β) ratings, which mean there are smaller pores in the media. Smaller media pores have flow resistance, resulting in higher-pressure drop.

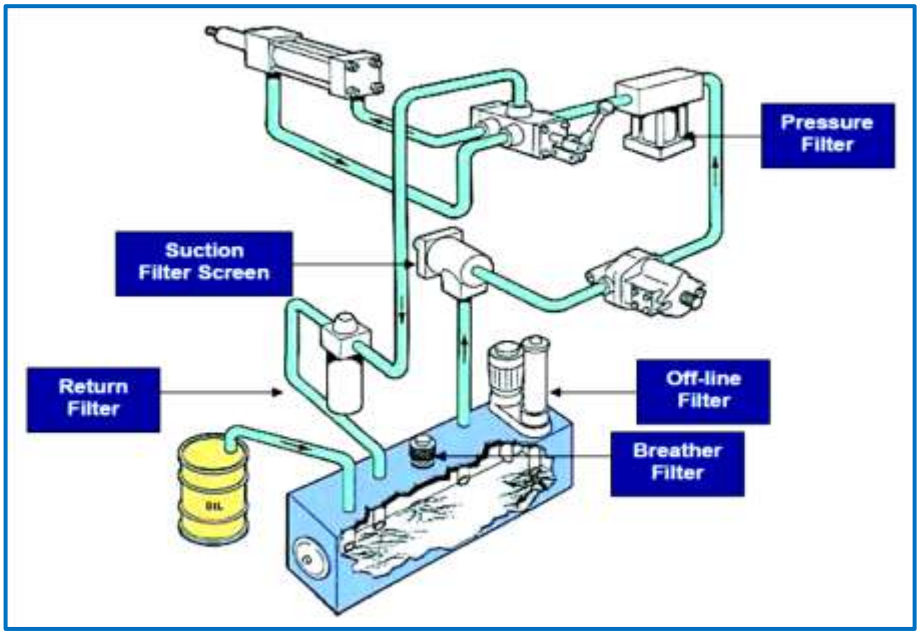
Synthetic fibers: The fibers are smooth, rounded, and provide the least resistance to flow. The consistent shape allows a pattern throughout the media to create the smoothest, least inhibited fluid flow, and allows the maximum amount of contaminant-catching surface area and specific size control. The result is media with predictable filtration efficiencies removing specified contaminants and maximum dirt holding capacity.

Wire-Mesh Media: Typically, wire-mesh filters will be applied to catch very large, harsh particulate that would rip up a normal filter. You may also find this media useful as a coarse filter in viscous fluid applications. Consists of stainless steel, epoxy-coated wire mesh available in 3 mesh sizes:

- 100-mesh yields 150-µm filtration
- 200-mesh yields 74-µm filtration
- 325-mesh yields 44-µm filtration

Super-Absorbent Polymer: This technology has a high affinity for water absorption; this media alleviates many of the problems associated with water contamination found in petroleum-based fluids. Water absorption media quickly and effectively removes free water from hydraulic systems.

Selection of Filters: Even today, the locations of hydraulic filters are subjective and it is up to the system designer to locate a filter to suit the system. However, a few locations are predominantly used in a lube or a hydraulic system, as shown below:



Suction Filter: Normally placed between the reservoir and the pump, suction filters are designed to remove particles in the 5 to 150 micron range. They are easier to service and less expensive than many other types of filters, but because restriction in the suction line must be kept very low, filter housing size tends to be larger than similar flow return or pressure filter housings.

Return-Line Filter: The advantages of return-line filters are many. They are usually low-pressure housings, which are less typically expensive. Their purpose is to collect the dirt from around the circuit as the oil returns to the reservoir. Much like the kidney loop, the return-line filter provides ultimate flexibility in positioning, it can perform almost anywhere within the return line circuit, either mounted inline or built into the reservoir.

Suction Filters:	Return Line Filters:
	

Pressure Filter: This is also known as “last-chance” filtration. High-pressure filters keep clean the oil that comes directly from the pump so that the more expensive downstream components (such as valves and actuators) are protected. Pressure line filters offer protection from catastrophic pump failure. They are a worthwhile investment for high value systems, as are found in the aircraft industry, paper and steel mills, plastic injection molding, and in die-casting machines.

Off-line Filter: This system is a self-contained filter system. It includes a pump-motor combination as a power source and a range of filtration flexibility to accomplish many desired results. It can easily be connected to a system reservoir. It can be fitted with a very fine filter element to clean the oil to several ISO codes below the required cleanliness, and can be used to remove water. This system can run 24/7 or intermittently. When the filter element reaches its terminal drop, it is serviced without shutting down the main system.

Mobile Off-line Filter: This system can offer the same impact and flexibility as dedicated to off-line filters while performing multiple tasks. They include a pump-motor combination as a power source and filters that can be fitted with many different elements depending on the application. Commonly referred to as filter carts, they can be fitted with quick disconnect fittings and connected to a reservoir or tote for conditioning, used to filter fluids during transfer, and used for filtering oil during recovery.

Pressure Filters:	Off-line & Mobile Off-line Filters:
	

Duplex Filters: High and low pressure. These types of filters are recommended to install when the system must be shut down or bypassed for maintenance purposes. The duplex features at least two filter housings with a transfer valve, where the flow can be routed through one housing or both depending on the valve. When one of the filters is fully loaded, the operator switches the valve to activate the standby and then services the dirty filter, avoiding the shutting down of the system.

Breather Filter: Plated breathers with glass media can remove particulate down to 1.0 micron with absolute efficiency. Desiccant breathers control particles, adsorb water from the air, and can even control oil mist exhaust. High efficiency breathers can extend the life of all filter elements, by controlling airborne ingression, which is one of the major sources of particulate contamination. High efficiency breathers can extend the life of all filter elements on hydraulic and lubrication systems by controlling airborne ingression, which is one of the major sources of particulate contamination.

Air filters: Are the most common form of compressed air purification. Fabricated with materials such as carbon steel, SS 304, SS 316 and aluminum, these filters remove liquid water and lubricants from compressed air, installed downstream or upstream in a desiccant dryer system.

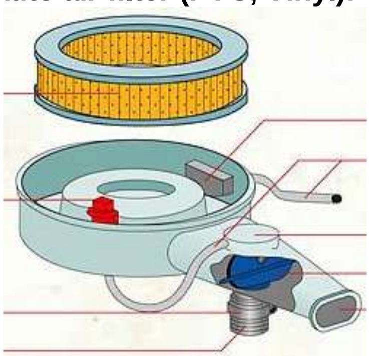
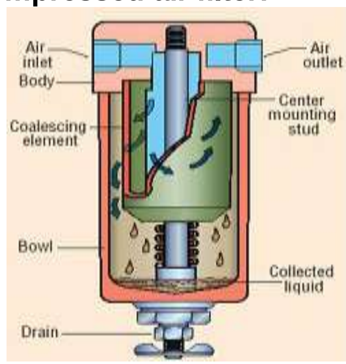
Auto air filter (PVC, Vinyl):	Compressed air filter:	Industrial filters:
		

Table for some typical ISO cleanliness recommendations:

Pressure	<3000 PSI ≤210 Bar	>3000 PSI >210 Bar
Pumps	--- ISO RATINGS ---	
Fixed Gear Pump	19/17/15	18/16/13
Fixed Vane Pump	19/17/14	18/16/13
Fixed Piston Pump	18/16/14	17/15/13
Variable Vane Pump	18/16/14	17/15/13
Varibale Piston Pump	17/15/13	16/14/12
Valves		
Directional (solenoid)	20/18/15	19/17/14
Pressure (modulating)	19/17/14	19/17/14
Flow Controls (standard)	19/17/14	19/17/14
Check Valves	20/18/15	20/18/15
Cartridge Valves	20/18/15	19/17/14
Load-sensing Directional Valves	18/16/14	17/15/13
Proportional Pressure Controls	18/16/13	17/15/12*
Proportional Cartridge Valves	18/16/13	17/15/12*
Servo Valves	16/14/11*	15/13/10*
Actuators		
Cylinders	20/18/15	20/18/15
Vane Motors	19/17/14	18/16/13
Axial Piston Motors	18/16/13	17/15/12
Gear Motors	20/18/15	19/17/14
Radial Piston Motors	19/17/15	18/16/13

* Requires precise sampling practices to verify cleanliness levels.
Source: Vickers

Auxiliary Valves: Complex hydraulic systems may have auxiliary valve blocks to handle various duties unseen to the operator, such as flow and pressure valves, accumulator charging, pressure gages, etc. They are usually custom valves designed for the particular machine, and may consist of a metal block with ports and channels drilled. Some valves are designed to be proportional (flow rate proportional to valve position), while others may be simply on/off. The control valve is one of the most expensive and sensitive parts of a hydraulic circuit.

- **Flow Control Valves:** The main function is to regulate the flow or pressure of a fluid. Control valves normally respond to signals generated by independent devices such as flow meters or temperature gauges. Control valves respond to electric or pneumatic signals, to open/close automatically the valves and are normally fitted with actuators and positioners. Pneumatically actuated globe valves and diaphragm valves are widely used for control purposes in many industries, although quarter-turn types such as ball, gate, and butterfly valves are commonly used.

- **Automatic Control Valves:** These types of valves are also known as hydraulic actuators or hydraulic pilots and the opening and closing of the valve requires no external power source (electric, pneumatic, or manual); it is done automatically, hence its name. Automatic control valves include pressure reducing valves, flow control valves, back-pressure sustaining valves, altitude valves, and relief valves. Altitude valves control the level of reservatories and remain open while the tank is not full and it will close when the tanks reaches its maximum level.

Flow Control Valve:	Automatic Control Valve
	

- **Pressure Relief Valves**: Are used in several places in hydraulic machinery such as on the return circuit to maintain a small amount of pressure for brakes, pilot lines, etc. On hydraulic cylinders, to prevent overloading and hydraulic line/seal rupture. On the hydraulic reservoir, to maintain a small positive pressure to avoid moisture and contamination.

Note: **Pressure Relief Valves** are typically used for incompressible fluids such as water or oil. **Pressure Safety Valves** are typically used for compressible fluids such as steam or other gases and can often be distinguished by the presence of an external lever at the top of the valve body, which is used as an operational check.

- **Pressure Regulator Valves:** Automatically cuts off the flow of a liquid or gas when reaches the required work pressure. Regulators are used to allow high-pressure fluid supply lines or tanks to be reduced to safe and/or usable pressures for various applications. Flowmeters, Rotometers, or Mass Flow Controllers are used to regulate gas flow rates. Sequence valves control the sequence of hydraulic circuits; to ensure that one hydraulic cylinder is fully extended before another starts its stroke.

Pressure Relief Valve:

Pressure Regulator Valve:

- **Shuttle Valves:** Are some types of valves, which allow fluid to flow through it from one of two sources. The basic structure of a shuttle valve is like a tube with three openings. A ball or other blocking valve element moves freely within the tube. When pressure from a fluid is exerted through an opening on one end, it pushes the ball towards the opposite end. Generally, is used in pneumatic systems, but may be also used in hydraulic systems.

- **Check Valves:** Hydraulic check valves permits flow of fluid in one direction. It is a one-way valve because it permits free flow in one direction and prevents any flow in the opposite direction. These valves are commonly installed in hydraulic systems, allowing an accumulator to charge and maintain its pressure after the machine is turned off, for example.

Shuttle Valve:

Check Valve:

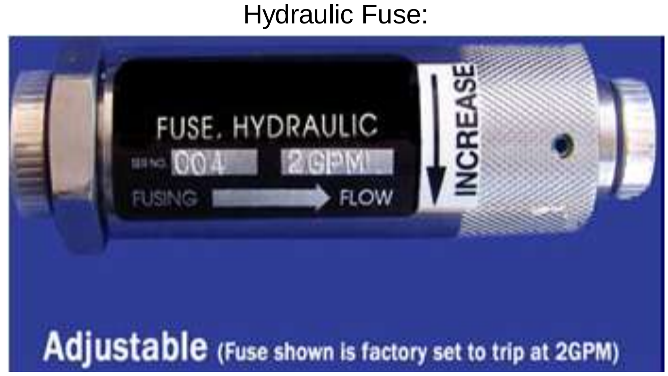
- **Pilot Operated Check Valves:** Also referred to as P.O. check valves, can be opened by an external pilot pressure. Thus, P.O. check valves, block flow in one direction, like standard check valves, but can be released once an adequate pilot pressure is applied, as free flow is allowed in the reverse direction and often used to positively lock a dual acting cylinder.

- **Counterbalance Valves:** A hydraulic counterbalance valve works to control the load pressure in hydraulic machinery, providing a free flow of hydraulic fluid and preventing from backing up or moving in the wrong direction. This type of valve is commonly positioned along the path of current to help maintain continuity in the actuating cylinder. This means that when a crane is in the up position and needs to be lowered, it can be done without the crane dropping too suddenly.

Pilot Operated Check Valve:	Counterbalance Valve:
	

- **Cartridge Valves:** Also known as, 2/2-way valves or logic elements are industrial hydraulic valves, used for directional, pressure, check, and flow control. The cartridge valves are available in many configurations, on/off, proportional, pressure relief, etc. They generally screw into a valve block and are electrically controlled to provide logic and automated functions. These products are ideal for applications, which require high flow rates and leak-free control.

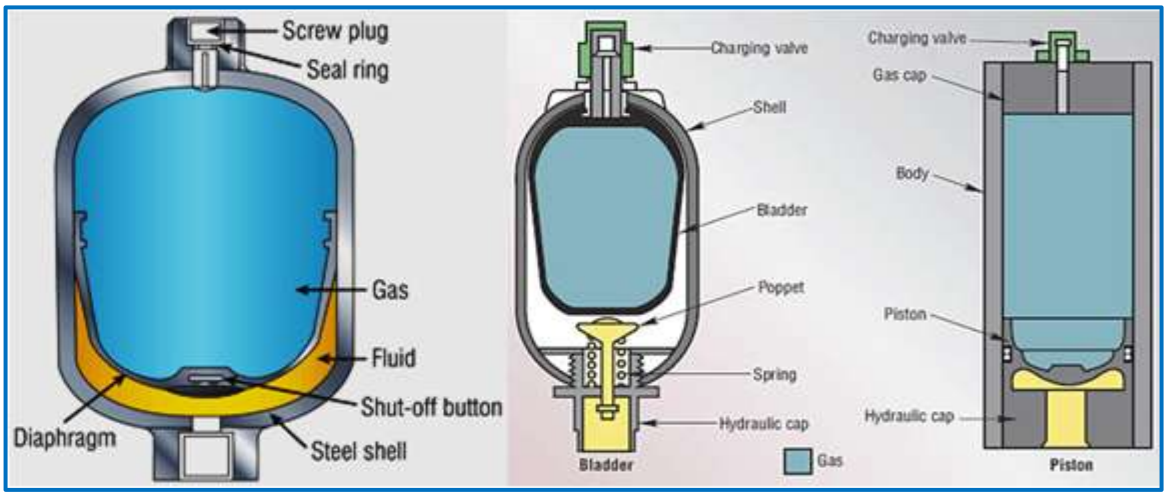
- **Hydraulic Fuses:** It is a safety component, designed to allow systems to continue operating, or at least to not fail catastrophically, in the event of a system break, by stopping the flow of the hydraulic fluid, if the flow exceeds a designed threshold (similar to an electrical fuse or circuit breaker). Hydraulic fuses are designed to automatically seal off a hydraulic line if pressure becomes too low, or safely vent the fluid if pressure becomes too high.

Cartridge Valve:	Hydraulic Fuse:
	

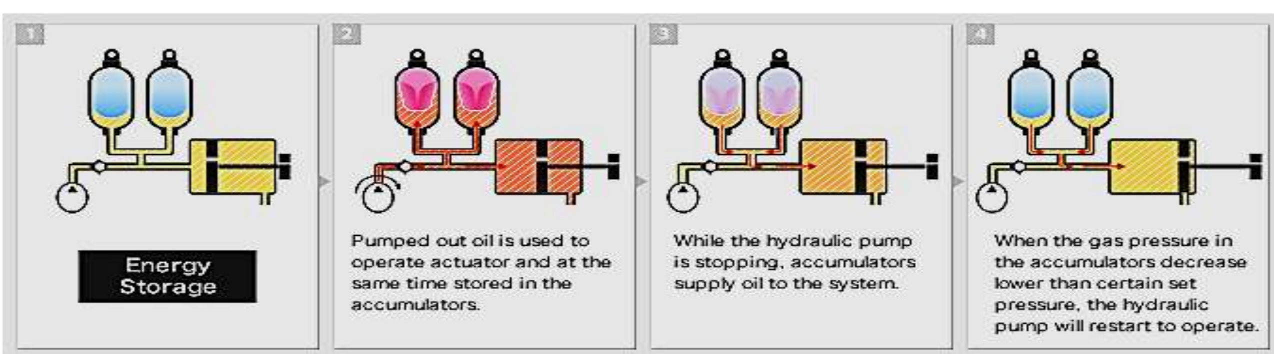
Hydraulic Accumulators: Is a pressure storage reservoir (a type of energy storage device) in which a non-compressible hydraulic fluid is held under pressure by an external source. The external source can be a spring, a raised weight, or a compressed gas. An accumulator enables a hydraulic system to adjust with extremes of demand using a less powerful pump, to respond more quickly to a temporary demand, and to smooth out pulsations. Compressed gas accumulators, also called hydro-pneumatic accumulators, are by far the most common type.

An accumulator may be placed close to a hydraulic pump with a non-return valve preventing flow back to the pump. In the case of piston-type pumps, this accumulator is placed to absorb pulsations of energy from the multi-piston pump. It also helps protect the system from fluid hammer, and protects system components, particularly pipework, from both potentially destructive forces.

An accumulator can maintain the pressure in a system for periods when there are slight leaks without the hydraulic pump being cycled on and off constantly. When temperature changes cause pressure excursions the accumulator, helps absorb them. Its size helps absorb fluid that may be positioned in a small system, without space for expansion, due to valve arrangement.



By installing an accumulator, oil pump capacity can be downsized and the idling operation of the electrical motor can be stopped. Then, temperature rise of the system fluid is suppressed and cooler becomes no need of use. Accumulators can also be used as hydraulic pressure source on an emergency case such as hydraulic pump or hydraulic source equipment trouble or electricity failure.



Hydraulic Motors: Is a mechanical actuator that converts hydraulic pressure and flow into torque and angular displacement (rotation). The hydraulic motor is the rotary counterpart of the hydraulic cylinder. Conceptually, a hydraulic motor should be interchangeable with a hydraulic pump because it performs the opposite function, similar to a DC electric motor and theoretically interchangeable with a DC electrical generator.

The design of a hydraulic motor and a hydraulic pump are very similar. For this reason, some pumps with fixed displacement volumes may also be used as hydraulic motors. However, most hydraulic pumps cannot be used as hydraulic motors because they cannot be back driven. Thus, a hydraulic motor is usually designed for working pressure at both sides of the motor. The hydraulic motor converts hydraulic energy into mechanical energy, and uses hydraulic pressure to generate torque and rotation.

Due to the very heavy loads imposed on car crushers, hydraulic motors are the preferred power delivery system. When the machine "stalls" due to something "uncrushable" creating a snag, the building pressure inside the supply circuit of the hydraulic operates a pressure relief valve preset to a specific pressure to return the supply of the fluid back to the reservoir. It also triggers a mechanism to reverse the direction of rotation to release the snagging material and free the machine after which normal rotational direction is resumed. An electric motor would either trip or burn out.

The hydraulic pump, powered by an electric motor or an internal combustion engine, draws the hydraulic fluid from the reservoir, and supplies it under pressure to the hydraulic motor linked mechanically to the workload. After going through the hydraulic motor, the hydraulic fluid is returned to the reservoir, filtered, and reused as required. Hydraulic motors are fluid power actuators capable of delivering linear or rotary motion depending on their design.

The power produced by a hydraulic motor is determined by the flow and pressure drop of the motor. The displacement and pressure drop of the motor determines the torque it generates. The power output is thus directly proportional to the speed. The motors range from high-speed motors of up to 10,000 rpm to low speed motors with a minimum of 0.5 rpm. Note that low speed hydraulic motors are designed in such a way that large torques are generated at low speeds. High-speed motors have better operational characteristics at speeds that are at least higher than 500 rpm.

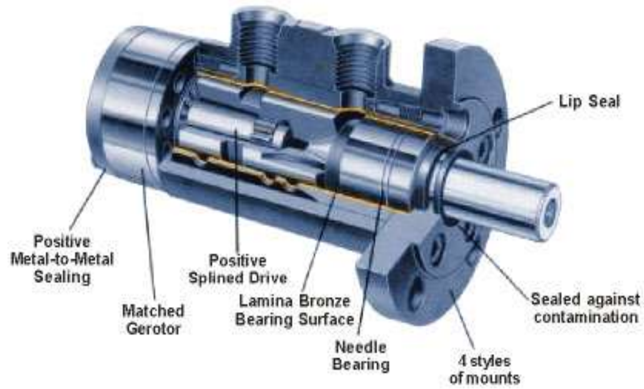
Gear Motors: The operating pressure of gear motors is usually quite low: between 100 and 150 bar. Modern gear motors, however, are capable of operating at continuous pressures of up to 250 bar. Gear motors with only one direction of rotation are designed exactly the same as external gear pumps and when change directions of rotation the drain case port and the axial pressure fields are different. The efficiency of gear motors is relatively low due to oil leakage.

There are two different types of hydraulic gear motors: The **gear motor**, which is very similar in design to the external gear pump, is a high-speed motor and the **epicyclic gear motor**.

Epicyclic Gear Motor: Also known as, orbit, gear ring motor, or gerotor is a slow speed motor. Unlike gear motors, the orbit motor has very low oil leakage and can produce large torques at very slow speeds (approximately 5 rpm).

Gear Motor

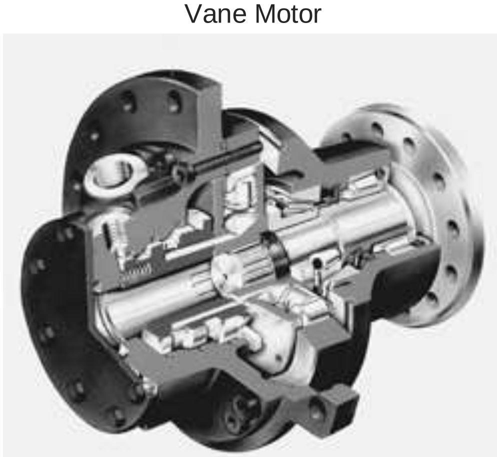
Epicyclic Gear Motor or Gerotor



- **Hydraulic Vane Motors**: Are used in both industrial applications, such as screw-drive and injection molding, and mobile applications, such as agricultural machinery. Hydraulic vane motors have less internal leakage than gear motors and are therefore better suited for lower speeds, about 100 rpm minimum. The maximum operating pressure of hydraulic vane motors is between 100 and 140 bar, and they are used in both hydraulics and pneumatics.

- **Track Drive Motors:** Specifically designed for use on tracked vehicles as, excavators and earthmoving machines with increased mechanical and volumetric efficiency, and smoother acceleration and deceleration may be used on a wide variety of machine applications. This range has high strength structure, short overall length, very high radial and axial load capability. All gearboxes are provided with integral multidisc brakes to allow direct mounting of hydraulic motors. Due to the high torque rating and the quality of the materials, these units are the best solution in heavy-duty applications.

Vane Motor



Track Drive Motor

Hydraulic Piston Motors: Whether a heavy-duty installation needs high torques or high speeds the correct choice is either a **radial piston** or **axial piston** motor. These hydraulic motors are used to drive mobile and construction equipment, winches, ship-cranes, and all kinds of heavy-duty hydraulic equipment for **offshore** and **onshore** operations. Multi-stroke piston motors increase displacement substantially because each piston carries out multiple strokes per revolution of the shaft. Hence, a hydraulic multi-stroke piston motor produces high operating torques.

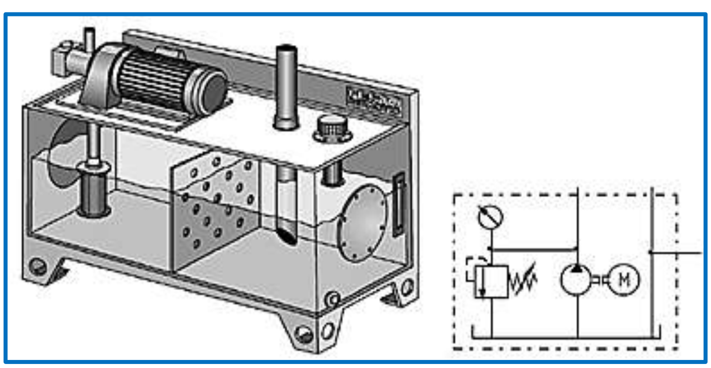
- **Axial Piston Motors**: Have a bent axis design or swash plate principle. The fixed displacement type works as a hydraulic motor, and the variable displacement type most often functions as a hydraulic pump. Fixed displacement motors may be used in both open and closed loop circuits. In the **bent axis** design, pistons move up and down within the cylinder block bores, converted into rotary movement via the piston ball joint at the drive flange. In the **swash plate design**, pistons move up and down within the cylinder block and turn it, which then turns the drive shaft via the connected cotter pin.

- **Radial Piston Motors:** Are used in caterpillar drives of dragline excavators, cranes, winches, and ground drilling equipment. Radial piston motors are capable of producing high torques at very low speeds, down to half a revolution per minute. Therefore, radial piston motors are also referred to as Low Speed High Torque (LSHT) motors. The pistons (or plungers) of a radial piston motor form a star-like shape and are perpendicularly connected to the shaft. The rectilinear motion of the pistons is transformed into a rotating movement by the eccentric shaft.

Axial Piston Motors	Radial Piston Motors
	

HYDRAULIC SYSTEMS – BASIC CALCULATIONS:

Any hydraulic system efficiency is very much dependent on the type of the involved hydraulic tool equipment. In practice, both hydraulic pumps and hydraulic motors used and power input may vary considerably. Each circuit must be evaluated and the load cycle estimated, as new or modified systems must always be program simulated and then tested in practical work, covering all possible load cycles.



Centrifugal Pump Power: The actual or brake horsepower (BHP) of a pump is the actual horsepower delivered to the pump shaft, defined as follows:

$$\textbf{BHP} = Q \times H \times SG / 3960 \times P\eta =$$

Where:

Q = Capacity (gpm)
H = Total Differential Head (feet)
SG = Specific Gravity of the liquid (1.0 for water)
Pη = Pump efficiency as a percentage (0.85 to 0.95)

Obs.: The constant 3960 is the number of foot-pounds in one horsepower (33,000) divided by the weight of one gallon of water (8.33 pounds).

Flow Velocity: The recommended flow velocity formulae may be:

Imperial Units:

$$\textbf{v} = Q \times 0.4085 / d^2 =$$

Or,

$$\textbf{v} = (Q \times 0.321) / A =$$

Where:

v = Velocity (ft/s);
Q = Volume flow (gpm);
d = Pipe inside diameter (inches).

Obs.: Constants 0.4085 and 0.321 (used to convert GPM into cubic feet and then, velocity in ft/s).

Metric Units:

$$\textbf{v} = 1.274\ Q / d^2 =$$

Where:

v = Velocity (m/s);
Q = Volume flow (m^3/s);
d = Pipe inside diameter (m).

Hydraulic Pump Power: A practical formula for calculating the hydraulic pump horsepower is:

$$\textbf{P}_{HP} = Q.\ p / 1714 =$$

Where:

P_{HP} = horsepower (HP)
Q = required pump capacity (gpm)
p = required pressure (psi)

Example 14: The power required by a hydraulic pump with 20 gpm capacity and 1500 psi pressure can be calculated as:

$\boldsymbol{P_{HP}} = 20\ (gpm)\ 1500\ (psi) / 1714 =$
$\boldsymbol{P_{HP}} = 17.5\ HP$

Hydraulic Pump Capacity: In general, the required hydraulic pump capacity can be calculated as:

$\boldsymbol{Q} = 0.26.\ A.\ s / t$

Where:

Q = Pump output capacity (gpm);
A = area of cylinder (in^2);
s = piston stroke (inches);
t = required time for full stroke (s).

Example 15: What is the capacity of a 3" hydraulic cylinder with cylinder area 7.065 in^2 moves a 30 inches stroke in 3 seconds?

$\boldsymbol{Q} = 0.26 \times 7.065\ (in^2) \times 30\ (in) / 3\ (s) =$
$\boldsymbol{Q} = 18\ gpm$

Hydraulic Pump Volume: The simple volume (in gallons) or simple cubic displacement of a hydraulic cylinder can be calculated as:

$\boldsymbol{q} = A.\ s / 231$

Where:

q = cubic displacement (gal)
A = cylinder area (in^2)
s = cylinder stroke (in)

Example 16: A *4"* cylinder with a cylinder area *12.57 in^3* moves a *30"* stroke. The volume displacement (gallons) can be calculated as:

$\boldsymbol{q} = 12.57\ (in^3)\ 30\ (in) / 231 = \boldsymbol{377\ gal.}$

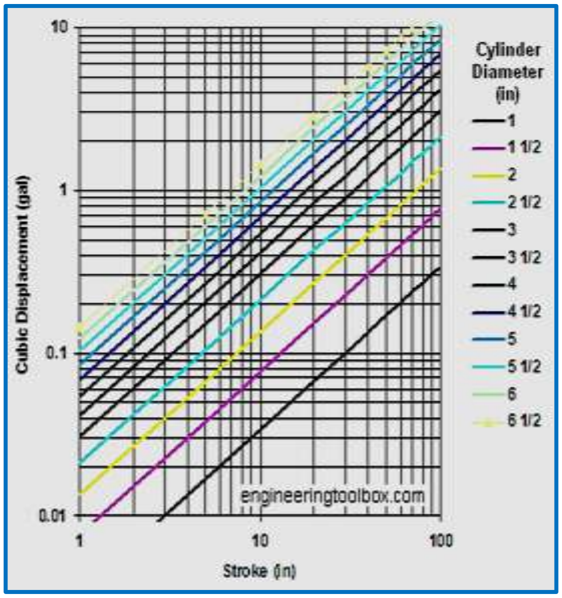
Capacity Relationship: As liquids are essentially incompressible, the capacity is directly related with the velocity of flow in the suction pipe. Using ***feet*** as the main unit, this relationship is as follows:

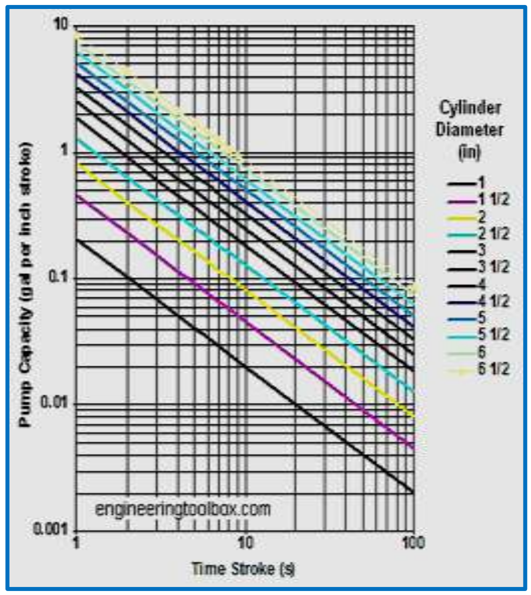
Q *= 449 * v * A =*

Where

Q = Pump output capacity (gpm)
v = Velocity of flow, feet per second (fps)
A = Area of pipe, ft²

Required pump output tables for hydraulic cylinders ranging 1 - 6 1/2 inches are indicated below. Multiply pump capacity with stroke length (in).





Rotating Peripheral Velocity: Also designated as the outside travelling point of a rotating body in one second is:

v = π D n / 60

Where:

v = Peripheral Velocity (ft/s);
D = Diameter of rotating body or impeller, inches;
n = Rotation of the rotating body or impeller in minutes, RPM.

Velocity Head: Also known as, dynamic head is a measure of a fluid's kinetic energy: If we rearrange the known falling body equation, we get:

h = v² / 2g.

Example 16: Installing an 1800 RPM centrifugal pump, calculate the rotating peripheral velocity and the necessary diameter of the impeller to develop a head of 200 ft.

The rotating **peripheral velocity** will be:

$\boldsymbol{v^2} = 2\ g\ h$
$\boldsymbol{v^2} = 2 \times 32.2 \times 200 = 12880\ ft^2/s^2 = \mathbf{113\ ft/s}$

The **necessary diameter** will be:

$\boldsymbol{v} = \pi\ d\ n / 60$, *then:*
$\boldsymbol{d} = 60\ v / \pi\ n = 60 \times 113 / \pi\ 1800 = $ ***1.2 ft (14.4 inches).***

Fluid Flow Velocity: Should be calculated using the pipe net (or internal) area and is recommended not exceed 4 ft/s and, depending on the pipe sizes involved. Thus always select the next larger pipe diameter, that will result in acceptable pipe velocities.

Net Pipe Area = $\boldsymbol{A} = 3.14 \times d^2 / 4 = 0.7854 \times d^2 = \square \times r^2$
Fluid Flow Velocity = $\mathbf{v} = (Q \times 0.321) / A$

Example: Calculate the hydraulic system with an inlet pressure gage is installed in a 2 inches pipe directly in front of a pump delivering 100 gpm oil with specific gravity SG = 0.9, reading 10 psig. Calculate velocity head.

Pipe Net Area: The practical formula to calculate the pipe net area is:

$\boldsymbol{A} = 3.14 \times d^2 / 4 = 3.14 \times 2^2 / 4 = \mathbf{3.14\ in^2}$

Fluid Flow Velocity:

$\boldsymbol{v} = (Q \times 0.321) / A = (100 \times 0.321) / 3.14 = \mathbf{10.2\ ft/s}$

Velocity Head:

$\boldsymbol{Vh} = v^2 / 2g = 10.2^2 / (2 \times 32.2) = \mathbf{1.6\ ft}$;
Or,
$\boldsymbol{Vh} = 1.6 \times 0.9 / 2.31 = \mathbf{0.6\ psi}$.

Affinity Laws for Pumps: The pump parameters (flow rate, head and power), will change with varying rotating speeds. The equations that explain these relationships are known as the "Affinity Laws":

Flow rate (Q) is proportional to the rotating speed (N);
Head (h) is proportional to the square of the rotating speed;
Power (P) is proportional to the cube of the rotating speed.

Impeller Diameter	Speed	Specific Gravity (SG)	To Correct for	Multiply by
Constant	Variable	Constant	Flow	$\left(\frac{\text{New Speed}}{\text{Old Speed}}\right)$
			Head	$\left(\frac{\text{New Speed}}{\text{Old Speed}}\right)^2$
			BHP (or kW)	$\left(\frac{\text{New Speed}}{\text{Old Speed}}\right)^3$
Variable	Constant		Flow	$\left(\frac{\text{New Diameter}}{\text{Old Diameter}}\right)$
			Head	$\left(\frac{\text{New Diameter}}{\text{Old Diameter}}\right)^2$
			BHP (or kW)	$\left(\frac{\text{New Diameter}}{\text{Old Diameter}}\right)^3$
	Constant	Variable	BHP (or kW)	$\frac{\text{New SG}}{\text{Old SG}}$

Note: As can be seen from the above laws, doubling the rotating speed of the centrifugal pump will increase the power consumption by **eight times**.

Example: A centrifugal pump, at 1750 RPM, has the following performance, Q = 1000 GPM; h = 150 ft.; N = 45 HP. What will the performance of this pump at 2900 RPM?

$\boldsymbol{Q} = 1000 \times (2900 / 1750) = \boldsymbol{1660\ gpm}$

$\boldsymbol{h} = 150 \times (2900 / 1750)^2 = \boldsymbol{411\ ft}$

$\boldsymbol{N} = 45 \times (2900 / 1750)^3 = \boldsymbol{205\ HP}$

Minimum Pipe Diameter: The recommended suction inlet size (D) may be:

$\boldsymbol{D} = (0.0744\ Q)^{0.5} =$

Where:

D = Pipe diameter, inches
Q = Flow rate in gallons per minute (gpm).

Clear fluids:

$$\mathbf{d} = \frac{{}^{0.73}\sqrt{Q / SG}}{\rho^{0.33}} =$$

Corrosive fluids:

$$d = \frac{^{1.03}\sqrt{Q / SG}}{\rho^{\,0.33}} =$$

d = Pipe inner diameter, in
Q = Flow rate, GPM
SG = Specific Gravity,
ρ = Fluid density, lb/ft²

Conversion Area - Volume:

1 in² = 6.452 cm² = 6.452 x 10⁻⁴ m² = 6.944 x 10⁻³ ft²;

$1\ in^2 = 6.452\ cm^2 = 6.452 \times 10^{-4}\ m^2 = 6.944 \times 10^{-3}\ ft^2$;
$1\ gal\ (US) = 3.785 \times 10^{-3}\ m^3 = 3.785\ dm^3$ (liter) $= 0.13368\ ft^3$;
$1\ gpm\ (US) = 6.31 \times 10^{-5}\ m^3/s = 0.227\ m^3/h = 0.0631\ dm^3$ (litre)$/s = 2.228 \times 10^{-3}\ ft^3/s = 0.1337\ ft^3/min$;
$1\ psi\ (lb/in^2) = 144\ psf\ (lb_f/ft^2) = 6{,}894.8\ Pa\ (N/m^2) = 6.895 \times 10^{-3}\ N/mm^2 = 6.895 \times 10^{-2}\ bar$;
$1\ hp = 745.7\ W$.

Pump Standards: Centrifugal pumps can be segmented into groups based on design, application, models, and service type. Pumps can belong to several different groups depending on their construction and application. The following examples demonstrate various segments:

HI - Hydraulic Institute Standards;
ANSI Pump - ASME B73.1 Specifications (chemical industry);
API Pump - API 610 Specifications (oil & gas industry);
DIN Pump - DIN 24256 Specifications (European standard);
ISO Pump - ISO 2858, 5199 Specifications (European standard);
Nuclear Pump - ASME Specifications;
UL/FM Fire Pump - NFPA Specifications.

Flow Velocity in Hydraulic Lines:

- ✓ Suction Line Low Pressure ……….2 - 4 feet/second;
- ✓ Return Lines Low Pressure ………10 - 15 feet/second;
- ✓ Medium Pressure Lines …………...500 - 3,000 PSI at 15 - 20 feet/second;
- ✓ High Pressure Lines ……………….3,000 PSI at 25 - 30 feet/second;
- ✓ Air-Oil Systems - All Pressures …..2 - 4 feet/second.

Other Formulae:

Torque (lb. in.) = GPM x PSI x 36.77 / RPM =

Horsepower - to drive a pump @ 100% efficiency HP = GPM x PSI x 0.000583.
Horsepower - to drive a pump @ 85% efficiency HP = GPM x PSI x 0.000686.

Rule of Thumb: 1 GPM @ 1,500 PSI = 1 HP.

HYDRAULIC VALVES:

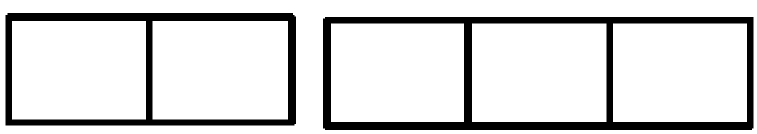
Hydraulic valves properly direct the flow of a liquid, usually oil, through a hydraulic system. The direction of the oil flow is determined by the position of a spool. Hydraulic valves are available in a variety of sizes. The size required is determined by the maximum flow of the hydraulic system through the valve and the maximum pressure in the hydraulic system. Hydraulic valves are available with different mountings, such as, mounting in pipelines, threaded connection as cartridges, sub-plate mounting, etc.

1. Directional Control Valves:

Directional control valves can control the start, stop, and change in direction of flow of a pressure of the fluid, this case, the hydraulic oil. For this reason, they are also referred to as switching valves. Directional control valves are available as spool valves and poppet valves. The directional control valves ensure the flow of air between air ports by opening, closing and switching their internal connections.

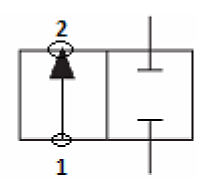
Similar to pneumatics, their classification is determined by the number of **ports** or openings also called **ways**, the number of switching **positions** and its method of operation. Common types of directional control valves include 2/2, 3/2, 5/2, etc. The **first** number represents the number of **ways** (2-way, 3-way, 4-way); the **second** number represents the number of **positions**.

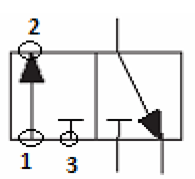
- ✓ **Number of positions**: Directional valves are always represented by a rectangle, divided ins squares. The number of squares represents the positions.



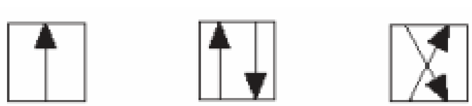
2 positions 3 positions

- ✓ **Number of ways (ports)**: Is the number of work connections of a pneumatic valve, such as the pressure inlet, utilization connection and a pressure outlet. As a thumb of rule, to find the number of ways, consists in separate one square of the valve symbol (position) and count how many times the internal symbols touch the sides of the square position, obtaining the number of orifices corresponding the number of ports (ways).

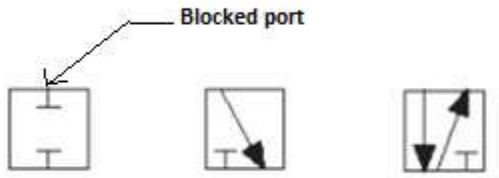




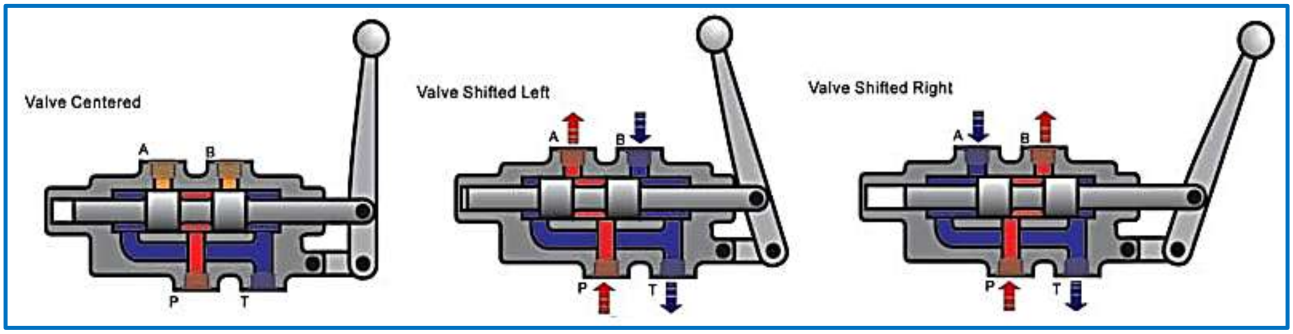
- ✓ **Flow direction:** In the represented valve positions below, the arrows indicate the internal connections, but not necessarily the flow direction.



- ✓ **Blocked port:** Is represented by a short vertical and horizontal line indicating as a "T", positioned in the internal rectangle, as can be seen below:



- ✓ **Spool-Type Hydraulic Directional Valves:** The simplest possible spool-type hydraulic valve has an inlet, an outlet port, and a cylindrical, grooved, linearly movable spool within the bore to control the flow between them. The spool is usually biased to one position by a spring, and displaced to the other position by a lever or actuator of some kind.



This type of hydraulic valve would typically be used to turn a system device such as a uni-directional hydraulic motor, on and off. It could also be used to connect or disconnect supply pressure to a portion of the hydraulic system. When the hydraulic valve is actuated, the spool is moved, compressing the spring. Depending on body design and initial spool position, either the grooves open a path between ports in the valve body, or the raised sections between the grooves close the ports. When the lever is released, the spring forces the spool back into the initial position.

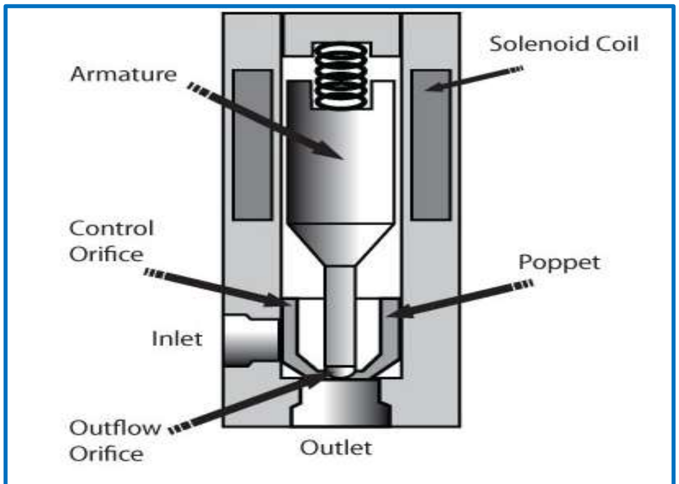
Increasing the number of ports from two to four increases the hydraulic valve's control capabilities. A four-port hydraulic valve, for example, can automatically apply pressure to one side of a cylinder while simultaneously opening a drain path back to the reservoir on the other side, or control rotation of a bi-directional hydraulic motor that does not require an unpowered position. A double-acting hydraulic cylinder normally requires a three-position spool valve to provide the ability to hold it stationary as well as to control its direction and speed. There are three common configurations:

Closed center circuit: The inlet pressure port of the valve spool blocks pumps flow in neutral and directs it to the appropriate work port when the spool is displaced.

Open center circuit: Allows the use of a fixed-displacement pump, but a control valve must also incorporate additional metering edges to dump the pump flow to a tank at low pressure drop, and restrict the pump's flow path to the reservoir, in order to build enough pressure to move the cylinder.

Load sensing circuit: Adds the requirement to drain a signal port in the neutral position and connect it to load pressure as the spool is displaced.

- ✓ **Poppet-Type Directional Valves:** In poppet-type valve, the fluid is routed through an internal opening, closed by the poppet mechanism, typically a spring and/or hydraulically-loaded ball or conical plug. The hydraulic fluid flow is controlled by the opening or closing of the poppet, which may be accomplished by a mechanical device or a solenoid.



2-Way Poppet Type Hydraulic Directional Control Valve

Hydraulic poppet-type valves can be configured to combine both fluid supply and a return path in a single valve to simplify the circuit design. A typical double acting hydraulic cylinder circuit using poppet-type valves would require two for each direction. Assuming a normally closed valve configuration, one valve would pressurize one side of the piston in the cylinder, while the other would open the flow path back to the reservoir for fluid from the opposite side of the piston.

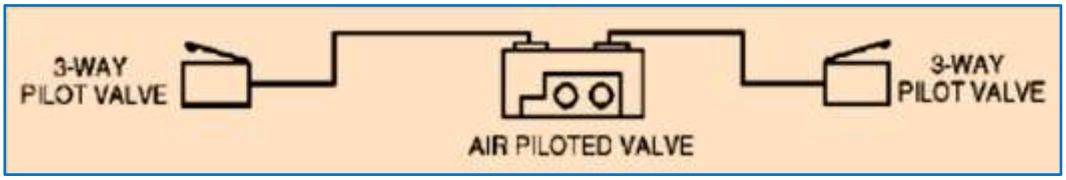
Because poppet-type valves use a metering element having metal-to-metal contact with the seat in their closed position, are capable of much less internal leakage in the “off” position than a spool-type valve. This can be important in situations such as holding the position of a loaded lift truck mast, where any leakage in the valve will permit the load to drift down, possibly necessitating the addition of a separate “lock” valve in the circuit.

Offsetting this advantage is the fact that spool-type hydraulic valves can be designed to provide a smooth operation of a cylinder or hydraulic motor, possibly eliminating the need for additional metering or cushioning devices in the system. On the other hand, poppet-type hydraulic valves may require special means to achieve fine metering.

Finally, the choice of valve type is dictated by the proper system requirements and application parameters. It is definitely not the case that one type of valve can be better than any other; these valves are simply “different”. Both have advantages for particular hydraulic applications.

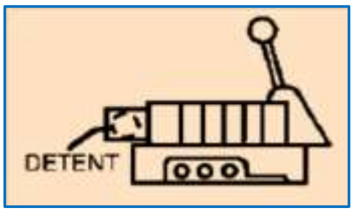
2. **Solenoid Valves:**

Solenoid actuation requires the presence of electric switches, wires, and all of the shielding necessary to reduce spark hazard and personal risk. Air actuation requires only a 3-way air pilot valves and tubing. There is no explosion, spark, or shock risk and the components are less expensive.



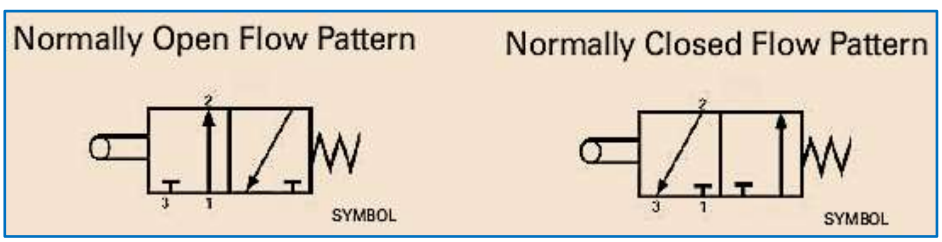
3. Detented valve:

A detented valve (means detainer) is one device that **holds its position** by some mechanical means such as a spring, ball, or cam. In addition, detents are also used to locate the middle position in 3- position valves. Most valves hold their position by means of the natural friction of the rubber seals. Where natural friction is low, such as in packless valves, or where it is not enough for safety purposes, detented models are recommended.

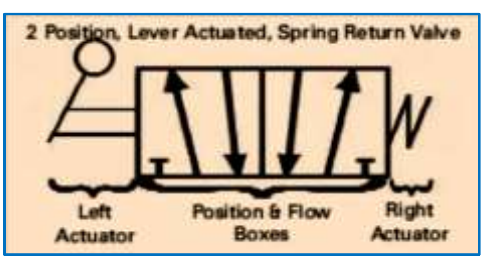


4. Normally Closed & Normally Open:

The difference between a 3-way normally **closed** valve and a 3-way normally **open** valve is; the normally open valve **allows fluid flow** to pass when **not actuated** and, normally closed valves **allow fluid flow** to pass only when **actuated**.



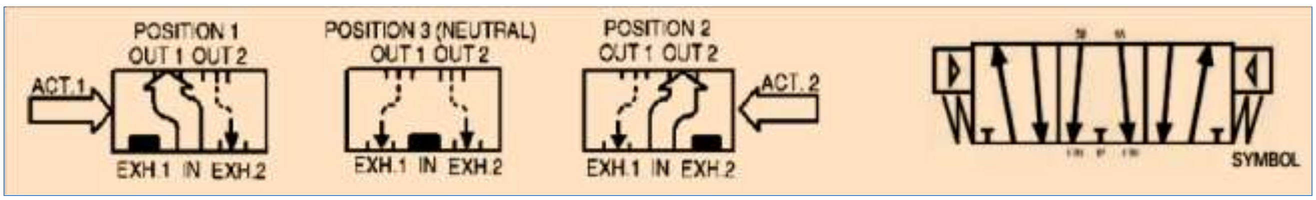
Understanding the Circuit Symbols: Directional control valves are the building blocks of hydraulic and pneumatic control. Symbols show the methods of actuation, the number of positions, the flow paths, and the number of ports. Every symbol has three parts (see figure below). The left and right actuators are the pieces that cause the valve to shift from one position to another.



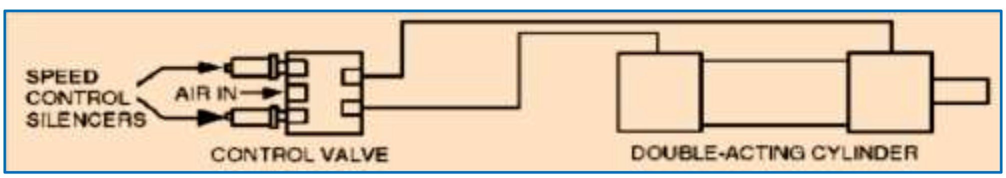
Every valve has at least two positions and each position has one or more flow paths. Looking at the example below, when the lever is not activated, the spring actuator (right side) is in control of the valve; the box next to the actuator is the current flow path. When the lever is actuated, the box next to the lever is in control of the valve.

In the example, above, there are a total of **5 ports**. A valve can only be in one "position" at a given time. Flow is indicated by the arrows in each box. These arrows represent the flow paths of the valve, when it is that position (depending upon which actuator has control over the valve). In hydraulic valves, the fluid (hydraulic oil) is exhausted back to the reservoir. In pneumatic valves, the exhaust port leaves air directly to atmosphere.

Pressure in Position Valves: When actuated, a 3-position 5-way directional valves work with a center or "neutral" position. Pressure held models are ideal for "inching" operations where you want the cylinder rod to move to a desired position and then hold.

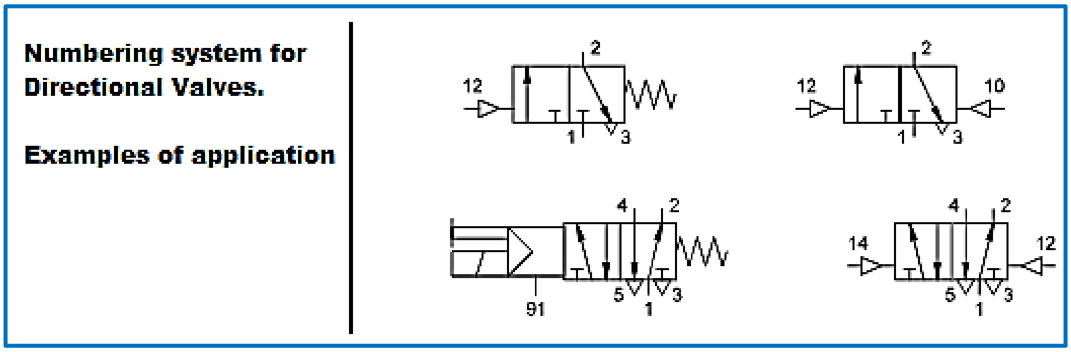


The advantage of using 5-way valves is why these valves have separate exhaust ports for each cylinder. If exhaust silencers with built-in speed controls are used, the speed of the cylinder motion may be individually controlled in each direction. Five ported valves can also function as dual pressure valves, where fluid flows and both cylinder ports use the inlet as a common fluid exit.

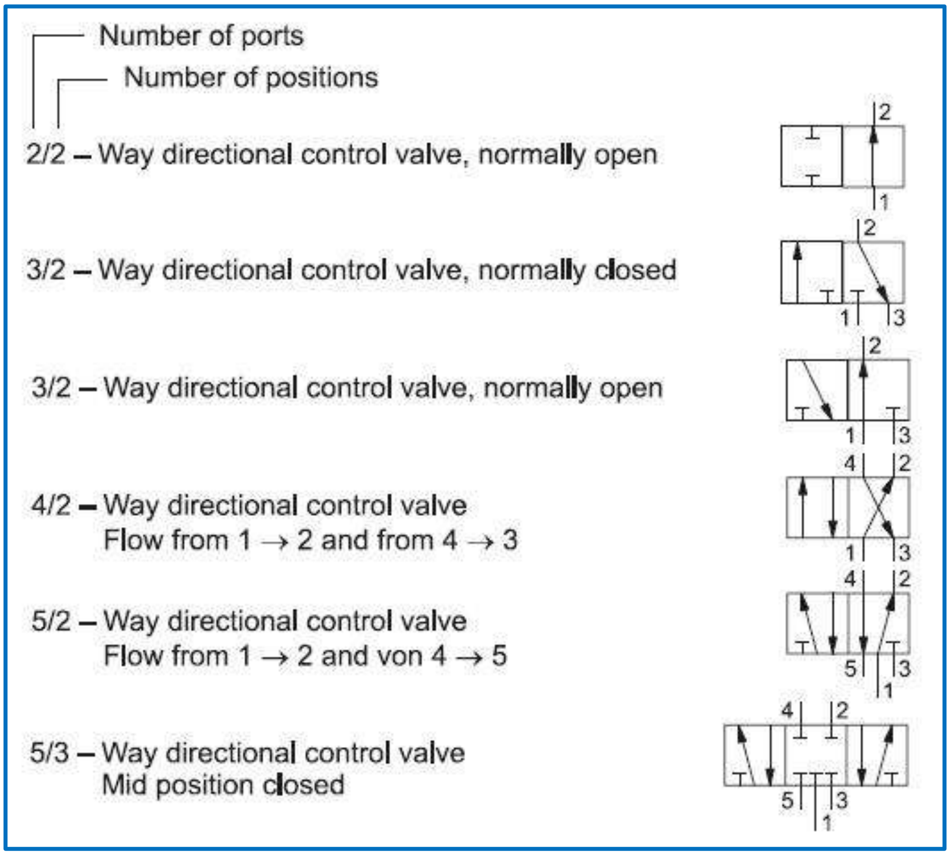


Valves numbering system: A numbering system is used to designate Directional Control Valves according to DIN/ISO 5599-3. Before this, a lettering system was utilized, as shown below:

Working lines	ISO 5599-3	Lettering System	Port or Connection
	1	P	Pressure port
	2, 4	A, B	Working lines
	3, 5	R, S	Exhaust ports
Pilot lines	10	Z	Applied signal inhibits flow from port 1 to port 2
	12	Y, Z	Applied signal connects port 1 to port 2
	14	Z	Applied signal connects port 1 to port 4
	81, 91	Pz	Auxiliary pilot air



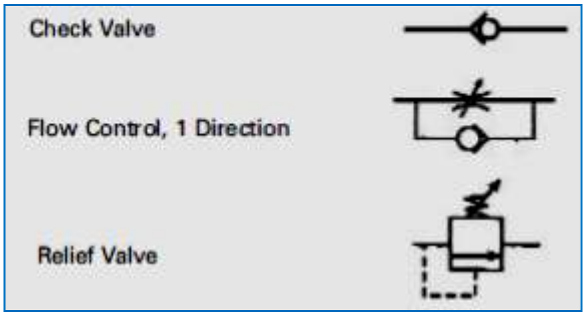
Valve identification: Thus, the directional control valve is represented by the number of controlled connections, the number of positions and the flow path. In order to avoid faulty connections, all the inputs and outputs of a valve are identified, as below:



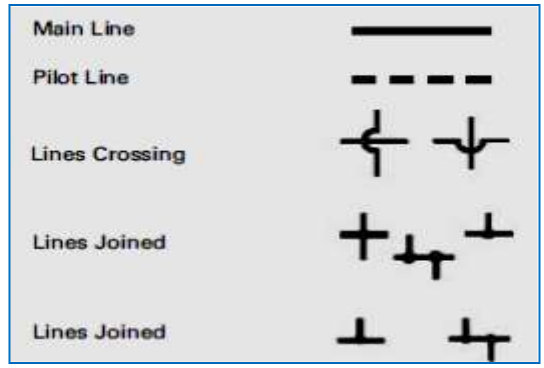
Methods of actuation: The methods of actuation of hydraulic and pneumatic directional control valves are dependent upon the requirements of the task. The symbols for the methods of actuation are detailed in DIN ISO 1219. The types of actuation vary as seen below:

- Electrically actuated and combined;
- Pneumatically actuated;
- Mechanically actuated;
- Manually actuated;

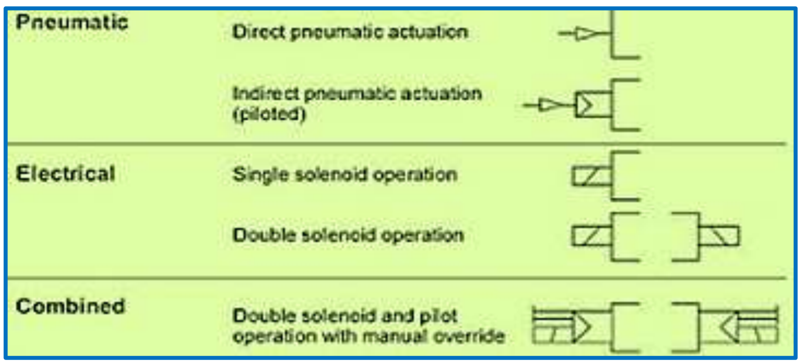
Simple Hydraulic Valves



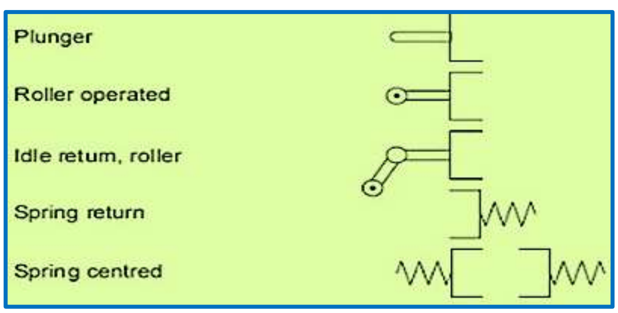
Basic Lines



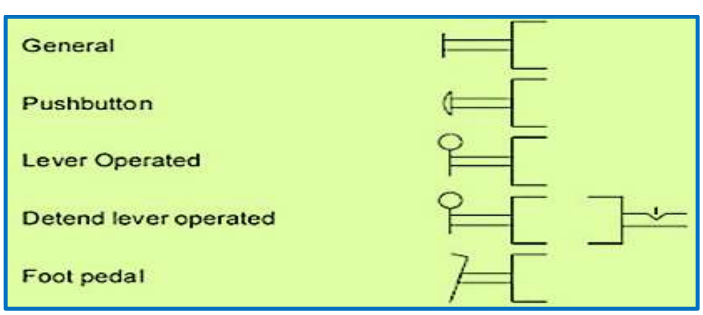
Electrical, Pneumatic, & Combined:



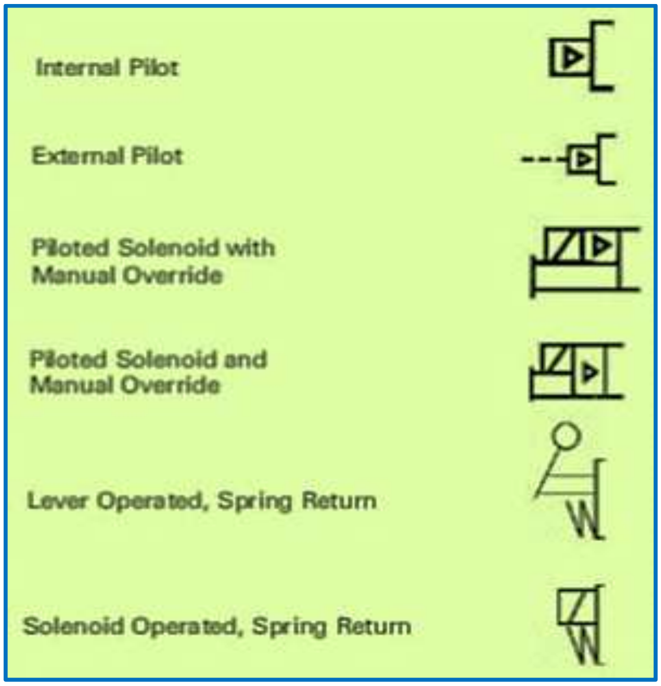
Mechanical:



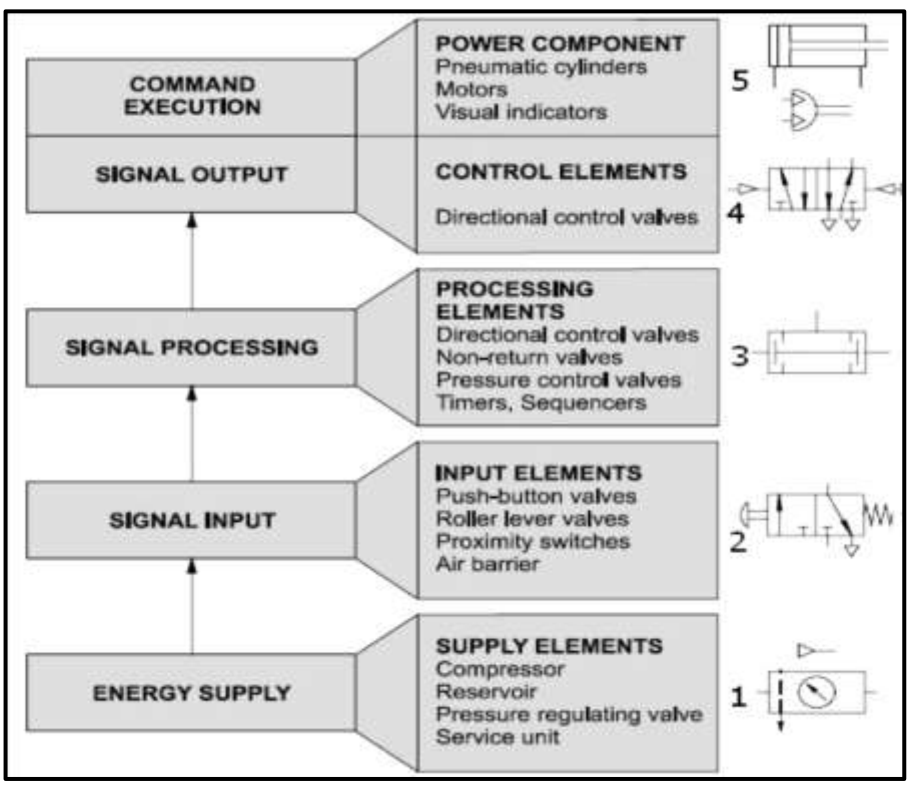
Manual:



Other Actuators:



Control Path for Signal Flow: Hydraulic or pneumatic systems consist of an interconnection of different groups of elements. This group of elements forms a control path for signal flow, starting from the signal section (input) through to the actuating section (output). Control elements control the actuating elements in accordance with the signals received from the processing elements.



TYPES AND FUNCTIONS OF VALVES:

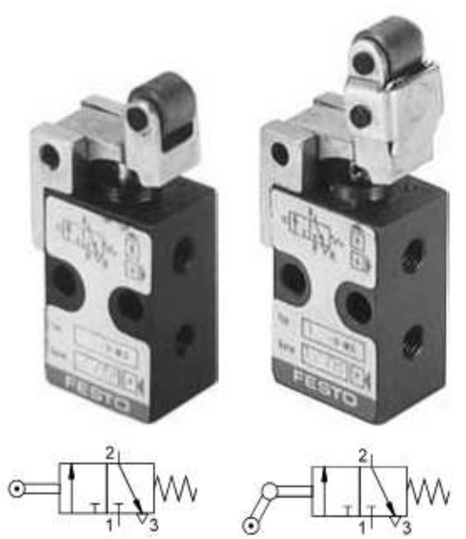
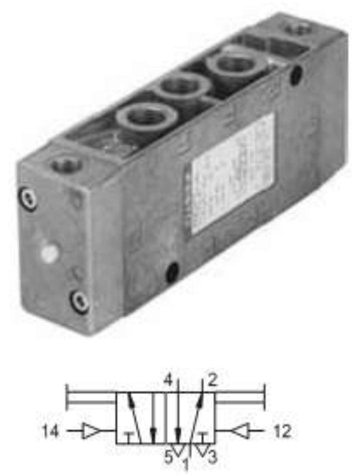
The main function of the valves is to control the pressure or flow rate of a fluid. Depending on design, these can be divided into the following categories.

- ✓ Directional Control Valves
  - Input/signaling elements
  - Processing elements
  - Control elements
- ✓ Non-return valves
- ✓ Flow control valves
- ✓ Shut-off valves

Input/signaling element: As a signalling element the directional control valve is operated by an external device, for example, by a roller lever to detect the piston rod position of a cylinder.

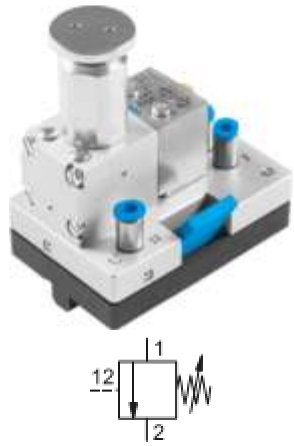
Processing element: As a processing element the directional control valve redirects or cancels signals, depending on the signal inputs received, as shown below.

Control element: As a control element the directional control valve must deliver the required quantity of air to match the necessary power components, as shown below.

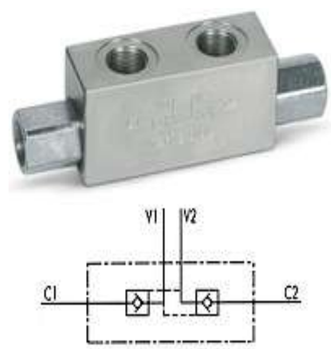
Input/signaling: A 3/2-way roller valve (without and with idle return). 	**Processing**: A 3/2-way actuated valve (single pilot with spring return). 	**Control**: A 5/2-way valve for cylinder control (double pilot). 

Pressure Valves: Its function is to regulate the pressure in an overall hydraulic and pneumatic system, commonly utilized on the up-stream side of hydraulic pumps or compressors to control pressure. Pressure regulating valves are the main types, generally adjustable through spring compression. Hydraulics relief valves are all fully adjustable over a wide range of operating pressures up to and including 5000 psi (350 bar) and 6000 psi (420 bar) intermittent.

- Pressure regulating valve with relief port;
- Pressure regulating valve without relief port;
- Pressure sequence valves;
- Pilot operated valves.

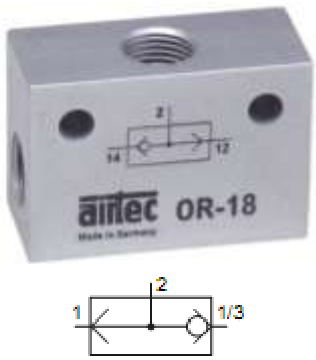
Pressure regulating valve with relief port.	Pressure regulating valve without relief port.	Pressure sequence valve.	Piloted operated valve.
			

Non-Return or Check Valves: Are valves that allow the flow through a single device in one direction, and in the other direction blocks the flow, commonly applied using the quick exhaust valves or the shuttle valves. There are two main configurations; with and without the spring return. In order to release flow, the pressure force on spring return must be greater than the spring force.

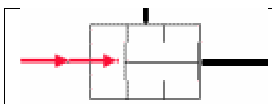
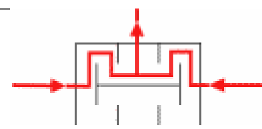
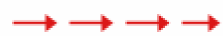
Ball check valve	Quick ball check valve	Dual check valve
		

Shuttle Valves (OR function): The shuttle valve is like a tube with three openings; one on each end, and one in the middle. A ball or other blocking valve element moves freely within the tube. When pressure from a fluid is exerted through an opening on one end it pushes the ball towards the opposite end, permitting the fluid to flow through the middle opening. In this way, two different sources can provide pressure without the threat of backflow from one source to the other.

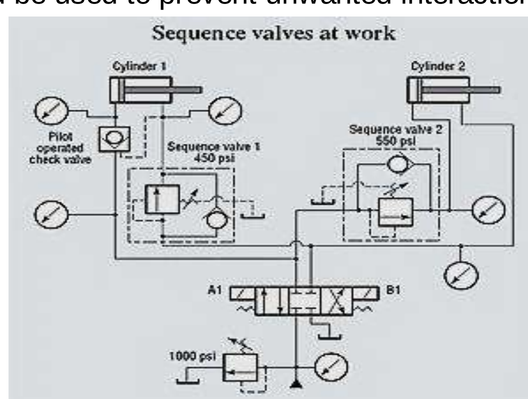
Note: The shuttle valves permit the combination of two input signals into an OR function. The OR gate has two inputs and one output. An output signal is generated when a pressure is applied at one of the two outputs.

Shuttle valve	Dual pressure valve
	

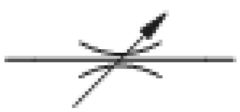
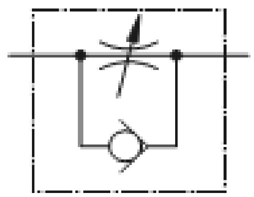
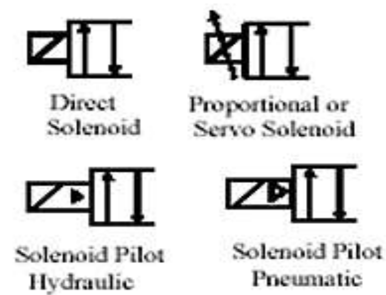
Dual Pressure Valves (AND function): Also called interlock control valves, is only possible when two operation conditions are wholly fulfilled, such as, when a hydraulic press may be operated only if the safety door is closed. This is achieved by an active input which slides to a shuttle valve, blocking the fluid flow. The dual valve requires two pressurized inputs to allow an output, and when is switched to the two inputs, the lower pressure reaches the output 2, (AND function).

 Dual Pressure Valve(closed)	 Dual Pressure Valve (open)	 Red arrows = Fluid flow direction

Sequence Valves: Sequence valves are normally closed that usually allow bidirectional flow when equipped with a bypass check valve and always have an external drain connected directly to tank. Sequencing circuits are those that automatically program two or more cylinders on a machine to cause them to **extend and retract** in a pre-determined sequential order on every cycle.

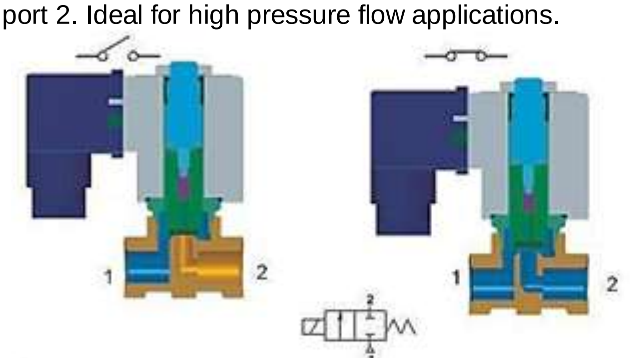
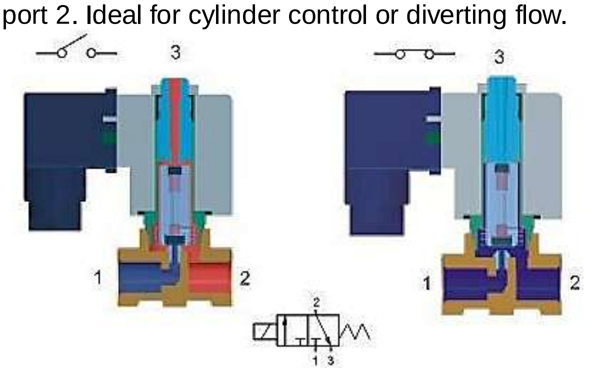
Sequence valve	If the cylinders are to be sequenced in both directions of travel, or if both will be in motion at the same time for the cycle, a 4-way valve should be used to prevent unwanted interaction.
	

Flow Control Valves: These valves are used to regulate the volumetric flow rate in both directions. The oil flows through the throttle point (2), which can be adjusted using a rotary knob (4). The most common control flow valves are:

Needle valve: Is a flow control valve, adjustable when control of fluid flow in both directions is necessary.	**Throttle valve**: This flow control valve is used when some processes must have a bypass and be pressure-compensated.	**Solenoid valve**: The main function is to shut off, release, dose, distribute or mix fluids, found in many industrial areas.
 	 	 

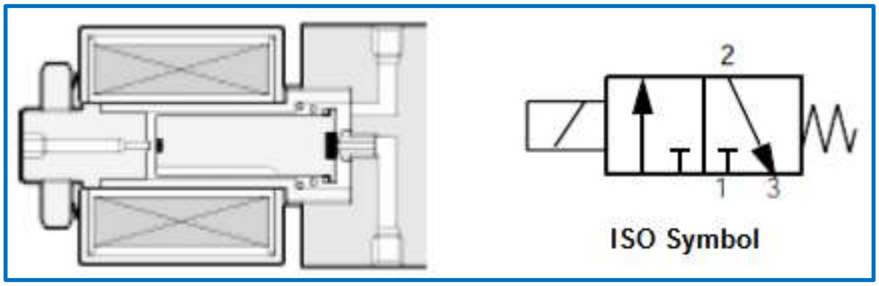
Solenoid Valves: Are electromechanically operated valves, controlled by an electric current passing through a solenoid, commonly used to control elements in fluidics. Solenoid valve coils are available for both DC and AC electricity. The most common voltages available are, 6-Volt DC, 12-Volt DC, 24-Volt DC, 24-Volt AC, 120-Volt AC, 220/240-Volt AC. Solenoids offer fast and safe switching, high reliability, good medium compatibility of the materials used, and low control power. There are two main types:

- The **two-way solenoid valve**, when the flow is switched on or off;
- The **three-way solenoid valve**, the flow is switched between the two outlet ports. Multiple solenoid valves can be placed together on a manifold.

2 Way Solenoid Valve: Power Off - Valve remains closed. Power On - Valve opens allowing flow from ports 1 to port 2. Ideal for high pressure flow applications.	**3 Way Solenoid Valve**: Power Off - Port 1 closed, port 2 open to port 3. Power On - Blocking Port 3, port 1 opens allowing flow to port 2. Ideal for cylinder control or diverting flow.
	

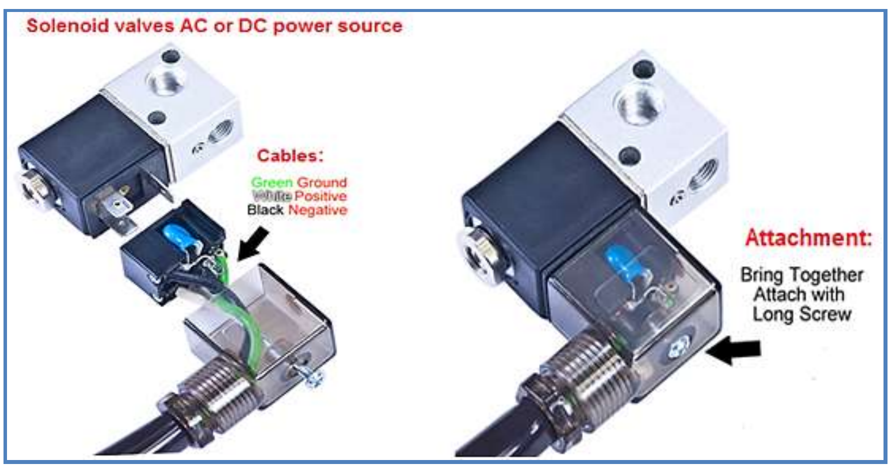
Solenoid Valve Operations: Applied in electro-pneumatically and electronically controlled systems, indicated here only to consider the electrical operation of directional control valves. In small size solenoid valves, an iron armature moves inside an airtight tube. The armature is fitted with an elastomer poppet that is lifted by a magnetic force of the energized coil.

Solenoid Valve Parts: A solenoid valve has two main parts; the solenoid, and the valve. As defined, the solenoid converts electrical energy into mechanical energy, which, in turn, opens or closes the valve mechanically. In some solenoid valves the solenoid acts directly on the main valve. Others use a small, complete solenoid valve, known as a pilot, to actuate a larger valve.

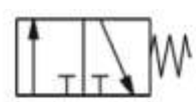


Piloted Solenoid Valves: These valves require much less power to control, however, are noticeably slower. Piloted solenoids usually need full power at all times to open and stay open, where a direct acting solenoid may only need a full power for a short period of time to open it, and only a low power to hold it. A direct acting solenoid valve typically operates in 5 to 10 milliseconds.

Normally Open, Normally Closed: The solenoid controls the fluid pressure to open and close the valve. When power is lost, the hydraulic or pneumatic valve closes automatically. When the valve is **closed**, the ports are isolated, and the valve is termed **normally closed** (N.C). When the valve is **open**, the solenoid is not energized, and the valve is commonly designated as **normally open** (N.O.). The working external power source is commonly 127 V (A.C) or 24 V (D.C), 50/60 Hz.



(a) Normally open type



(b) Normally closed type

Common Application: Solenoid valves are used in fluid power, either pneumatic or hydraulic systems to control cylinders, fluid power motors, or larger industrial valves. Solenoid valves are also, commonly used to control valves used to control a propellant (usually compressed air or CO_2). In addition, these valves are used in domestic washing machines and dishwashers to control water entry into the machines, and in household water purifiers (RO systems).

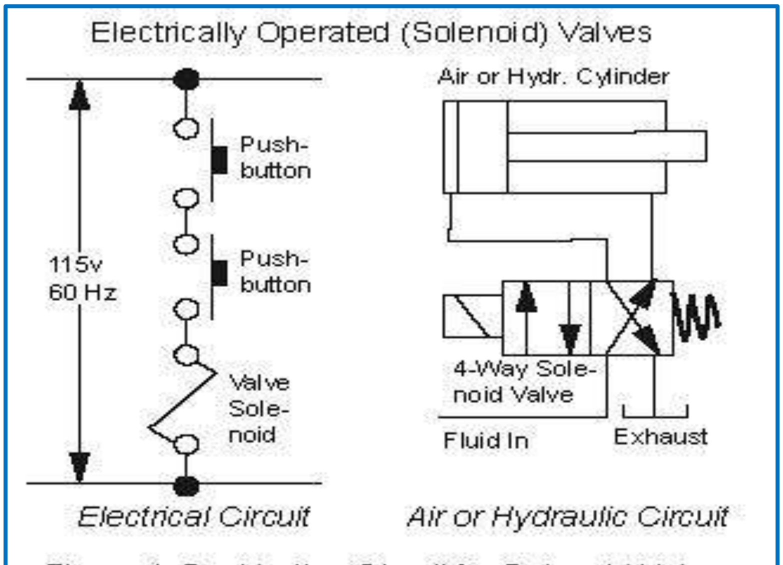
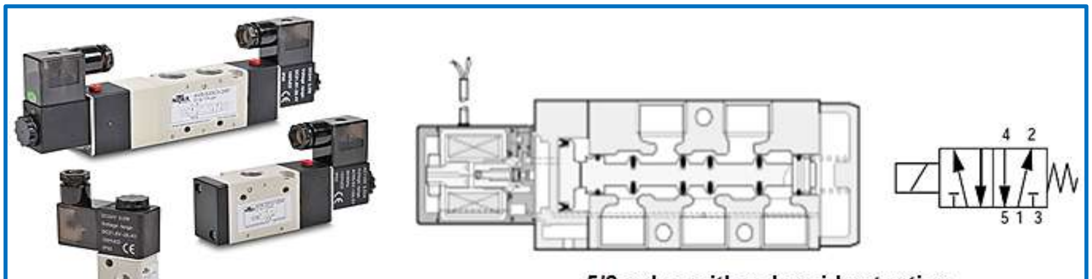


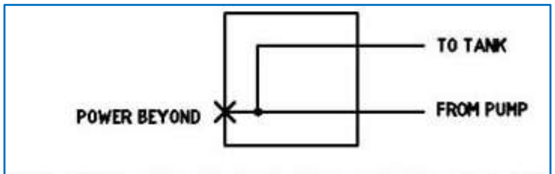
Figure 4. Pushbutton Circuit for Solenoid Valves.

Types of Solenoid Valves: There are two types, single-acting and double-acting types. The single-acting solenoid valves size from **M5 to 1/2''**, mainly used for controlling the single-acting type cylinders. The most common solenoid valves can be subdivided into 2-position & 3-ports and 2-position & 5-ports according to the main function. The control mode is subdivided into single and double electric control. According to the fluid flow and application, the valve body is available in many types.

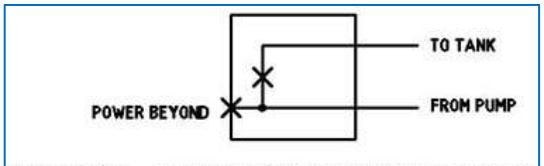


5/2 valve with solenoid actuation

Power Beyond: Also called high-pressure carry over (HPCO), is a facility on a mobile hydraulic directional control valve that enables the pressure circuit to be isolated from the tank circuit and be carried over to an additional valve, usually another directional control valve. Thus, this directional control valve (DCV) must be very well sized to handle the maximum rated flow from the pump.



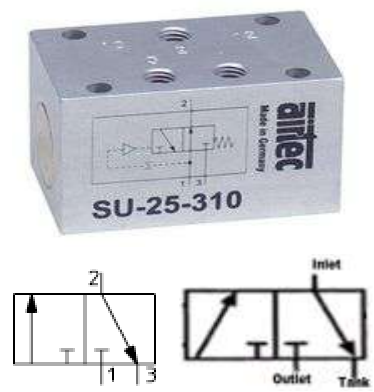
OPEN CENTER - EXISTING DCV WITHOUT ALTERNATIVE TANK PORT

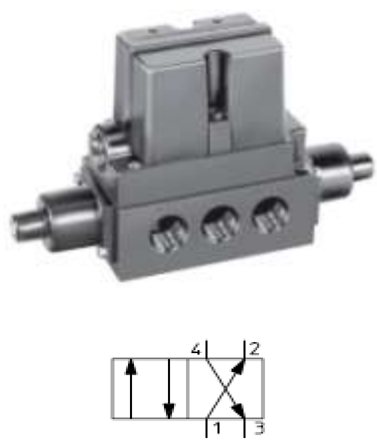
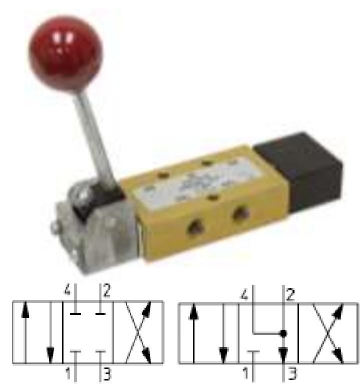
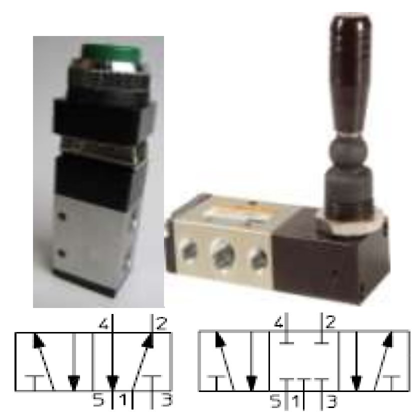


CLOSED CENTER - EXISTING DCV WITHOUT ALTERNATIVE TANK PORT

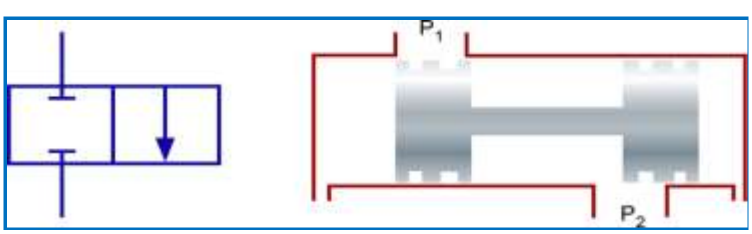
DIRECTIONAL CONTROL VALVES:

Directional Valves Classification: Hydraulic directional valves function to control pressure, and control direct fluid flow in response to external commands. These valves are usually servo-commands where the servo is positioned in response to solenoids, torque motors or mechanical input and may be either open or closed (in one position or another).

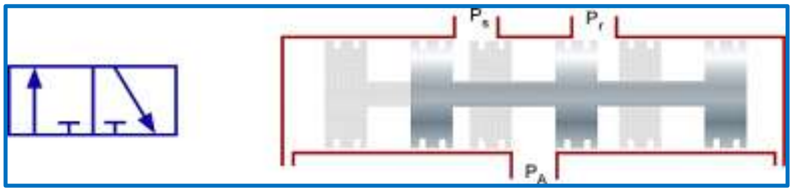
2/2 valves	3/2 valves	3/3 valves
 Normal closed Normal open	 Normal closed Normal open	 Middle position closed.

4/2 valves	4/3 valves	5/2 vias & 5/3 vias
	 Middle closed Outlet blocked	

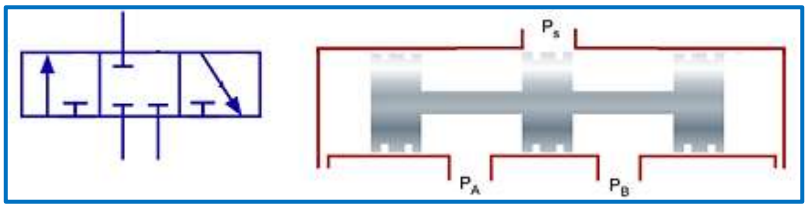
- ✓ **2-Way, 2-Position**: Are only used to allow or stop fluid flow, providing a simple on and off function in a hydraulic or pneumatic circuit, ideal for use in rugged applications. This valve simply blocks or opens a flow. It can be compared to a slide in a watercourse. Slide open, - fluid flows. Slide closed, - fluid stops flow.



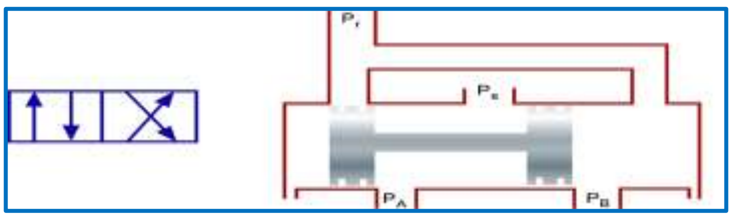
- **3-way, 2-Position**: Three-way valves are the same as 2-way valves with the addition of a third port for exhausting air or oil back to tank. These valves always have three working ports. inlet, outlet, and exhaust (or tank), used to operate double acting air cylinders, for example, actuating a single-acting cylinder. The hydraulic oil flows from 1 to 2 through the valve (and the cylinder extends), or port 1 is blocked, while port 2 is exhausted to reservoir via port 3.



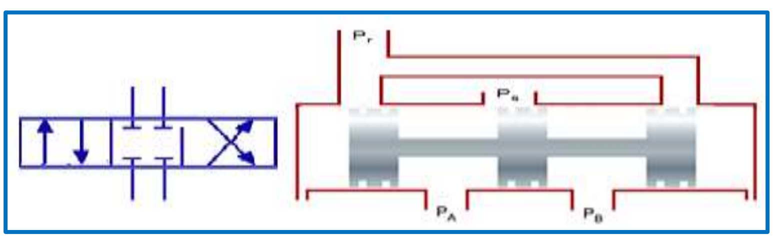
- **3-way, 3-Position**: A 3-way valve allows fluid flow to an actuator in one position and exits the fluid from it in other position. During start-up, when the lockout and exit port is opened, the blocked center condition does not allow fluid to return to the cylinder. Example: Position 1, left - cylinder advance. Position 2, middle - cylinder neutral (pressureless circuit). Position 3, right - cylinder retracts.



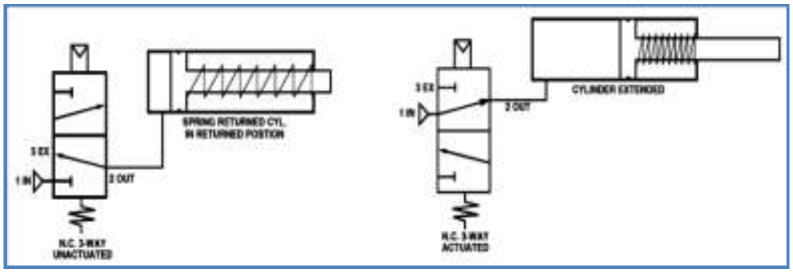
- **4-Way, 2-Position:** Are one of the most commonly used hydraulic/pneumatic components for directional control. The flow paths for an unactuated valve are inlet to cylinder 2 and cylinder 1 to exhaust. When actuated, the inlet is connected to cylinder 1 and cylinder 2 is connected to exhaust.



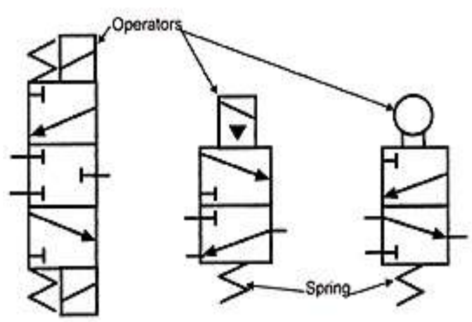
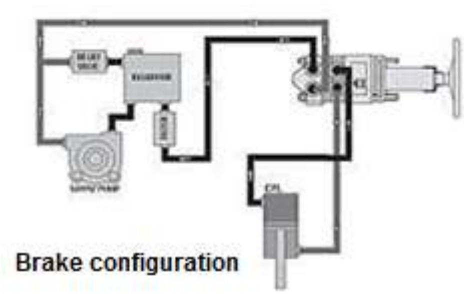
- **4-Way, 3-Position**: The 4-way 3-position is a common type of directional control valve for both air and hydraulic circuits. Four-way valves use two 3-way valve functions operated at the same time, one normally closed and one normally open. With four distinct flow paths, these valves make it easy to reverse the motion of a cylinder or motor.



Normally Open 3-Way Valves: When unactuated, the pass inlet flows to the outlet and blocks the exhaust port. When actuated, the inlet flow is blocked and the outlet port is connected immediately to the exhaust port. **Example:** A three-way valve applied to a spring return cylinder.



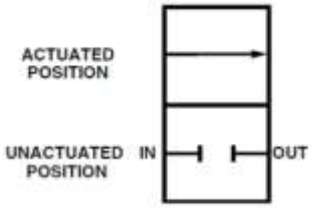
Combination or Proportioning Valves: Are valves whose work is to produce a new function, as an example, the time delay of a 2-way flow control valve to a pressure tank or a 3/2-way valve using a throttle knob setting, to let a greater or lesser amount of fluid flow per unit of time, to do a specific work or sometimes into a pressure tank. When the necessary time pressure is reached, the valve switches to pass the fluid flow. Summarizing, multifunction, or proportioning valves combine two or more functions into a single valve, providing easy and smart solution for recurrent hydraulic circuits.

Directional valves configuration	Proportioning valves
	 

Directional Valves Configuration: As defined before, may vary to almost infinite. 3-Way, 4-Way and 5-Way types of valves range from the simple 2-position, direct solenoid or spring-return, to the more complex three-position, double solenoid, pilot-operated, spring-centered, external-pilot supply and external drain valve. For example, 4-way **poppet valves** have one exhaust port which is shared by all cylinder ports. Always consult the manufacturer´s catalog to choose the right application.

Poppet Valves: Is a valve that continually opens and closes in response to variations in pressure which poppet is attached to a spring-loaded diaphragm. Its components covers an internal passage held in place by air pressure and a spring. 2-Way & 3-Way valves, with an internal poppet design, require the combination of a spring & fluid pressure to hold the valve in the unactuated position.

Example: A Poppet Valve, 2-Way, 2-Port. Normally closed 2-way valves block inlet flow when in the unactuated position. Inlet flow is passing when actuated.



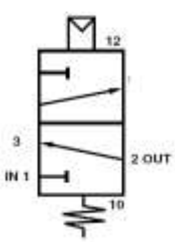
Normally Closed: 2-Way 2-Position Valve:

Advantage: The larger internal surface area required by the poppet results in a higher flow rate than spool-style valves.
Disadvantage: Poppet valves are unbalanced; pressure must be supplied under the poppet to hold the valve in the unactuated position.

Spool Valves: A spool valve consists of cylindrical spools that alternately block and open channels and controls the direction of the fluid flow. When the valve is actuated, the spool shifts causing the seals to travel along the bore, opening ports to allow the fluid flows.

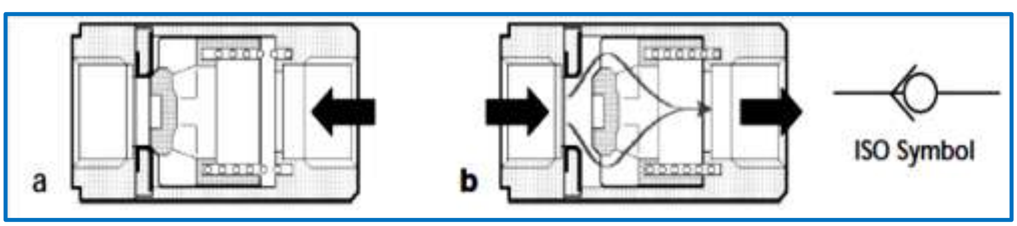
Advantage: Spool valves can be used as selector valves providing the ability to choose from high and low pressures or vacuum pressure.
Disadvantage: Open crossover, all ports are momentarily open to flow as the spool shifts during actuation.

Example: A Spool Valve, 3-Way, 3-Port used as a normally closed 2-Way, 2-Port. To use a 3-way spool valve type as a 2-way normally closed valve, is necessary to plug port 3 and connect the inlet to port 1 and the outlet to port-2.

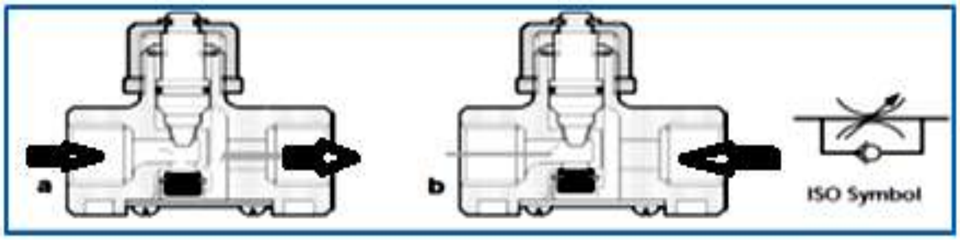


3-Way valve used as a N.C 2-Way valve:

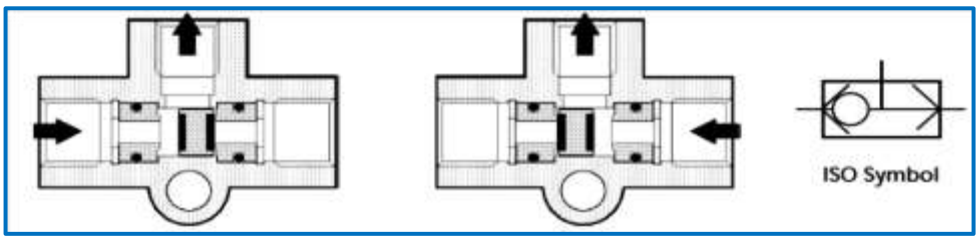
Non-Return Valves: As defined before, these valves allow free either hydraulic or pneumatic flow in only one direction and seals it off in the opposite. These valves are also referred to as **check valves**. Non-return valves are incorporated in speed controllers and self-seal fittings etc.



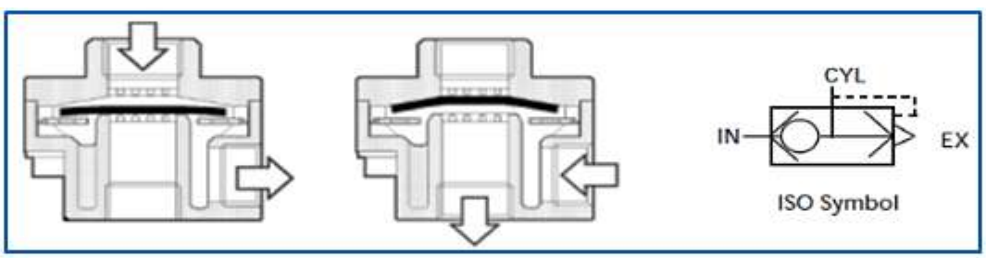
Fluid Flow Control Valves: These valves are sometimes referred to Uni-Directional Flow Control Valves or Speed Controllers; consist of a check valve and a variable throttle, all in one construction. The fluid flows back to the exhaust port of the valve with a restricted flow.



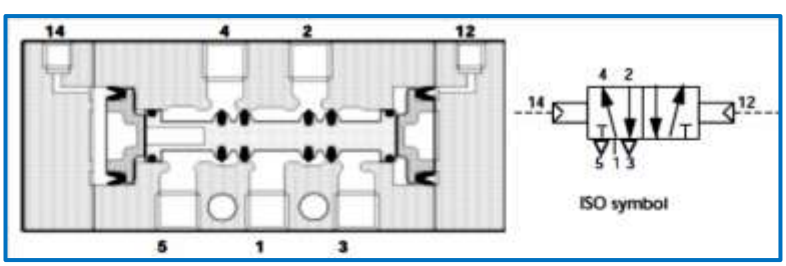
Shuttle Valves: These types of valves are three-ported valves with two signal pressure inlets and one outlet, connected to a signal input. If only one input is pressurized, the shuttle prevents the signal pressure from escaping through the exhausted signal port on the opposite side.



Quick Exhaust Valves: These types of valves close the inlet port and automatically open the wide exhaust port. When the directional control valve, connected to the inlet port on top is reversed, the supply tube is exhausted and the disc lifted by the cylinder pressure. The rubber disc closes off the exhaust port on the bottom, as the supply air flows to the cylinder.



Monostable and Bistable Valves: The spring returned valves are **monostable**, that is, have a defined preferred position to which they automatically return. The **bistable** valve has no preferred position and remains in any position until one of its two impulse signals are operated, as example below:



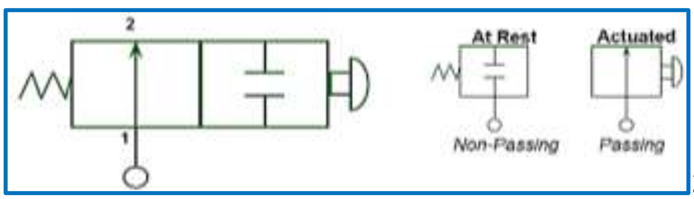
Example: In this bistable, using an operated 5/2 valve below, a short pressure pulse was applied to the pilot port **"14"**, shifting the spool to the right and connecting the supply port **"1"** to the cylinder port **"4"**. The port **"2"** is exhausted through **"3"**. The valve will remain in this operated position until a counter signal is received. This is referred to as a **"memory function"**.

Valve Port Identification: The identification of the various ports is not uniform; it is more a tradition than a respected standard. Originally, the codes previously used the older hydraulic nomenclature. **"P"** for the supply port, which comes from "pump" the hydraulic source of fluid energy. The **outlet** of a 2/2 or 3/2 valve has always been **"A"**, the second, ambivalent **outlet** port **"B"**.

The ISO work groups had the idea that ports should have **numbers** instead of letters, delaying the termination of the standard ISO 1219 by another 6 years. Then, the **supply port** should be **"1"**, the outputs **"2"** and **"4"**, the **pilot port** connecting **"1"** with **"2"** is currently **"12"**, etc. The table below shows the four main sets of port identifications in use. The preferred option is now numbers.

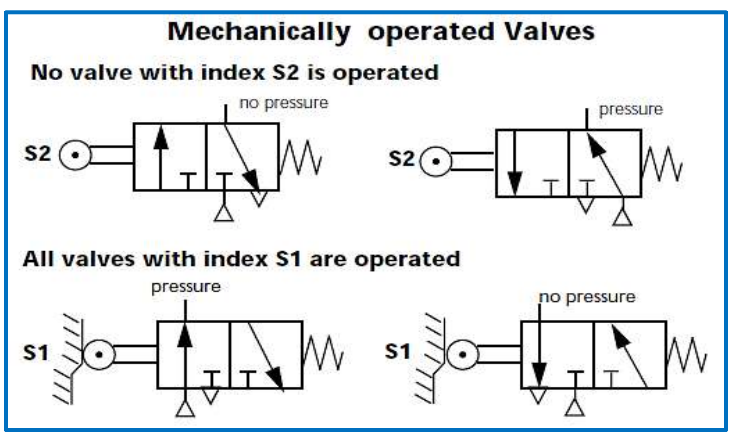
Supply	output	output	Exhaust	Exhaust	Pilot Port	Pilot Port
P	A	B	R	S	Z	Y
P	A	B	R1	R2	Z	Y
P	A	B	EA	EB	PA	PB
1	2	4	3	5	12	14

Manual Operation Valves: Manual or mechanically operated, monostable (spring returned) valves, are generally used for starting, stopping and otherwise controlling a pneumatic control unit. For many applications, it is more convenient if the valve maintains the same position.

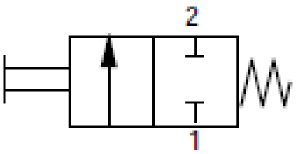
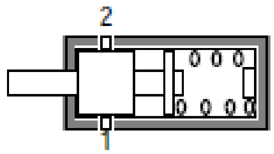
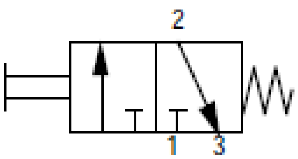
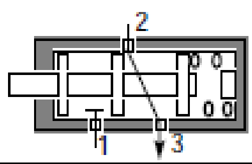
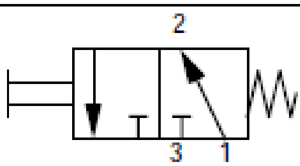
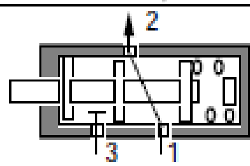
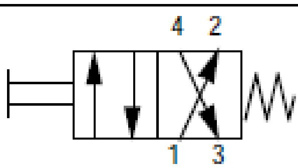
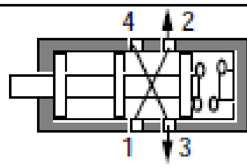
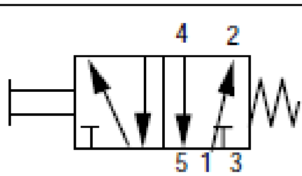
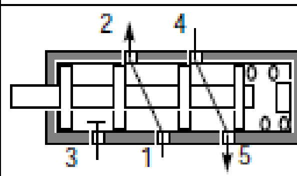
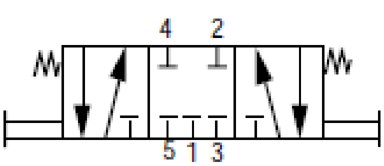
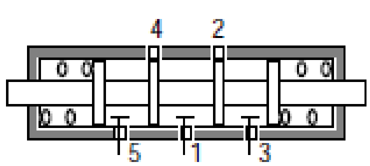
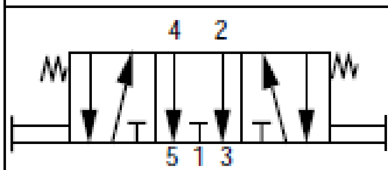
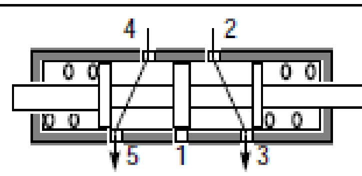
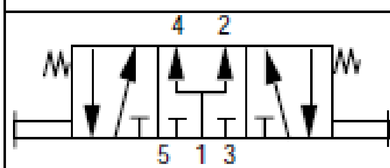
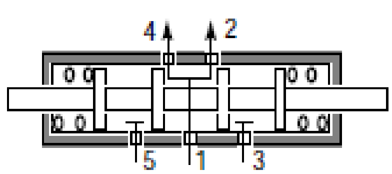


2-way, 2-position, push button, spring return.

This configuration is generally obtained by attaching an operator device, with an index S1 or S2 in the main diagrams, suitable for manual control, onto a mechanically operated valve.



Valve Functions: Directional control valves determine the flow of air between its ports by opening, closing or changing its internal connections. The directional valves are described in terms of the number of ports, the number of switching positions, normal position (not operated), and the method of operation. The first two points are normally expressed in the terms 5/2, 3/2, 2/2 etc. The first number relates to the number of ports (excluding pilot ports) and the second to the number of the valve positions. The main functions and ISO symbols are:

SYMBOL	PRINCIPAL CONSTRUCTION	FUNCTION	APPLICATION
		2/2 ON/OFF without exhaust.	Air motors and pneumatic tools.
		3/2 Normally closed (NC) ,pressurizing or exhausting the output A.	Single acting cylinders (push type), pneumatic signals.
		3/2 Normally open (NO), pressurizing or exhausting the output A.	Single acting cylinders (pull type), inverse pneumatic signals.
		4/2 Switching between output A & B with common exhaust.	Double acting cylinders.
		5/2 Switching between output A & B with separate exhausts.	Double acting cylinders.
		5/3 Closed centre: As 5/2 but with mid position fully shut off.	Double acting cylinders with stopping possibility.
		5/3 Open centre:As 5/2 but with outputs exhausted in mid position.	Double acting cylinders, with the possibility to de pressurize the cylinder.
		5/3 Pressurized centre.	Special applications e.g Locking head cylinders.

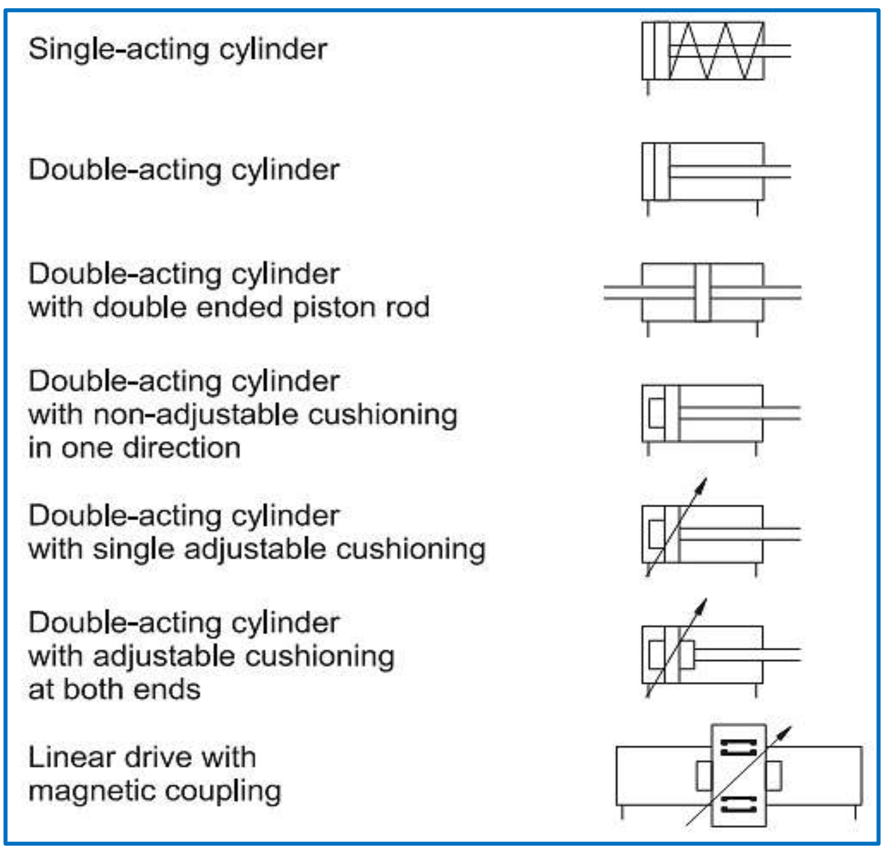
CYLINDERS AND ACTUATORS:

Hydraulic and pneumatic cylinders (sometimes known as air or hydraulic cylinders) are mechanical devices which use the power of compressed gas or hydraulic fluids to produce a force in a reciprocating linear motion. Air and hydraulic cylinders are very similar considering the application, as air or hydraulic fluid forces a piston rod to move in a desired direction. The piston rod is always a disc or cylinder, and the piston rod transfers the force it develops to the object to be moved.

Hydraulic actuators and hydraulic cylinders are technically **synonyms** and also consist of a piston, a cylinder, and valves or ports and hydraulic valves are required to operate the actuators and usually double or triple the input force. The larger the size of the piston, the larger the output pressure can be.

Fluid pressures may be large enough to crush objects. Using a 100 kPa (~15 psi) pneumatic input, you could lift a small car (up 1,000 lbs) easily, and this is only a basic, small pneumatic valve. Hydraulic pressures may reach up to 410 bar (~6000 psi, however, the pneumatic actuators may only have one spot for a signal input, top or bottom, depending on action required.

The input pressure is the "control signal" and a typical standard signal is 20 - 100 kPa (3 – 15 psi). For example, a valve could control the pressure in a vessel with a constant out-flow, and a varied in-flow. As pressure rises, the output of the transmitter rises, this increase in pressure is sent to the valve, which causes the valve to stroke downward, and start closing the valve, decreasing flow, reducing pressure, as excess pressure is evacuated to reservoir. The main cylinder types are described below:

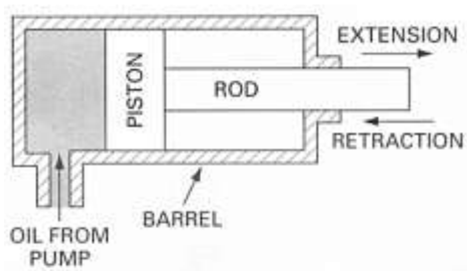
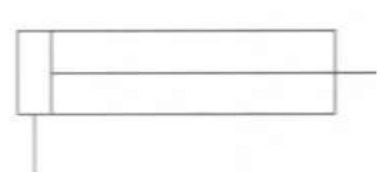


Power Components: Consist of control valves, power elements or actuators, including various types of linear and rotary actuators with various sizes and construction profiles. The motion of a cylinder is always effected via directional control valves. The actuators can be divided into two common processing groups, as indicated below:

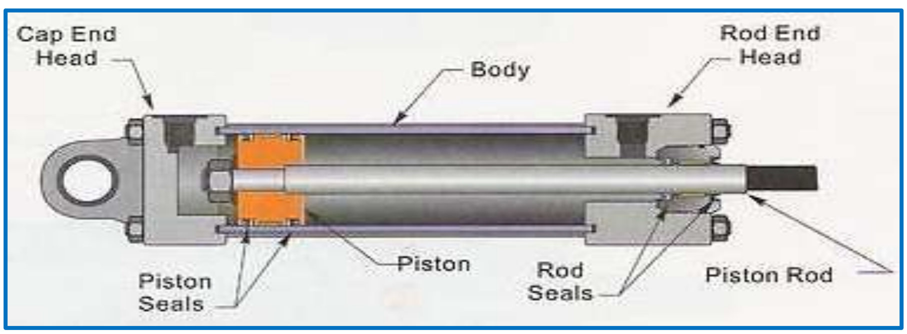
- Linear actuators:
  - Single-acting cylinder
  - Double-acting cylinder

- Rotary actuators:
  - Air motors
  - Rotary actuators

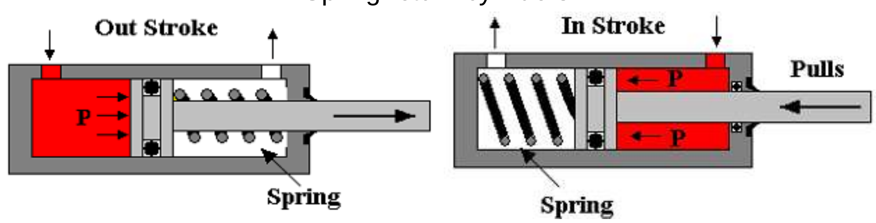
Single Acting Cylinders: These types of cylinders have only one port. The air pressure is applied to the movable element (piston) in only one direction. If the piston needs to return to its initial position, the air is simply expelled from the cylinder. The piston returns commonly by gravity.

<table>
<tr><td>Single-acting cylinder:</td><td>Symbol</td></tr>
<tr><td>
</td><td></td></tr>
</table>

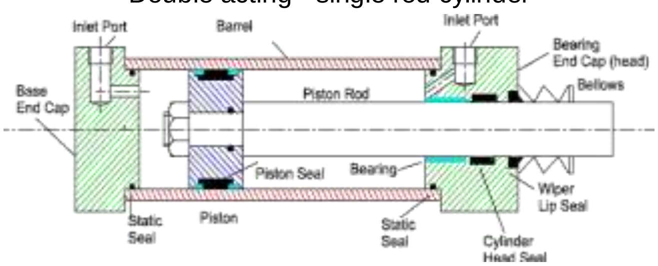
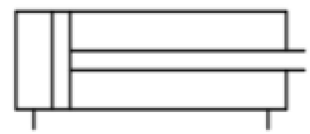
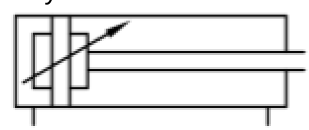
Single-acting cylinders has only one entrance that allows compressed air to flow through. Therefore, it can only produce thrust in one direction. The piston rod is propelled in the opposite direction by an internal spring, or by the external force provided by mechanical movement or weight of a load. Single acting cylinders are used in stamping, printing, moving materials, etc.



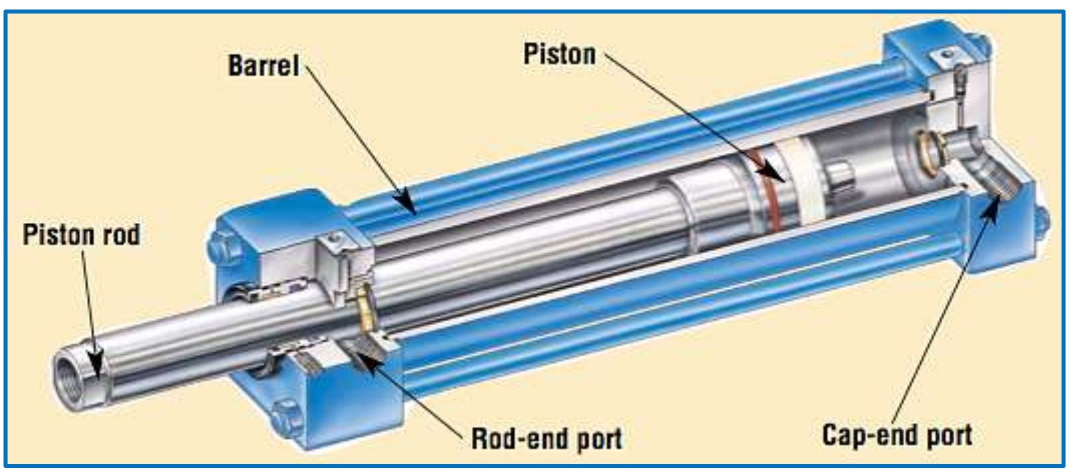
Spring Return Cylinder: The hydraulic pressure is applied to the movable element (piston) in only one direction and needs another force to return the mechanical stem, as an internal spring. When the valve shifts, the fluid is exhausted from the back end, and the spring drives the piston back, thereby retracting the rod.

Spring return cylinders	Symbol
	

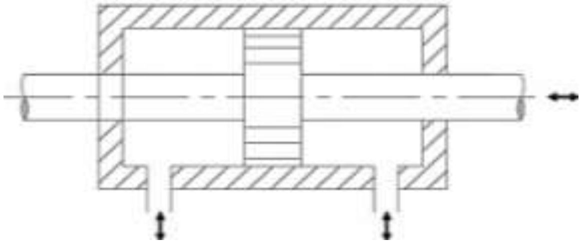
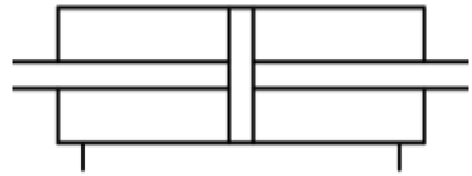
Double Acting - Single Rod Cylinder: Has a single piston rod, and the hydraulic fluid pressure may be alternately applied in both inlet bores, for advancing and retracting directions. The simplest and most common way of actuating a double-acting cylinder is using a 4/2-way, 4/3 or a 5/2-way valve.

Double acting - single rod cylinder	Double-acting cylinder
	 Symbol with a cushion 

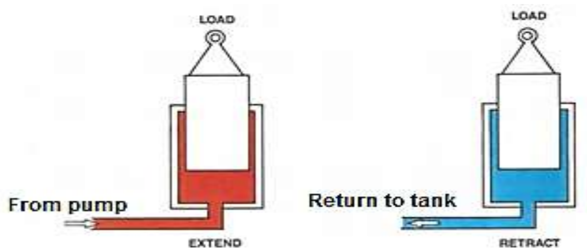
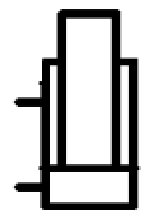
The hydraulic fluid pressure is applied alternately to the relative surface of the piston, producing a propelling force and a retracting force. As the effective area of the rod is small, the thrust produced during retra-ction is relatively weak. The tubes of the double acting cylinders are usually made of carbon steel. The working surfaces are also polished and coated with chromium to reduce friction.



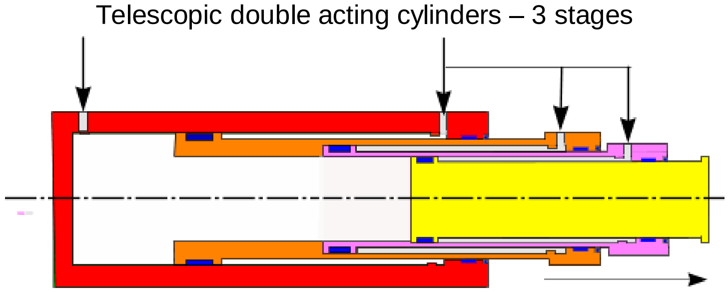
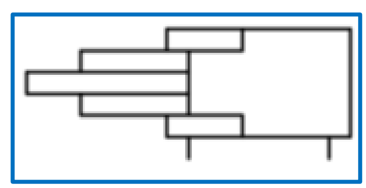
Double Acting – Double Rod Cylinder: Has a piston rod extending from each end, where the piston rods are connected to the same piston. As the single rod cylinders, the hydraulic fluid pressure may also be alternately applied in its inlet bores, for advancing and retracting directions, where it is necessary to produce a force in both directions. Double-acting cylinders are common in steam engines but unusual in other engine types.

Double acting – double rod cylinder	Symbol:
	

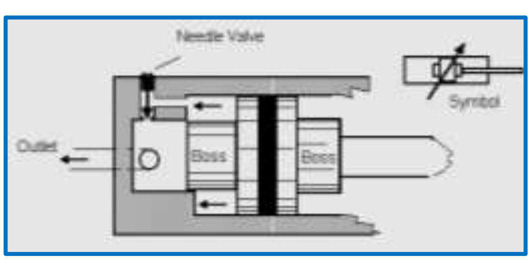
Ram Cylinder: A cylinder in which the movable element is the piston rod. Single-acting rams are often mounted vertically up and are weight returned. When a ram cylinder is mounted vertically down or horizontally, it must have some method of retracting it to the home position. Small ram cylinders may be returned manually or via a spring and are available providing forces more than 1000 tonnes.

Ram cylinders	Symbol
	

Telescopic Cylinders: Are installed where is necessary to produce long strokes from a initial short length. These cylinder usually have 2 to 5 stages, typically used in trash trucks (or refuse lorries) for compacting and ejecting the trash or refuse. However, are also used for lifts, tipping platforms and other vehicle applications.

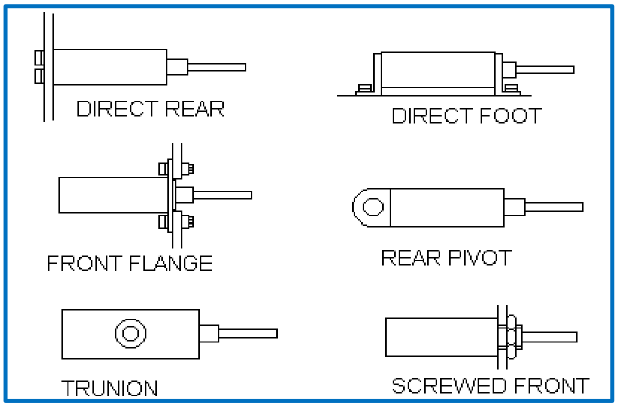
Telescopic double acting cylinders – 3 stages	Symbol
	

Cushioning: The fluid is expelled through the outlet port directly, but when the cushioning boss enters the recess, the fluid around the piston is trapped and the only way for exhausting is through the secondary path, restricted by a needle valve.



Double-acting cylinder with a cushion.

Cylinder Supports: Selecting the type of cylinders, and determined the shape and size of a work-piece and the process involved, the critical factor is to hold the pneumatic system. The diagram below shows typical ways of mounting the cylinders and attaching them to the pneumatic process.



Selection of Hydraulic Cylinders: Cylinders or actuators convert hydraulic or pneumatic energy to mechanical work. They usually consist of a movable element such as a piston and piston rod, or plunger, operating within a cylindrical bore. To select a cylinder installation, consider the following:

- Single or double acting;
- Dimensional standards like ISO, VDMA, CETOP, AFNOR;
- Constructional details – Piston rod, tie rod, square tube, rodless, etc.;
- Force to be exerted (Bore dia.);
- Distance to be moved (stroke);
- Surrounding medium (special material of construction / type of seals);
- Air pressure available;
- Cushioned / Non-cushioned;
- Ambient temperature for selection of seal material;
- Speed of actuation;
- Position detection (Reed switch type);
- Mounting type;

Cylinder Calculations: Most pneumatic systems operate in the 80 - 100 psi range, and hydraulic systems in the 1000 – 5000 psi. The pressure supplied to an actuator is literally the driving force and the higher the pressure, the higher the force the actuator can apply to the work piece.

Basic calculations: To calculate the theoretical force output of a cylinder, follow these steps:

1. Single Acting Cylinder: calculate the area of the cylinder piston:

Area = $\Pi \times d^2/4$
d = the bore diameter

F = **p x A** = Pressure x Area = Force Output.

Example: What could be the theoretical force output of a 2-1⁄2″ bore cylinder, operating at 1000 psi hydraulic pressure?

Step 1.) Area = $\Pi.d^2/4 = \prod.\ 2.5^2/4 =$ **4.91 square inches**;
Step 2.) 4.91 sq. in. x 1000 psi = **4910 lb-force**.

The real force output of a cylinder may be less than the theoretical output because of internal friction and external side loading. Thus, always use a cylinder that generates from 25% to 50% more than the theoretical force needed. The force exerted by a single acting pneumatic cylinder is (in metric):

$F = p \times A$
$A = \square \times d^2/4$
F = Force exerted (N), (kg), (lb);
p = Gauge pressure (N/m^2, Pa);
A = Full bore area (m^2), (ft^2), (in^2);
d = Full bore piston diameter (m), (ft), (in).

Example: Single-acting cylinder. What is the force exerted by a single-acting pneumatic cylinder using hydraulic pressure 10.0 bar (1,000,000 N/m^2) with a bore diameter of 100 mm (0.1 m)?

$F = p \times \square \times d^2 / 4 = p \times 0.7854 \times d^2 =$
$F = (10^6\ N/m^2) \times \prod \times (0.1\ m)^2 / 4 =$ **7854 N** - (Obs.: **1 N** (Newton) = ~0.225 lb-force).

Example: What is pressure that could be necessary to develop 50,000 pounds of push force from a 6" diameter cylinder?

Step 1.) Area = 28.26 in^2
Step 2.) 50,000 psi / 28.26 sq. in = **1769 psi**

2. Double Acting Cylinder: The force exerted on in-stroke can be expressed as:

$F = p \times \square \times (d_1^2 - d_2^2) / 4 = p \times 0.7854 \times (d_1^2 - d_2^2) =$
d_1 = Full bore piston diameter (in), (ft), (m);
d_2 = Piston rod diameter (in) (ft), (m).

Example: Double-acting cylinder. The force exerted from a double-acting pneumatic cylinder with *10.0 bar ($10^5\ N/m^2$)*, full-bore diameter of *100 mm (0.1 m)* and piston rod diameter *10 mm (0.01 m)* can be calculated as:

$F = p \times \square \times (d_1^2 - d_2^{2)} / 4$
$F = (10^6\ N/m^2) \times \square \times [(0.1\ m)^2 - (0.01\ m)^2] / 4 =$ **7775 N**

Example: What pressure is necessary to develop 50,000 pounds of pull force from a 6 inches diameter cylinder, which has a 3 inches diameter rod?

Step 1.) Area = 0.7854 x (d_1^2 - $d_2^{2)}$ = 0.7854 x (6^2 x 3^2) = 21.2 in².
Step 2.) 50,000 psi / 21.2 sq. in = **2358 psi**

Required Cylinder Bore Size: To determine the required bore size for a cylinder application, use the table below and follow these four easy steps:

1. Determine, in pounds, the force needed to do the job. When necessary, add 25% for friction.
2. Find out how much air or hydraulic pressure will be used in the system.
3. Select a power factor from the table below, when multiplied by the planned air or hydraulic pressure, will produce the necessary force.
4. The required cylinder bore diameter is found directly above the power factor, determined in Step 3.

Bore Diameter:	3/4	1	1 1/8	1 1/2	2	2 1/4	2 1/2	3	3 1/4	4	6
Power Factor:	0.4	0.8	1.0	1.8	3.1	4.0	4.9	7.1	8.3	12.6	28.3

Example: Checking the first example above, estimate the necessary cylinder bore size, for a 4900 lb. needed force. The available air pressure to be used is 1000 psi.

Power Factor = 4900 lb / 1000 psi = **4.9**. See the table where and find the power factor **4.9**. According to table, this application will require a **2-1/2 inches** cylinder bore size.

Cylinder Velocity Calculation: The first general rule of thumb is choosing a cylinder that may allow at least 25% more force of what is required. This will leave 25% or 50% of inlet pressure to satisfy the system losses. The velocity of a hydraulic cylinder can be calculated by the following formula:

V = (231 X GPM) / (60 X Net Cylinder Area) = 3.85 x GPM / Net Cylinder Area.

Example: How fast will a 6" diameter cylinder with a 3" diameter rod extend with 15 gpm input?

Step 1.) Area = p x 0.7854 x d^2 = 0.7854 x 6^2 = 28.3 in².
Step 2.) Speed = (231 X GPM) / (60 X Net Cylinder Area) = (231 X 15) / (60 x 28.3) = **2.04 in/s**.

Needed Fluid Flow = Q = Cylinder Area X Stroke Length in Inches / 231 X 60 / Time in seconds for one stroke.

Example: How many GPM are needed to extend a 6" diameter cylinder 8 inches in 10 seconds?

Step 1.) Area = 28.3 in²;
Step 2.) Velocity = 8 / 10 = 0.8 inches/ second.

Flow Rate (GPM) = (60 x Velocity (inches/sec) x Net Area (square inches)) / 231 =

Flow Rate (GPM) = (60 x 0.8 (inches/sec) x 28.3 (square inches)) / 231 = **5.88 GPM.**

Hydraulic cylinders: are actuation devices that utilize pressurized hydraulic fluid to produce linear motion and force.
Rodless cylinders: are linear devices that use pressurized fluid to move a load within many power transfer operations.
Piston rings: are used for sealing cylinders. They can work at higher temperatures than elastomeric, fabric, or polymer seals.

Standards: The National Fluid Power Association (NFPA) is an American industry trade association, founded in 1953, that develops and publishes standards related to the hydraulic and pneumatic industries, headquartered in Milwaukee (USA). **NFPA's** mission is to serve as a forum where all fluid power partners to advance the fluid power technology, and also serves with sub-committees for ISO/TC 131.

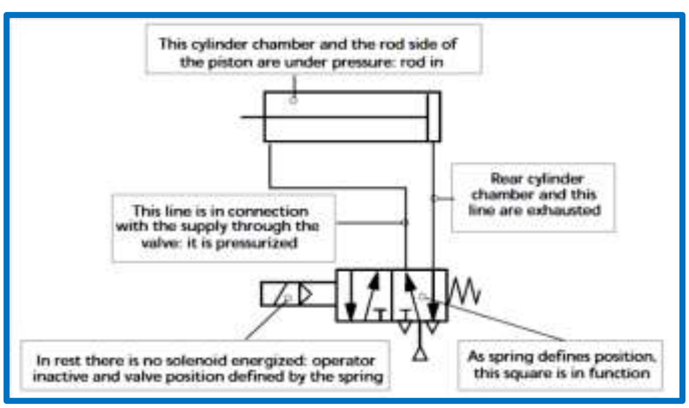
Cylinders Maintenance: The majority of cylinders for industrial, heavy-duty applications are usually conform to **National Fluid Power Association** standards. These standards establish dimensional uniformity, so cylinders from multiple manufacturers can be interchanged. However, care should be exercised when interchanging cylinders, because even though a cylinder conforms to NFPA dimensional standards, it may have proprietary features unavailable from another manufacturer.

Contamination: Cylinders can be contaminated internally from the fluid supply or externally from the operating environment. Types of contamination include solids, water and dust. As an example of the potential adverse effects of contamination, solids such as particulates, pipe rust and scale and thread sealant debris can curtail seal life, plug orifices and damage surface finishes.

Lubrication: Potential solutions to lubrication-related problems include selecting a 'non-lube' cylinder, adding a lubricator to the air-preparation system or integrating an injection lube system. The specifier could also select an air-cushion cylinder option, add a shock absorber or lower system pressure via a regulator, if applicable to the system configuration. A final option in this case would be to add flow control to the cylinder, if high speed is not a major concern.

CYLINDER CONTROL DIAGRAMS:

Control diagrams are natural and intuitive ways of easily visualizing all devices and circuit relationships in a pneumatic or hydraulic application data. The hydraulic or pneumatic designers may use simulating softwares and can manipulate the data, as well as, interacting directly with the circuit every time.



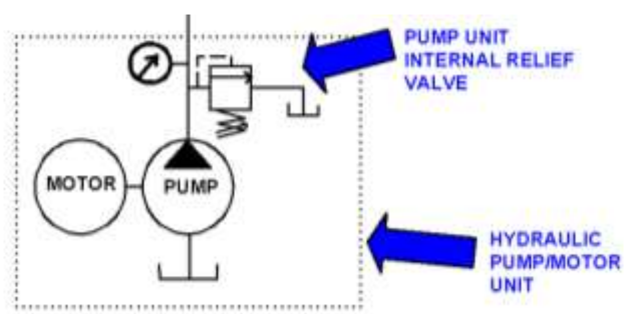
Hydraulic & Pneumatic Circuits: All control devices are placed downstream to air systems; including directional valves and velocity control valves, as well as, standard symbols signifying hydraulic or pneumatic actuators (cylinders, etc.). A circuit diagram is drawn in the rest position of the controlled machine, with the supply under pressure, but in the case of mixed circuits, without electrical power. All components must be drawn in the positions resulting from these assumptions.

Basic System Components: Fluid power systems are constructed of various components for specific system functions. The number and appearance of componentes required to perform these functions vary considerably depending on the complexity and accuracy of the work performed, the environment in which the system operates, and the manufacturer of the components.

In basic hydraulic systems, the commonly designated as hydraulic Power Pack contains the pump, tank (reservoir), filters and commonly a relief valve for protection of the system. The unit is usually next to the machine that is using the system. The usually hydraulic pumps, are positive displacement devices, which means that displace all the oils they pump.

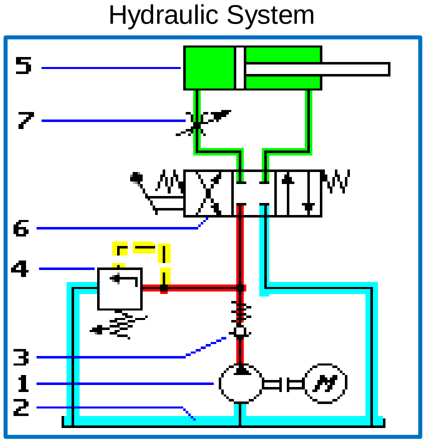
Hydraulic Power Pack

Symbol



Hydraulic Systems: Function and sequence of individual components within a system are represented on a circuit diagram by means of symbols. All hydraulic devices and connections must be identifiable on the diagram. The circuit diagram is indispensable for assembling a system and for later fail finding.

Hydraulic System

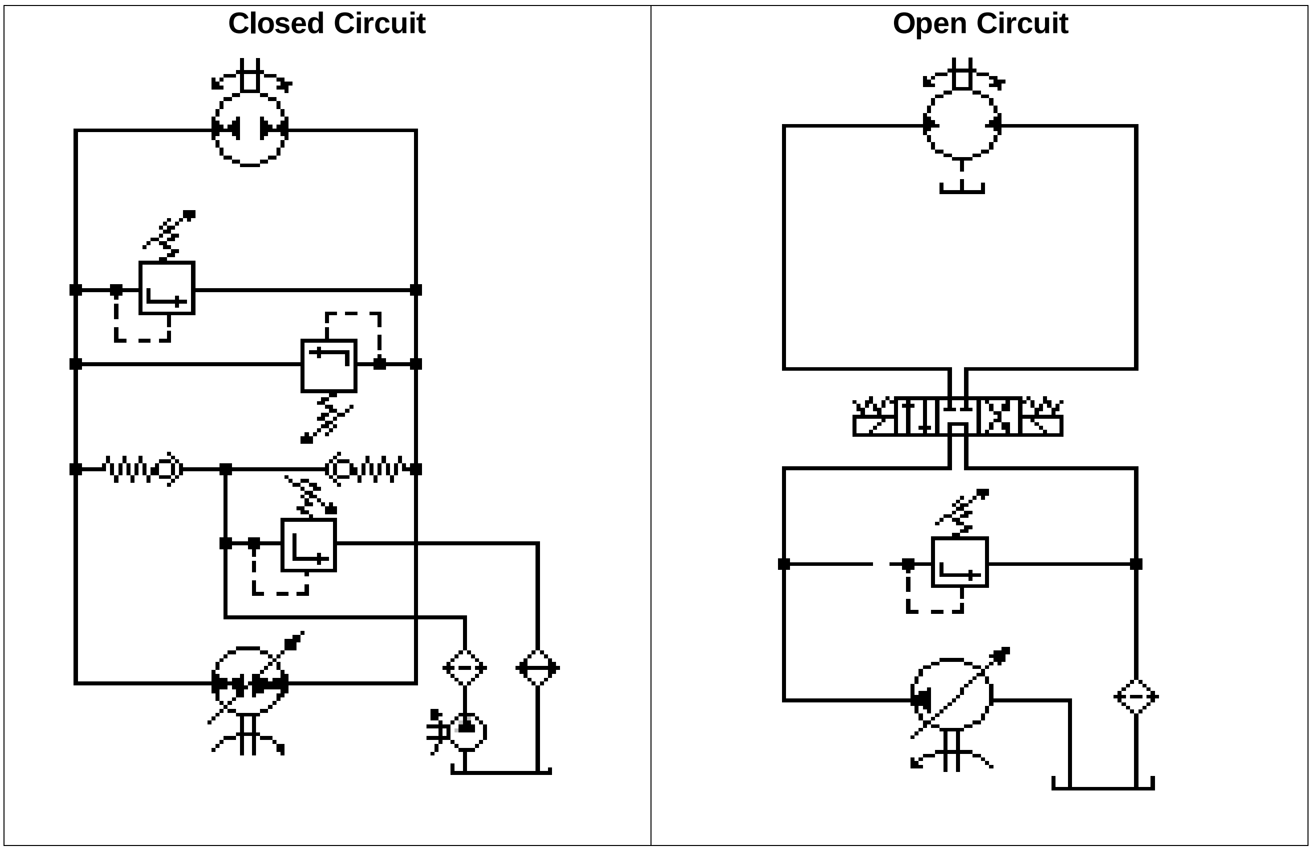


Control devices

1. Pump
2. Tank
3. Non return valve
4. Pressure unloading valve
5. Cylinder
6. Directional valve
7. Flow control valve.

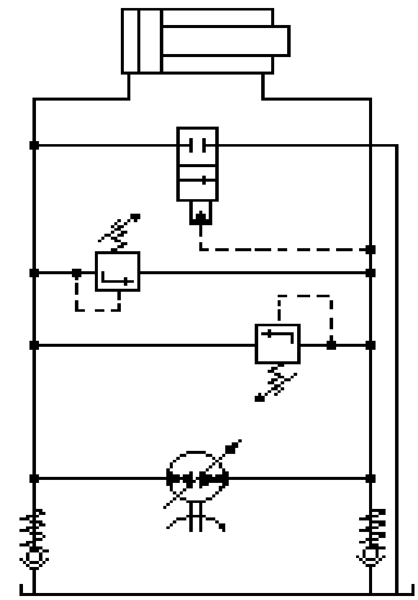
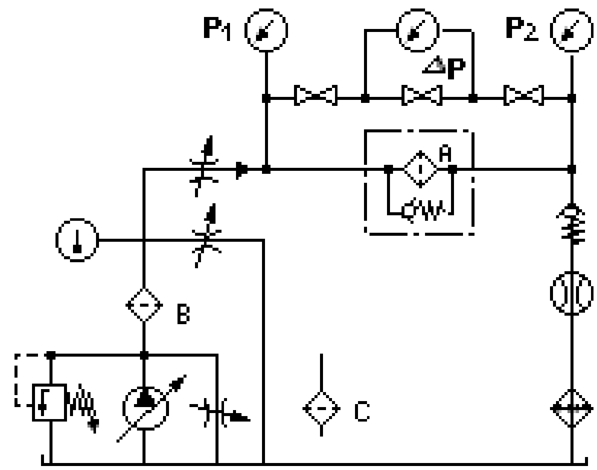
Closed Circuit: In the closed circuit the operating fluid, flows back from the hydraulic motor directly to the hydraulic pump. In order to fill the circuit and to compensate an inevitable leakage, a feed pump is used with a delivery, which must normally amount to approx. 15 % of the main flow. Separately adjustable pressure limiting valves protect the system against overloading.

Open Circuit: With an open circuit, the operating fluid flows from the tank to the hydraulic pump and is then transported to the hydraulic motor. From the hydraulic motor the fluid flows, unpressurized, back to the tank, to be carried once more to the hydraulic pump. The output direction of the hydraulic motor can be changed by means of a directional control valve. The pressure limit valve protects the system against overloading. The operating fluid is filtered on return.



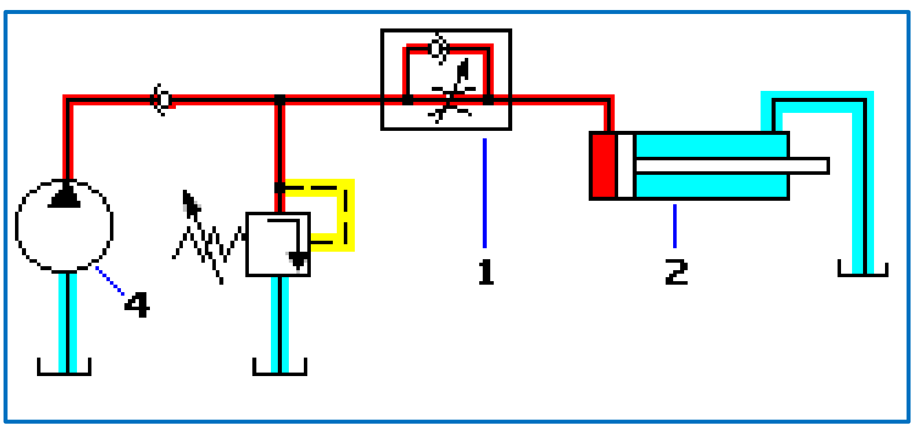
Half-open Circuit: With a half-open circuit an insufficient volume flows in a certain flow direction from the hydraulic motor back to the hydraulic pump. The remaining amount is sucked out of the tank by means of an anti-cavitation valve. The output device is normally a single rod cylinder, so that in the other flow direction more operating fluid is directed to the hydraulic pump than it can take. The difference is directed by means of a directional control valve to the tank. Two pressure limit valves protect the system against overloading.

Pressure Loss Test: With this test according to ISO-3968, the pressure lost from filter housing equipment and filter elements is determined by flow and viscosity using a variable pump. Hydraulic oil viscosity class **ISO VG 32** is normally used, as the test fluid. Pressure loss through the housing and filter element is recorded. Measuring points P1 and P2 must be upstream of the test filter.

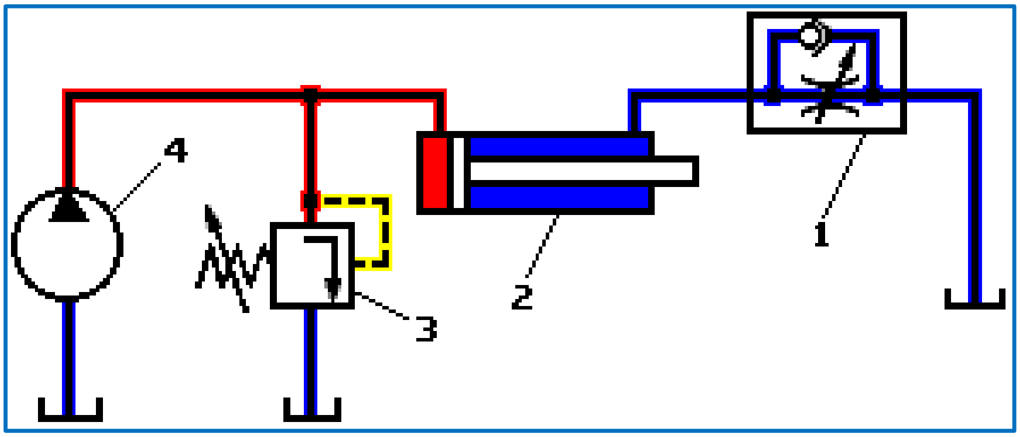
Half-open Circuit	Pressure Loss Test
	

Basic Flow Control Circuits: There are three types of basic flow control circuits: **meter-in, meter-out, and bleed-off (bypass) circuit**. Hydraulic and pneumatic circuits normally need control flow valves, because the fluid power plants, are always greatly oversized for almost any given circuit.

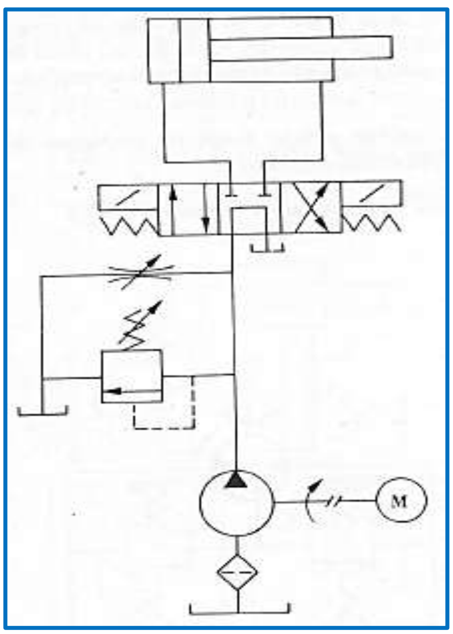
1. **Meter-in:** This circuit commonly uses 2-way flow control valves, as shown below. The flow control valve (1) is placed in the pressure line between hydraulic pump (4) and actuator (2). This type of control is recommended for hydraulic systems in which the actuator acts as a positive resistance (opposing force) to the controlled flow.

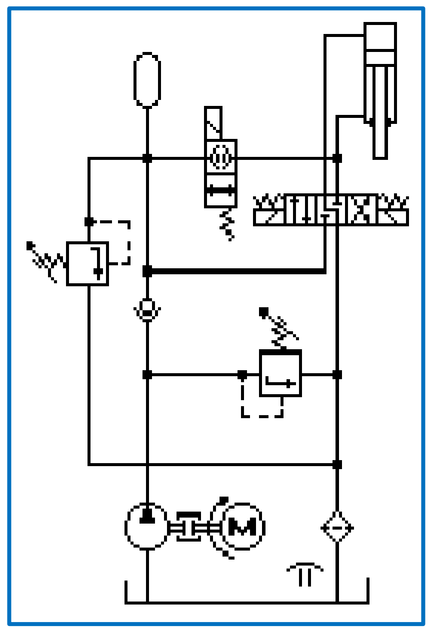


2. **Meter-out:** This circuit also commonly uses 2-way flow control valves, as shown below. The flow control valve (1) is situated in line between actuator (2) and the tank. This type of control is recommended for hydraulic systems with negative (pulling) working loads, which tend to cause the cylinder piston to move more quickly than the speed, which corresponds, to the delivery flow of the pump (4). The pressure-unloading valve (3) must be set according to the highest actuator pressure.



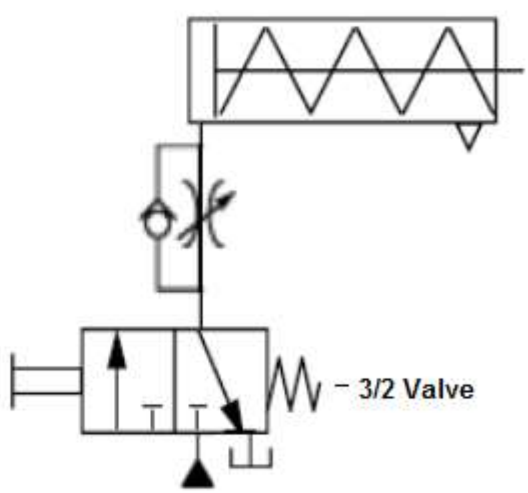
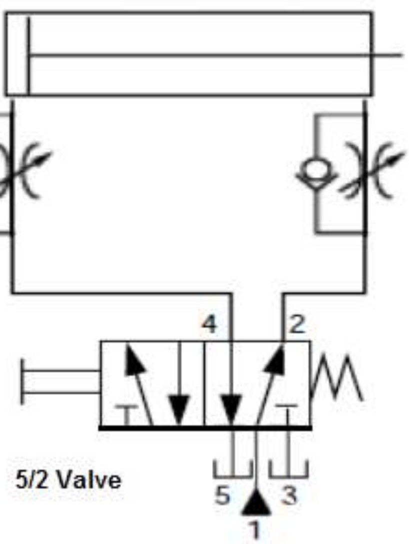
Bleed-off (Bypass) Circuit: In this type of circuit, the flow control valve is placed between the pressure line and return line. Thereby, it controls the fluid by bleeding off the excess not needed by the working cylinder. In an emergency, the valve reacts and the oil available in the accumulator is fed to the piston rod side of the cylinder. This causes the piston to retract.



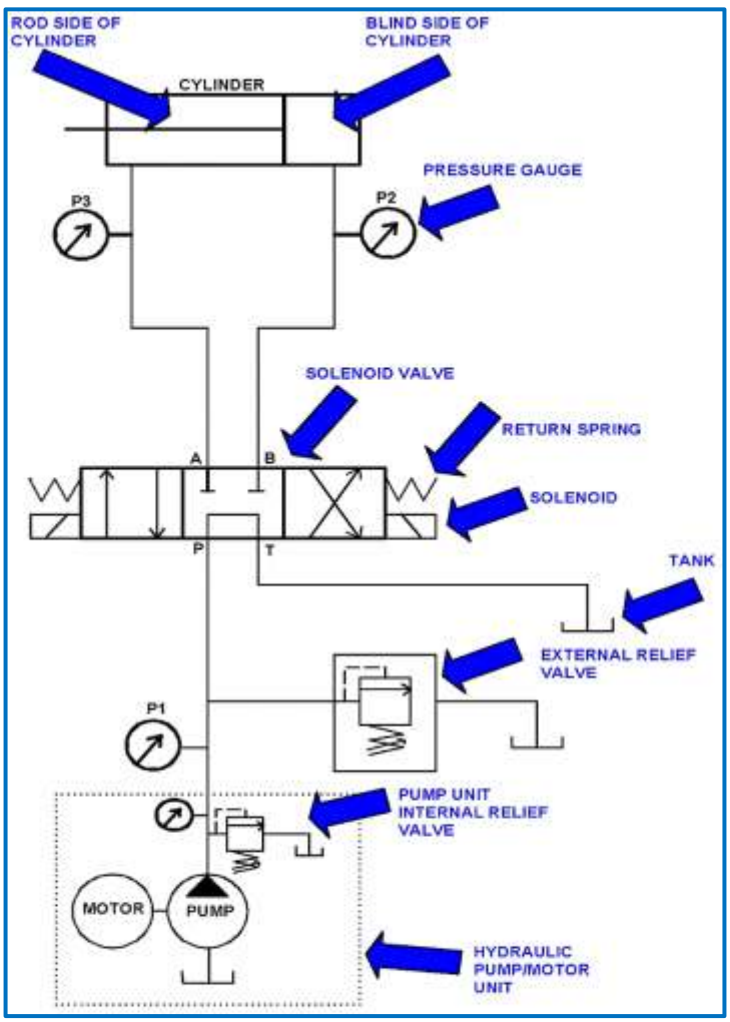


***Direct Control - Single-Acting Cylinder**:* Direct control for a single-acting cylinder is when this equipment is always connected to a manual 3/2 valve, and extends when the valve is air operated and returns upon release, by force of an internal spring. This is the so-called “direct control”. The only way to regulate the out stroking piston speed of a single-acting cylinder is to throttle the flow into it.

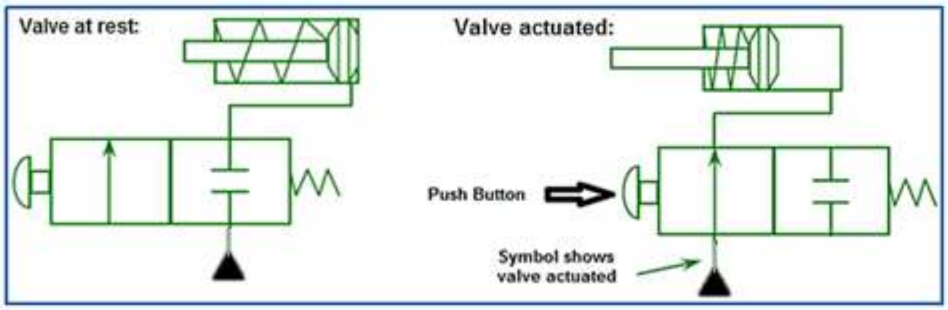
***Direct Control - Double-Acting Cylinder**:* The only difference between the operation of a double acting and a single-acting cylinder is when a **4/2** or a **5/2** valve is commonly used instead of a **3/2** valve. In its normal position (not operated), the port **2** is connected with the supply port **1**. It has to be connected to the rod side of the piston if the cylinder is naturally in the negative position. For speed control in both directions, a speed controller has to be attached to both connections.

Direct control - Single-acting cylinder:	***Direct control - Double-acting cylinder:***
	

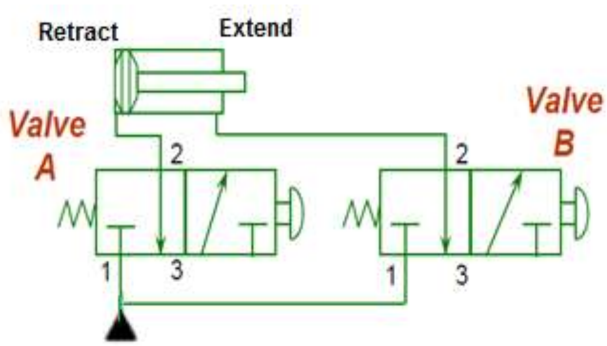
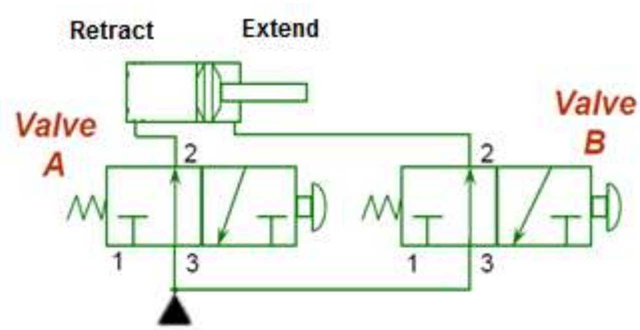
Sample Hydraulic Diagram: Concerning to a particular solenoid valve, as an example, is possible to see what happens to the fluid path under different circumstances.



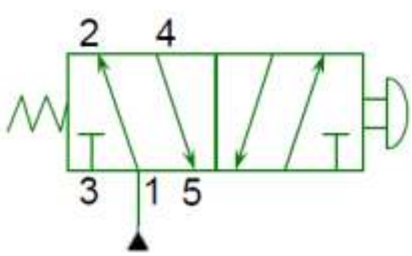
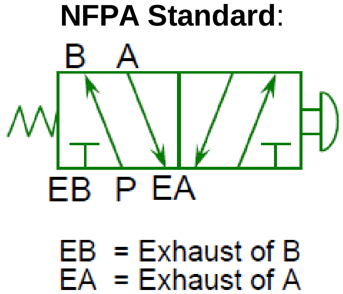
Basic Single Acting Cylinder: The most common valve for this application is a 2-way, 2-positions valve either passing or non-passing, with one port to let the fluid exhausts. When the button is pushed, the hydraulic fluid flows through the inlet port, the spring retracts, and the cylinder extends, and when the button is released, the spring and the cylinder retracts and the valve comes at rest:



Valves 3/2 - Both Directions: For independent moving in both directions, two 3/2 valves may be attached to both connections of a double-acting cylinder. This gives a positive and steadier movement than throttling the fluid supply, with an additional automatic or manual push button can be added as a backpressure, as shown below. The fluid supply to both valves can be from a unique source, so pressure at valve **A** is the same as at valve **B**, as shown below:

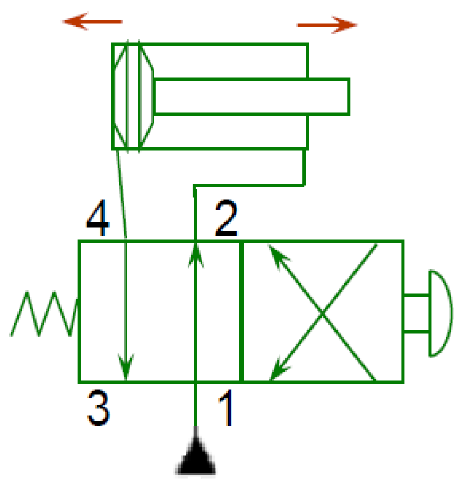
Start position:	**Actuated**:
	 Observe arrows representing the correct flow directions.

Common Labeling Standards: The most common labeling standard for a 5/2, designated as 5-Port 4-way is according with the following basic description:

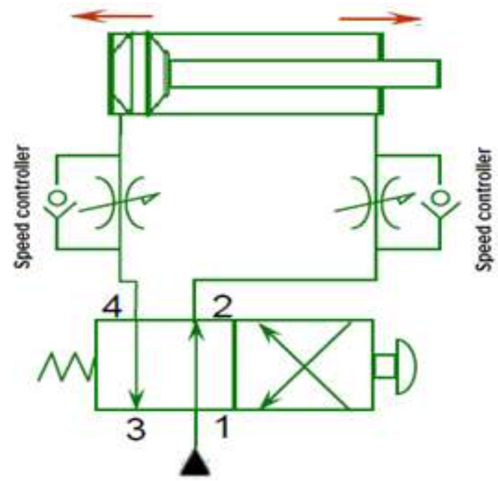
ISO Standard:	**NFPA Standard**:	4-Way - four flow directions; 2-Position actuated/at rest; Normally passing N/A; Push Button, Spring Return type; Five Ports 1, 2, 3, 4, and 5; Flow is normally passing from 1 to 4 when actuated.
		

Valve 4/2 Application: The most single circuit uses a 4/2 valve to actuate a double-acting cylinder to extend and retract at the same speed. On the other hand, when a metering device is installed to make the cylinder rod actuate with an identical speed, flow control valves restrict the exhausting air at each cylinder port, as can be seen below.

Start: Without flow control:

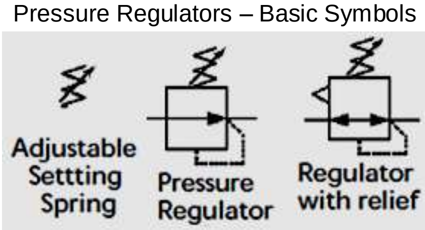


Actuation: With flow controls:

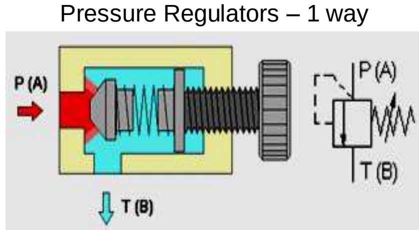


Airflow Regulators: The air pressure regulator is useful for reducing the outlet pressure by shutting off the fluid flow when downstream pressure tries to go above the regulator's setting.

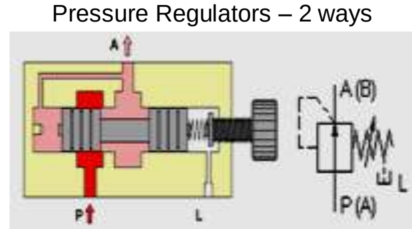
Pressure Regulators – Basic Symbols



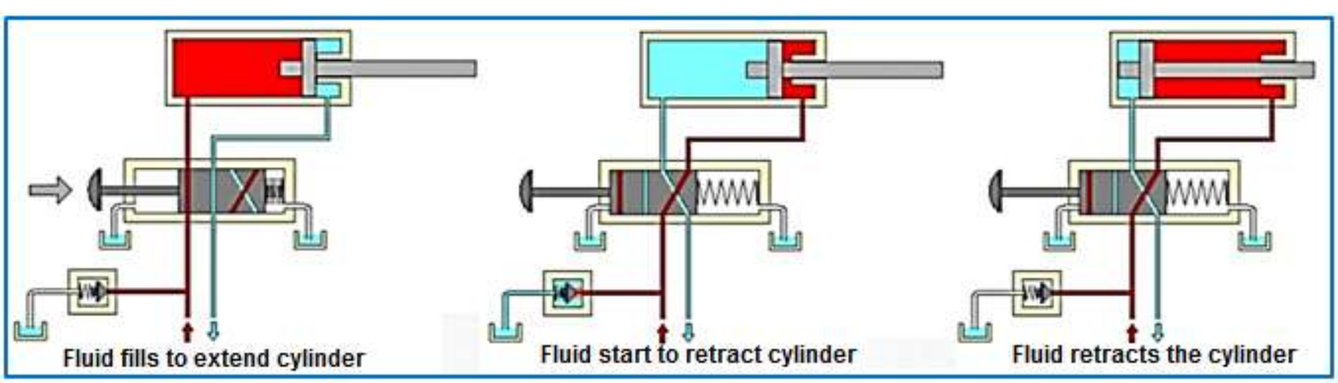
Pressure Regulators – 1 way



Pressure Regulators – 2 ways

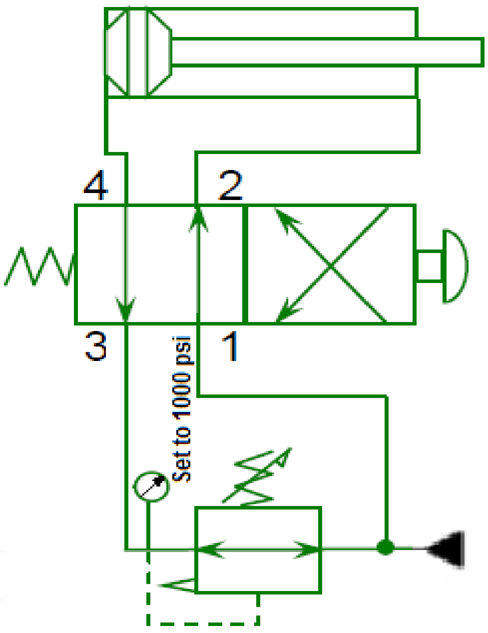


Sequence Control: Hydraulic or pneumatic modular systems may contain just a few valves or dozens, with many built-in functions, such as pressure, temperature, filtration, and other operating conditions, as well as, manual or automatic control requirements, start, stop, and so on. The available input signals from limit pressure valves, sensors, controls, mechanical and safety interlocks are required considering a systematic sequence of operations, as can be seen below a single cylinder sequence:



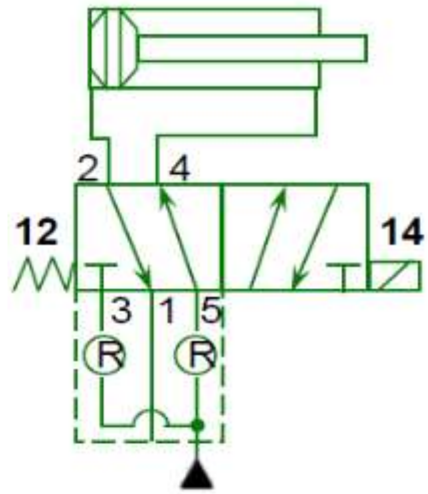
Pressure Regulators Application: Application of pressure regulators to control the circuit pressure is reducing the pressure on the return stroke of actuators, and use low power to retract. Many cylinders need high force to extend, but the retract portion of the cycle needs very low force. The pressure regulator positioned, as shown below, can save every the cycle of many cylinder operations.

Valve 4/2 with an Air Regulator:



Regulated to 1500 psi

Valve 5/2 with a Regulator short symbol:

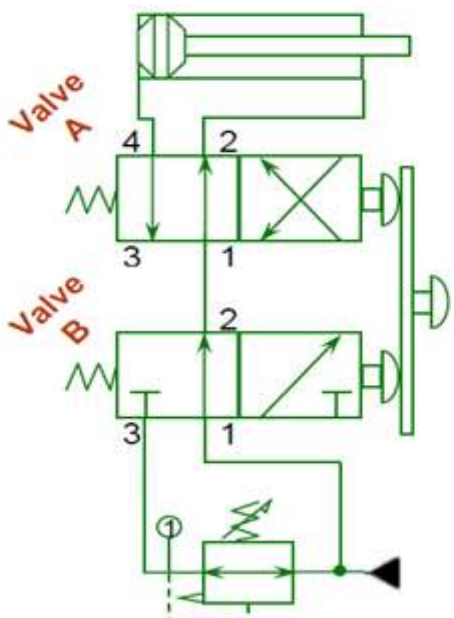


Ⓡ Is a short symbol for a Regulator.

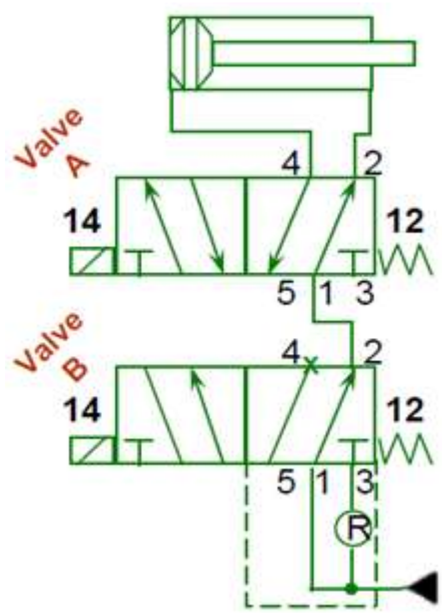
Lines that don´t connect.

Selector Valves: A 3/2 valve or a 5/2 valve may be used as a "selector", that is, this valve selects line pressure or also reduces pressure. Cylinder extends and retracts with signal to main valve.

3/2 valve used as a "selector":

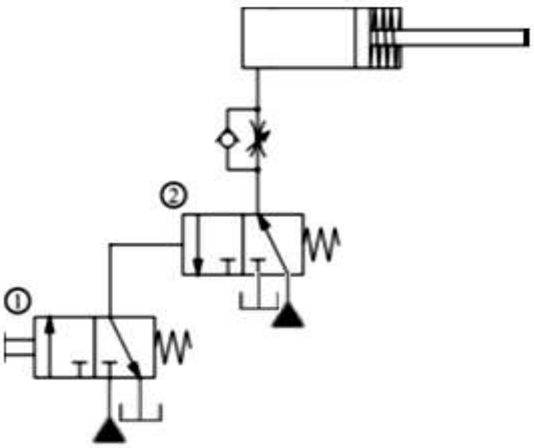


A 5/2 valve used as a "selector":

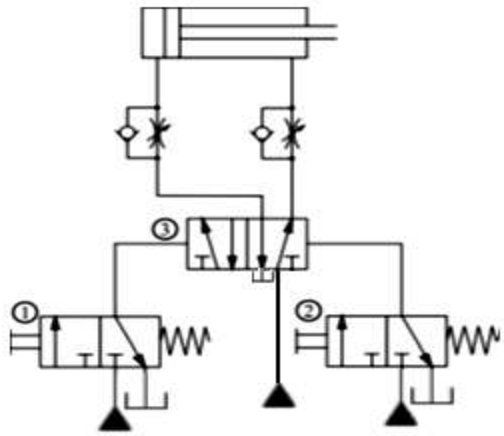


Holding Final Positions: In many cases, a cylinder has to maintain its position, when signal has disappeared, requiring a "Memory" function. As shown below, a double acting cylinder is activated by a control valve "1", while retraction is governed by a control valve "2". The control valve "3", maintains the position of the cylinder holding its own position, changing only when one of the manual control valves is pushed. If both control valves "1" and "2" are operated at the same time, control valve "3" will be subject to the same pressure, and will remain in its original position.

Single Spring Cylinder - NOT Function:



Double Cylinder -Holding final positions:

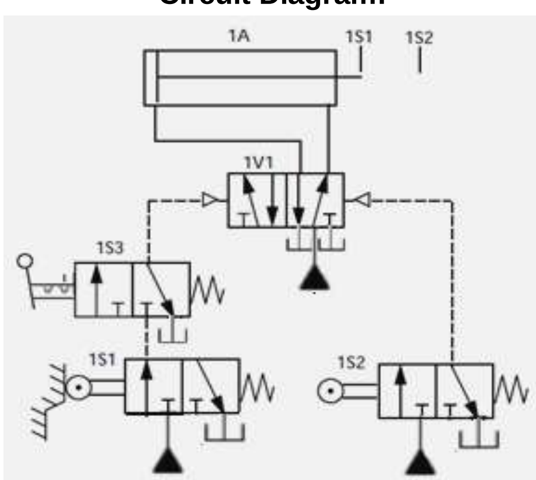


a) **Sequence of two Cylinders**:

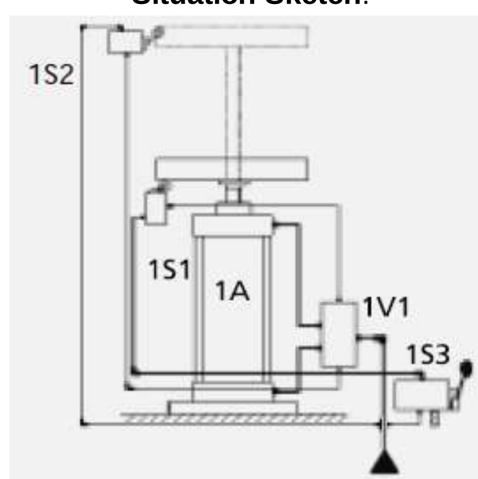
Each component in a diagram has an identity capital letter: Actuators - **A**, Valves - **V**, Switch Valves & Sensors - **S** and all other equipment - **Z**. The valves that control the actuators are identified as, **1V1, 2V1**, etc., and all other valves are identified according to the hierarchy as, **1V2, 1V3, 2V2**, **2V3**, etc.

Switch Valves and sensors are identified as **1S1, 1S2, 2S1, 2S2**, etc., and all other equipment, **1Z1, 1Z2, 2Z1, 2Z2**. The cylinder "rest position" is identified as **S1**, the cylinder "working position" with a **S2**. Only in a simulation with a training kit, we consider "rod in" as the rest position.

Circuit Diagram:

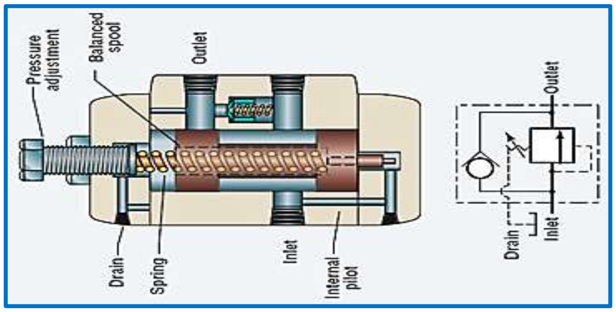


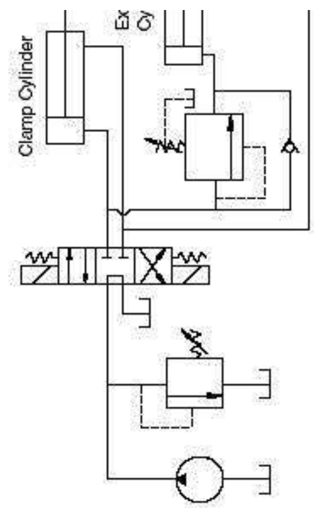
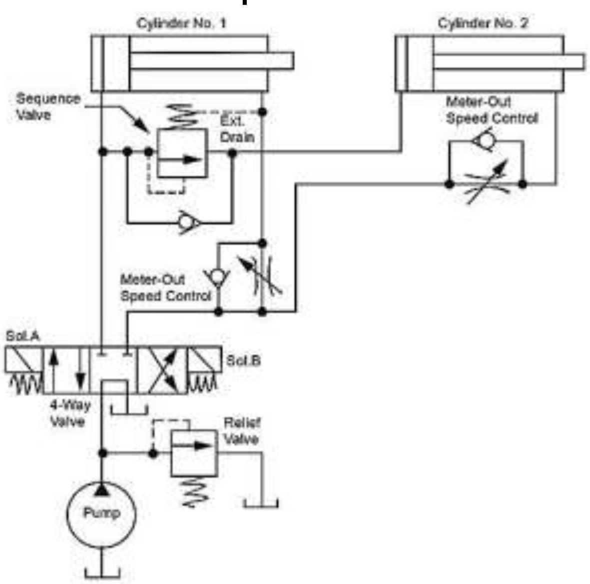
Situation Sketch:



b) Pressure Sequence Valve:

The pressure sequence valve is similar to a combination valve, having two sections. The sensing pressure signal is introduced at the inlet port of the valve and the manual adjustment of pressure setting is done with the help of a knob, spring loaded. The clockwise rotation of the knob sets for higher pressure, and anticlockwise rotation of knob sets for lower pressure.



Pressure Sequence Valve Circuit:	**Sequenc**  **plication:**
	

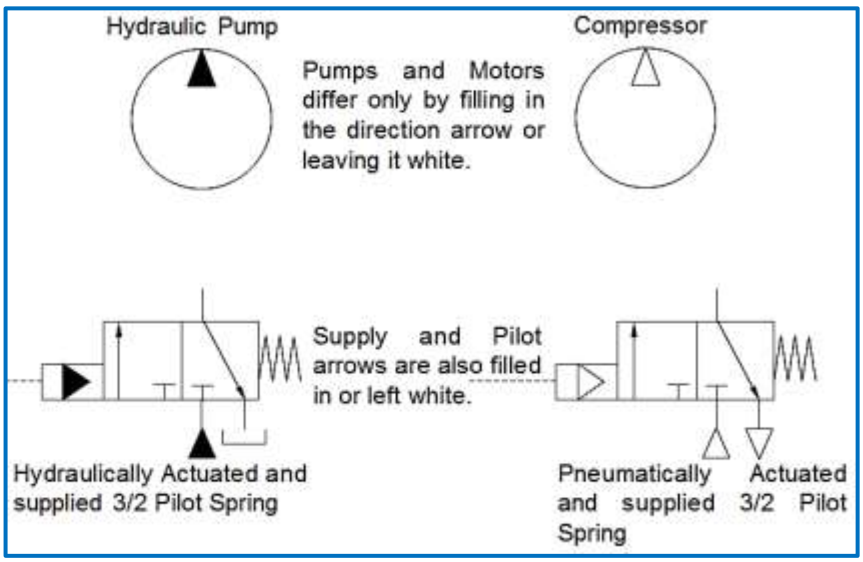
Hydraulic Line Colors: The table below shows the recommended hydraulic line colors and passages to be used in many circuit diagrams.

Line/Passage	Color
Operating pressure	Red
Exhaust	Blue
Intake or drain	Green
Metered flow	Yellow

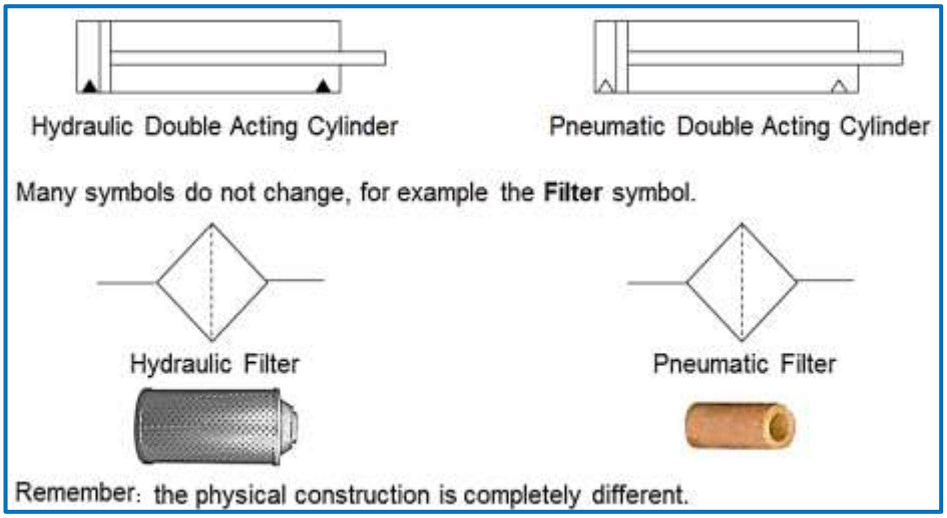
HYDRAULICS AND PNEUMATICS – DIFFERENCES:

The most important differences between hydraulics and pneumatics, is explained below:

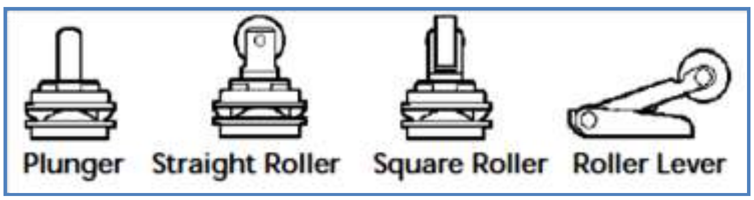
- Pumps and Motors differ only by filling in the direction arrow or leaving it white. Supply and pilot arrows are also filled in or left white.



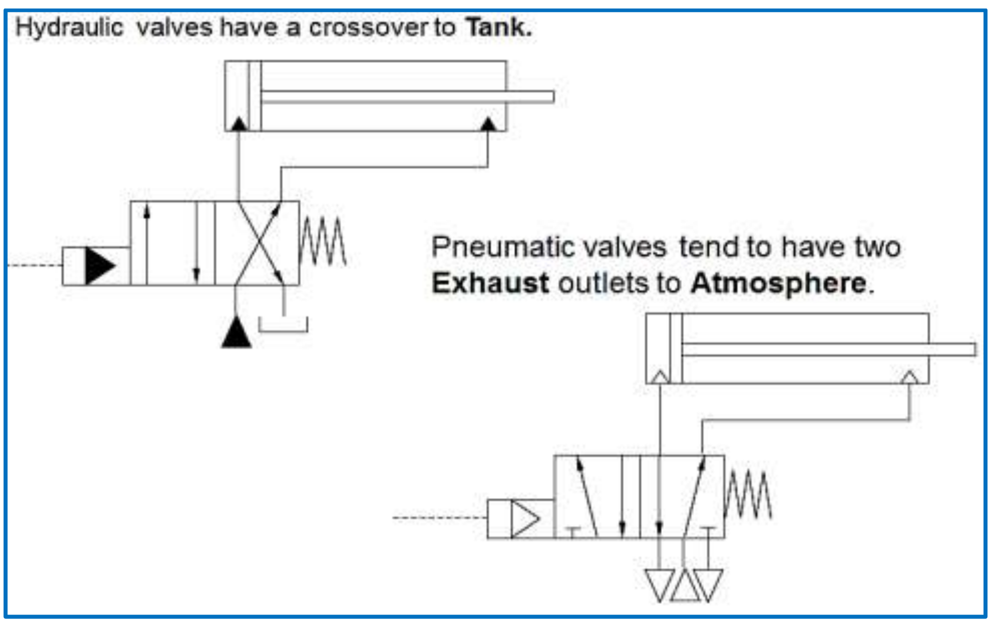
- Cylinders and other actuators also differ with respect to supply and direction arrows. Hydraulic filters can be **Suction Strainers** (suction side of the pump), **Pressure Filters** (pressure side of the pump) or **Return Filters** (in the return to tank line). Each filter requires different properties.



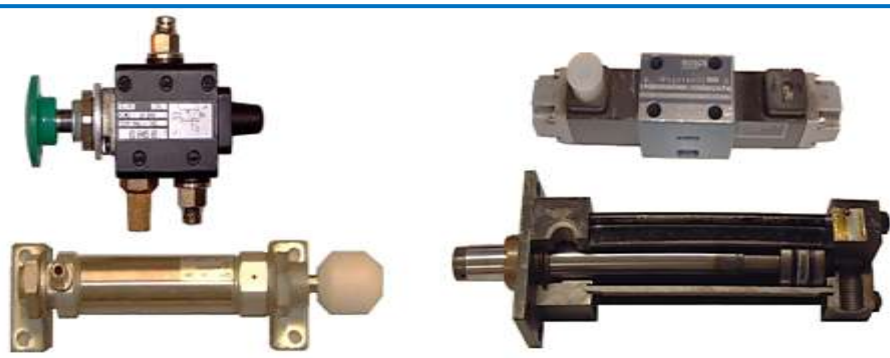
- Mechanically operated directional valves have the moving machine parts, such as roller levers, to provide signals for the automatic control with the same function. Special care must be taken when using cams to operate roller lever valves as the working portion of the roller's total travel may not go until the end of stroke. The slope of a cam should have an angle of about 30°; steeper slopes will produce mechanical stresses on the lever.



- Hydraulic valves have a discharge port to a tank or reservoir. Pneumatic valves may have two exhaust ports to atmosphere.



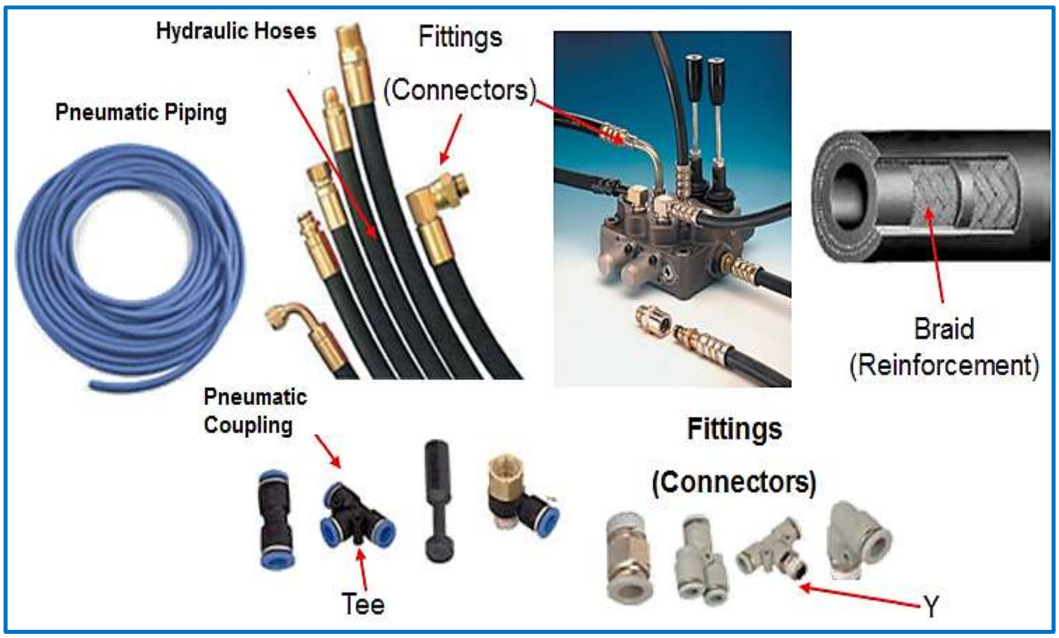
- Hydraulic valves and actuators are much more heavily constructed than pneumatic components, because the components must deal with pressures up to 400 bar (~5000 psi) and can be very large when compared with common pneumatic actuators. Pneumatic valves and actuators are generally of light construction, due components are fabricated to hold pressures up to a maximum of 10 bar (~150 psi).



Pneumatic valves and actuators are generally of light construction as they need to deal with pressure up to a maximum of 10 Bar.

Hydraulic valves and actuators are much more heavily constructed than pneumatic components. This is because the components must deal with pressures up to 400 Bar.

- Hydraulic hoses and connectors are heavily constructed to hold the higher pressures. Rubber hoses are steel reinforced (braided) to strengthen the hydraulic connections and hold high pressures. Pneumatic piping and fittings are of light construction for low pressures. The pneumatic pipe is made from nylon and generally connects to the fittings using "**push fit**" connectors.



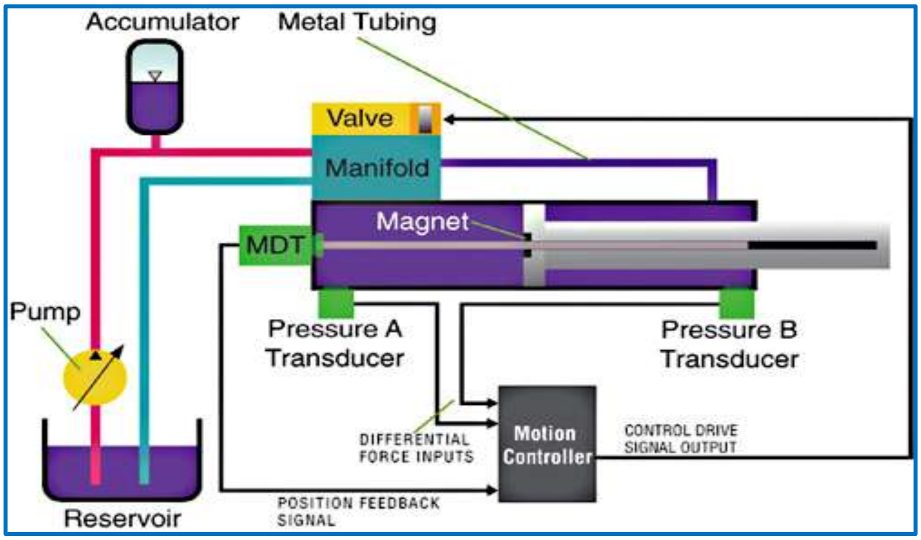
- Hydraulic systems are used where large forces are required such as in earth moving equipment, heavy cutting, pressing and clamping. Pneumatic systems are used for relatively light moving, clamping and process operations.

BASIC ELECTRO-HYDRAULIC CONTROL:

Electro-hydraulic control is commonly used to integrate hydraulic and electrical technologies for large applications, using the electrical signal either AC or DC source, operating voltages from 12 V to 220 Volts. The setting or final control is activated by solenoid valves whose actuation/reset is achieved by a pilot assisted solenoid actuation to reduce size and cost.

Hydraulic motion has benefits over electric or pneumatic systems, especially when high-speed linear travel is involved, heavy loads must be moved or held in place, or when very precise and smooth position or pressure control is required. Hydraulic actuators have a number of advantages including the fact that they produce less heat and electrical interference at the machine than do electric actuators.

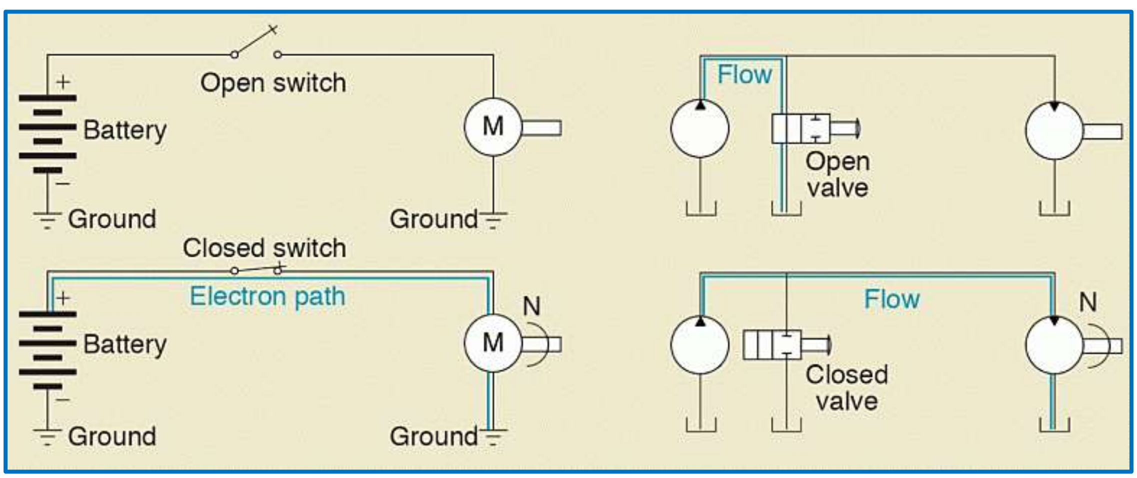
More often, the valve control using the electro-hydraulic system is carried out using a combination of relays and contactors or with the help of Programmable Logic Controllers (PLC), conveniently used to obtain the outputs for the required logic, time delay, and sequential operation. A typical hydraulic circuit is shown below, with the main components along with the electro-hydraulic motion controller.



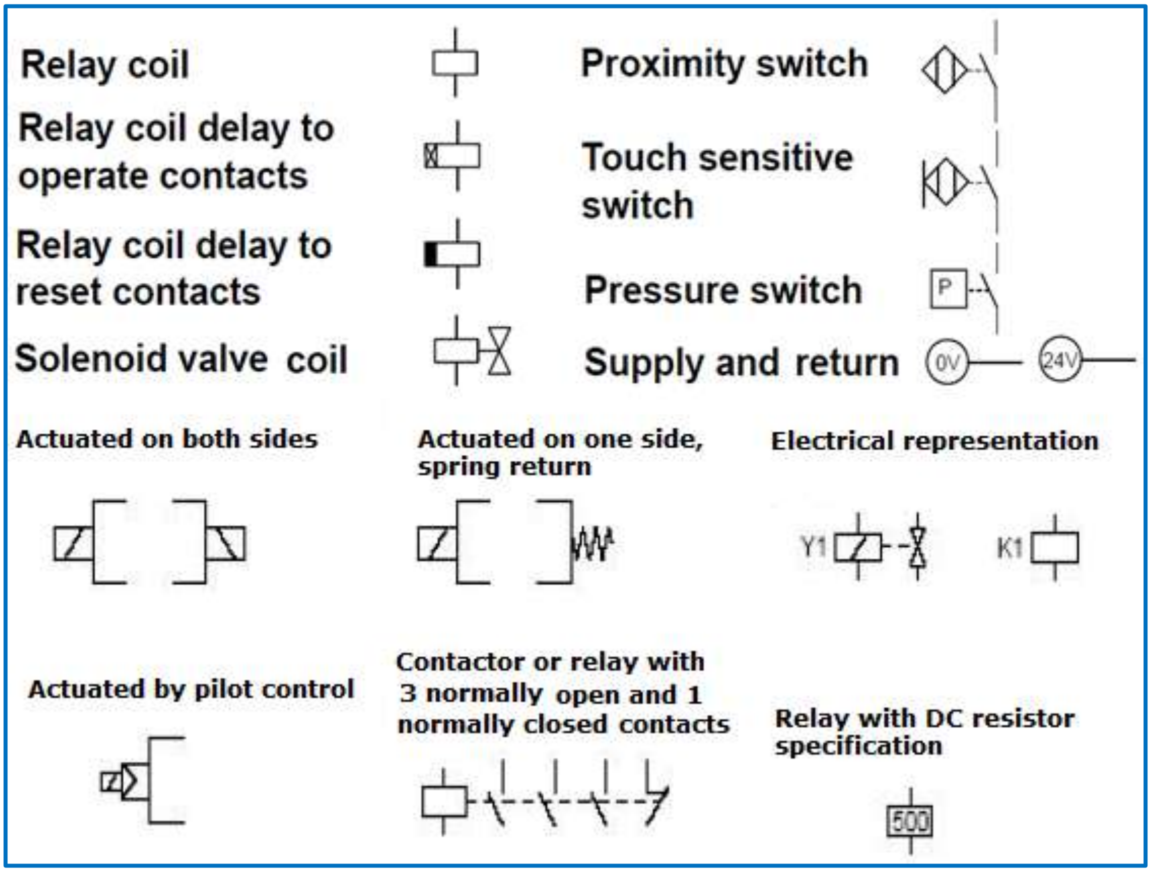
Electricity & Fluid Power: The hydraulic pump raises the energy content of the fluid in the form of pressure, and the pump pressure sends energized fluid into the load to do some work. The fluid particles make their way around the circuit and return back to the reservoir. Voltage is analogous to pressure, and drives the electrons to migrate from regions of high voltage to regions of low voltage.

Consider the left of the diagram below, which shows a battery, switch, motor, and connecting wiring that ties the components together and to ground. The purpose of this circuit is to be able to turn a motor on and off. The hydraulic complement of the motor circuit is shown on the right side of the diagram.

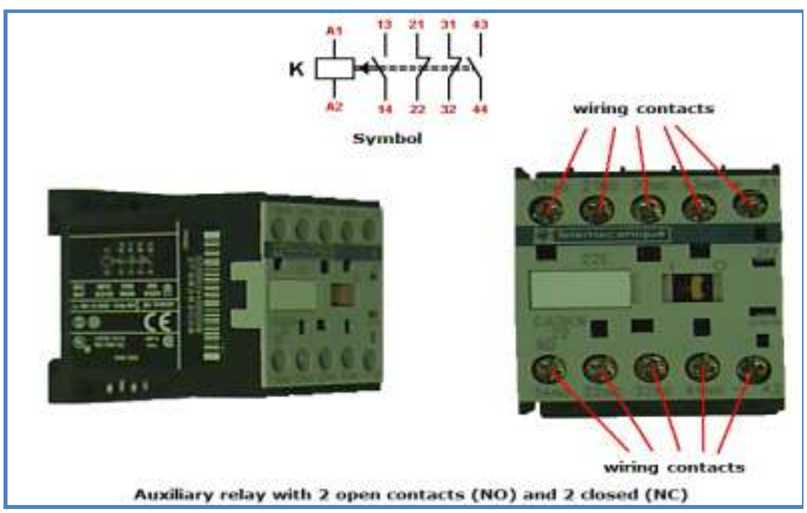
The longer line denotes the positive terminal of the battery, and the shorter, the negative. The battery symbol could be a lead-acid type used in cars, an alkaline type found in flashlights, or a lithium-ion type for a laptop computer. Likewise, the pump symbol used in hydraulics does not designate the type of construction, as it could be a gear pump, vane pump, or piston pump.



Switches, push buttons, contactors, and relays are often used to convert signal input from sensors and switches to a varied number of output signals (normally closed or normally open). Thus, the signal processing can also be easily achieved using relays and contactors combinations. Finally, the greatest advantage of electro-pneumatics is the integration of various types of proximity sensors (electrical) and PLC for a very effective control as the symbolic representation, shown below:



Auxiliary Relays: The auxiliary relays are electric keys of four or more contacts, triggered by electro-magnetic coils. There is a great diversity of types of auxiliary relays which, basically, although constructively are different, share the same operating characteristics.

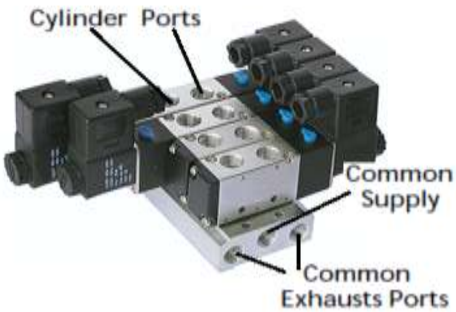


Auxiliary relay with 2 open contacts (NO) and 2 closed (NC)

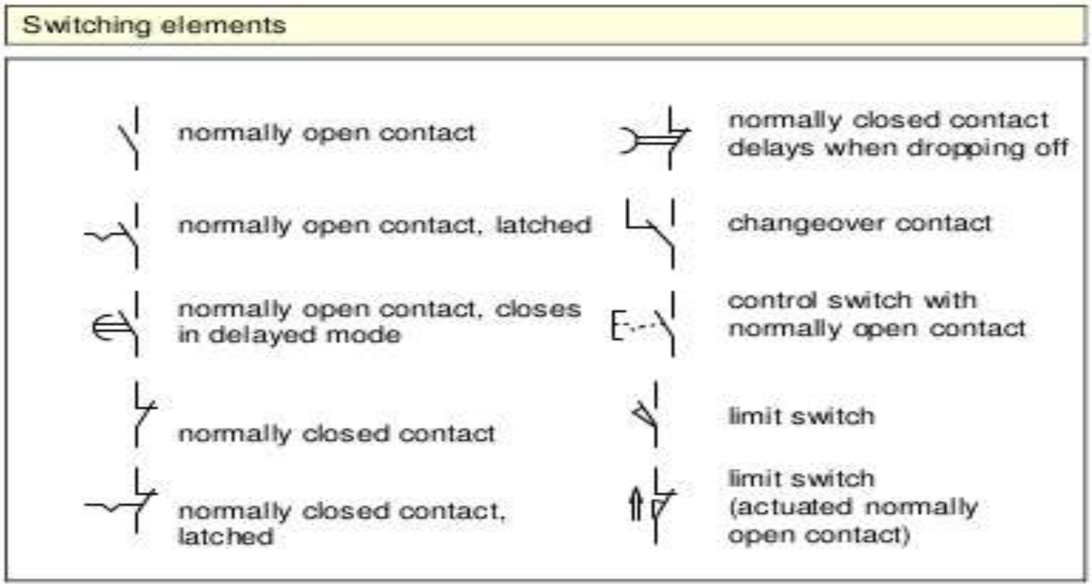
Contactors: A contactor is also an electrically controller switch, similar to a relay, except with higher current ratings and come in many forms with varying capacities and features. Unlike a circuit breaker, the contactor is not intended to interrupt a short circuit current. Contactors range from those having a breaking current to thousands of amperes and from 24 V DC to many kilovolts. The physical size of contactors ranges from a device very small, to large devices approximately a meter (yard) on a side.

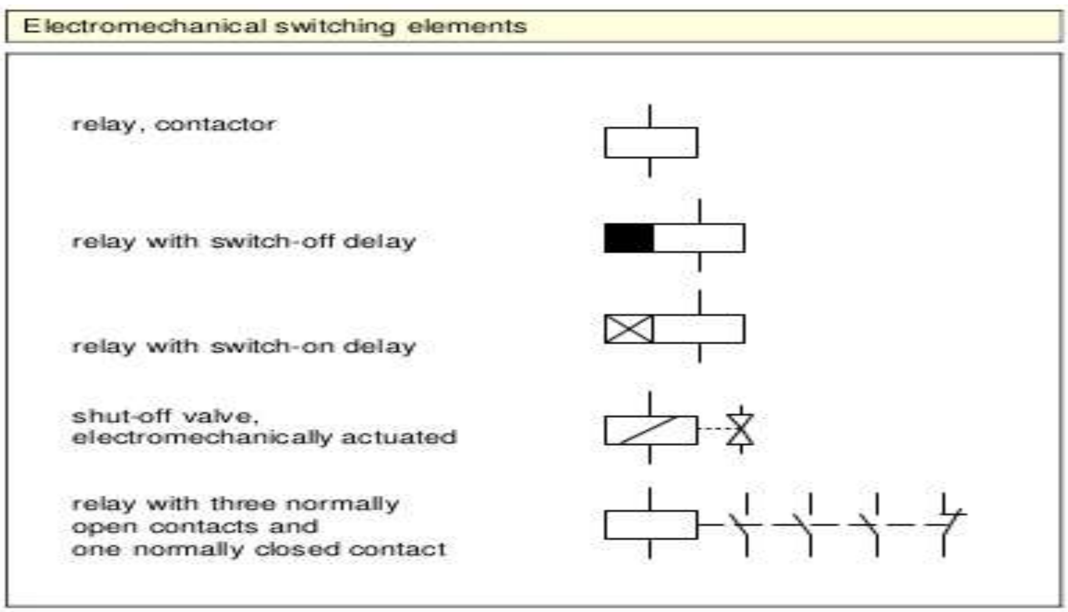
AC Contactor for a circuit application:	**Power DC Contactor – electro-pneumatic drive**:
	

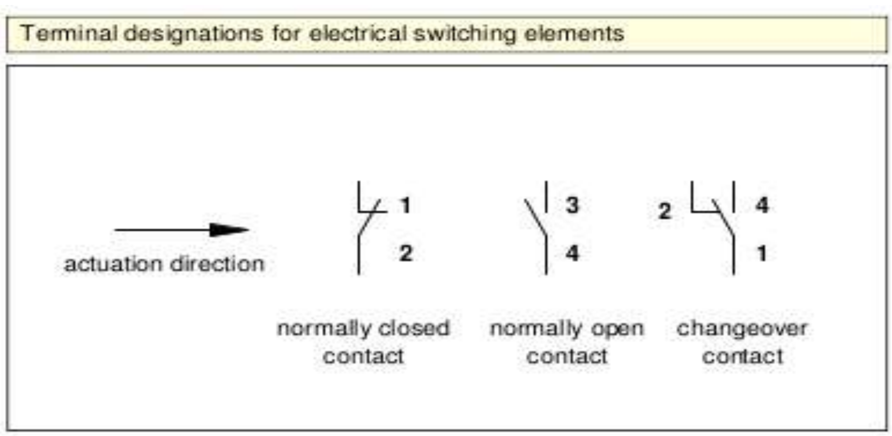
Manifolds: Manifolds have common supply and exhaust channels for a given number of body- ported valves. The outputs are connected separately to each valve. A manifold accommodate the required number of valves, since extension is not possible, and spare positions can be sealed by a blanking kit. With five or more valves, it is recommended that silencers be mounted at both ends.

Manifold with four valves:	**Manifold with six valves:**
	

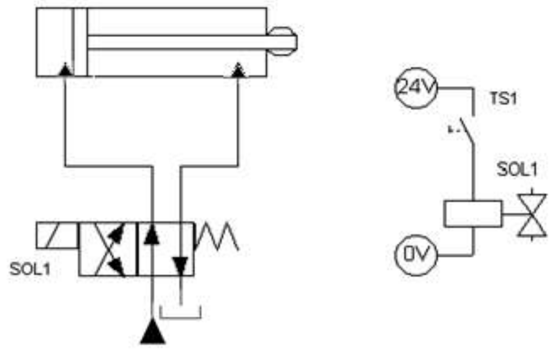
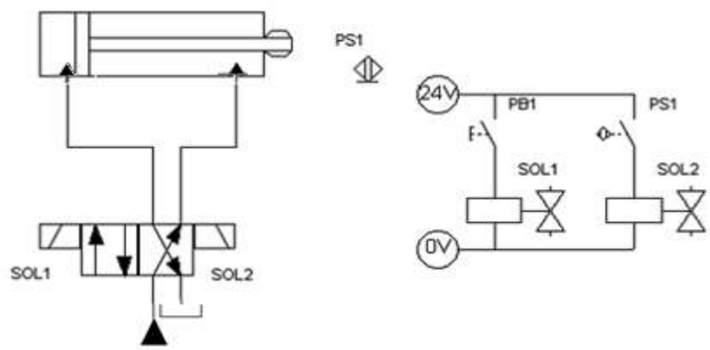
Electromechanical Switching Elements: Can, for example, be used to activate electric motors or hydraulic valves. The symbols for the most important types are shown below:



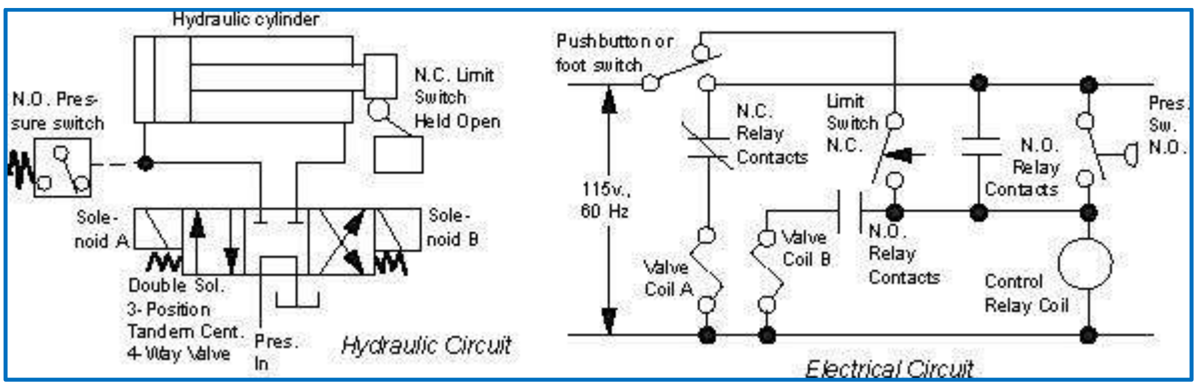




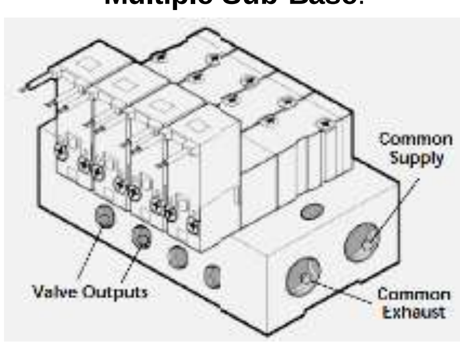
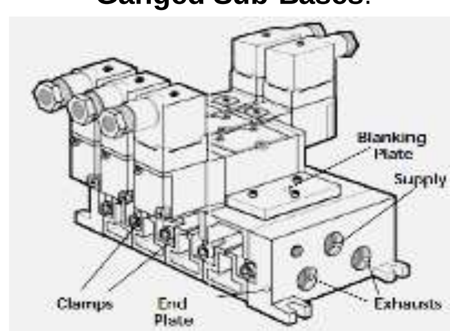
Electro-Hydraulic Circuits: See examples below, using power supplies 0V and 24V. Part 1 circuit, has one manual switch (TS1) and one solenoid valve (SOL1) N.O (normally open). Part 2 circuit, was added a SOL2 and changed the push button (PB1) to a N.O with a proximity sensor (PS1) to the circuit.

Part 1 circuit:	**Part 2 circuit**:
	

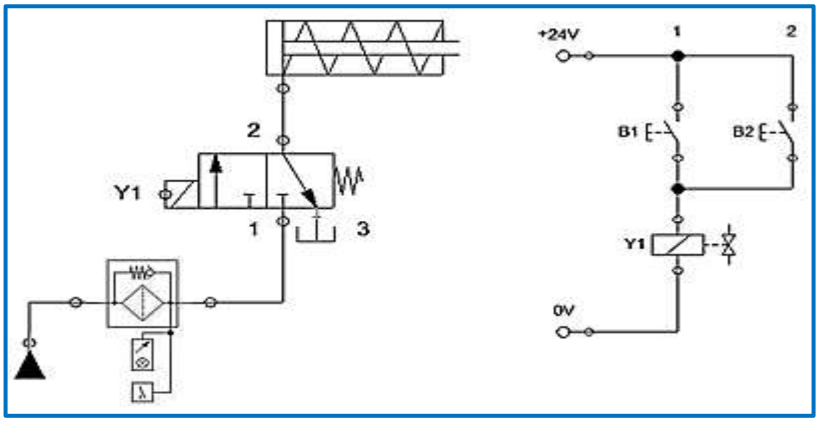
Example: A foot switch controls this hydraulic press cylinder. The operator steps on the switch to start the cylinder, and keeps the switch actuated during closure of the press. When the tonnage reaches to the adjusted pressure, the cylinder retracts even though the foot switch is still depressed. This action is accomplished by the electrical circuit with a control relay when the pressure switch contacts close, and the relay locks itself closed electrically through its own N.O. (normally open) set of contacts.



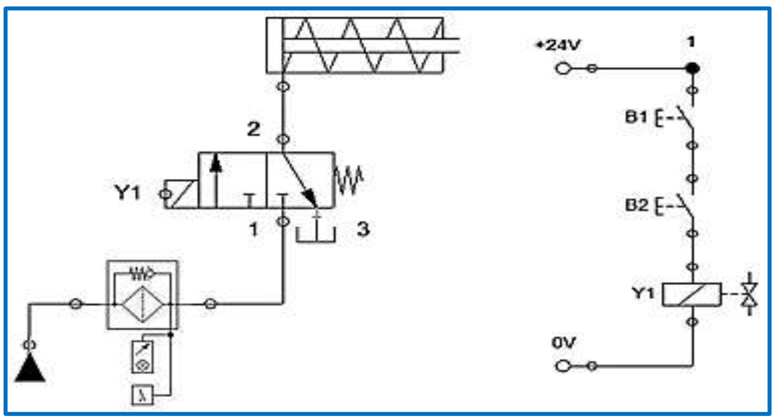
Sub-Bases: Valves with all of their ports on one face are gasket mounted on a sub-base, to which all the external connections including sensors are made, as shown below:

Multiple Sub-Base:	**Ganged Sub-Bases**:
	

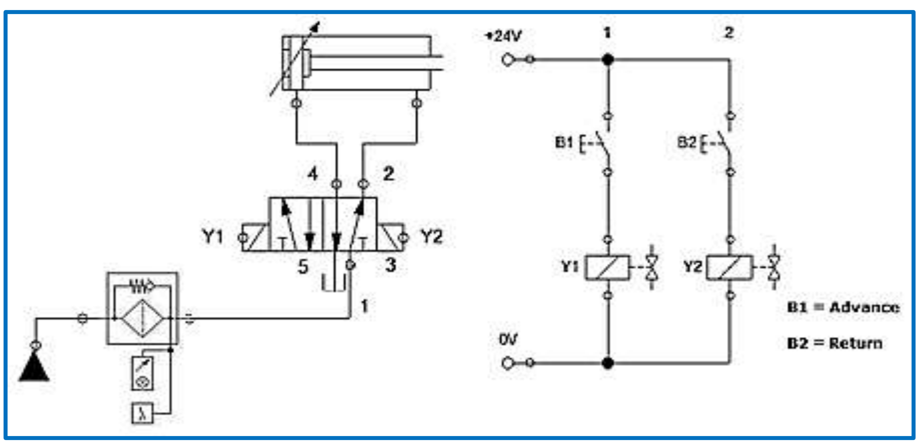
Single-Acting Cylinder – Electrically in Parallel: This cylinder can be actuated from two different places (B1 and B2), as long as we keep the button pressed, the rod will advance.



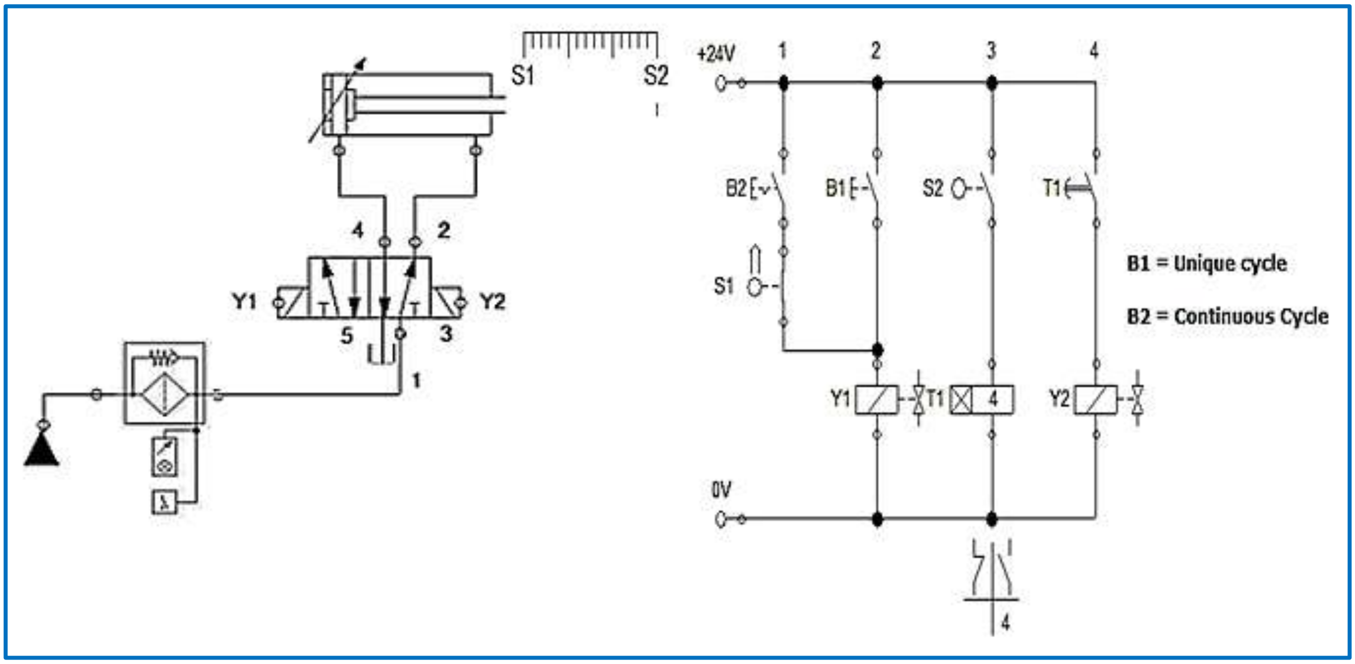
Single-Acting Cylinder – Electrically in series: The two command buttons (B1, B2) can be actuated simultaneously on a single-acting cylinder with spring return. When one of the buttons is loosed, the cylinder will return to its initial position.



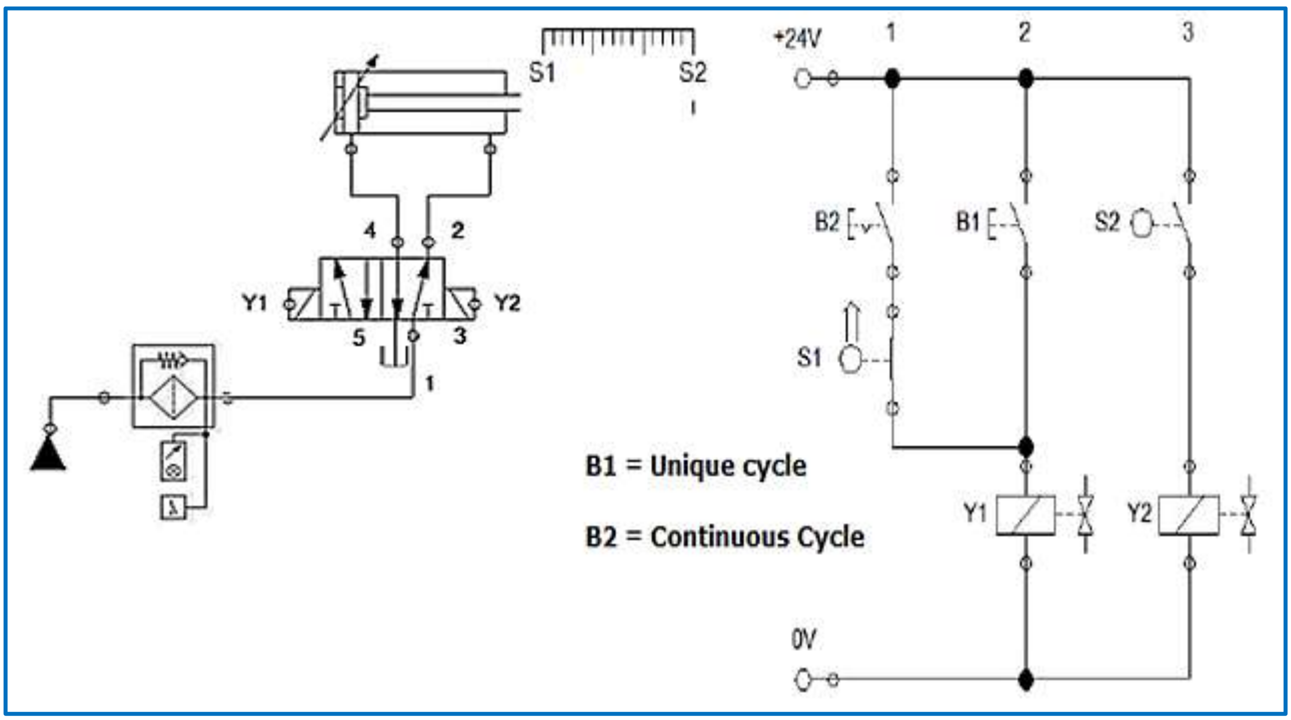
Double-Acting Cylinder – Two Switch Buttons: A double-acting cylinder is actuated by two switch buttons. Pressing the first button (B1) the cylinder must move forward and remain, even if the advanced button is not actuated. The return must be controlled by pulse in the second button (B2).



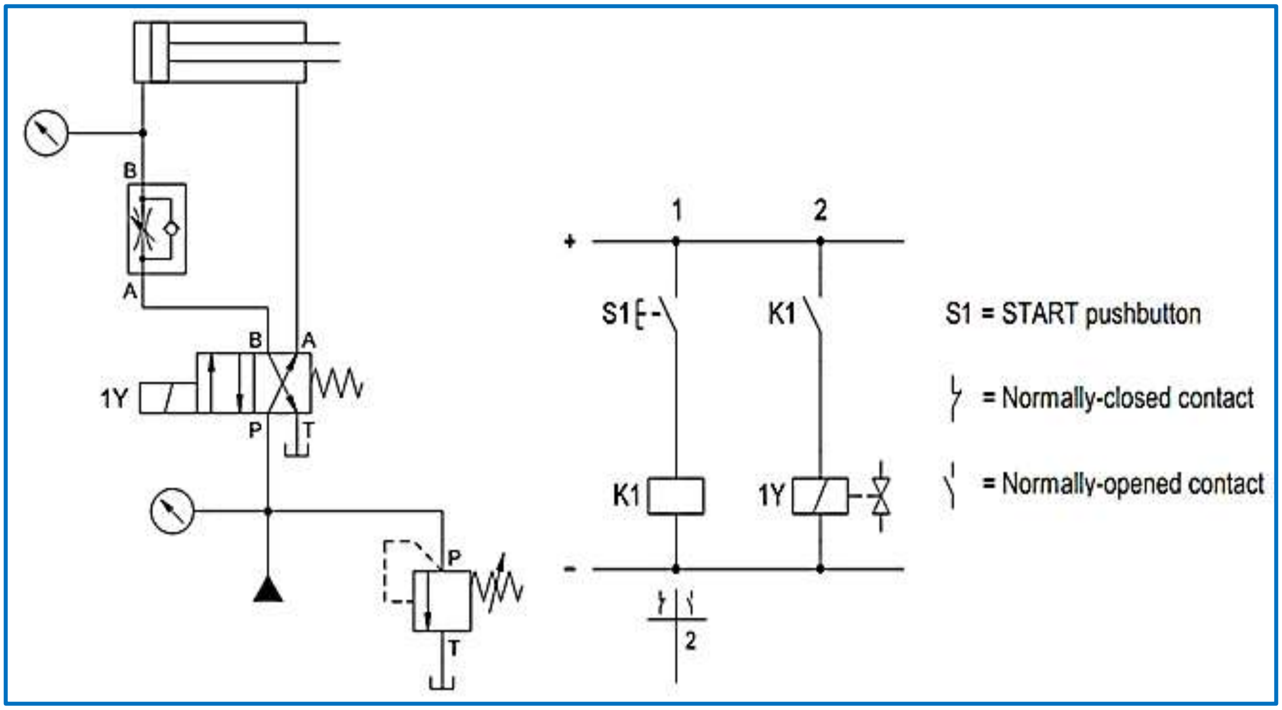
Double-Acting Cylinder – Time Relay: The double-acting cylinder must move forward when actuated the start button (B1), remain stationary for 4 seconds at the end of the course, and return automatically.



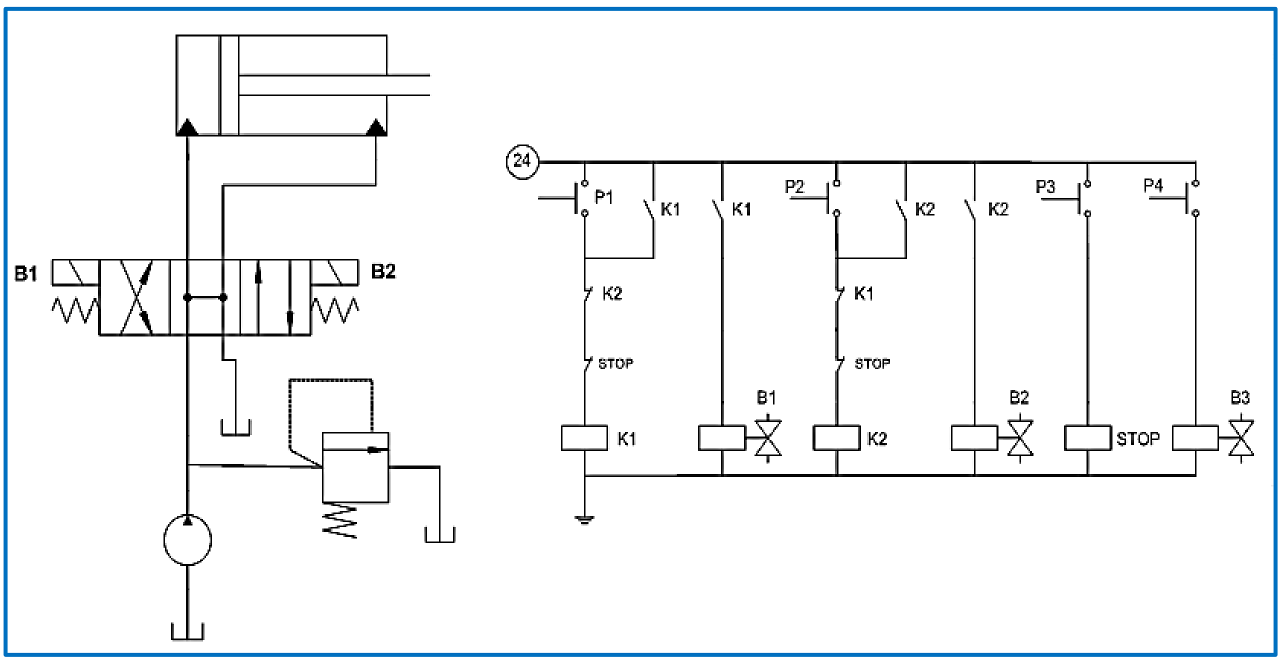
Double-Acting Cylinder – Unique Cycle and Continuous: A double-acting pneumatic cylinder, with end-of-stroke bumpers, must move forward and return automatically, making a single cycle, once pressed the switch button to start (B1). The second button (B2), when activated, shall cause the cylinder forward and return, in continuous cycle limited, this and the number of cycles shall be selected in accordance with the will of the operator.



Electro-Hydraulic – Flow Control Valves: This system can be used to adjust the advance-stroke speed. When the push button (S1) is pressed, the relay K1 is energized, and supplies current to the solenoid (Y1) and the 4/2 valve causes the piston rod of the cylinder to advance. As soon the S1 is released, the cylinder retracts.



Electro-Hydraulic – Relief Valves: This system protects circuits controlled remotely, available to a variable electrical input signals (0 to 24 VDC), and serves as pilot valves or proportional control valves to control pressure and fluid flow.



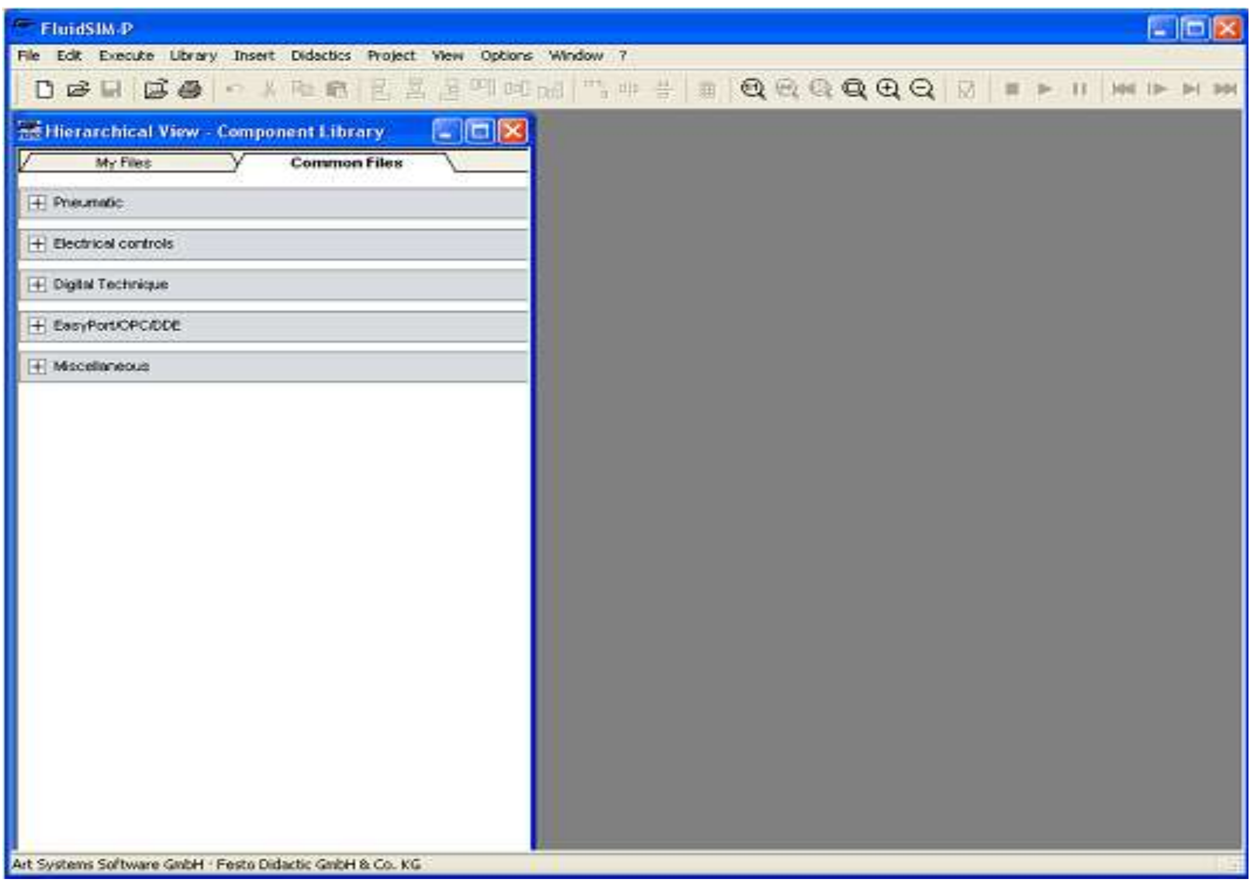
HYDRAULICS – SOFTWARE SIMULATIONS:

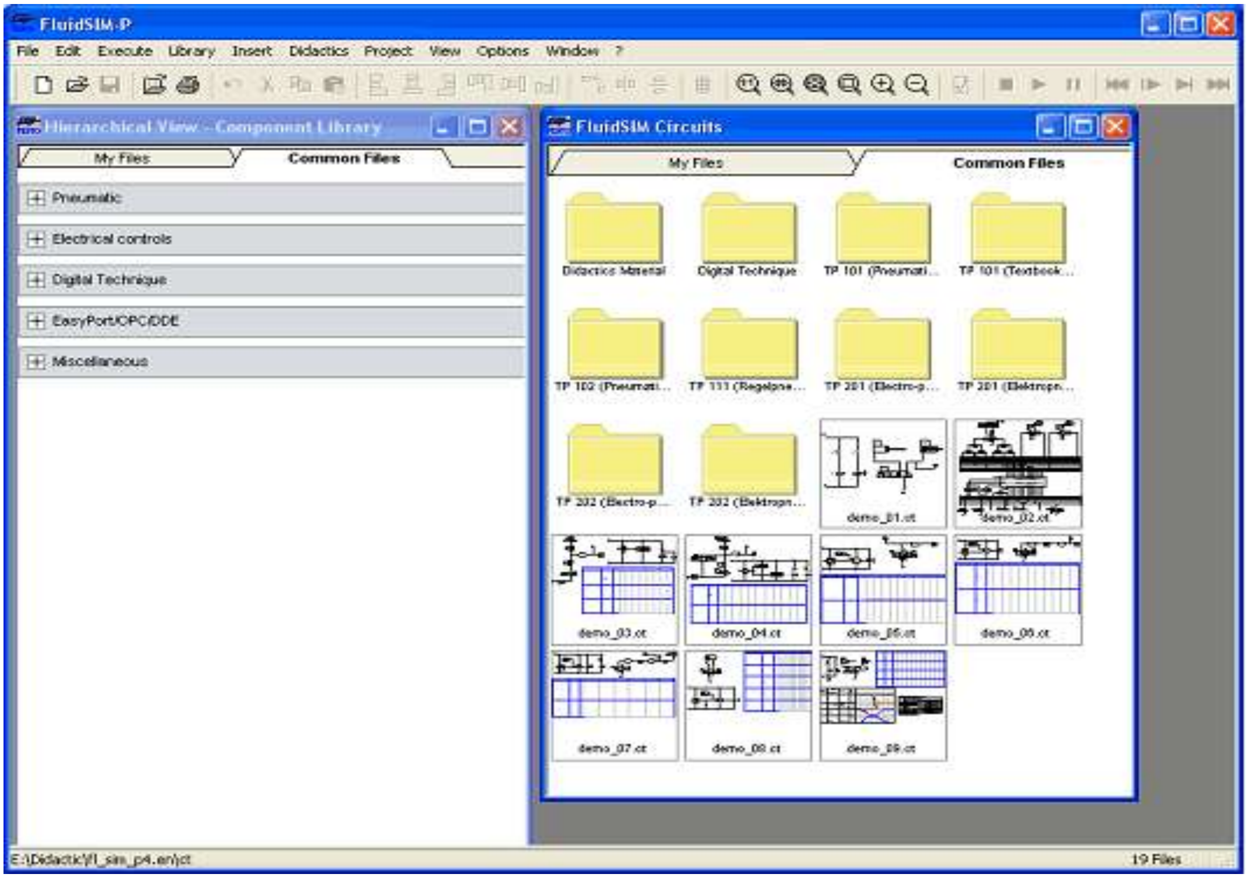
FluidSIM: Is a comprehensive and easy software for the creation, simulation, instruction and study of electro-pneumatics, electro-hydraulics, digital and electronic circuits. All of the programme functions interact smoothly, combining different media forms and sources of knowledge in an easily accessible fashion. FluidSIM unites an intuitive circuit diagram editor, with detailed descriptions of all components, component photos, sectional view animations and video sequences.

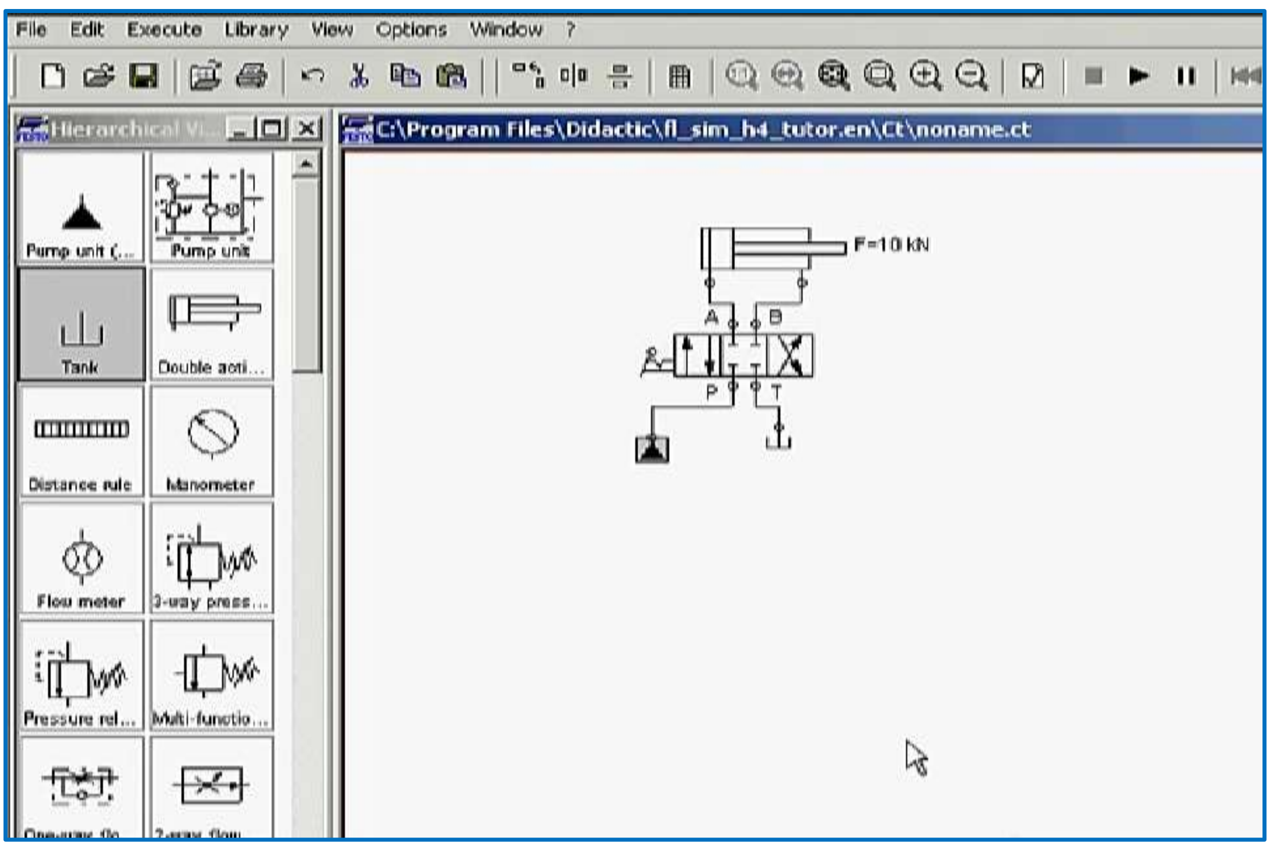
As a result, FluidSIM is perfect not only for use in lessons, but also for preparation and as a self-study programme. Despite complex physical models and precise mathematical procedures, simulation is amazingly fast. FluidSIM also provides a whole range of possibilities for communication with other software via OPC and a link up to real hardware is also possible. FluidSIM is distributed worldwide by Festo Didactic GmbH & Co. KG, extendable and customizable component libraries.

If you intend to draw simple circuit diagrams, 128 MB RAM is adequate, however, minimum 256 MB RAM is recommended to simulate complex circuit diagrams. The interested user can **download** a FluidSIM Pneumatic **Demo** version to experiment how to use the software, or buy a full version in two CD-ROMs and a possibly a license connector, in both full and student version.

After the installation, FluidSIM is very easy to start. Click on the program icon that appears in your computer work area and after a few seconds the main window will open in your screen, as below:




FluidSIM-P
File Edit Execute Library Insert Didactics Project View Options Window ?
Hierarchical View - Component Library
My Files
Common Files
Pneumatic
Electrical controls
Digital Technique
EasyPort/OPC/DDE
Miscellaneous
FluidSIM Circuits
Didactics Material
Digital Technique
demo_01.ct
demo_03.ct
demo_04.ct
demo_05.ct
demo_06.ct
demo_07.ct
demo_08.ct
demo_09.ct
19 Files


File Edit Execute Library View Options Window ?
C:\Program Files\Didactic\fl_sim_h4_tutor.en\Ct\noname.ct
Pump unit
Tank
Double acti...
Distance rule
Manometer
Flow meter
3-way press...
Pressure rel...
Multi-functio...
F=10 kN
A
B
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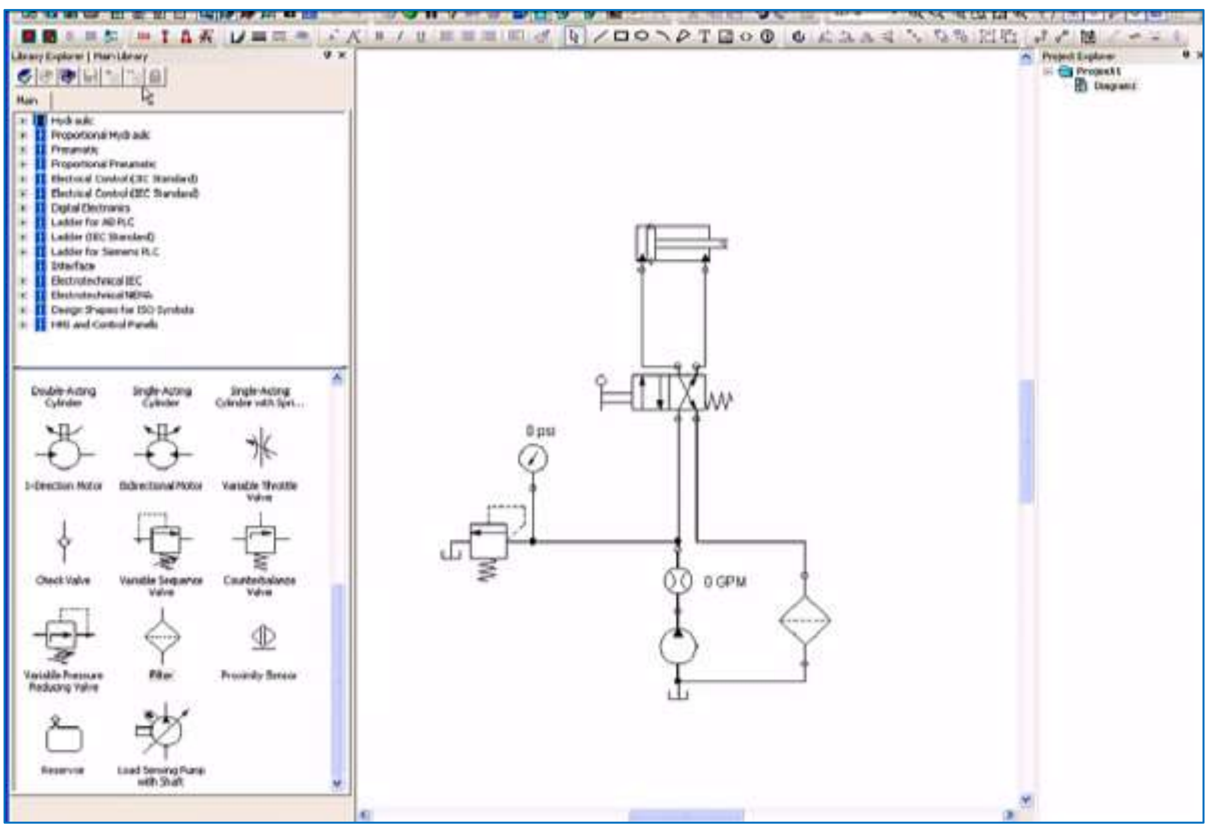
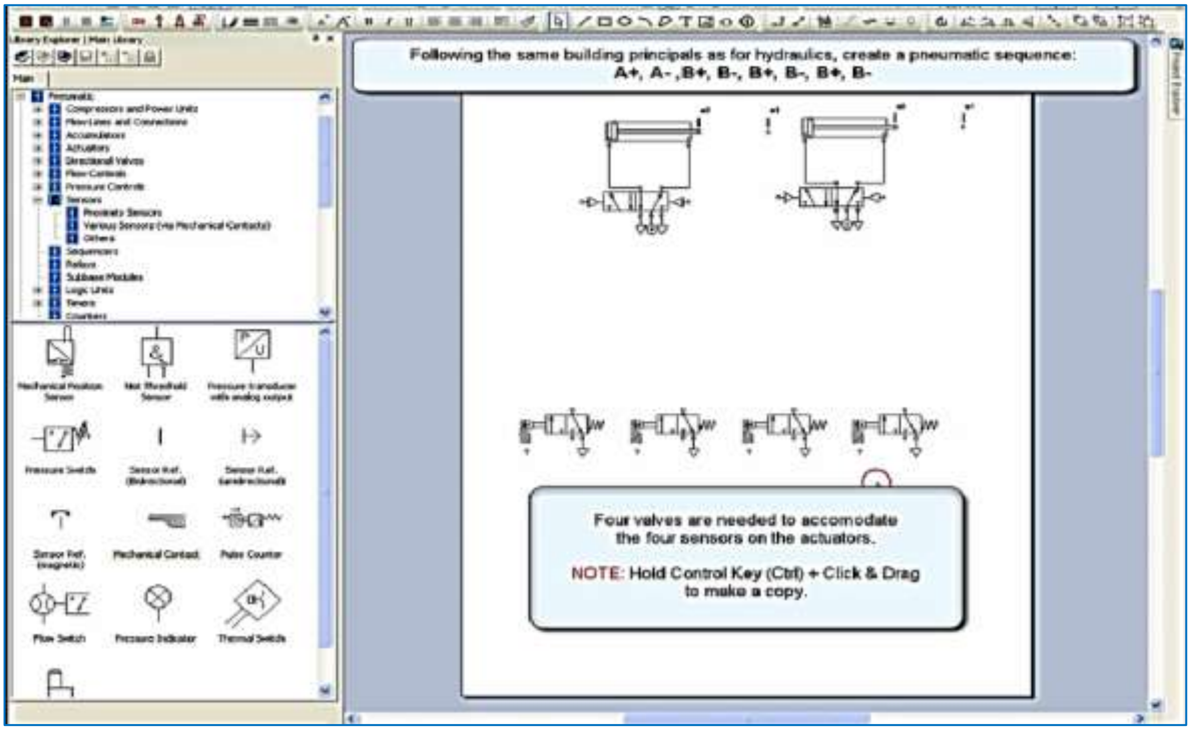
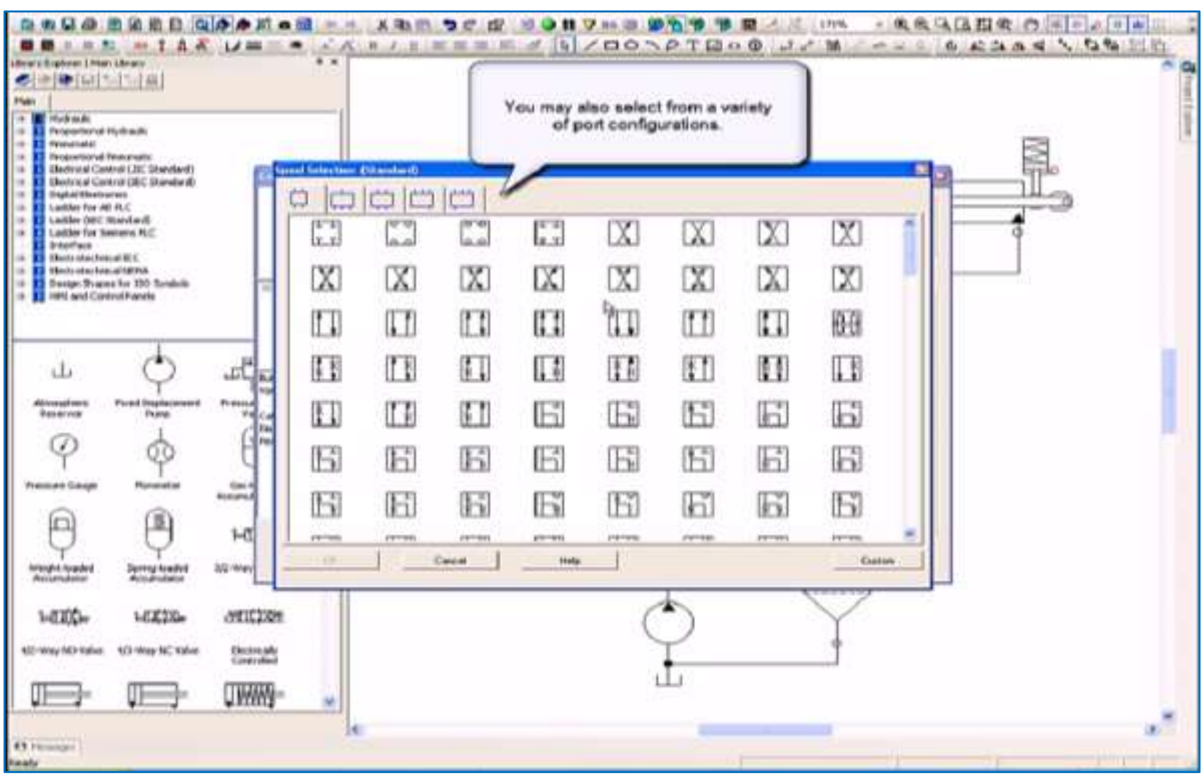
T

Automation Studio: Is another circuit simulation for design and project software for fluid power systems and electrical projects conceived by Famic Technologies. Automation Studio can be applied in the design, training of hydraulics, pneumatics, and electrical control systems. It is also used for PLC, CAD, maintenance, and training purposes.



The AS Hydraulics is the main aspect of Automation Studio, used to conceive and to test hydraulic systems. It displays inside views of the elements in the schematics. The AS library (proportional hydraulics), includes additional elements such as commands and control devices. The AS Pneumatics is similar to AS Hydraulics, but the simulation is done for air rather than fluids. The work sheet is similar to FluidSIM, but much more interactive, as shown below:





HYDRAULICS & PNEUMATICS - BASIC DESCRIPTION:

2/2 Valve	A directional control valve with two ways, two ports, and two positions.
3/2 Valve	A directional control valve with three ways, three ports, and two positions.
4/2 Valve	A directional control valve with four ways, four ports, and two positions.
4/3 Valve	A directional control valve with four ways, four ports, and three positions.
Two-Way Valve	A valve with one inlet pressure port that services one of two possible outlets, depending on the position of the valve.
Three-Way Valve	A directional control valve that diverts flow between two possible paths. Three-way valves allow flow from the pressure port to two other ports.
Four-Way Valve	A directional control valve typically used for double-acting actuators.
Valve	A mechanical device that controls air in a pneumatic system. Valves are responsible primarily for the proper control of a pneumatic system.
Valving Element	The component of a valve that covers a port. Depending on the design of the valve, the valve element controls direction, pressure, or flow by opening and closing.
Way	A characteristic of a valve that indicates how a fluid can flow through it.
Bleed-Off Circuit	A flow control configuration in which a valve exhausts air when actuated. The valve of the bleed-off circuit can be located anywhere along the main line.
Cam-Operated Directional Control Valve	A directional control valve that is actuated by the distinct physical geometry of a cam. As the cam rotates, its shape actuates the valve mechanism of the valve.
Check Valve	A control valve that allows air to flow in only one direction. Check valves prevent backflow.
Detent	A linear or rotary device with fixed points of resistance. Each point of a detent represents a distinct phase of valve actuation.
Diaphragm	A spring-loaded valve mechanism that moves in response to variations in pressure in a pneumatic system. The diaphragm is a flexible membrane that responds to changes in pressure and moves the poppet.
Directional Control Valve	Directional control valves are used to move actuators into various positions.
Direct-Operated	Actuated by compressed air pressing directly on the valve element.
Electrical Actuation	The act of tripping or seating a valve element with an electrical device such as a solenoid.

Filter	A screen used for trapping very fine and fine particulate matter.
Flow Control Valve	A fluid component that controls the rate of airflow. Flow control valves make it possible to control other system variables like the speed of an actuator.
Full Line Pressure	The maximum pressure that a line can withstand during operation.
Full-Flow Pressure	The point at which a relief valve is diverting air at its maximum rate.
Gripper	A double-acting linear actuator that has the capability to repeatedly clamp and release.
Hydraulic Actuation	The act of tripping or seating a valve element with pressurized liquid.
Hysteresis	The tendency of the position of a component to be dependent on the previous position of the component when reacting to a physical stimulus. Hysteresis leads to varying degrees of inaccuracy relative to valve actuation and target pressure.
Infinite Positioning	Characterized by being fully on, fully off, or anywhere in between. Infinite positioning allows any range of possible positions.
In-Line Check Valve	A check valve with the inlet and outlet located directly opposite each other.
Limit Switch	A device used for making, breaking, or for changing the connections in an electric circuit.
Lunging	A situation in which the actuator and the load are moving in the same direction. Lunging, or overrunning, often causes the actuator to suddenly jump.
Manual Actuation	The act of tripping or seating a valve element by hand.
Master Control Valve	A directional control valve that directs air to different areas of the pneumatic system.
Mechanical Actuation	The act of tripping or seating a valve element through the intervention of a mechanical device such as a plunger or cylinder.
Meter-In Circuit	A flow control configuration in which the valve is located between the compressor and the actuator.
Metering Valve	A valve with infinite positioning and variable control that is capable of regulating the flow of fluid. A needle valve is a type of metering valve.
Meter-Out Circuit	A flow control configuration in which the valve is located at the outlet of the actuator.
Needle Valve	A valve that adjusts the flow of air between and including fully on and fully off. The needle valve consists of a sharp conical obstruction that is extended or retracted to block or allow flow.
Normally Closed Position	A valve position in which the valve element is unactuated and covering a port. A normally closed valve opens when it actuates.

OSHA	The Occupational Safety and Health Administration. A government agency under the U.S. Dept. of Labor that helps employers reduces injuries, illnesses, and deaths in the workplace.
Outstroke	The motion of the cylinder piston as it extends. Some flow controls are best located downstream of the outstroke in order to regulate the speed of the cylinder.
Overpressure	A situation in which the pressure in a pneumatic system has exceeded recommended levels. Overpressure can lead to equipment damage and personal injury.
Override	A means of bypassing the essential function of a device, such as a valve. Overrides exist for various exceptions that can occur during normal operation.
Pilot Port	The port through which compressed air travels when actuating the pilot portion of a pilot operated valve.
Pilot-Operated	Actuated by compressed air coming from a pilot or ancillary port for the purpose of an overriding a valve.
Pilot-Operated Check Valve	A check valve that is direct operated under normal circumstances and actuated by a pilot signal under circumstances that call for a valve override.
Pilot-To-Close Check Valve	A check valve that allows flow in the forward direction and stops flow in the reverse direction under normal circumstances. The pilot port stops flow in either direction by closing the poppet when needed.
Pilot-To-Open Check Valve	A check valve that allows flow in the forward direction and stops flow in the reverse direction under normal circumstances. The pilot port allows flow in the reverse direction by opening the poppet when needed.
Piston-Type Regulating Valve	Hydraulic pressure from the inlet and pressure from the piston act against each other, allowing only a predetermined level of pressure to leave the valve.
PLC	A processor-driven device that uses logic-based software to provide electrical control to machines.
Poppet	A conical valve element that continually opens and closes in response to variations in pressure.
Port	An opening on a valve through which fluid can flow.
Position	The number of physical settings on a directional control valve. A three-position valve can be placed in three different physical settings with a control such as a lever.
Pressure Differential	The difference between two levels of pressure in a pneumatic system. Since high pressure moves toward low pressure, a pressure differential causes pneumatic flow.

Pressure Drop	The pressure from a load on an actuator minus the cracking pressure of a valve. Pressure drop is also called pressure differential and represents the difference between two pressure levels.
Pressure Override	The full-flow pressure minus the cracking pressure. The pressure override is a measure of the increase in pressure over the cracking pressure when additional flow passes through the valve after it cracks.
Pressure Port	A valve inlet port closest to the pump.
Reducing Valve	A pneumatic power device that protects the pneumatic system against overpressure. Reducing valves are sometimes called air regulating or regulating valves.
Regulating Valve	A pneumatic power device that protects the pneumatic system against overpressure. Regulating valves are sometimes called air regulating valves or reducing valves.
Relief Valve	A component that exhausts air into the environment once a pneumatic system reaches a critical pressure, beyond which damage or injury can occur.
Right Angle Check Valve	A check valve with the inlet and outlet located at right angles of each other.
Rotary Valve	A directional control valve that directs the flow of fluid when turned.
Sequence Valve	A pneumatic valve that actuates and allows air into a secondary system after a critical pressure is reached.
Solenoid	A coil of wire that generates an electromagnetic force when a current is applied. When activated, solenoids can open and close valves.
Speed Of Sound	The speed at which sound moves through air. At normal elevation and at 70° F (21° C), the speed of sound is 770 mph (344 m/s).
Spool	A cylindrical valve element that alternately allows and blocks flow depending on its linear position.

HYDRAULICS - TRAINING:

The list of links below, introduces the basic concepts, terminology, applications, and automation processes used for training purposes.

http://www.nfpa.com/education/learningresources-pneumaticsonlinetraining.aspx
http://www.automationstudio.com/educ/en/Product/movies.htm#.U1AhHfldWQh
http://www.automationstudio.com/educ/en/support/Training_Videos.htm
https://www.youtube.com/watch?v=8G8zX4M-4CY
https://www.youtube.com/watch?v=EvbNWZIheOw
https://www.youtube.com/watch?v=m8VoFOr4Ezg
http://pt.slideshare.net/lalitaggarwalstiff/hydraulics-actuation-system

LINKS AND REFERENCES:

http://www.nfpa.com/
http://www.thermopedia.com/content/858/?tid=110&sn=12
http://www.automationstudio.com/
http://www.thelearningpit.com/hj/plcs3.asp#pgfId-867369
http://www.festo-didactic.com/

Electrohydraulics – Workbook Basic Level – Festo Didactic;
Hydraulic & Pneumatic Symbols – Festo, Norgren;
Festo FluidSim – Hydraulics & Pneumatics;
Herbert Merritt, Hydraulic Control Systems. Wiley, 1967;
Noah Manring, Hydraulic Control Systems. Wiley, 2005;
W. Durfee and Z. Sun, Fluid Power System Dynamics. University of Minnesota, 2009;