المحاضرة الثامنة : تصميم الدارات الهيدروبنيوماتيكية

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Fundamental physical principles of hydraulics

Hydraulics is the science of forces and movements transmitted by means of liquids. It belongs alongside hydro-mechanics. A distinction is made between hydrostatics – dynamic effect through pressure times area – and hydrodynamics – dynamic effect through mass times acceleration

By hydraulics, we mean the generation of forces and motion using hydraulic fluids. The hydraulic fluids represent the medium for power transmission

range of applications for which it can be used.

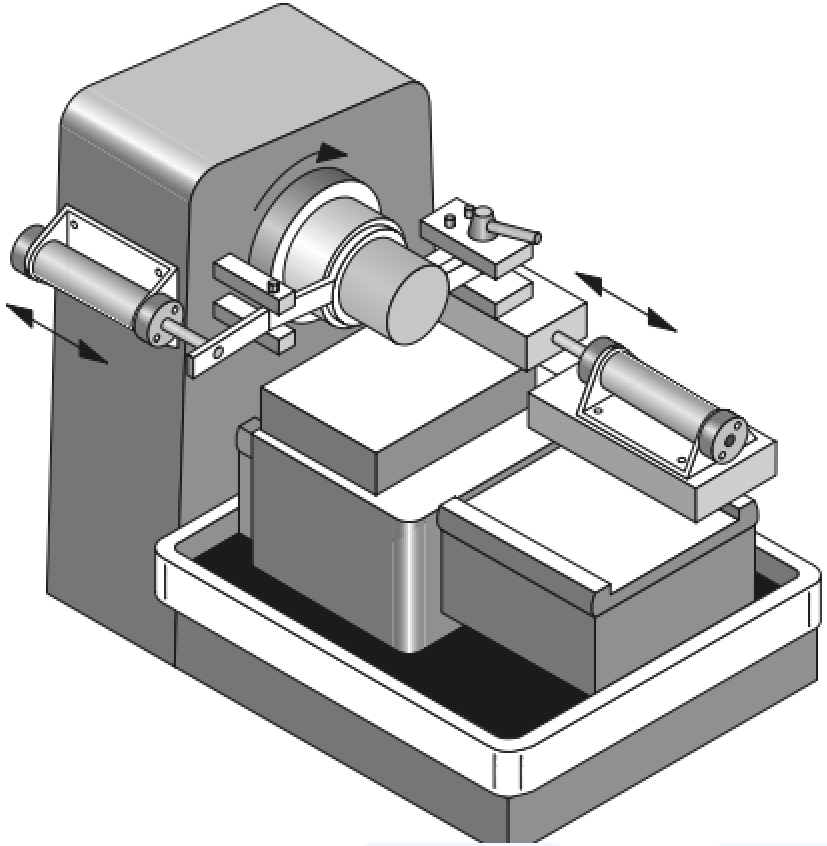
A basic distinction is made between:

- stationary hydraulics
- and mobile hydraulics

Stationary hydraulics

The following application areas are important for stationary hydraulics:

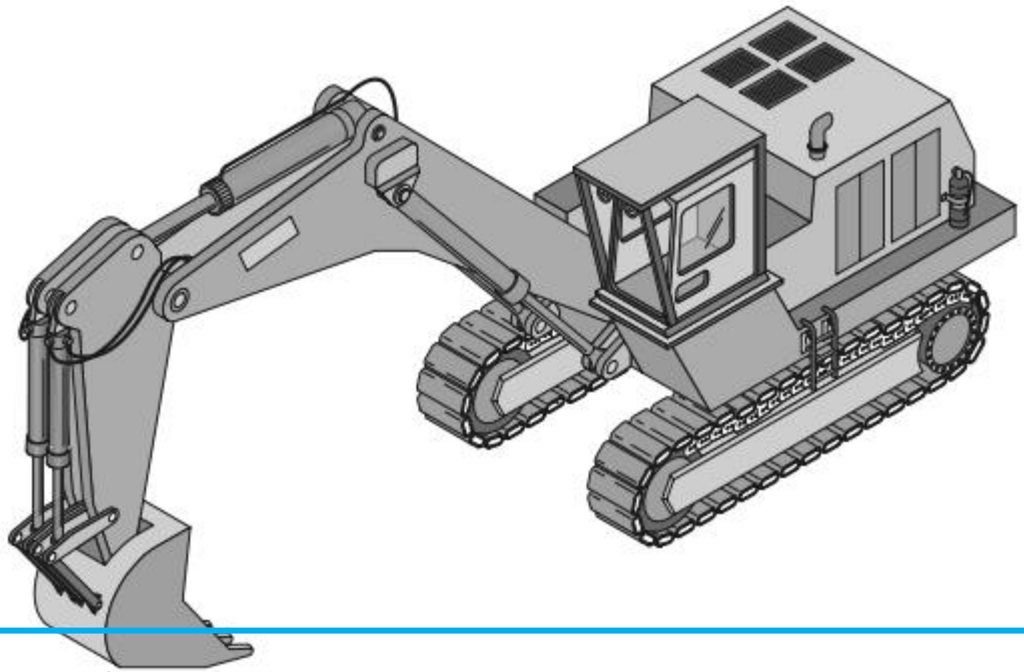
- Production and assembly machines of all types
- Transfer lines
- Lifting and conveying devices
- Presses
- Injection moulding machines
- Rolling lines
- Lifts



Mobile hydraulics

Typical application fields for mobile hydraulics include:

- Construction machinery
- Tippers, excavators, elevating platforms
- Lifting and conveying devices
- Agricultural machinery



Comparison of hydraulics with other control media

This comparison reveals some important advantages of hydraulics:

- Transmission of large forces using small components, i.e. great power intensity
- Precise positioning
- Start-up under heavy load
- movements independent of load
- Smooth operation and reversal
- Good control and regulation
- Favourable heat dissipation

Compared to other technologies, hydraulics has the following **disadvantages:**

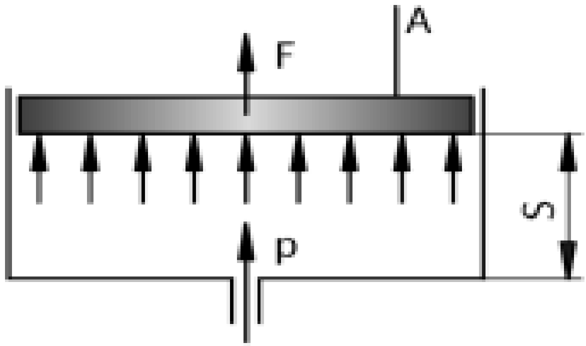
- Pollution of the environment by waste oil (danger of fire or accidents)
- Sensitivity to dirt
- Danger resulting from excessive pressures (severed lines)
- Temperature dependence (change in viscosity)
- Un favourable efficiency factor

1.Pressure

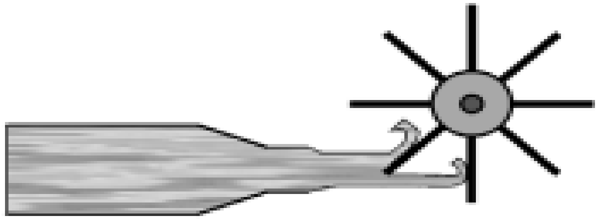
Hydro-mechanics

Hydrostatics

Hydrodynamics



Force effect through
pressure area



Force effect through
mass accelaration

Hydrostatic pressure

Hydrostatic pressure is the pressure which rises above a certain level in a liquid owing to the weight of the liquid mass:

ps= hydrostatic pressure (gravitational pressure) [Pa]

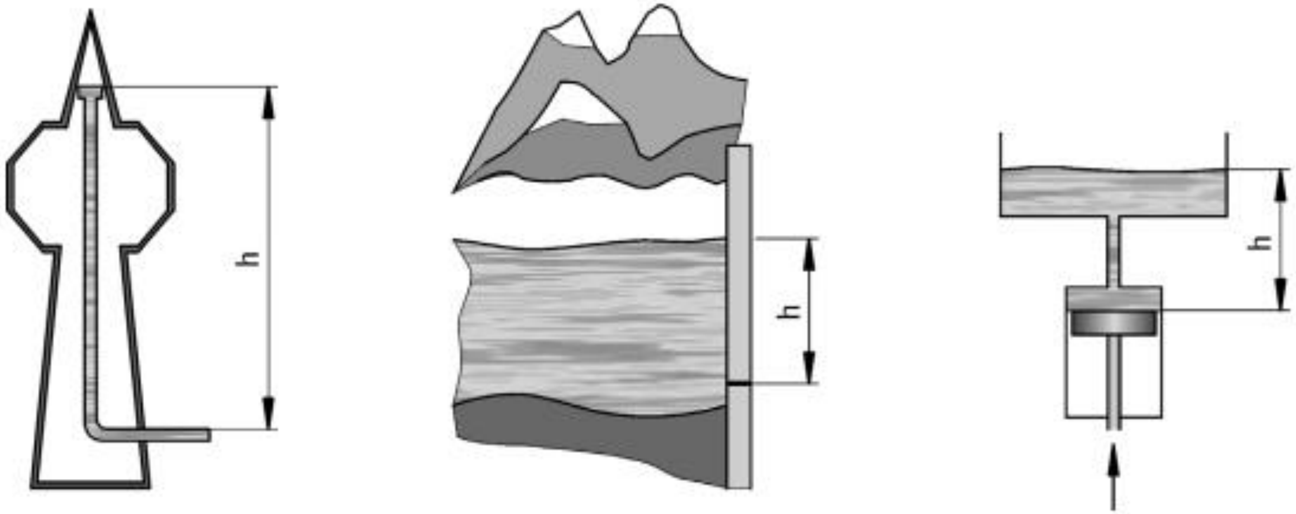
h = level of the column of liquid [m]

ρ = density of the liquid [kg/m 3]

g = acceleration due to gravity [m/s 2]

$$p_s = h \cdot \rho \cdot g$$

The **hydrostatic pressure**, or simply "pressure" as it is known for short, does not depend on the type of vessel used. It is purely **dependent on the height and density of the column of liquid**



Column: $h = 300\ m$

$\rho = 1000\ kg/m^3$

$g = 9.81\ m/s^2 = 10\ m/s^2$

$$p_S = h \cdot \rho \cdot g = 300\ m \cdot 1000\ \frac{kg}{m^3} \cdot 10\ \frac{m}{s^2} = 3\ 000\ 000\ \frac{m \cdot kg \cdot m}{m^3 \cdot s^2} = 3\ 000\ 000\ \frac{N}{m^2}$$

$p_S = 3\ 000\ 000\ Pa = 30\ bar$

Reservoir: $h = 15\ m$

$\rho = 1000\ kg/m^3$

$g = 9.81\ m/s^2 = 10\ m/s^2$

$$p_S = h \cdot \rho \cdot g = 15\ m \cdot 1000\ \frac{kg}{m^3} \cdot 10\ \frac{m}{s^2} = 150\ 000\ \frac{m \cdot kg \cdot m}{m^3 \cdot s^2} = 150\ 000\ \frac{N}{m^2}$$

$p_S = 150\ 000\ Pa = 1{,}5\ bar$

Elevated tank: $h = 5\ m$

$\rho = 1000\ kg/m^3$

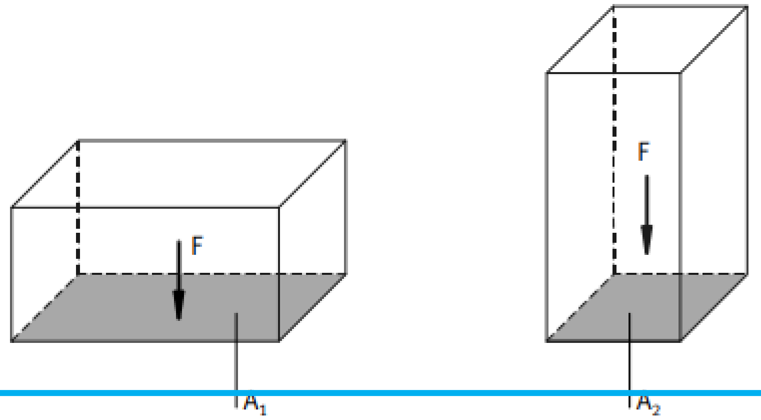
$g = 9.81\ m/s^2 = 10\ m/s^2$

$$p_S = h \cdot \rho \cdot g = 5\ m \cdot 1000\ \frac{kg}{m^3} \cdot 10\ \frac{m}{s^2} = 50\ 000\ \frac{m \cdot kg \cdot m}{m^3 \cdot s^2} = 50\ 000\ \frac{N}{m^2}$$

$p_S = 50\ 000\ Pa = 0{,}5\ bar$

2.Force, area

The diagram shows two bodies with different bases (A 1 and A 2). Where the bodies have identical mass, the same force due to weight (F) acts on the base. However, the pressure is different owing to the different sizes of base. Where the force due to weight is identical, a higher pressure is produced in the case of a small base than in the case of a larger base ("pencil" or "concentrated" effect). This is expressed by the following formula



$$1Pa = 1N/m^2$$

1bar =100.000N/m^2 =10^5pa

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

P-pressure { pa}

F- Force [N]

A- Area – square metr [m^2]

Example

A cylinder is supplied with 100 bar pressure, its effective piston surface is equal to 7.85 cm^2. Find the maximum force which can be attained.

Given that: $p = 100 \text{ bar} = 1000 \text{ N/cm}^2$

$A = 7.85 \text{ cm}^2$

$$F = p \cdot A = \frac{1000 N \cdot 7.85 cm^2}{cm^2} = 7850 \text{ N}$$

Example

A lifting platform is to lift a load of 15 000 N and is to have a system pressure of 75 bar.

How large does the piston surface A need to be?

Given that: $F = 15\ 000 \text{ N}$

$P = 75 \text{ bar} = 75 \cdot 10^5 \text{ Pa}$

$$A = \frac{F}{p} = \frac{15000 N}{75 \cdot 10^5 Pa} = 0.002 \frac{N \cdot m^2}{N} = 0.002 \text{ m}^2 = 20 \text{ cm}^2$$

3.Pressure transmission

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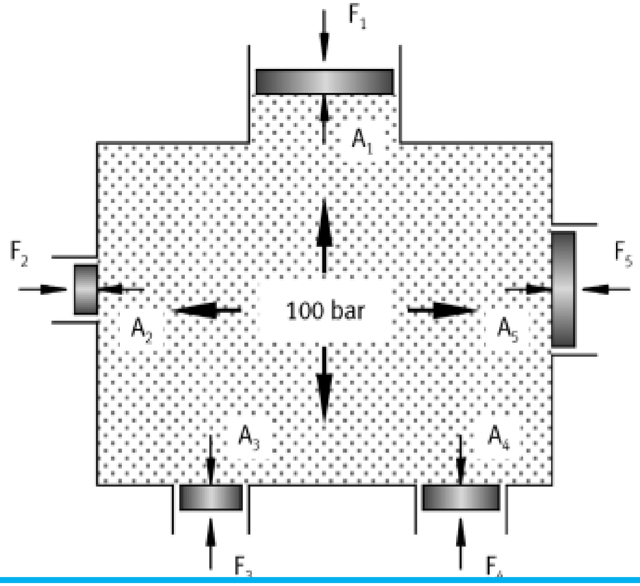
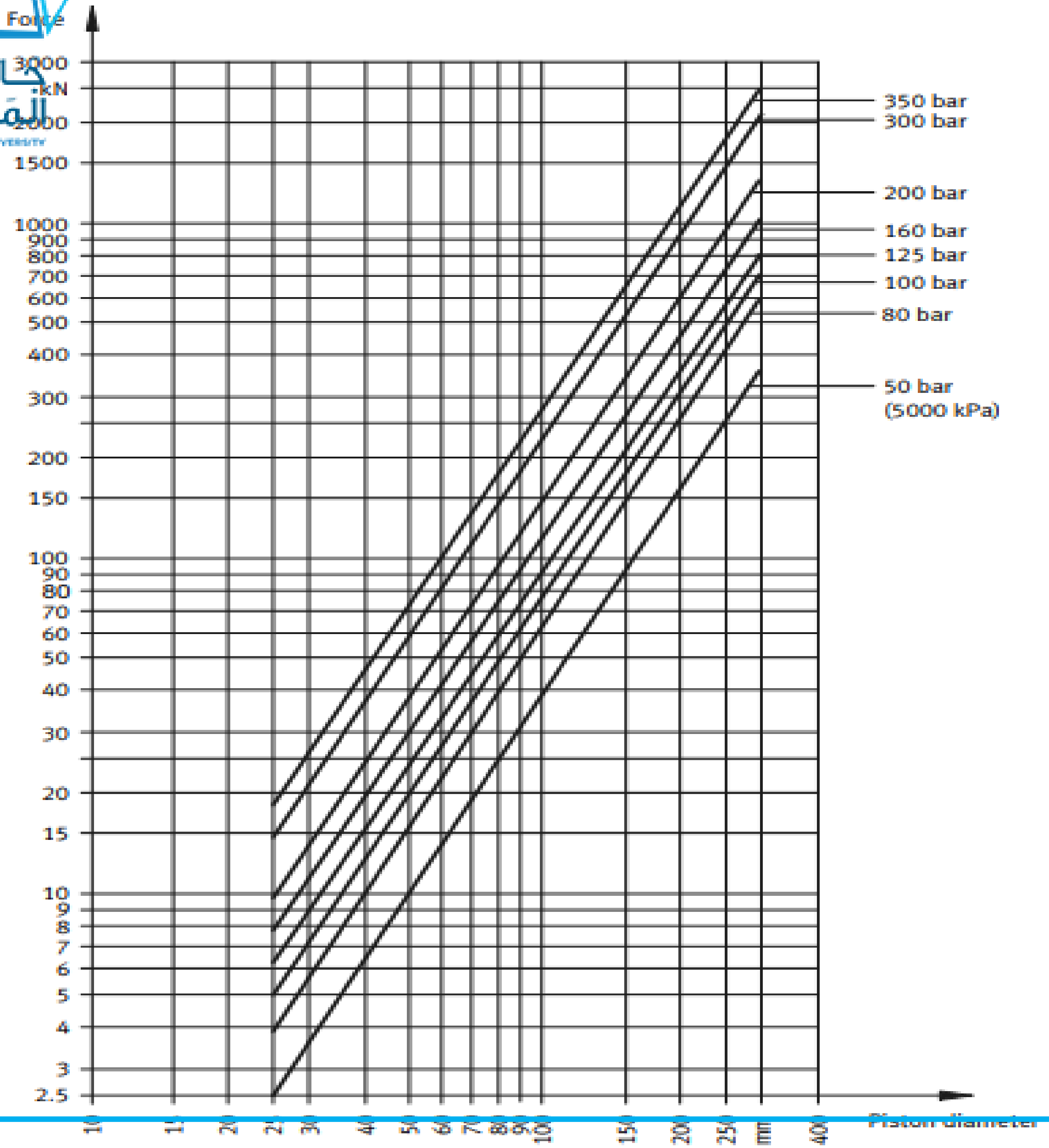
If a force F1 acts via an area A1 on an enclosed liquid, a pressure p is produced which extends throughout the whole of the liquid (Pascal's Law). The same pressure applies at every point of the closed system.

The same pressure acts on the surfaces A2 , A 3 as on A1 . For solid bodies, this is expressed by means of the following formula

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



Given that: Force F = 100 kN Operating pressure p = 350 bar. What is the piston diameter? Reading: d = 60 mm



Example

Given that: $A_1 = 10\ cm^2 = 0.001\ m^2$

$F = 10\ 000\ N$

$$p = \frac{F}{A} = \frac{10000\ N}{0.001\ m^2} = 10000000 \frac{N}{m^2} = 100 \cdot 10^5\ Pa\ (100\ bar)$$

Example

Given that: $P = 100 \cdot 10^5\ Pa$

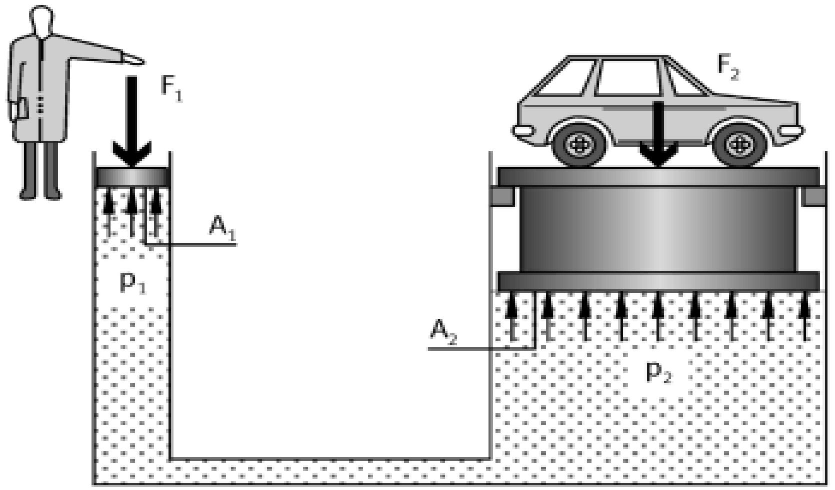
$A_2 = 1\ cm^2 = 0.0001\ m^2$

$$F = p \cdot A = 100 \cdot 10^5\ Pa \cdot 0.0001\ m^2 = 1000 \frac{N \cdot m^2}{m^2} = 1000\ N$$

4. Power transmission

- . The fluid pressure can be described by means of the following equations: $P_1 = \frac{F_1}{A_1}$ and $P_2 = \frac{F_2}{A_2}$, The following equation applies when the system is in equilibrium: $P_1 = P_2$ When the two equations are balanced, the following formula is produced: $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

$F_1 = \frac{A_1.F_2}{A_2}$, $A_2 = \frac{A_1.F_2}{F_1}$



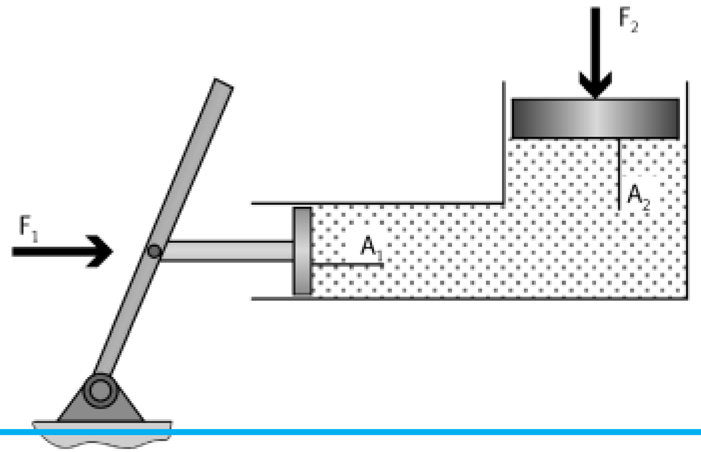
Small forces from the pressure piston can produce larger forces by enlarging the working piston surface

Small forces from the pressure piston can produce larger forces by enlarging the working piston surface. This is the fundamental principle which is applied in every hydraulic system from the jack to the lifting platform. The force F1 must be sufficient for the fluid pressure to overcome the load resistance.

Example

A vehicle is to be lifted by a hydraulic jack. The mass m

amounts to 1500 kg. What force F 1 is required at tl



Given that: Load $m = 1500\ kg$

Force due to weight $F_2 = m \cdot g = 1500\ kg \cdot 10 \frac{m}{s^2} = 15000\ N$

Given that: $A_1 = 40\ cm^2 = 0.004\ m^2$

$A_2 = 1200\ cm^2 = 0.12\ m^2$

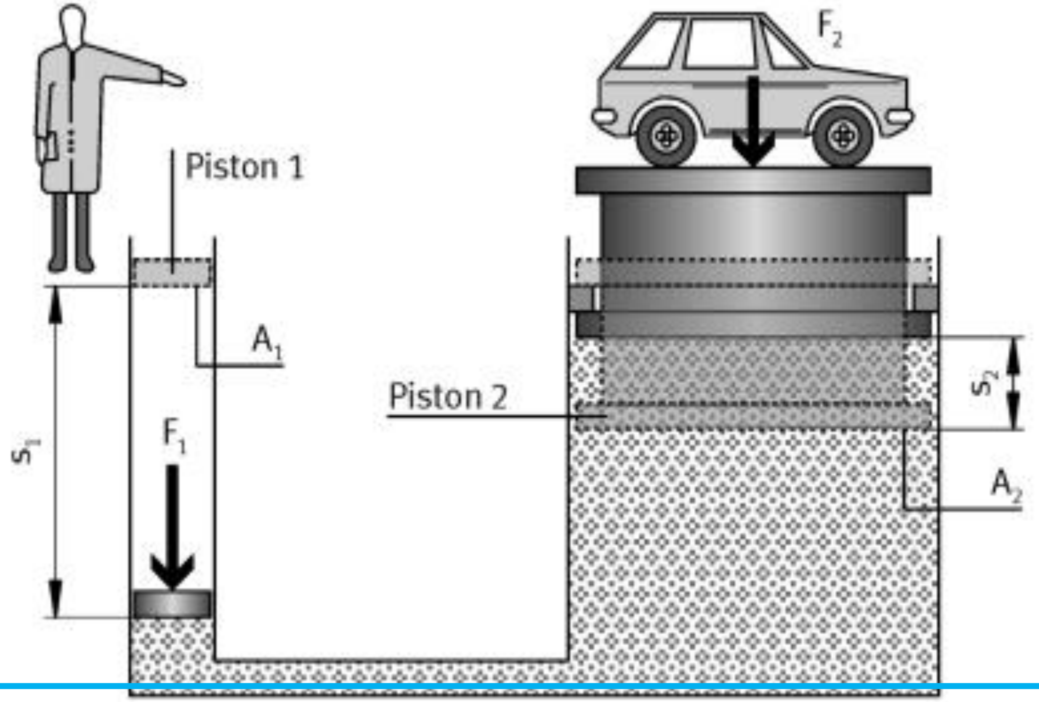
$$F_1 = \frac{A_1 \cdot F_2}{A_2} = \frac{0.004\ m^2 \cdot 15000\ N}{0.12\ m^2} = 500\ N$$

5.Displacement transmission

If a load F 2 is to be lifted a distance s 2 in line with the principle described above, the piston P 1 must displace a specific quantity of liquid which lifts the piston P 2 by a distance s 2

The necessary displacement volume :

$$V_1 = S_1 . A_1 \qquad V_2 = S_2 . A_2$$

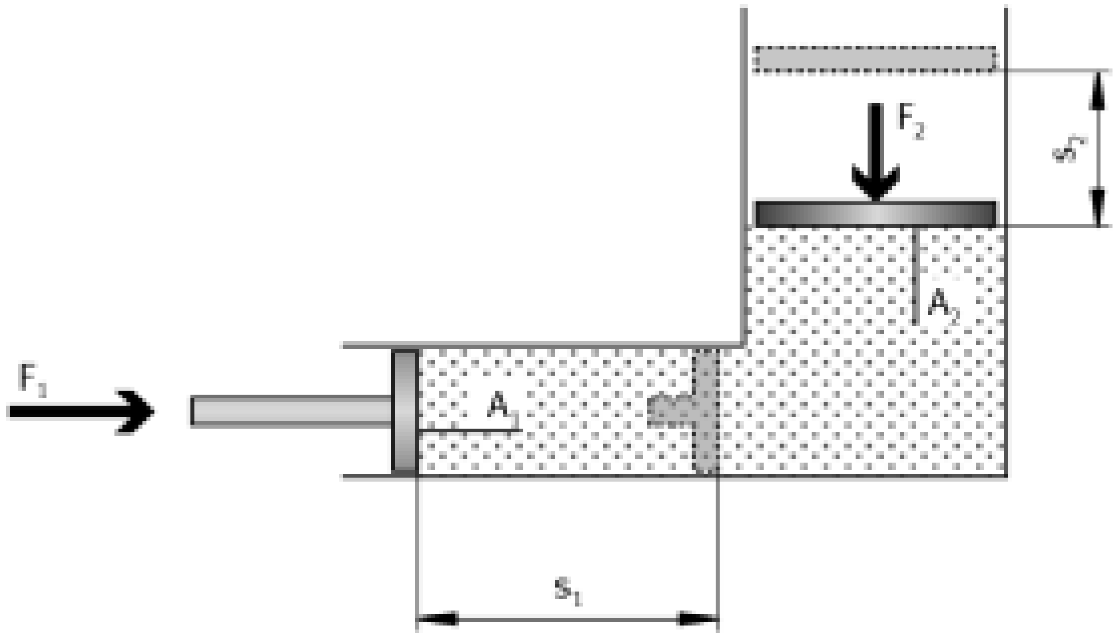


Since the displacement volumes are identical (V1 = V2),

$$S_1 . A_1 = S_2 . A_2$$

the distance s1 must be greater than the distance s2 since the area A1 is smaller than the area A2.

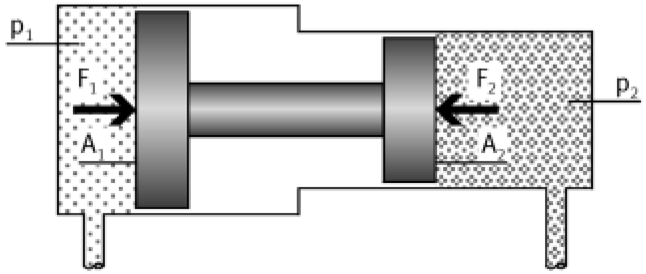
The displacement of the piston is in inverse ratio to its area. This law can be used to calculate the values s1 and s2. For example, for s2 and A1



$$s_2 = \frac{s_1 \cdot A_1}{A_2} \quad \text{and} \quad A_1 = \frac{s_2 \cdot A_2}{s_1}$$

6.Pressure transfer

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



$$F_1 = P_1 . A_1 \qquad F_2 = P_2 . A_2$$

Since the two forces are equal (F1 = F2), the equations can be balanced:

$$P_1 . A_1 = P_2 . A_2$$

The values p1, A1 and A2 can be derived from this formula for calculations. For example, the following equations result for p2 and A2:

$$p_2 = \frac{p_1 \cdot A_1}{A_2} \quad \text{and} \quad A_2 = \frac{p_1 \cdot A_1}{p_2}$$

Given that: $P_1 = 10 \cdot 10^5$ Pa

$A_1 = 8\ cm^2 = 0.0008\ m^2$

$A_2 = 4.2\ cm^2 = 0.00042\ m^2$

$$p_2 = \frac{p_1 \cdot A_1}{A_2} = \frac{10 \cdot 10^5 \cdot 0.0008}{0.00042} \frac{N \cdot m^2}{m^2 \cdot m^2} = 19 \cdot 10^5\ Pa\ (19\ bar)$$

Given that: $p_1 = 20 \cdot 10^5$ Pa

$p_2 = 100 \cdot 10^5$ Pa

$A_1 = 8\ cm^2 = 0.0008\ m^2$

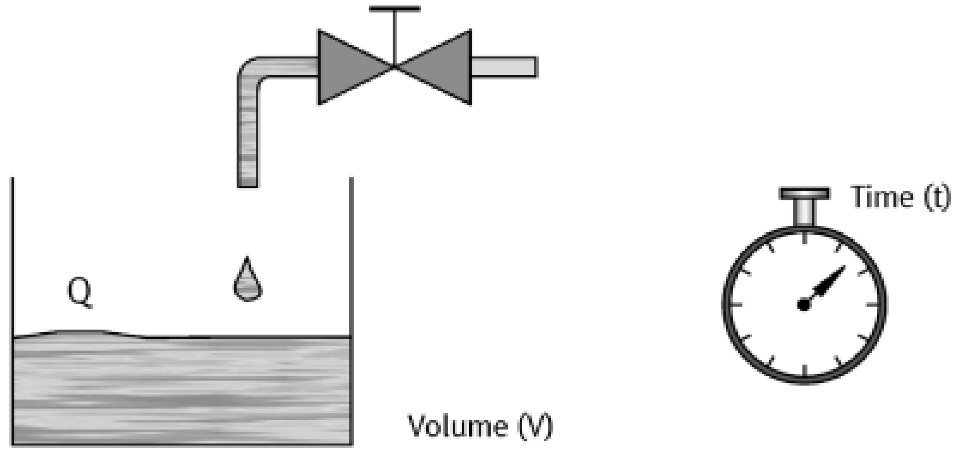
$$A_2 = \frac{p_1 \cdot A_1}{p_2} = \frac{20 \cdot 10^5 \cdot 0.0008}{100 \cdot 10^5} \frac{Pa \cdot m^2}{Pa} = 0.00016\ m^2 = 1.6\ cm^2$$

7. Flow rate

Flow rate is the term used to describe the volume of liquid flowing through a pipe in a specific period of time. For example, approximately one minute is required to fill a 10 litre bucket from a tap. Thus, the flow rate amounts to 10 l/min.

$$Q = \frac{V}{t}$$

Q	= Flow rate	[m^3/s]
V	= Volume	[m^3]
t	= time	[s]



8 .Continuity equation

If the time t is replaced by s/v ($v = s/t$) in the formula for the flow rate ($Q = V/t$) and it is taken into account that the volume V can be replaced by A•s, the following equation is produced:

$$Q = A \cdot v$$

Q	= Flow rate	$[m^3/s]$
v	= Flow velocity	$[m/s]$
A	= Pipe cross-section	$[m^2]$

Example

Given that: $Q = 4.21\ l/min = \frac{4.2\ dm^3}{60\ s} = 0.07 \cdot 10^{-3}\ \frac{m^3}{s}$

$v = 4\ m/s$

$$A = \frac{Q}{v} = \frac{0.07 \cdot 10^{-3}}{4}\ \frac{m^3 \cdot s}{s \cdot m} = 0.00002\ m^2 = 0.2\ cm^2$$

To achieve a flow velocity of 4 m/s with a flow rate of 4.2 l/min, a pipe cross-section of 0.2 cm 2 is required

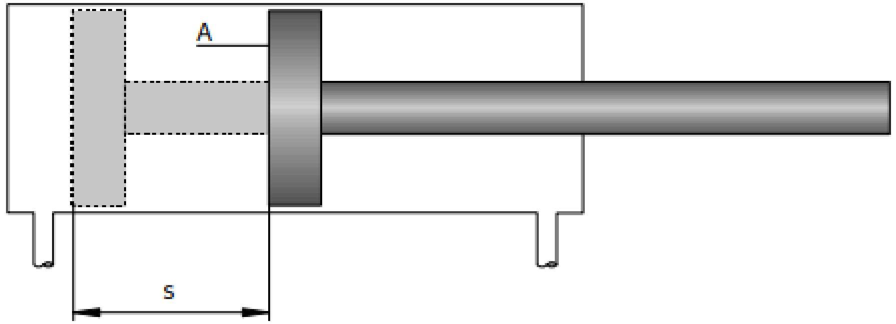
Example

Given that: $Q = 4.2\ l/min = 0.07 \cdot 10^{-3}\ m^3/s$

$A = 0.28\ cm^2 = 0.28 \cdot 10^{-4}\ m^2$

$$v = \frac{Q}{A} = \frac{0.07 \cdot 10^{-3}}{0.28 \cdot 10^{-4}}\ \frac{m^3}{s \cdot m^2} = \frac{0.7}{0.28} \cdot 10^1\ \frac{m}{s} = 2.5\ m/s$$

Cylinder



If in the formula for the flow rate

$$Q = \frac{V}{t}$$

the volume replaced by the displacement volume V

$V = A \cdot s$ results in $Q = \frac{A \cdot s}{t}$

Given that: $A = 8\ cm^2$

$s = 10\ cm$

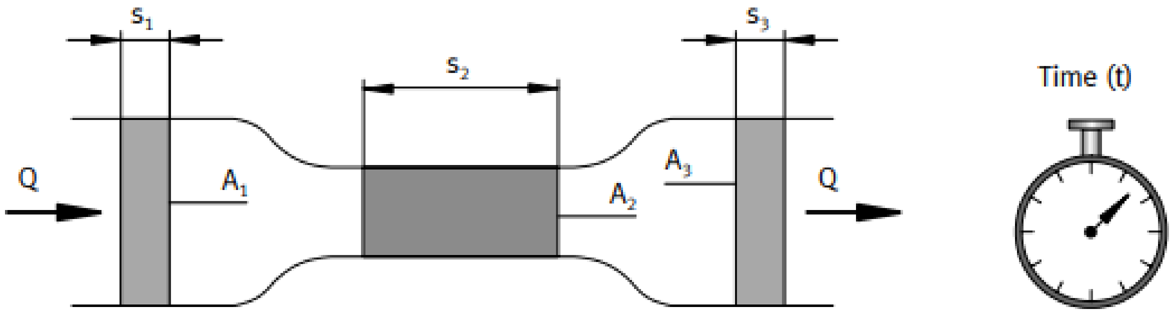
$t = 1\ min$

$$Q = \frac{A \cdot s}{t} = \frac{8 \cdot 10}{1} \frac{cm^2 \cdot cm}{min} = 80 \frac{cm^3}{min} = 0.08 \frac{cm^3}{min}$$

he flow rate of a liquid in terms of volume per unit of time which flows through a pipe with several changes in cross-section is the same at all points in the pipe. This means that the liquid flows through small cross-sections faster than through large cross-sections. The following equation applies

$$Q_1 = A_1 \cdot v_1 \qquad Q_2 = A_2 \cdot v_2 \qquad Q_3 = A_3 \cdot v_3 \qquad \text{etc....}$$

As within one line the value for Q is always the same, the following equation of continuity applies: $A_1 \cdot v_1 = A_2 \cdot v_2 = A_3 \cdot v_3 =$ etc...



Cylinder

Example

Given that:

Pump delivery $Q = 10\,\frac{l}{min} = 10\,\frac{dm^3}{min} = 10 \cdot 10^3\,\frac{cm^3}{min} = \frac{10 \cdot 10^3}{60}\,\frac{cm^3}{s}$

Inlet internal diameter $d_1 = 6$ mm

Piston diameter $d_2 = 32$ mm

To be found: Flow velocity v_1 in the inlet pipe
Extension speed v_2 of the piston

$$Q = v_1 \cdot A_1 = v_2 \cdot A_2$$

$$A_1 = \frac{d^2 \cdot \pi}{4} = \frac{0.6^2 \cdot cm^2 \cdot \pi}{4} = 0.28\,cm^2$$

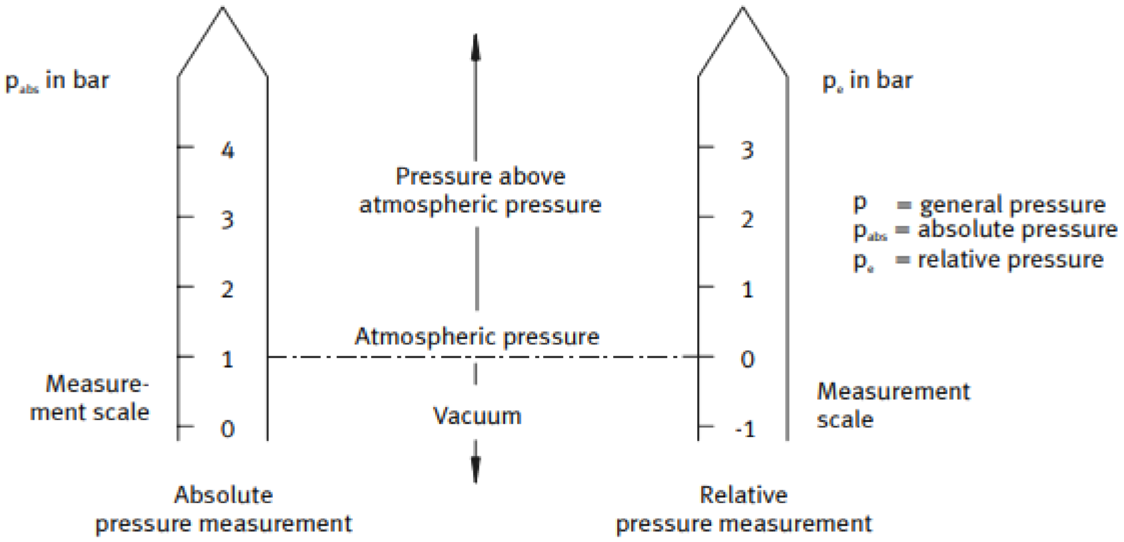
$$A_2 = \frac{d^2 \cdot \pi}{4} = \frac{3.2^2 \cdot cm^2 \cdot \pi}{4} = 8.0\,cm^2$$

$$v_1 = \frac{Q}{A_1} = \frac{\frac{10 \cdot 10^3\,cm^3}{60\,s}}{0.28\,cm^2} = \frac{10 \cdot 10^3}{60 \cdot 0.28} = \frac{cm^3}{cm^2 \cdot s} = 595\,\frac{cm}{s} = 5.95\,\frac{m}{s}$$

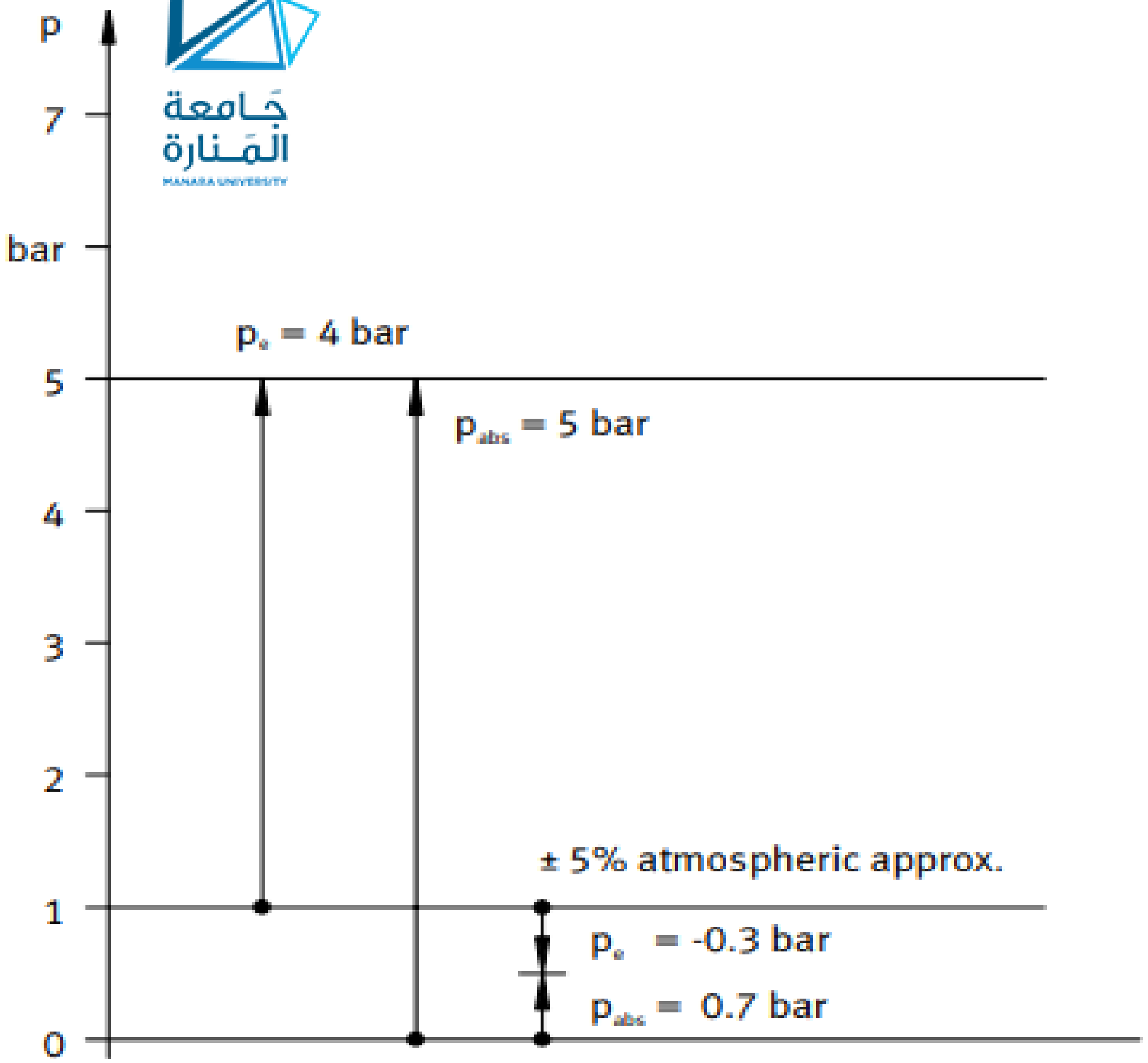
$$v_2 = \frac{Q}{A_2} = \frac{\frac{10 \cdot 10^3\,cm^3}{60\,s}}{8\,cm^2} = \frac{10 \cdot 10^3}{60 \cdot 8} = \frac{cm^3}{cm^2 \cdot s} = 20.8\,\frac{cm}{s} = 0.21\,\frac{m}{s}$$

9 .Pressure measurement

absolute pressure measurement where the zero point on the scale corresponds to absolute vacuum and relative pressure measurement where the zero point on the scale refers to atmospheric pressure. In the absolute system of measurement, vacuums assume values lower than 1, in the relative system of measurement, they assume values lower than 0.



Absolute pressure, relative pressure


p
7
bar
p_e = 4 bar
5
p_{abs} = 5 bar
4
3
2
± 5% atmospheric approx.
1
p_e = -0.3 bar
p_{abs} = 0.7 bar
0

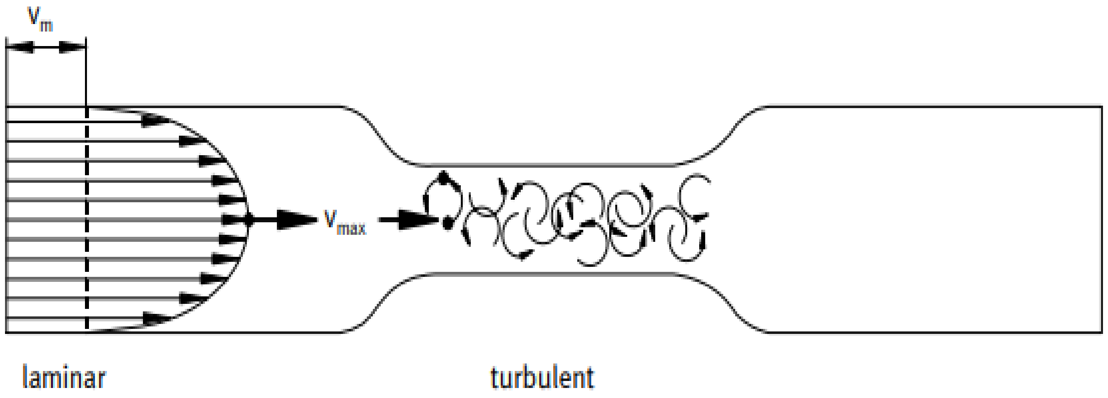
Example

10. Types of flow

Laminar and turbulent flow:

A method of calculating the type of flow in a smooth pipe is enabled by the Reynolds' number (Re). This is dependent on

- the flow velocity of the liquid V (m/s)
- the pipe diameter d (m)
- and the kinetic viscosity ν (m2/s)



$$Re = \frac{v \cdot d}{\nu}$$

A value for Re calculated with this formula can be interpreted as follows:

- laminar flow: Re < 2300
- turbulent flow: Re > 2300

Determining of the Reynolds' number

Q = 50 dm 3 /min

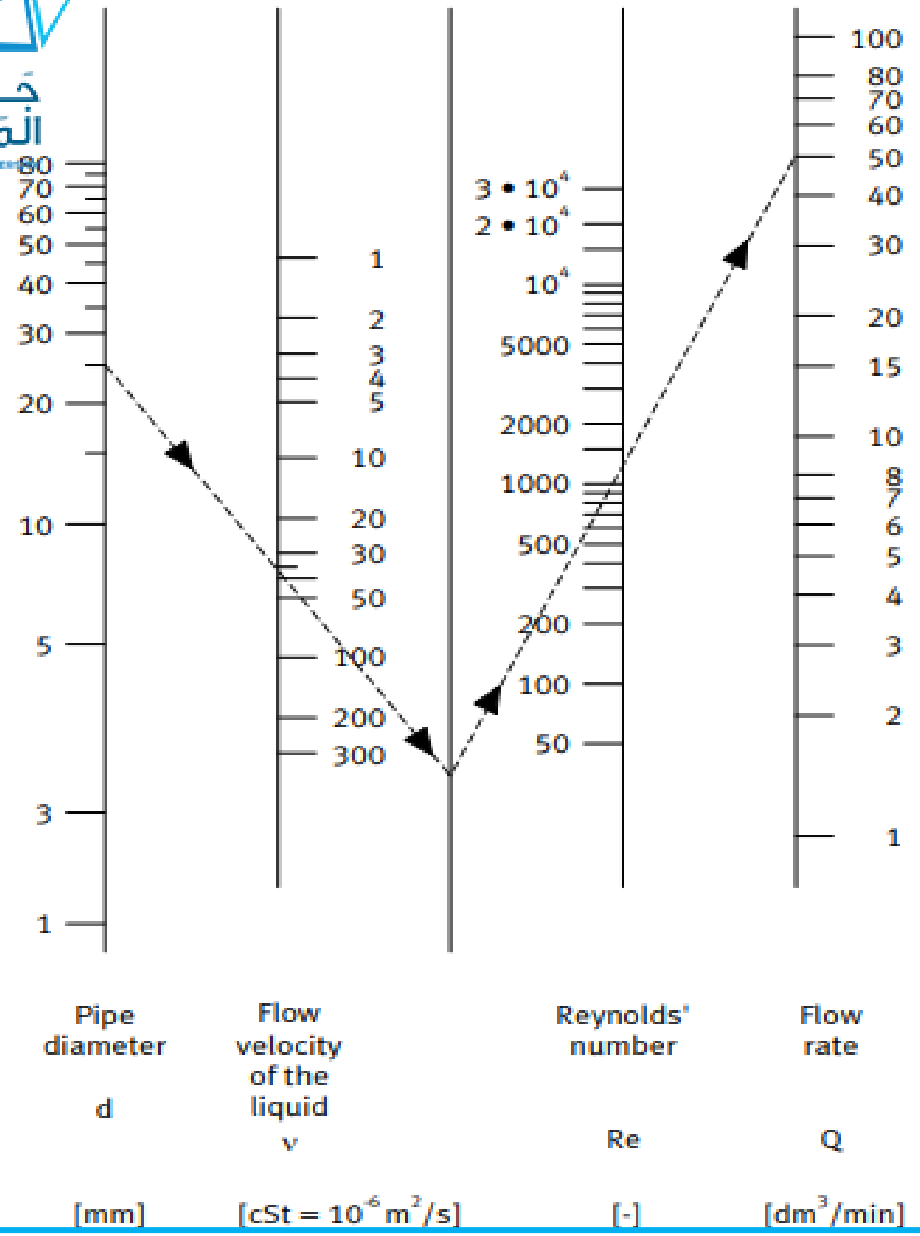
d = 25 mm

ν = 36 cSt

Re = 1165

The critical velocity mentioned above is the velocity at which the flow changes from laminar to turbulent.

$$v_{krit} = \frac{Re_{crit} \cdot \nu}{d} = \frac{2300\,\nu}{d}$$



Given that: $v_1 = 1\ m/s$ $\quad v_3 = 4\ m/s$ $\quad v_4 = 100\ m/s$

$\nu = 40\ mm^2/s$

$d_1 = 10\ mm$ $\quad d_3 = 5\ mm$ $\quad d_4 = 1\ mm$

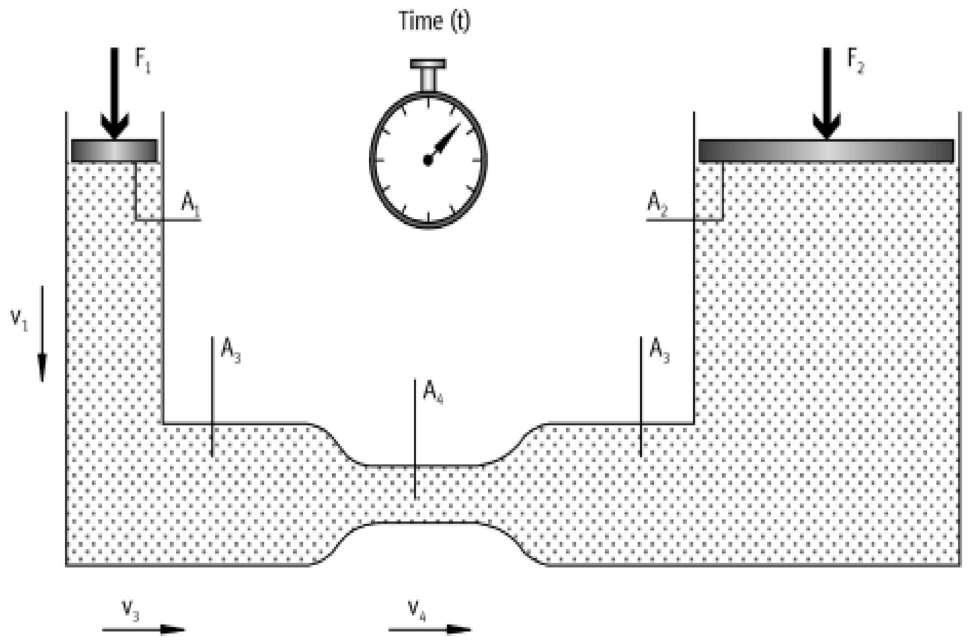
The type of flow at cross-sections A_1, A_3, A_4 is to be found.

$$Re = \frac{v \cdot d_1}{\nu}$$

$$Re_1 = \frac{1000\ mm \cdot 10\ mm \cdot s}{s \cdot 40\ mm^2} = 250$$

$$Re_3 = \frac{4000\ mm \cdot 5\ mm \cdot s}{s \cdot 40\ mm^2} = 500$$

$$Re_4 = \frac{100000\ mm \cdot 1\ mm \cdot s}{s \cdot 40\ mm^2} = 2500$$



The flow is only turbulent at cross-section A4 since 2500 > 2300. The flow becomes laminar again at cross-section A3 after the throttling point as 500 < 1150. However, this is only after a steadying period.

11.Friction, heat, pressure drop

Friction occurs in all devices and lines in a hydraulic system through which liquid passes. This friction is mainly at the line walls (external friction). There is also friction between the layers of liquid (internal friction). The friction causes the hydraulic fluid, and consequently also the components, to be heated. As a result of this heat generation, the pressure in the system drops and, thus, reduces the actual pressure at the drive section

The size of the pressure drop is based on the internal resistances in a hydraulic system. These are dependent on:

- Flow velocity (cross-sectional area, flow rate),
- Type of flow (laminar, turbulent),
- Type and number of cross-sectional reductions in the system of lines (throttles, orifices),
- Viscosity of the oil (temperature, pressure),
- Line length and flow diversion, • Surface finish,
- Line arrangement.

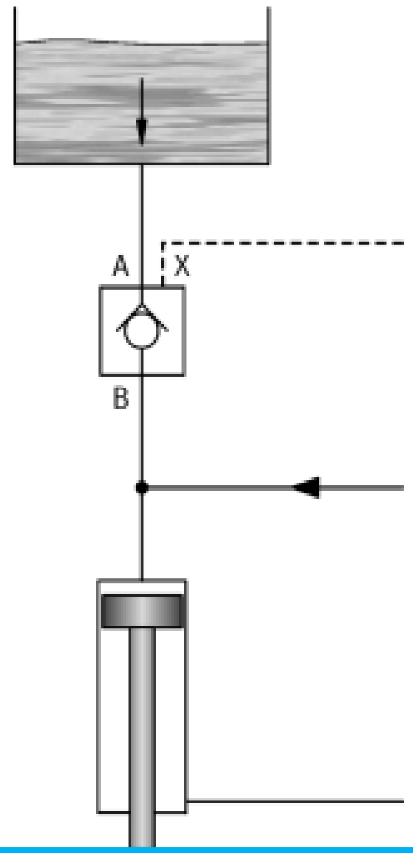
12.Energy and power

The total energy is the sum of the various forms of energy:

- Static :Potential energy – Pressure energy
- Dynamic : Motion energy – Thermal energy

Potential energy

Potential energy is the energy which a body (or a liquid) has when it is lifted by a height h. Here, work is carried out against the force of gravity. In presses with large cylinders, this potential energy is used for fast filling of the piston area and for pilot pressure for the pump.



press with elevated reservoir

$W = m \cdot g \cdot h$

W	= Work	[J]
m	= mass of the liquid	[kg]
g	= acceleration due to gravity	$[m/s^2]$
h	= height of the liquid	[m]

from: $W = F \cdot s$ $\quad F = m \cdot g$

is produced: $W = m \cdot g \cdot h$ $\quad s = h$

unit: $1\ kg \cdot m/s^2 \cdot m = 1\ Nm = 1\ J = 1\ W/s$ [1 J = 1 Joule, 1 W = 1 Watt]

Given that: $m = 100\ kg$

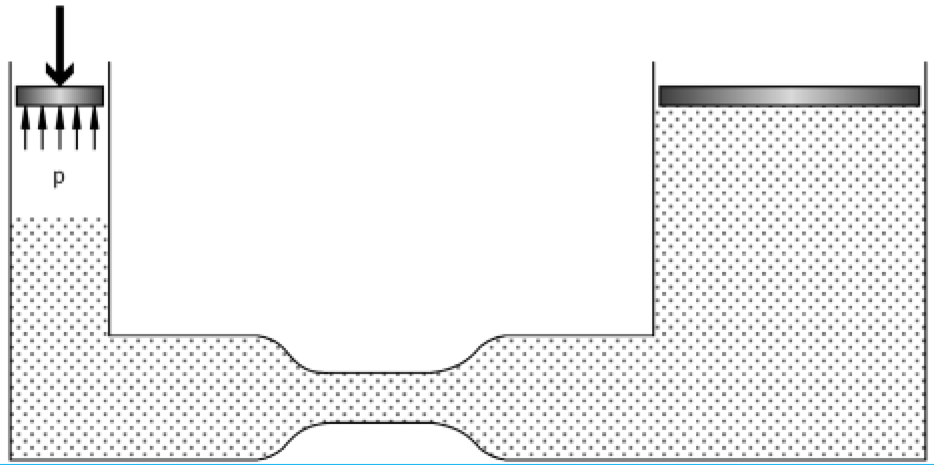
$g = 9.81\ m/s^2 \approx 10\ m/s^2$

$h = 2\ m$

$$W = m \cdot g \cdot h = 100\ kg \cdot 10\ m/s^2 \cdot 2\ m = 2000 \frac{kg \cdot m \cdot m}{s^2} = 2000\ Nm = 2000\ J$$

Pressure energy

If a liquid is pressurized, its volume is reduced, the amount by which it is reduced being dependent on the gases released. The compressible area amounts to 1-3 % of the output volume. Owing to the limited compressibility of the hydraulic fluid, i.e. the relatively small ΔV, the pressure energy is low. At a pressure of 100 bar ΔV amounts to approx. 1 % of the output volume.



$W = p \cdot \Delta V$

p = Liquid pressure [Pa]
ΔV = Liquid volume [m^3]

from: $W = F \cdot s$ and $F = p \cdot A$
is produced: $W = p \cdot A \cdot s$

$A \cdot s$ is replaced by ΔV, producing: $W = p \cdot \Delta V$
Unit: $1\ N/m^2 \cdot m^3 = 1\ Nm = 1\ J$

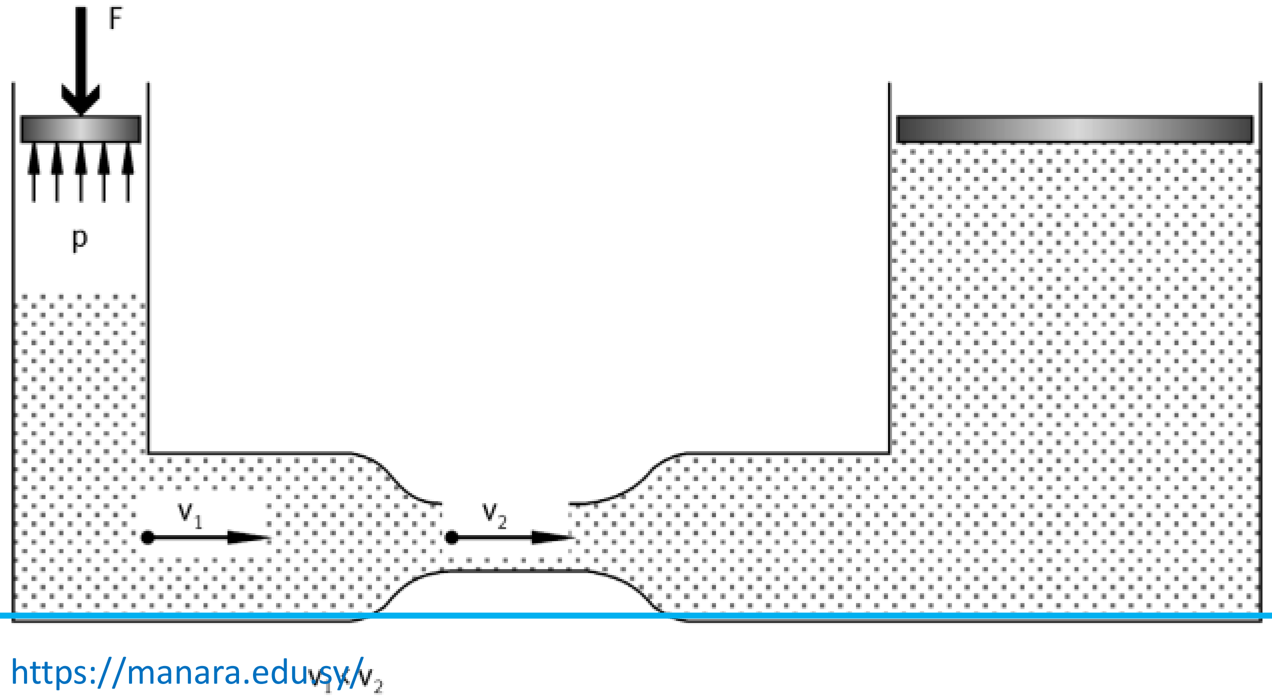
Given that: $p = 100 \cdot 10^5$ Pa
$\Delta V = 0.001\ m^3$

$$W = p \cdot \Delta V = 100 \cdot 10^5\ Pa \cdot 0.001\ m^3 = 0.1 \cdot 10^5\ \frac{N \cdot m^3}{m^2} = 10000\ J$$

Pressure energy is obtained from the resistance with which the fluid volume meets the compression.

Motion energy

Motion energy (also known as kinetic energy) is the energy a body (or fluid particle) has when it moves at a certain speed. The energy is supplied through acceleration work, a force F acting on the body (or fluid particle). **The motion energy is dependent on the flow velocity and the mass.**



$$W = \frac{1}{2} m \cdot v^2$$

v = velocity [m/s]

a = acceleration [m/s²]

$$W = F \cdot s = m \cdot a \cdot s$$

$$F = m \cdot a \qquad s = \frac{1}{2} a \cdot t^2 \qquad v = a \cdot t$$

$$W = m \cdot a \cdot \frac{1}{2} a \cdot t^2 = \frac{1}{2} m \cdot a^2 \cdot t^2 = \frac{1}{2} m \cdot v^2$$

Unit: $1\ kg \cdot (m/s)^2 = 1\ kg \cdot m^2/s^2 = 1\ Nm = 1\ J$

Example

Given that: $m = 100\ kg$
$v_1 = 4\ m/s$

$$W = \frac{1}{2} m \cdot v^2 = \frac{1}{2} \cdot 100\ kg \cdot (4\ m/s)^2 = 800 \frac{kg \cdot m^2}{s^2} = 800\ J$$

$$W = \frac{1}{2} m \cdot v^2 = \frac{1}{2} \cdot 100\ kg \cdot (100\ m/s)^2 = 500000 \frac{kg \cdot m^2}{s^2} = 500000\ J$$

Every change in the flow velocity (in the case of a constant flow rate) automatically results in a change in the motion energy. Its share of the total energy increases when the hydraulic fluid flows faster, and decreases when the speed of the hydraulic fluid is reduced.

Owing to varying sizes of line cross-section, the hydraulic fluid flows in a hydraulic system at various speeds as shown in the diagram since the flow rate, the product of the flow velocity and the cross-section are constant

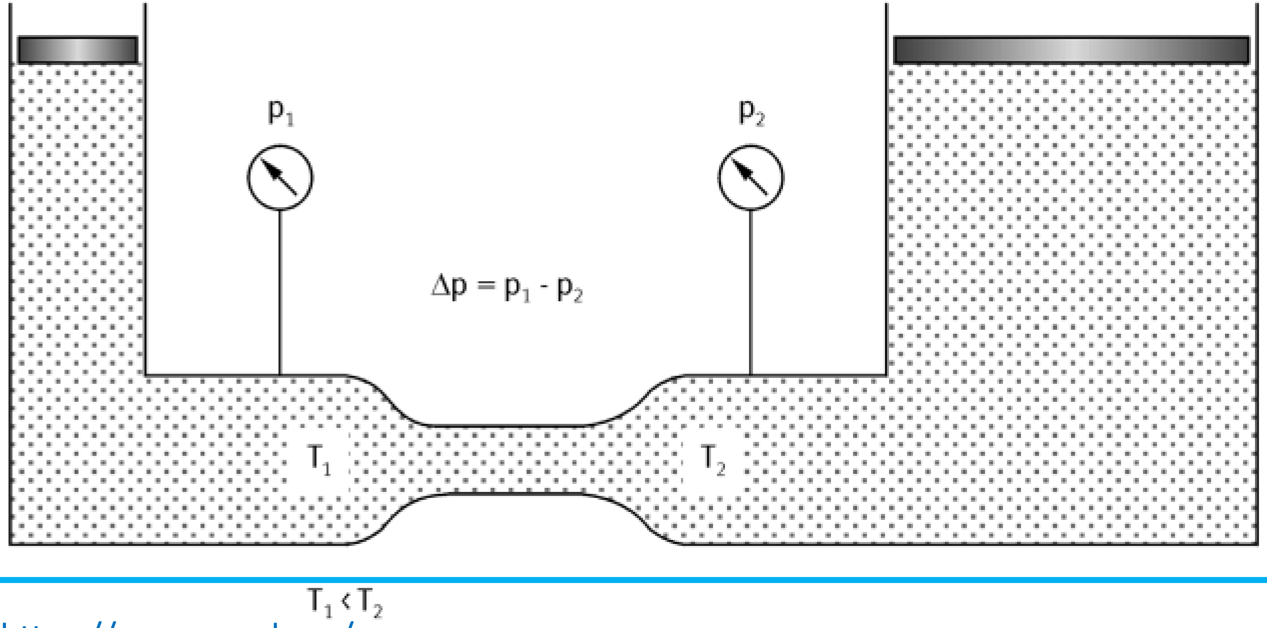
Thermal energy

part of the energy is converted into thermal energy as a result of friction. This leads to heating of the hydraulic fluid and of the components. Part of the heat is emitted from the system, i.e. the remaining energy is reduced. The consequence of this is a decrease in pressure energy. The thermal energy can be calculated from the pressure drop and the volume.

$$W = \Delta p \cdot V$$

Δp = Pressure loss through friction [Pa]

Unit: $1\,Pa \cdot m^3 = 1\,N \frac{m^3}{m^2} = 1\,Nm = 1\,J$



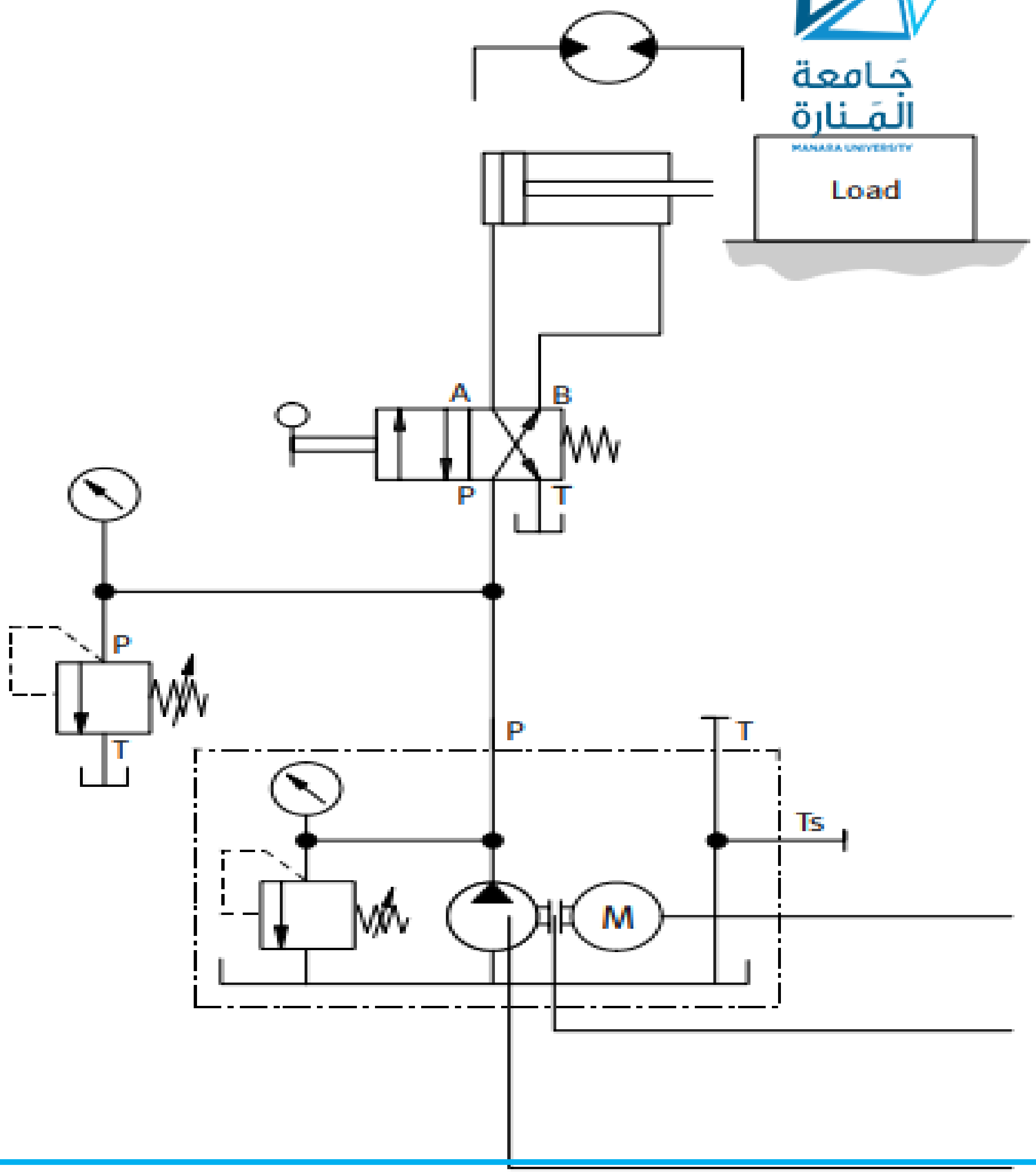
Power

Power is usually defined as work or a change in energy per unit of time. In hydraulic installations, a distinction is made between mechanical and hydraulic power. Mechanical power is converted into hydraulic power, transported, controlled and then converted back to mechanical power. Hydraulic power is calculated from the pressure and the flow rate. The following equation applies

POWER = P.Q

$$P = p \cdot Q$$

P	= Power (W)	[Nm/s]
P	= Pressure	[Pa]
Q	= Flow rate	[m^3/s]



Mechanical power — $P = F \cdot v$

Electrical power — in watts

Mechanical power — $P = 2\pi n \cdot M$

M = Turning moment (Nm)

Hydraulic power — $P = p \cdot Q$

Example

Given that: $p = 60 \cdot 10^5\ Pa$

$$Q = 4{,}2 l/min = 4{,}2 \cdot 10^{-3} m^3/min = \frac{4{,}2}{60} \cdot 10^{-3} m^3/s = 0{,}07 \cdot 10^{-3} m^3/s$$

$$P = p \cdot Q = 60 \cdot 10^5 Pa \cdot 0{,}07 \cdot 10^{-3} m^3/s = 4{,}2 \cdot 10^2 \frac{Nm^3}{m^2 s} = 420\ W$$

Example

Given that: $P = 315\ W$

$$Q = 4.2\,l/\min = \frac{4.2}{60}\,dm^3/s = 0.07 \cdot 10^{-3}\,m^3/s$$

$$p = \frac{315}{0.07 \cdot 10^{-3}}\,\frac{Nm \cdot s}{s \cdot m^3} = 4500 \cdot 10^3\,N/m^2\,(Pa) = 45 \cdot 10^5\,Pa\,(45\,bar)$$

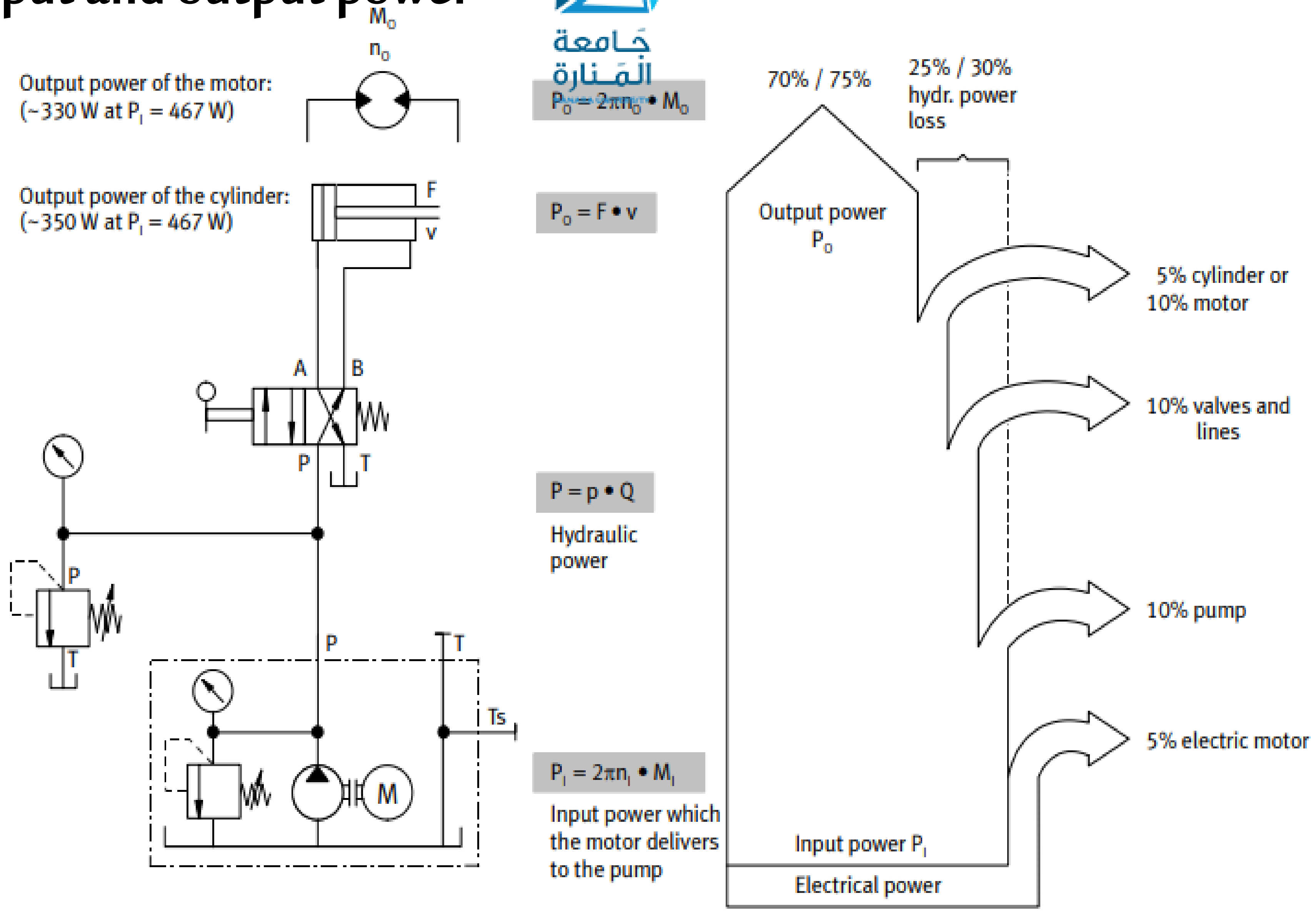
Efficiency

The input power in a hydraulic system does not correspond to the output power since line losses occur. The ratio of the output power to the input power is designated as efficiency (h).

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}}$$

In practice, distinction is made between volumetric power loss caused by leakage losses and hydro-mechanical power loss caused by friction.

Calculation of input and output power



13التكهف: Cavitation

التكهف عبارة عن إطلاق جزيئات صغيرة من على سطح المادة

يحدث التكهف على أطراف الأجهزة الهيدروليكية (صمامات ، مضخات) ،

نتيجة لحدوث قمم في قيم الضغط وارتفاع كبيرفي درجة الحرارة

الطاقة الحركية مشتقة من طاقة الضغط ،

قد ينخفض الضغط في نقاط الخنق إلى مجال ضغط الخلخلة

تتشكل فقاعات نتيجة للهواء المنحل في الزيت ،

إذا ارتفع الضغط مرة ثانية ، نتيجة لانخفاض السرعة ، فهذا يؤدي إلى انهيار وانفجار فقاعات الغاز

بعد منطقة الخنق تحدث الظواهر التالية :

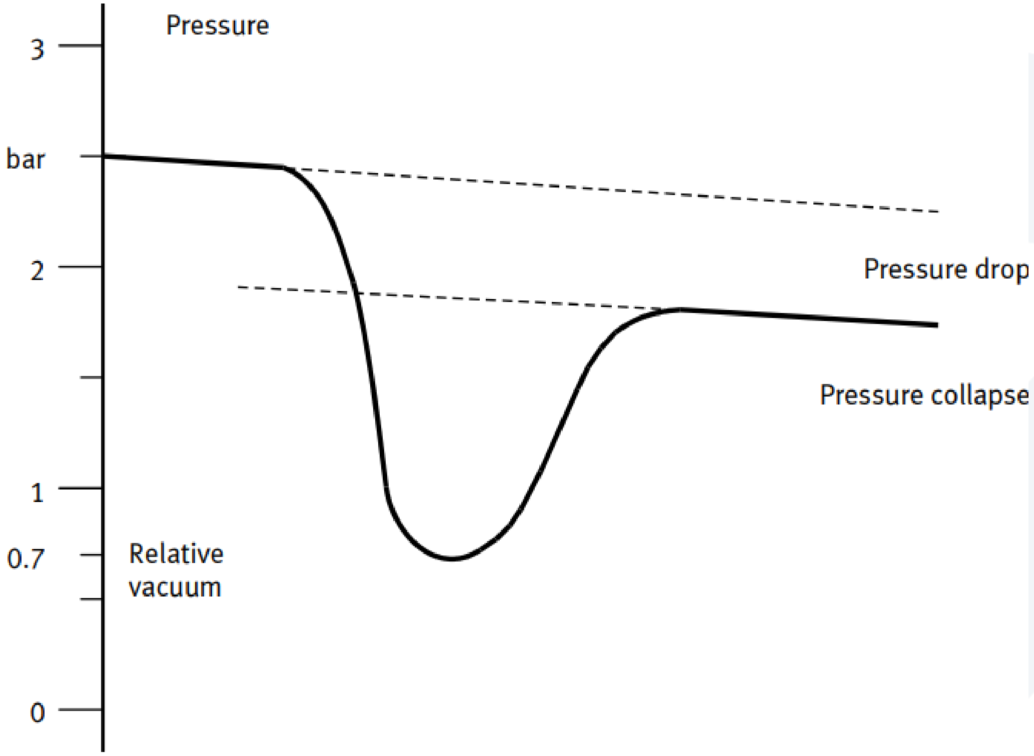
قمم الضغط :

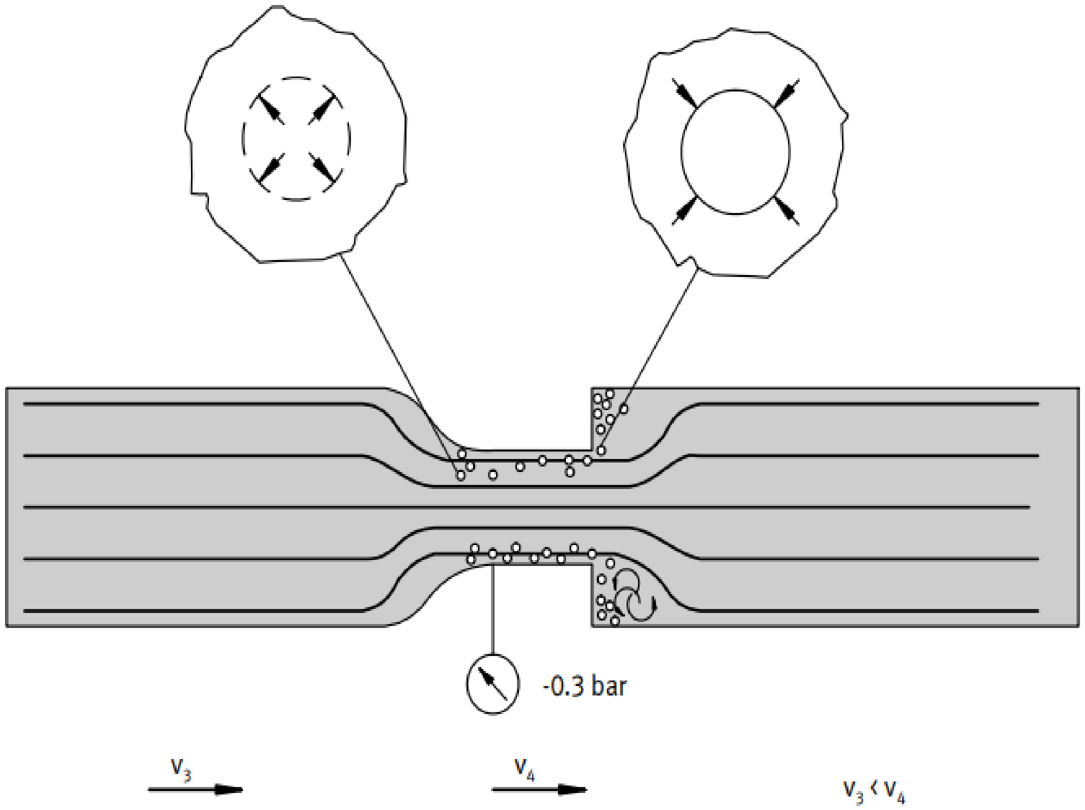
تتآكل جزيئات صغيرة من المادة من جدران الأنبوب في منطقة توسع المقطع العرضي ،
تتسبب هذه الجزيئات بالتعب والتشقق أحيانا للأنابيب ، ويرفق ظاهرة التكهف ضجيج ملموس .

اشتعال تلقائي لخليط الزيت/الهواء :

عندما تنفجر فقاعات الهواء، يقوم الزيت بإزاحة الفقاعات.
نظرا للارتفاع الضغط بعد التضييق، يتم إنتاج درجات حرارة عالية جدًا نتيجة فإن الضغط يؤدي
إلى انفجار الفقاعات. كما هو الحال مع محرك الديزل،
(اشتعال تلقائي لخليط الزيت/الهواء في الفقاعات (تأثير الديزل.

Pressure drop at the narrow point





نقاط الخنق :

في نقاط الخنق يكون رقم «رينولدز" أكبر من 2300 ، نتيجة لتضيق المقطع العرضي ، من أجل تدفق ثابت،

- ينتج زيادة في سرعة التدفق ، والوصول إلى السرعة الحرجة التي يتغير فيها التدفق
- ، من التدفق الصفائحي إلى التدفق المضطرب بسرعة عالية .

ينص قانون حفظ الطاقة على أن « الطاقة الكلية في النظام تبقى ثابتة »

تؤدي زيادة الطاقة الحركية ، كنتيجة لزيادة سرعة التدفق ، إلى انخفاض نوع آخر من الطاقة .

تتحول طاقة الضغط إلى طاقة حركية ، وطاقة حرارية .

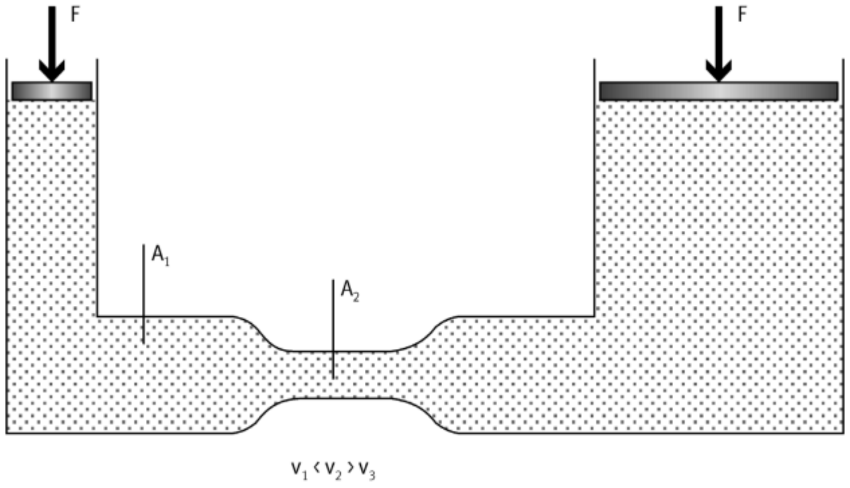
الزيادة في سرعة التدفق تؤدي إلى زيادة في الاحتكاك ، وهذا يؤدي إلى تسخين السائل الهيدروليكي ، وزيادة في الطاقة الحرارية

بالتوازي : تكون سرعة التدفق بعد الخانق هي نفس السرعة قبل الخانق

يحدث انخفاض في الضغط نتيجة لزيادة الطاقة الحرارية ،
وهذا يؤدي إلى انخفاض الضغط بعد نقطة الخنق

يعتمد فقدان الضغط على العوامل التالية :

اللزوجة ،سرعة التدفق ، نوع وطول الخانق ،
نوعية التدفق (صفائحي ، مضطرب)



Poiseuille's formula:

$$Q = \alpha \cdot A_D \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

α	= Flow reference number	
A_D	= Throttle cross-section	$[m^2]$
Δp	= Pressure drop	[Pa]
ρ	= Density of the oil	$[kg/m^3]$
Q	= Volumetric flow rate	$[m^3/s]$

can be expressed more simply by leaving out the constants:

$$Q \approx \sqrt{\Delta p}$$

Flow through a throttle is dependent on the pressure difference.

1.Directional control valves

Directional control valves are shown by means of several connected squares.

- The number of squares indicates the number of switching positions possible for a valve.
- Arrows within the squares indicate the flow direction
- Lines indicate how the ports are interconnected in the various switching positions.

There are two possible methods of port designation. One method is to use the letters P, T, A, B and L, the other is to label ports alphabetically A, B, C, D, etc. The former method is generally preferred. Ports should always be labelled with the valve in the rest position. Where there is no rest position, they are allocated to the switching position assumed by the valve when the system is in its initial position

When labelling directional control valves, it is first necessary to specify the number of ports followed by the number of switching positions. Directional control valves have at least two switching positions and at least two ports. In such an instance, the valve would be designated a 2/2-way valve. The following diagrams show other directional control valves and their circuit symbols.

Number of ports

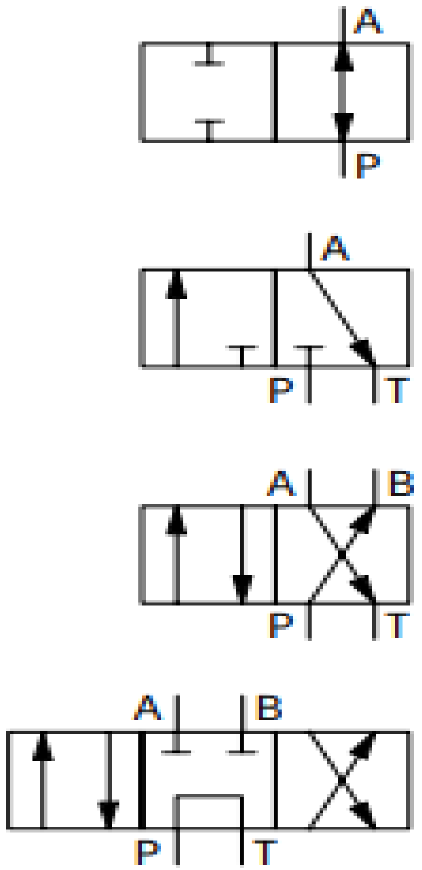
Number of switching positions

2/2 – way valve

3/2 – way valve

4/2 – way valve

4/3 – way valve



Port designations

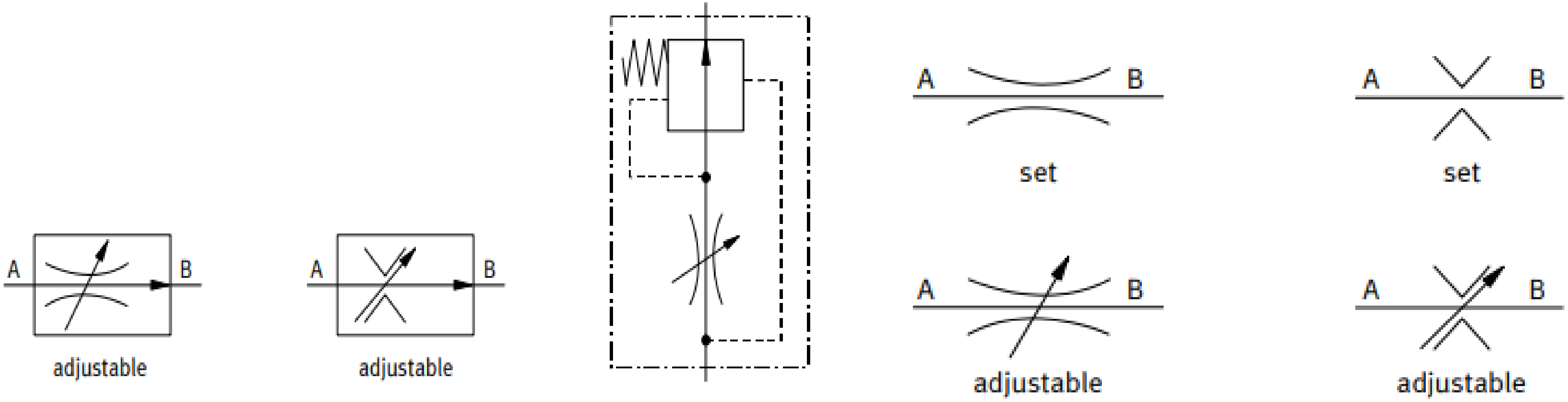
P	pressure port
T	return port
A, B	power ports
L	leakage oil

or:

A	pressure port
B	return port
C, D	power ports
L	leakage oil

2.Flow control valves

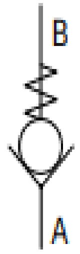
In the case of flow control valves, a distinction is made between those affected by viscosity and those unaffected. Flow control valves unaffected by viscosity are termed orifices. Throttles constitute resistances in a hydraulic system. The 2-way flow control valve consists of two restrictors, one setting restrictor unaffected by viscosity (orifice) and one adjustable throttle. The adjustable throttle gap is modified by changes in pressure. This adjustable throttle is also known as a pressure balance. These valves are depicted as a rectangle into which are drawn the symbol for the variable throttle and an arrow to represent the pressure balance. The diagonal arrow running through the rectangle indicates that the valve is adjustable. There is a special symbol to represent the 2-way flow control valve



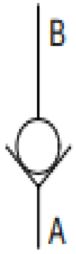
with throttle   with orifice   in detail   Throttle   Orifice

3.Non-return valves

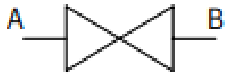
The symbol for non-return valves is a ball which is pressed against a sealing seat. This seat is drawn as an open triangle in which the ball rests. The point of the triangle indicates the blocked direction and not the flow direction. Pilot controlled non-return valves are shown as a square into which the symbol for the non-return valve is drawn. The pilot control for the valve is indicated by a control connection shown in the form of a broken line. The pilot port is labelled with the letter X. Shut-off valves are shown in circuit diagrams as two triangles facing one another. They are used to de pressurise the systems manually or to relieve accumulators. In principle, wherever lines have to be opened or closed manually



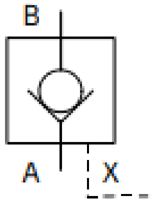
spring loaded



unloaded



shut-off valve



pilot-controlled non-returned valve

The control edges of the valve are by-passed by oil causing dirt particles to be washed away (self-cleaning effect). As a result, poppet valves are relatively insensitive to dirt. However, if dirt particles are deposited on the valve seat, the valve only partially closes resulting in cavitation.

Various aspects are taken into consideration when classifying valves:

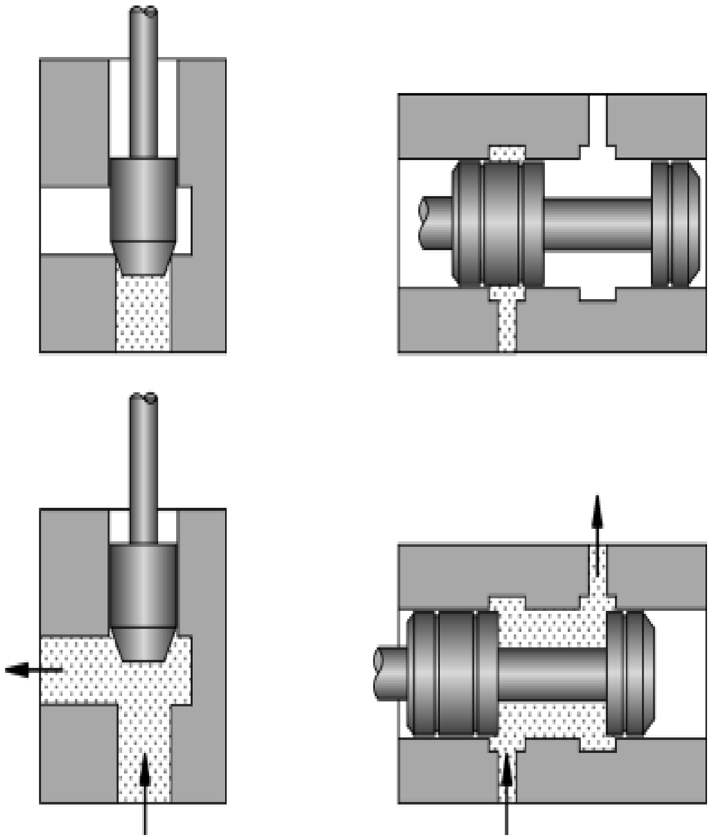
- Function
- Design
- Method of actuation.

A selection is made between the following types of valve based on the tasks :

- Pressure valves
- Directional control valves
- Non-return valves
- Flow control valves.

Design

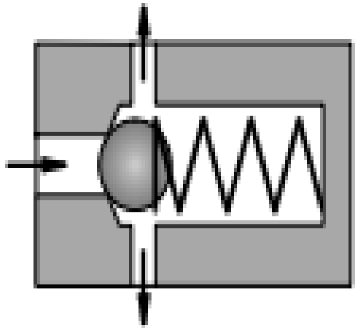
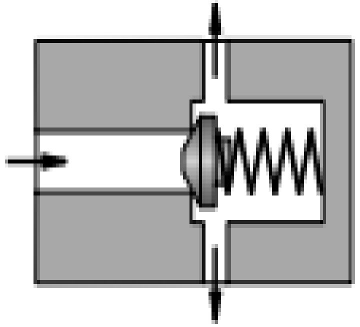
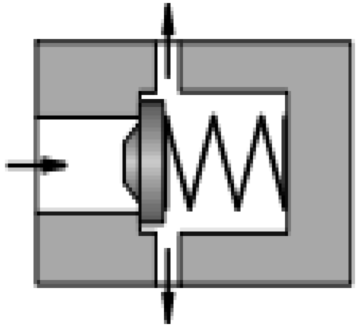
Poppet valves and piston slide valves are distinguished from one another by the difference in their design. Overlapping and the geometry of the control edges are also of significance for the switching characteristics of the valve



Poppet principle and Slide principle

Poppet valves

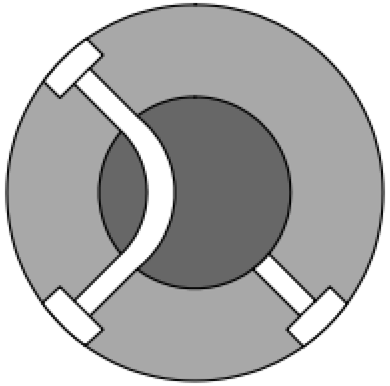
In poppet valves a ball,
cone, or occasionally a disk,
is pressed against the seat are
as a closing element. Valves o
this design form a seal when
they are closed.

Valve type	Sectional diagram	Advantages and disadvantages/use
Ball poppet valves		simple manufacture; tendency for ball to vibrate when flow is passing through producing noise; Non-return valves
Cone poppet valves		considerable precision is required to manufacture the cones, good sealing properties; Directional control valves
Disk poppet valves		only small stroke area; Shut-off valves

Spool valves

as a rule, shorter than longitudinal slide valves, when used as directional control valves.

A distinction is made between longitudinal and rotary slide valves. A rotary slide valve is made up of one or more pistons which are turned in a cylindrical bore

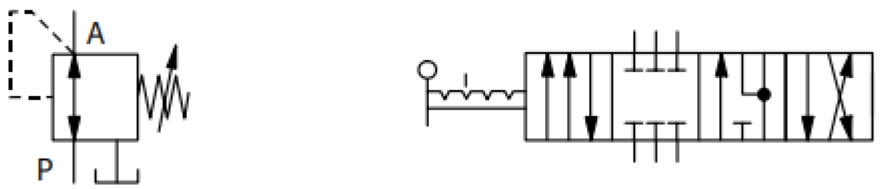


as a rule, shorter than longitudinal slide valves, when used as directional control valves.

Rotary slide valve

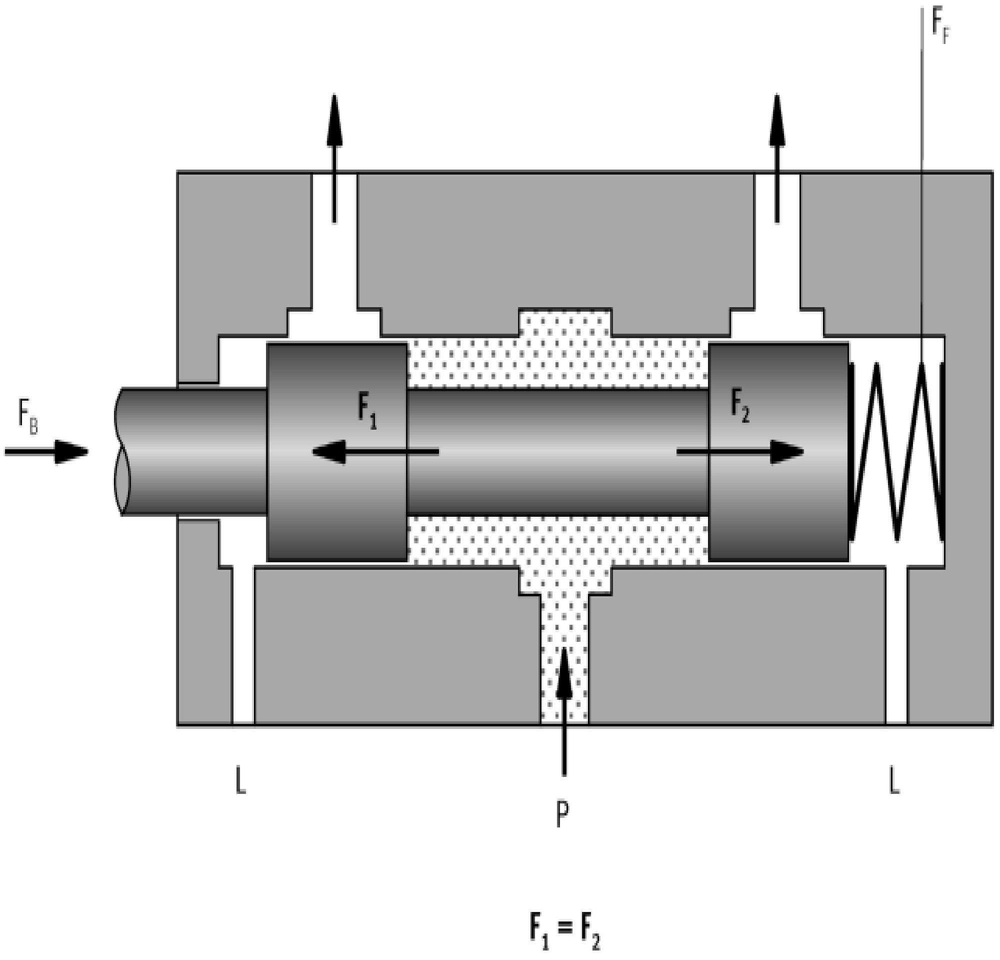
The elongated spool valve consists of one or more connected pistons which are axially displaced in a cylindrical drilled hole. Moving these pistons within the spool valves can open up, connect together or close any number of connection channels

Example Both a 3-way pressure regulator and a 6/4-way directional control valve can be realised by this principle



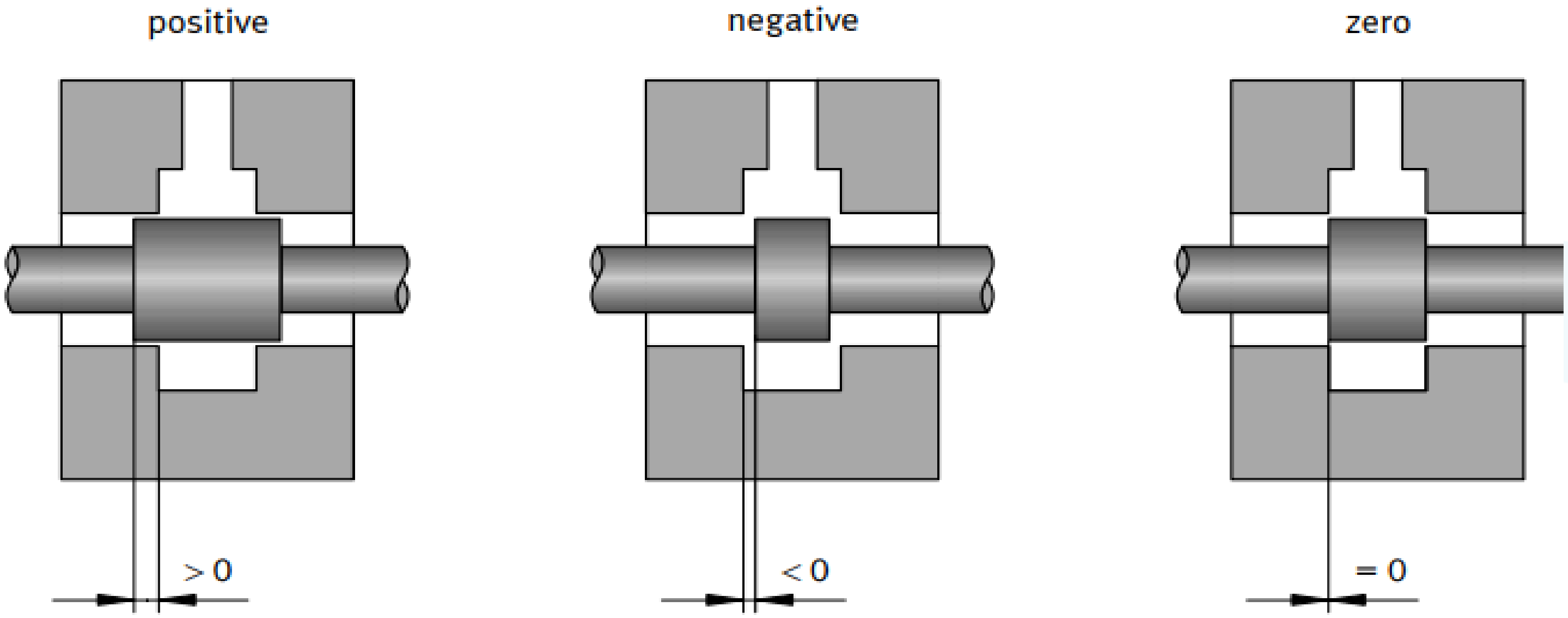
Elongated spool valve

To actuate elongated spool valves, it is only necessary to overcome the frictional and spring forces. Forces resulting from the existing pressure ar balanced out by
the opposing surfaces.



Piston overlap

تداخل المكبس



- Positive switching overlap

During the reversing procedure, all ports are briefly closed against one another; no pressure collapse (important in the case of systems with reservoirs); hard advance;

- Negative switching overlap

During the reversing procedure, all ports are briefly interconnected; pressure collapses briefly (load drops down);

- Pressure advanced opening

The pump is first of all connected to the power component, then the power component is discharged to the reservoir;

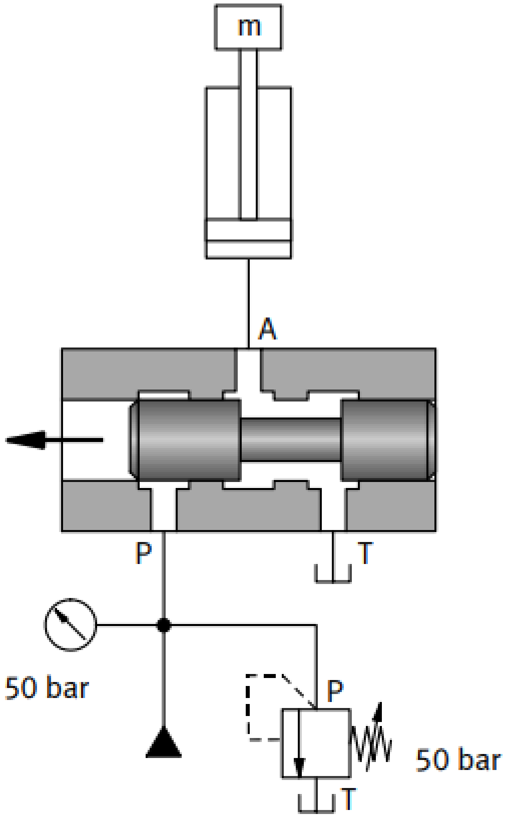
- Outlet advanced opening

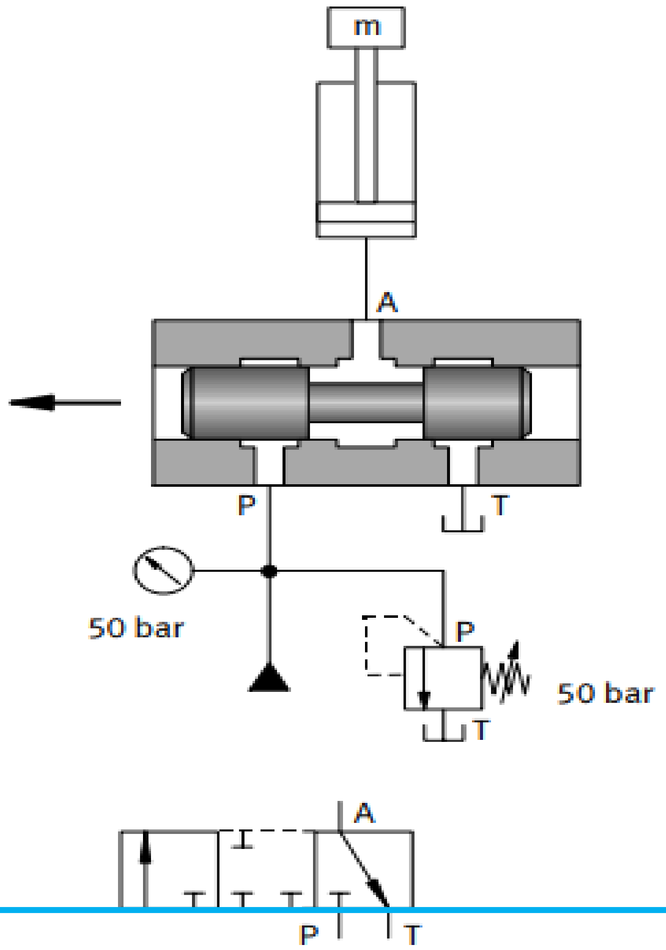
The outlet of the power component is first discharged to the reservoir before the inlet is connected to the pump;

- Zero overlap: Edges meet. Important for fast switching, short switching paths

Positive switching overlap

System pressure affects the cylinder immediately, hard advance.

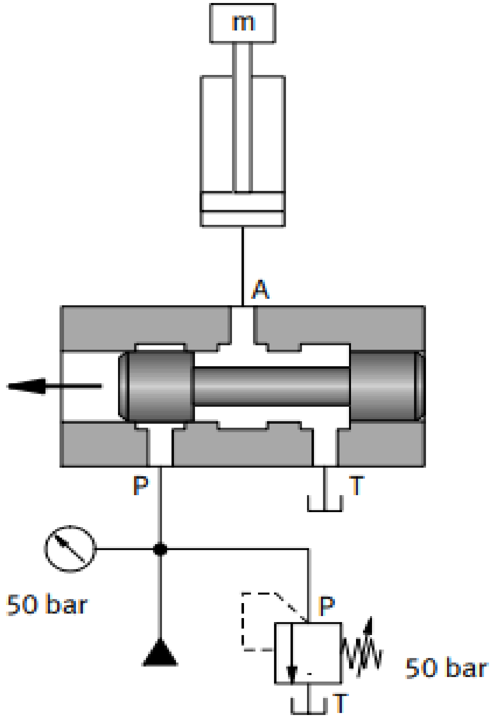


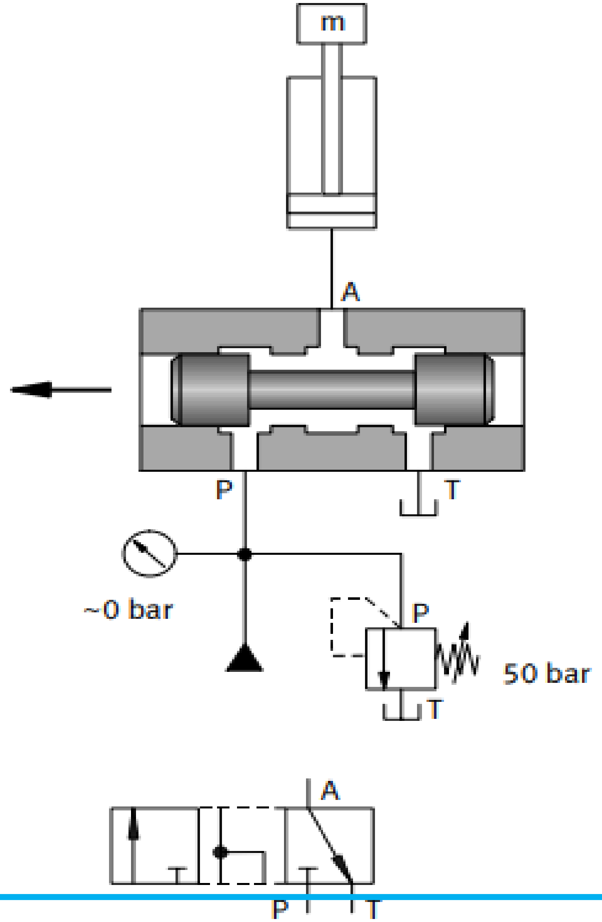


Port P → A is opened only after A → T is closed.

Negative switching overlap

Pressure is reduced during the reversing procedure, gentle build-up of pressure for approach

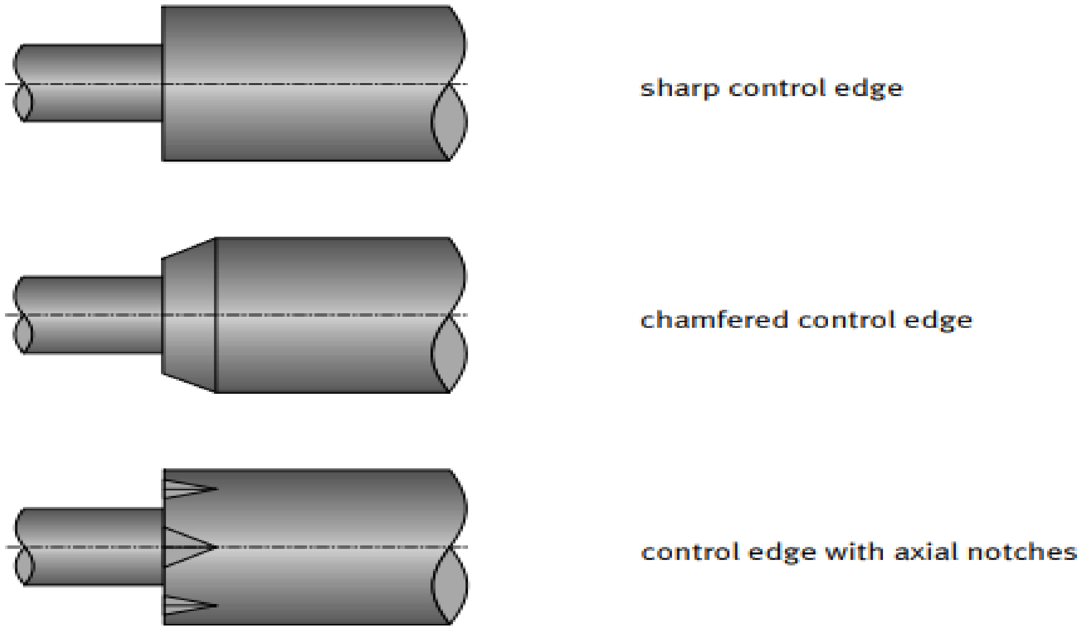




Port P → A is opened although port A → T is not closed yet.
Thus, all ports are briefly interconnected.

Control edges أشكال النهايات الطرفية للمكابس

The control edges of the piston are often either sharp, chamfered or notched. This profiling of the control edge has the effect that there is gradual rather than sudden throttling of the flow on switching.



تستخدم أخاديد حلقية من أجل تخفيف الاحتكاك وتوازن الضغط

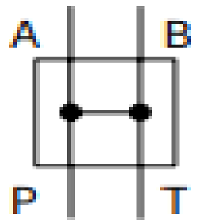
من أجل تغيرتدريجي وليس اختناق مفاجئ للتدفق عند التشغيل

Port designations

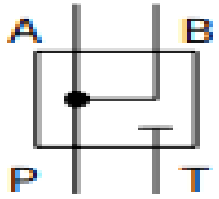
There are two methods of port designation. The ports can be labelled either with the letters P, T, A, B and L or they can be labelled alphabetically.

- A horizontal line between the letters for the ports (e.g. P-A) means that the ports are connected together;
- An individual letter separated by a comma (e.g. P-A, T) signifies that this port(here: T) is blocked

Examples P-A-B-T: all ports are interconnected.



P-A-B, T: P, A and B are connected, T is blocked.



Pressure valves

Pressure valves have the task of controlling and regulating the pressure in a hydraulic system and in parts of the system.

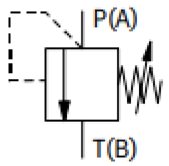
- ## Pressure relief valves

The pressure in a system is set and restricted by these valves. The control pressure is sensed at the input (P) of the valve.

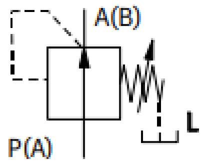
- ## Pressure regulators

These valves reduce the output pressure where there is a varying higher input pressure. The control pressure is sensed at the output of the valve

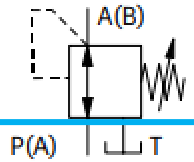
Pressure relief valve



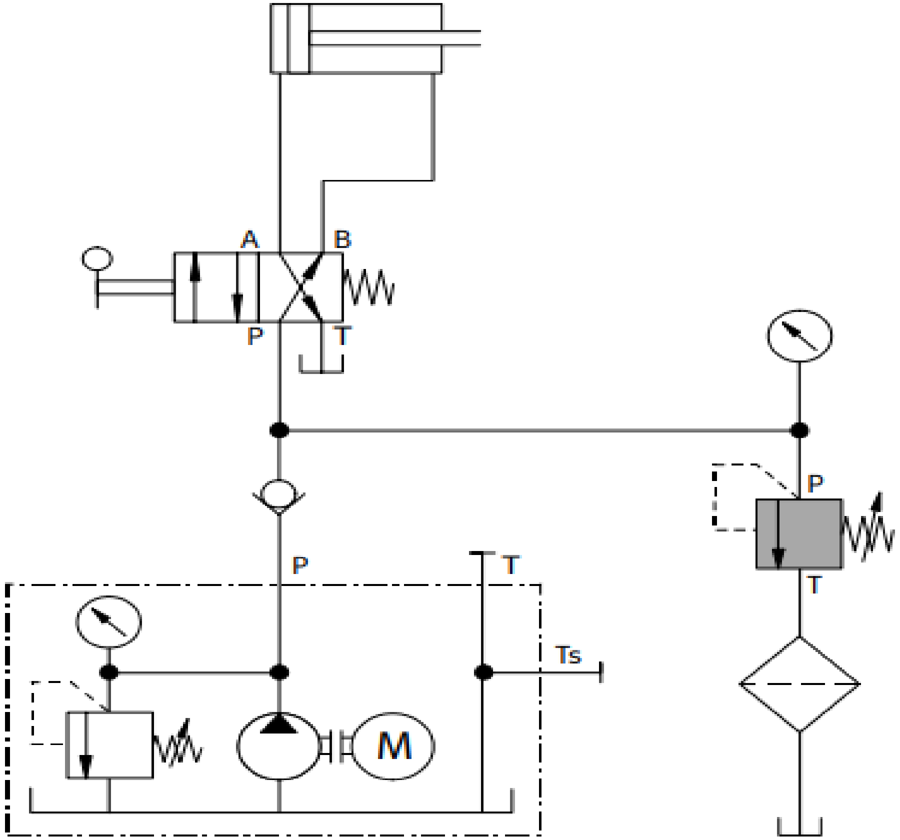
2-way pressure regulator

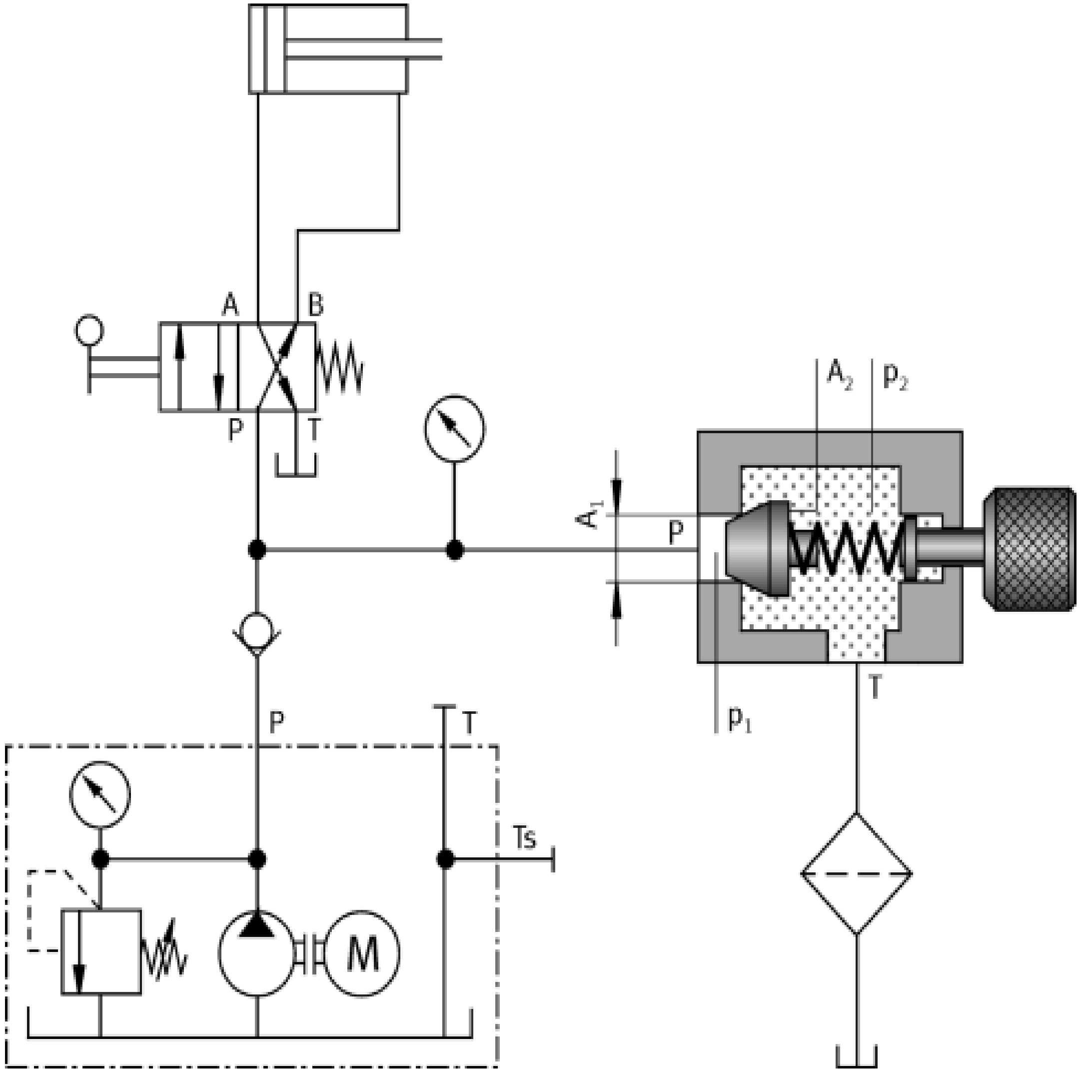


3-way pressure regulator



Pressure relief valves



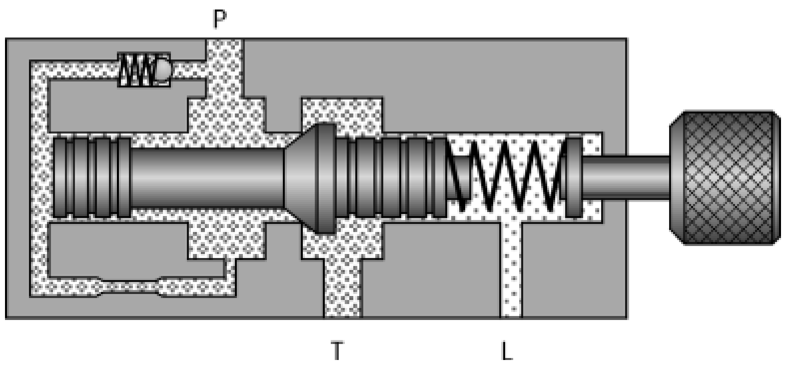


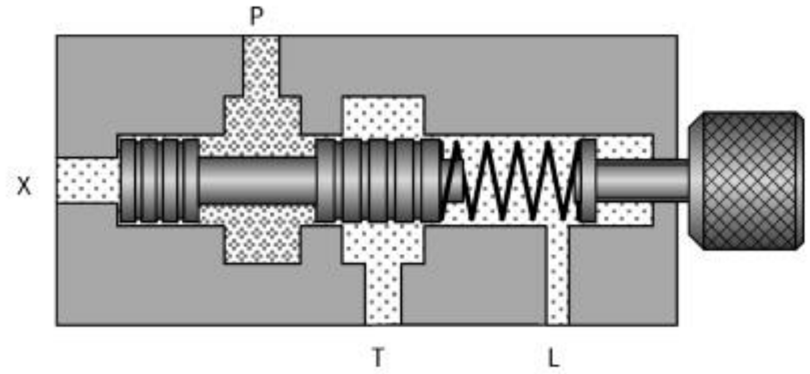
Cushioning pistons and throttles are often installed in pressure relief valves to eliminate fluctuations in pressure. The cushioning device shown here causes:

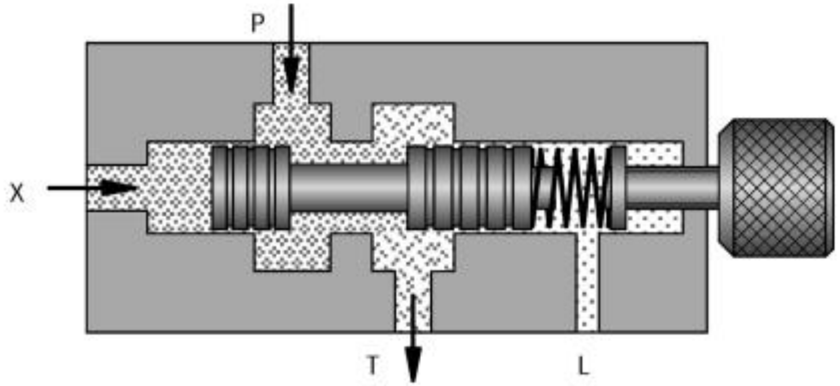
- fast opening
- slow closing of the valve.

By these means, damage resulting from pressure surges is avoided (smooth valve operation). Pressure knocks arise when the pump supplies the hydraulic oil to the circuit in an almost unpressurised condition and the supply port is suddenly closed by a directional control valve. In the circuit diagram shown here, the total pump delivery flows at maximum pressure via the pressure relief valve to the tank. When the directional control valve is switched, the pressure in the direction of the cylinder decreases and the cushioned pressure relief valve closes slowly. An un cushioned valve would close suddenly and pressure peaks might occur.

صمام حد الضغط مع تخميد

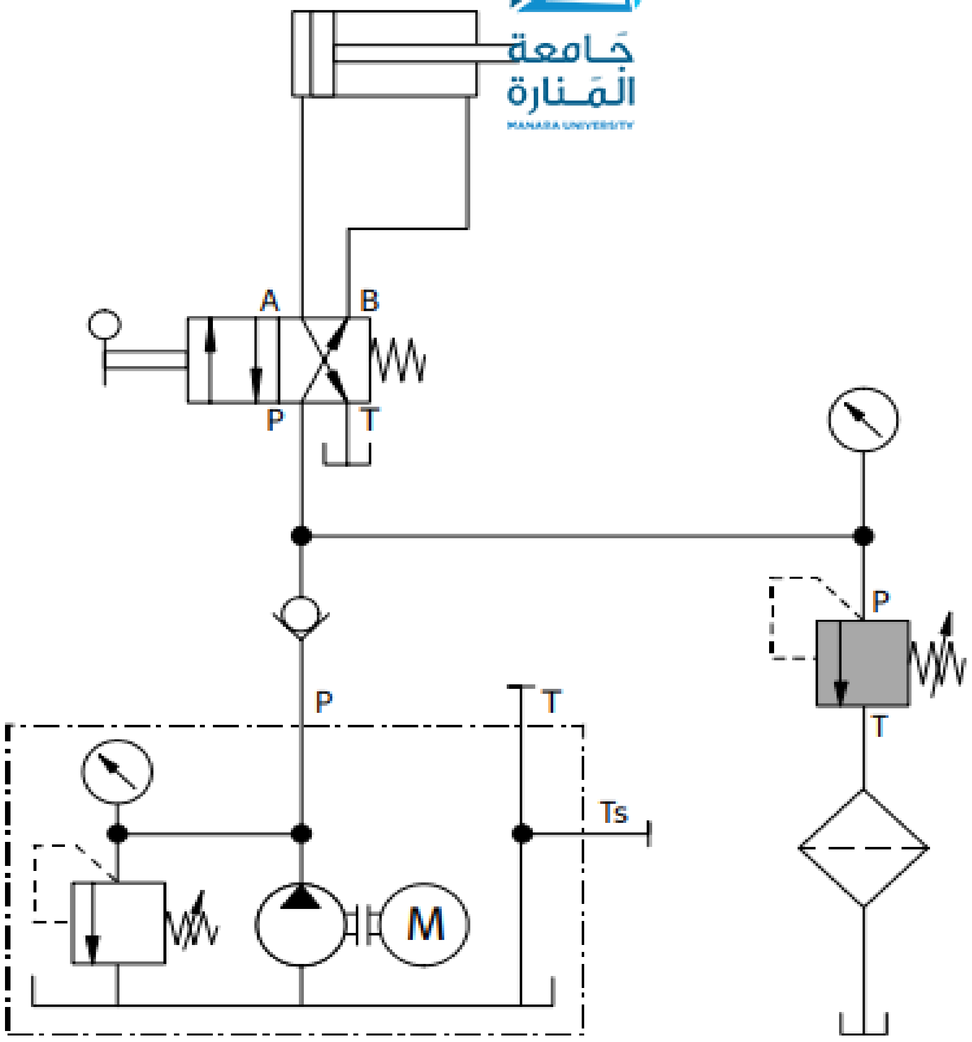






Pressure relief valve, internally controlled, cushioned

Pressure relief valve, externally controlled

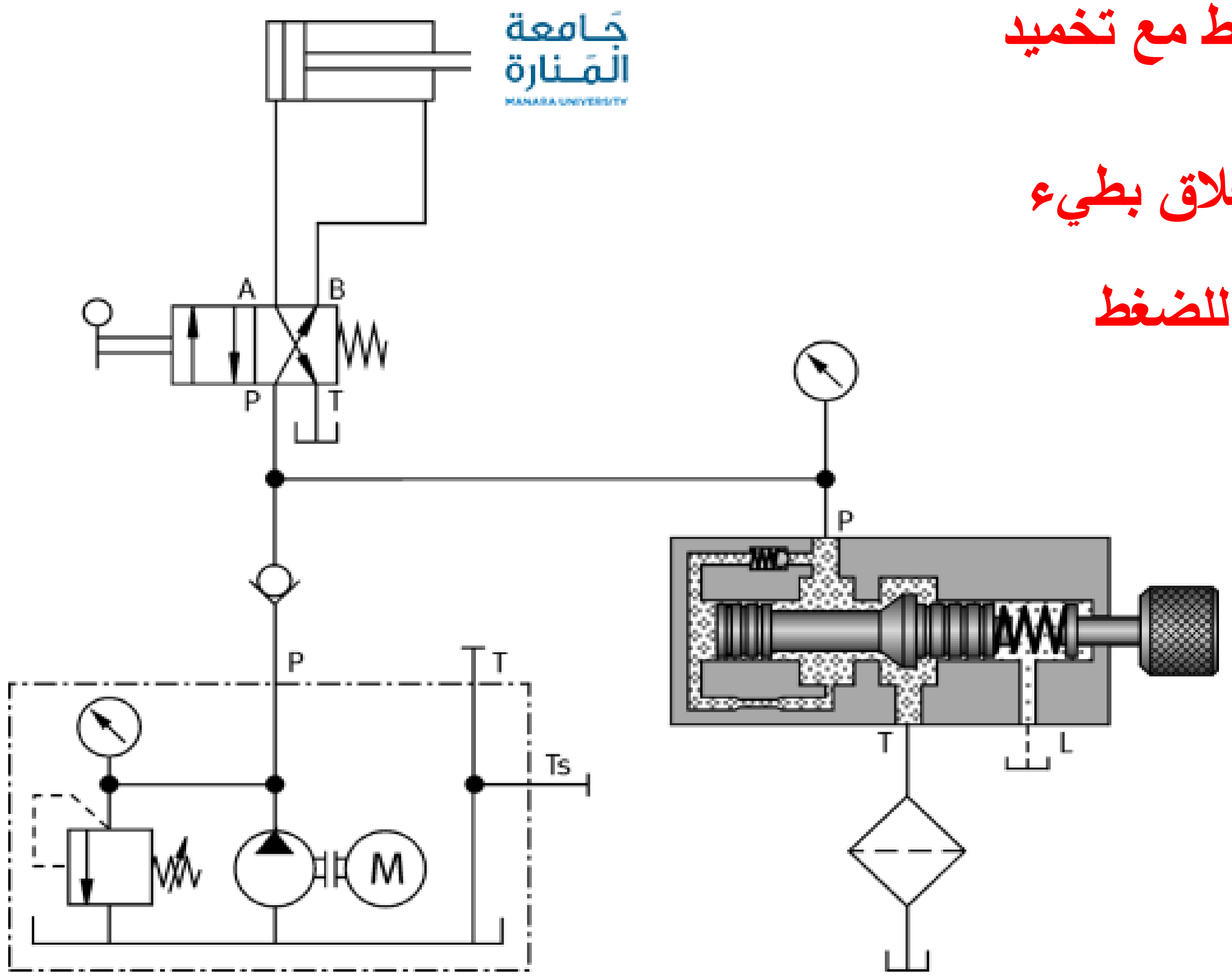


Pressure relief valve (circuit diagram)

صمام حد الضغط مع تخميد

ميزات : فتح سريع - إغلاق بطيء

يمنع حدوث قمم للضغط



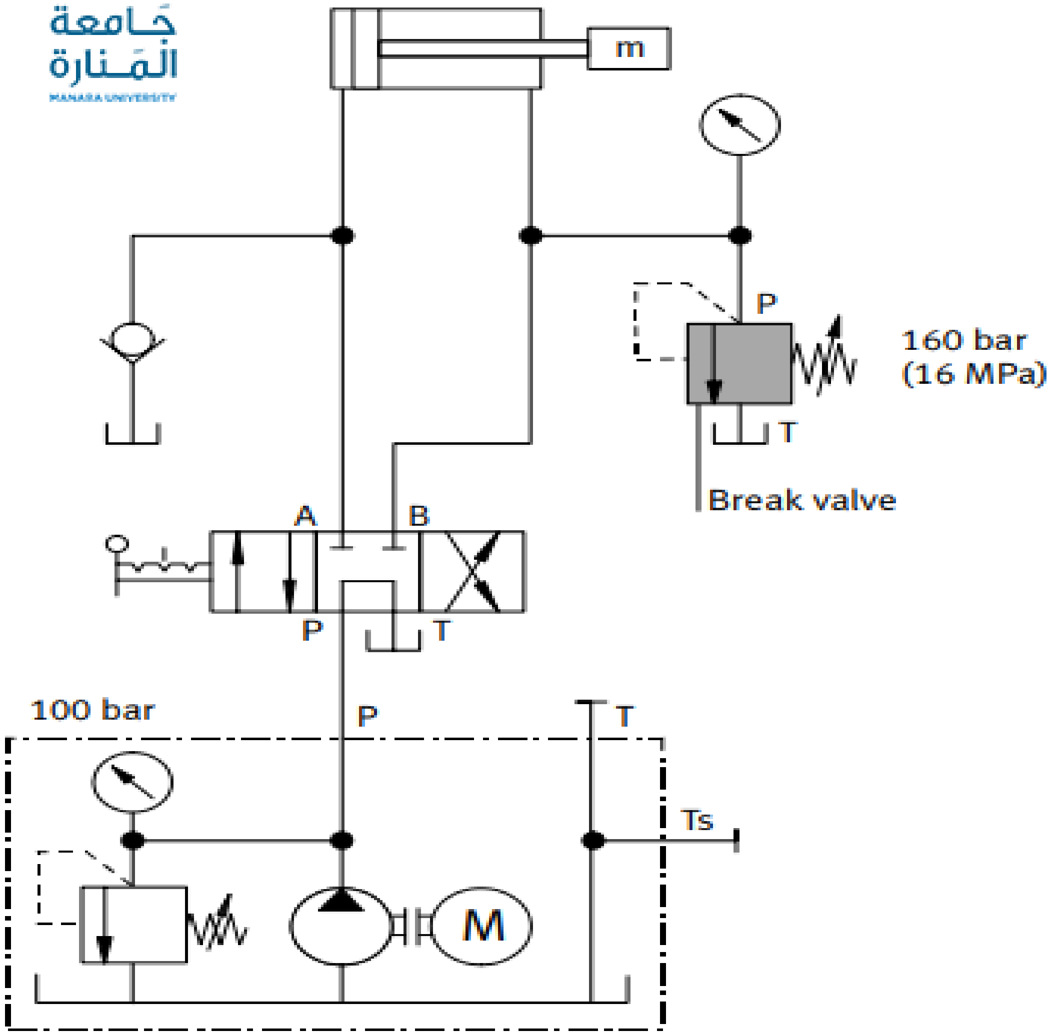
Pressure relief valve with cushioning (sectional diagram)

إغلاق بطيء ناتج عن انخفاض الضغط بعد الصمام التوجيهي

Pressure relief valves are used as:

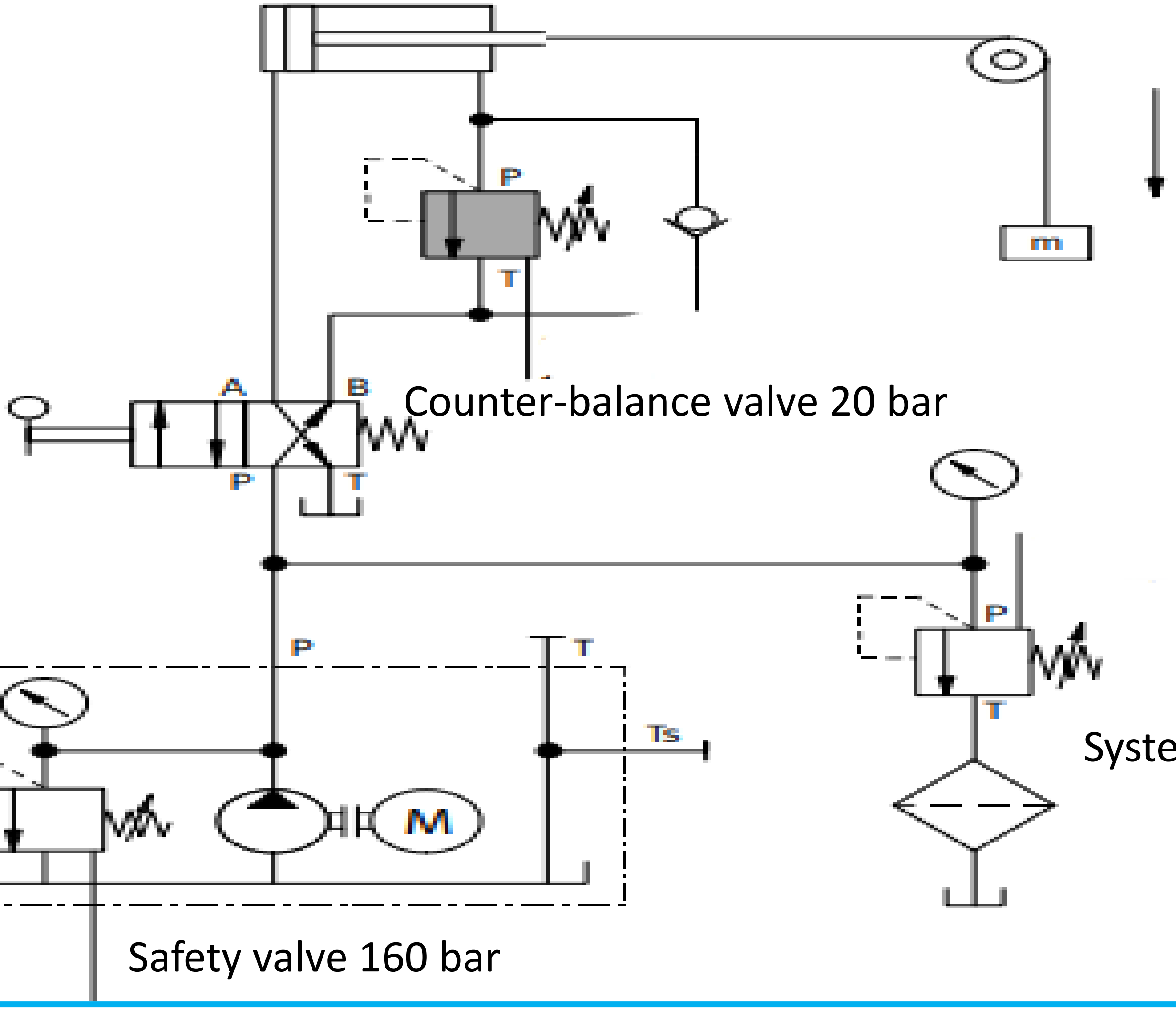
- **Safety valves** A pressure relief valve is termed a safety valve when it is attached to the pump, for example, to protect it from overload. The valve setting is fixed at the maximum pump pressure. It only opens in case of emergency.
- **Counter-pressure valves** These counteract mass moments of inertia with tractive loads. The valve must be pressure-compensated and the tank connection must be loadable.
- **Brake valves** These prevent pressure peaks, which may arise as a result of mass moments of inertia on sudden closing of the directional control valve.
- **Sequence valves** (sequence valves, pressure sequence valves) These open the connection to other consuming devices when the set pressure is exceeded.
- There are both internally and externally controlled pressure relief valves. Pressure relief valves of poppet or slide design may only be used as sequence valves when the pressure is compensated and loading at the tank connection has no effect on the opening characteristics

- **Brake valves**



Application example: brake valve

Application example: counter-balance valve



Counter-balance valve 20 bar

System pressure limit 100 bar

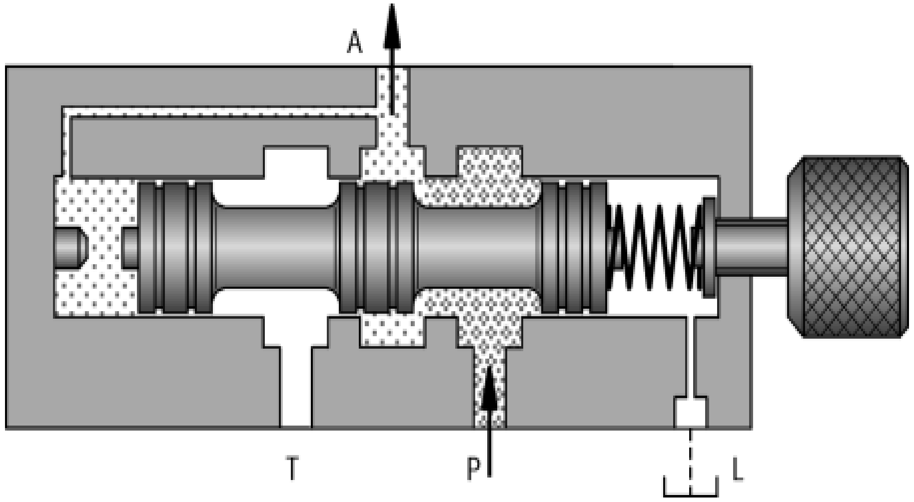
Safety valve 160 bar

Pressure regulators

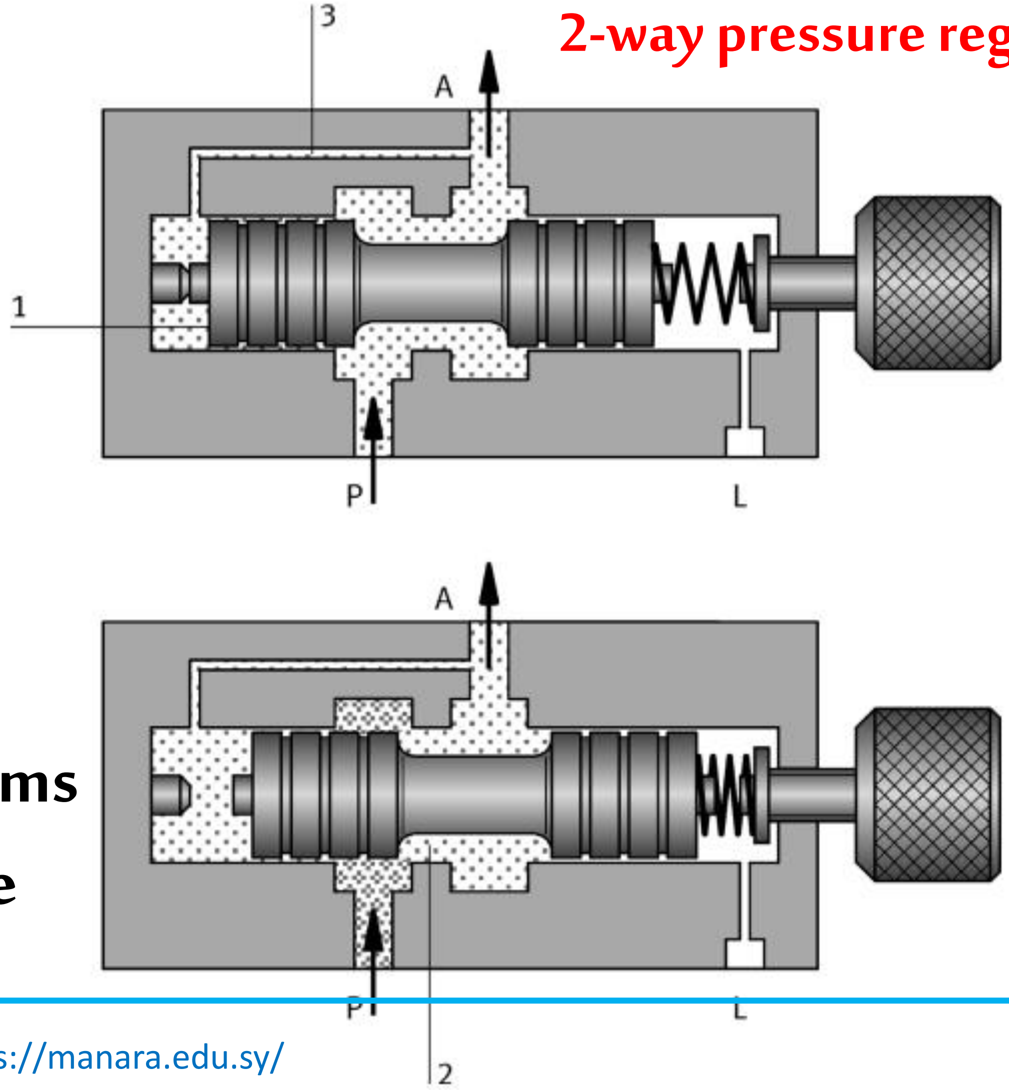
صمام تنظيم الضغط

Pressure regulators reduce the input pressure to a specified output pressure.

3-way pressure regulator



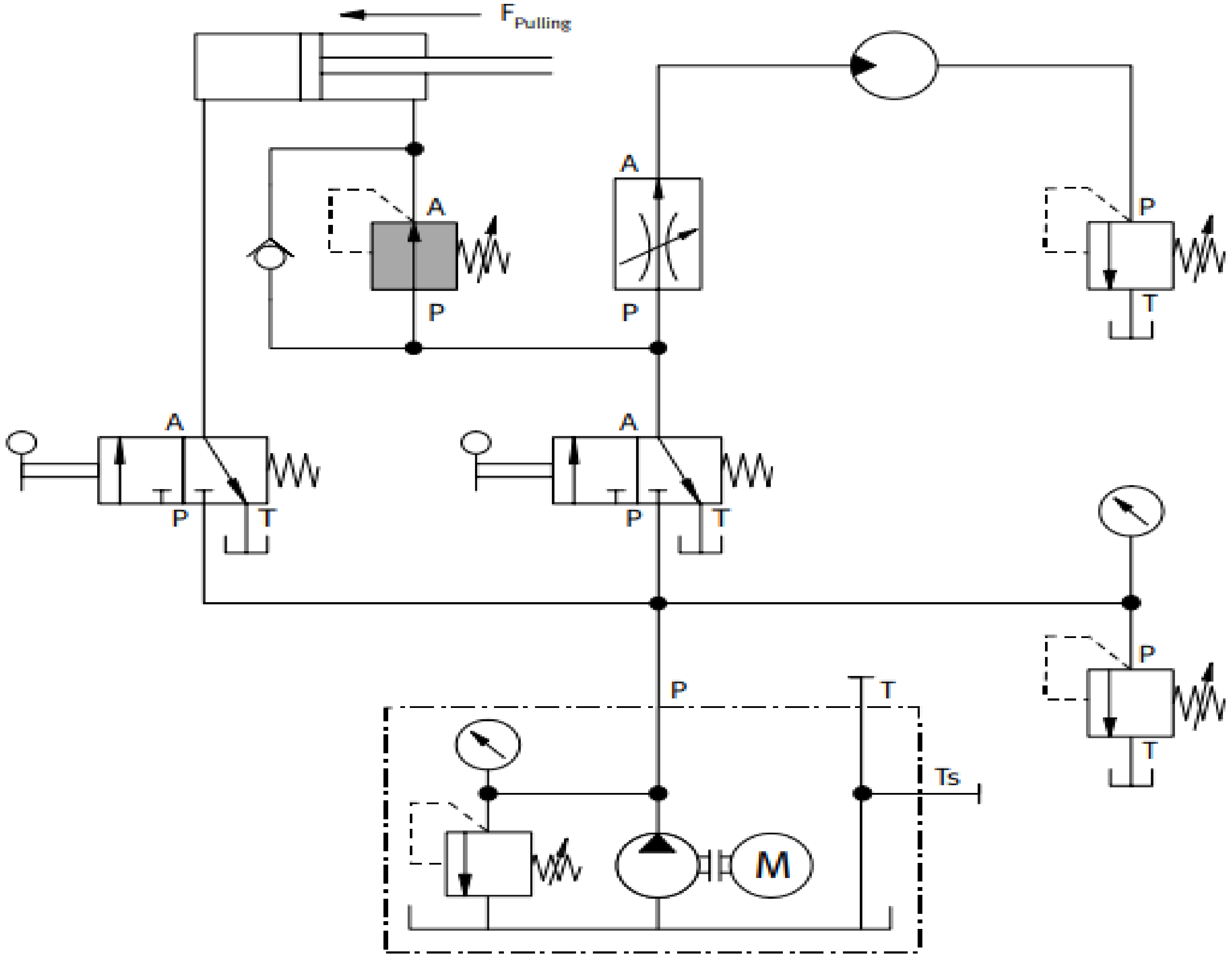
2-way pressure regulator



They are only used to good effect in systems where a number of different pressures are required

They are only used to good effect in systems where a number of different pressures are required. To clarify this, the method of operation is explained here with the help of an example with two control circuits:

- The first control circuit operates on a hydraulic motor via a flow control valve in order to drive a roller. This roller is used to stick together multi-layer printed wiring boards.
- The second control circuit operates on a hydraulic cylinder which draws a roller towards the boards at a reduced, adjustable pressure. The roller can be lifted with a cylinder to allow the boards to be inserted (piston rod extends).



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