fundementals of fluid power

Power transmission is done via

- **Hydraulic** (Higher stifness)
- **pneumatic** → weak stifness
- **Mechanical** → higher stiffness
- **Electro_Mechanical**
  - weak Stifness
  - lowest friction
  - more sensitive to external noise

Hydraulic and pneumatic:

- high torque to load inertia ratio
- high power to weight ratio

Advantages of hydraulics and pneumatics systems:

1. Ease of control
2. Force Amplification
3. Steady Force and Torque provided
4. Safety
5. high power to weight ratio

Disadvantages of hydraulics and pneumatics systems:

1. noise
2. liquid leakage
3. Dangerous

Comparison Between pneumatic and hydraulic systems

Pneumatics	Hydraulics
Fluid is compressible (Air)	Fluid is incompressible (Oil)
Relatively low fluid pressure	Very high fluid pressure
Limited dynamic response	Good dynamic response
Delay time of pistons is big	Very smaller delay time
Higher friction due to dryness	Lower friction due to viscous lubrication
No cavitation effect	Exposed to cavitation
Ability of operation at high temperatures	Temperature is limited to oil characteristics

10–12 bar (Relatively low fluid pressure)

up to 1200 bar (Very high fluid pressure)

Components of a hydraulic System

- Tank
- Pump
- A control valve : decides the required operation and direction of fluid
- Actuator (piston or motor)
- Filter or strainer
- set of pipes: Accumulation of the flow in the pipes leads to pressure increase

Components of a pneumatics Systems

- Compressor : Extracts air from the atmosphere through a filter and to the storage tank / turns off when pressure is high enough in the tank
- Storage tank for the air
- A control valve : decides the required operation and direction of air
- Actuator (piston or motor)
- Filter or strainer

Basic theory

- [x] Newton's law
- [x] Perfect gas law
- [x] Torricelli's theorem
- [x] Pascal's law
- [ ] Bernoulli's equation

Newton's law

$$F = ma = m\frac{dv}{dt} = \rho V \frac{dv}{dt} \quad \text{or} \quad = \rho \frac{dV}{dt} v$$

($m \to \rho V$; $\frac{dV}{dt} \to Q$)

$$F = \rho Q v$$

Perfect Gas law

$$PV = mRT$$

P → absolute, so gage + atm

T → Kelvin

$$R = \frac{R_u}{MW} = 287 \text{ for air}$$

R_u → universal gas constant

MW → molecular weight

Special cases

constant temperature → $P_1V_1 = P_2V_2$ Boyl's low

constant pressure → $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ charle's law

constant mass → $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ Laussac's law

combining all previous → $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \text{const.}$ Combined gas law

Torricelli's Theorem

"The velocity of a free jet of a fluid is proportional to the square root of the head producing the jet"

$$K_B + U_B = K_A + U_A$$

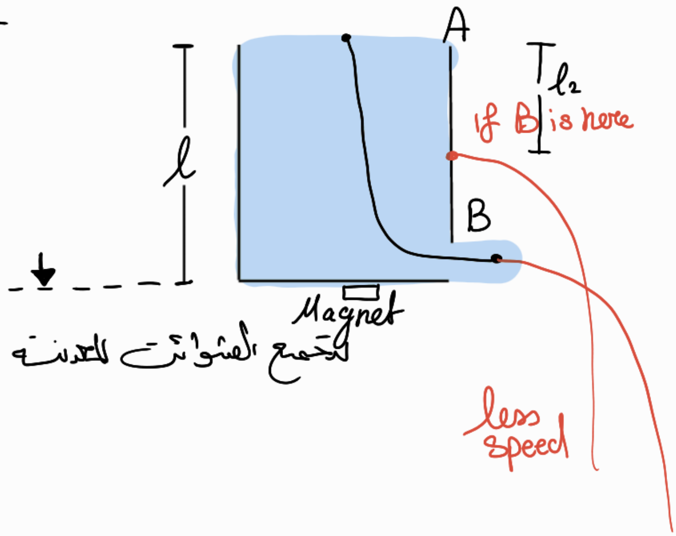
$$\frac{1}{2} m v^2 = mgh$$

$$v = \sqrt{2gh}$$

Also, $h = \frac{P}{\rho g}$

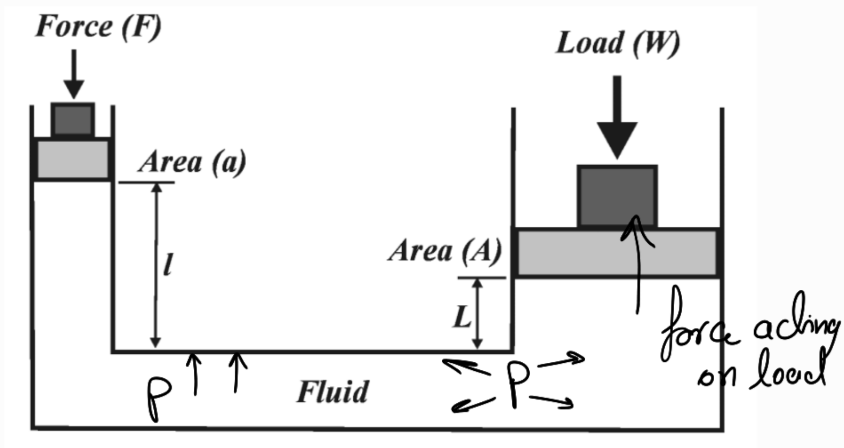
if B was on another height

$$v_B = \sqrt{2g(l - l_2)}$$



Pascal's law

- power transmission
- Pressure acts equally in all directions at the same time
- Pressure is perpindicular on all surfaces
- Pressure is constant



$$P = \frac{F}{a} = \frac{W}{A} \rightarrow \frac{W}{F} = \frac{A}{a}$$

Force Magnification

Work = PV = PAL [N.m]

hydraulic power = PQ

P → Pressure (N/m^2)

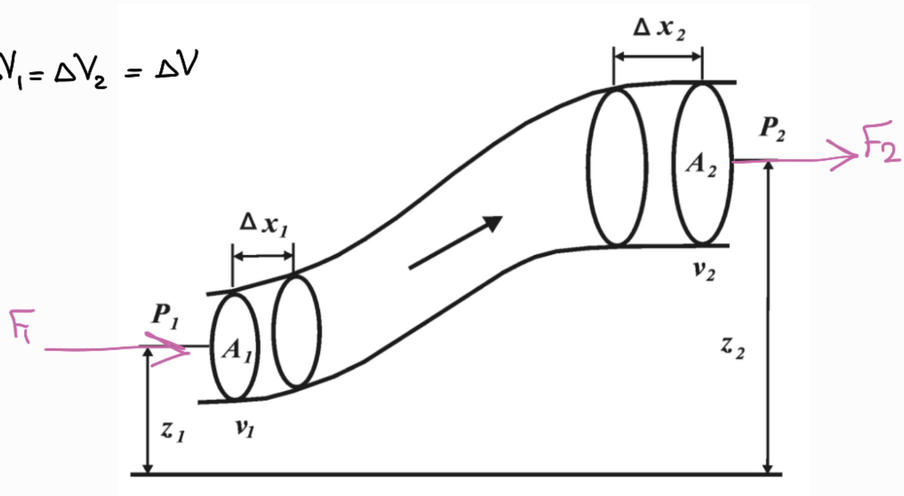
Q → $\frac{\text{Volume}}{\text{time}}$ ($\frac{m^3}{s}$)

commercial units
Q → l/min
P → Bar $\times 10^5$ $\frac{N}{m^2}$

$$\text{Power} = \frac{Q(l/min) \times P(bar)}{600} = P\ (KW)$$

Bernoulli's Theory

- Conservation of energy: energy can neither be created or destroyed
- Assumptions:-
  - Incompressible fluid : $\Delta V_1 = \Delta V_2 = \Delta V$
  - nonviscous fluid
  - no leakage



$$z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} + H_p - H_m - H_L = z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g}$$

Friction losses

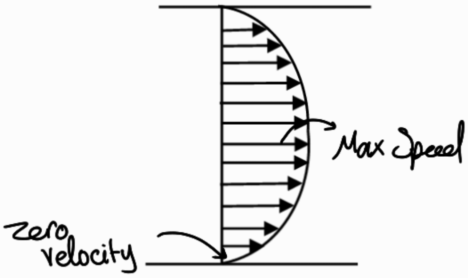
- Friction losses in hydraulic systems

check valves → prevents oil from returning to the tank in stall conditions

Friction losses Depends on

- Path roughness ↑ → friction loss ↑
- Pipe dimensions: Dp ↓ → L ↑ → friction losses ↑
- Viscosity ↑ → friction losses ↑

Reynolds number



Flow can be:

- Laminar
- transient
- turbulent

} Depends on
- fluid velocity
- fluid viscosity
- size & shape of pipe

$$Re = \frac{vD}{\nu} = \frac{vD\rho}{\mu}$$

Hydraulic diameter D_h

$$= \frac{4 \times A\ (\text{Section})}{\text{Perimeter}}$$

1 stoke = 1 cm²/s → $\nu = \frac{\mu}{\rho}$ (μ → poise; 10 poise = 1 kg/m.s)

$2000 \leq Re \leq 4000$ Smooth surface
Transition

$1200 \leq Re \leq 2500$ corrugated surface
Transition

Darcy's equation

$$H_L = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

- L → pipe length
- v → fluid velocity
- D → inside diameter

f:
- → laminar flow : $f = \frac{64}{Re}$
- → Turbulent flow : Moody chart

$\frac{\epsilon}{D}$ = Relative Roughness (ϵ → height of the inside corrugation in the pipe)

Valve and fittings

$$H_L = K\frac{v^2}{2g}$$

$$H_L \text{ fittings} = H_L \text{ pipe}$$
$$K\frac{v^2}{2g} = f\left(\frac{L_e}{D}\right)\left(\frac{v^2}{2g}\right)$$

$$L_e = \frac{KD}{f}$$

To find $(H_L)_{total}$:

$$(H_L)_{tot} = f\left(\frac{L_T}{D}\right)\left(\frac{v^2}{2g}\right)$$

- Friction losses in pneumatic systems

Harris formula

pressure loss in british units

$$P_f = \frac{CLQ^2}{(3600)(CR)D^5}$$

- P_f: pressure loss in psi
- L: pipe length in ft
- Q: flow rate in (ft^3/min)
- D: inside diameter in inch
- CR: compression ratio

$$C = \frac{0.1025}{D^{0.31}}$$

$$CR = \frac{\text{Pressure in pipe}}{\text{Atmospheric pressure}}$$