Aalto University
School of Engineering

Introduction to Fluid Power

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From a mechanical engineering perspective

The world

Consists mainly of…

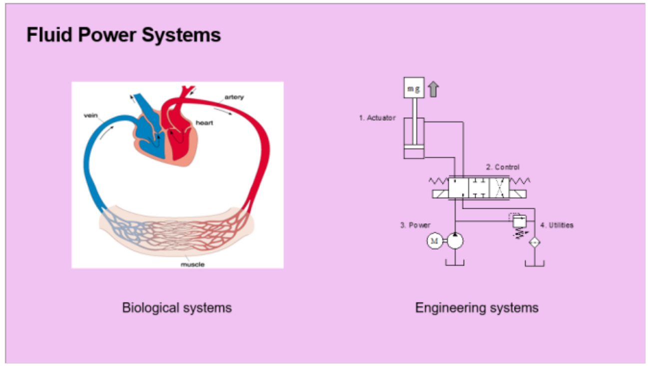
Solids

FEM

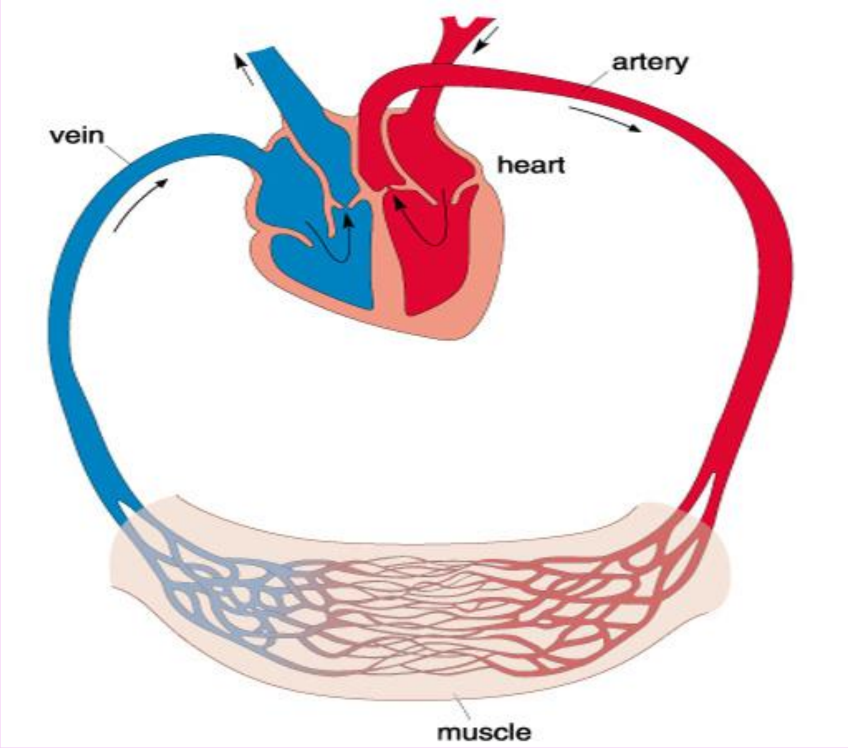
Fluids

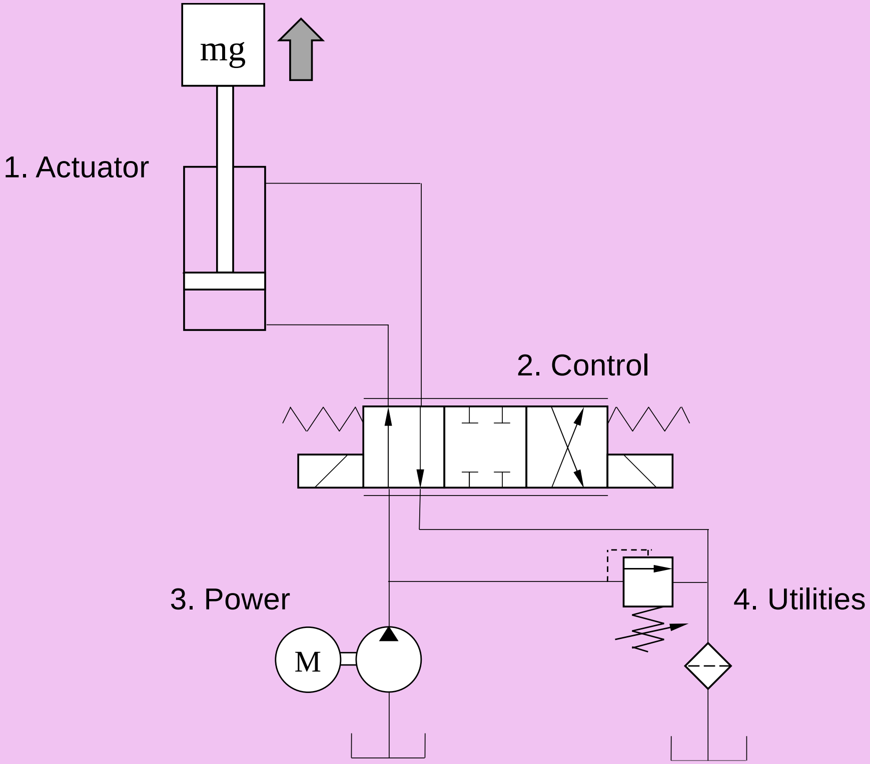
CFD

Physics: Statics, dynamics, thermodynamics, kinematics, mechanics…
Data: capturing things we can't explain with physics



Fluid Power Systems





Biological systems

Engineering systems

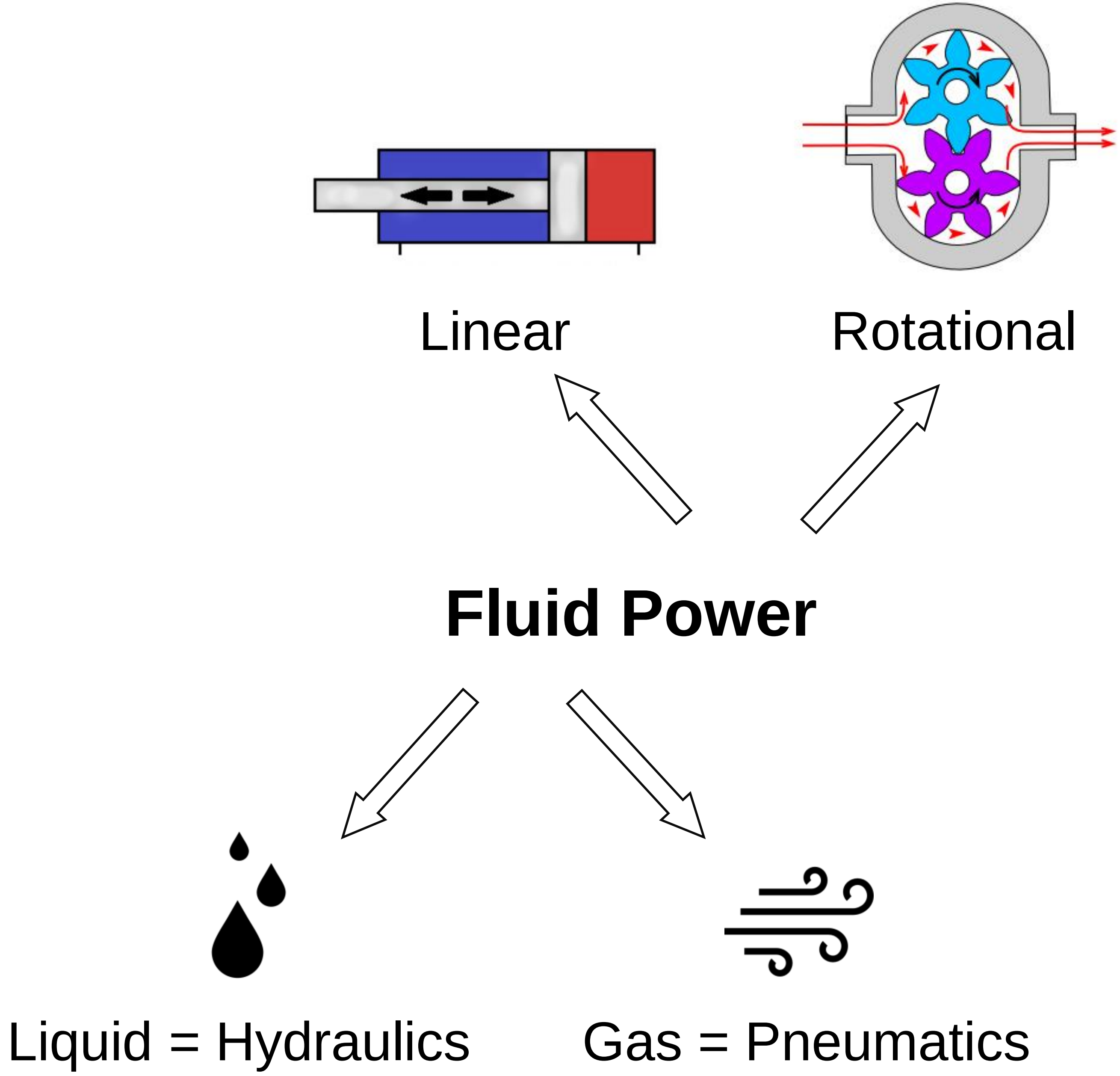
Intended learning outcomes

After this session, the student can…

1. Understand the fundamental principles of fluid power
2. Identify hydraulic system and its components
3. Understand the working principles of hydraulic components
4. Identify fluid power applications

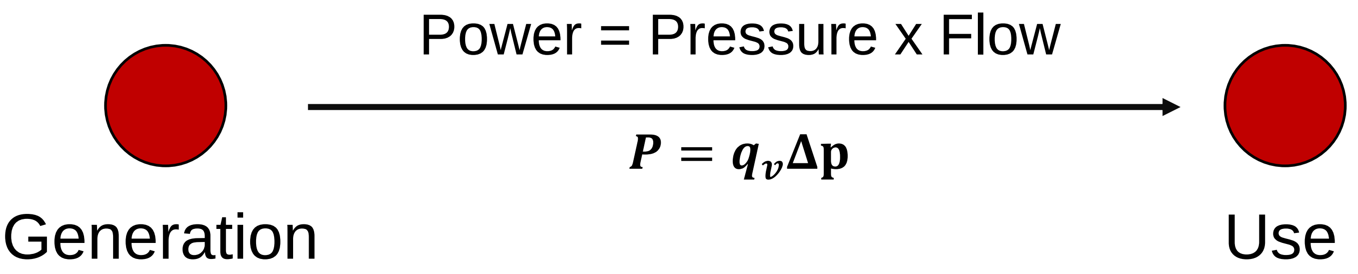
Contents

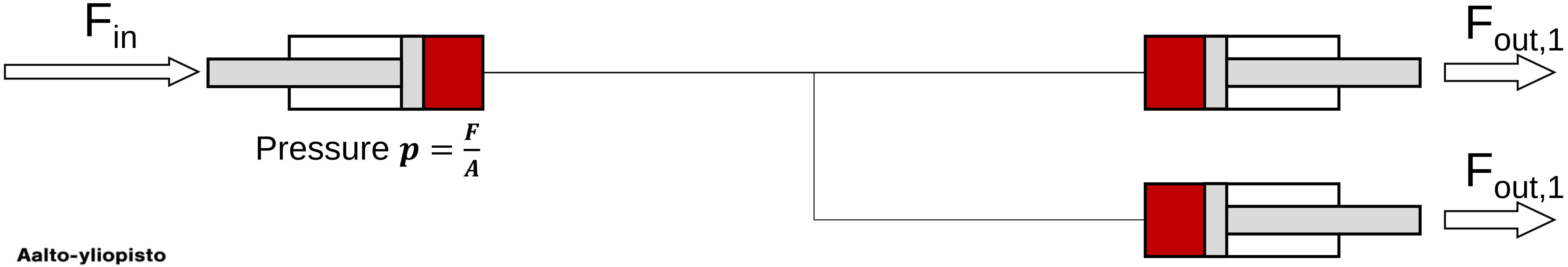
1. What is Fluid Power?


Linear
Rotational
Fluid Power
Liquid = Hydraulics
Gas = Pneumatics

How it works?

- **Power transmission with fluid**
- **Distribution of power**



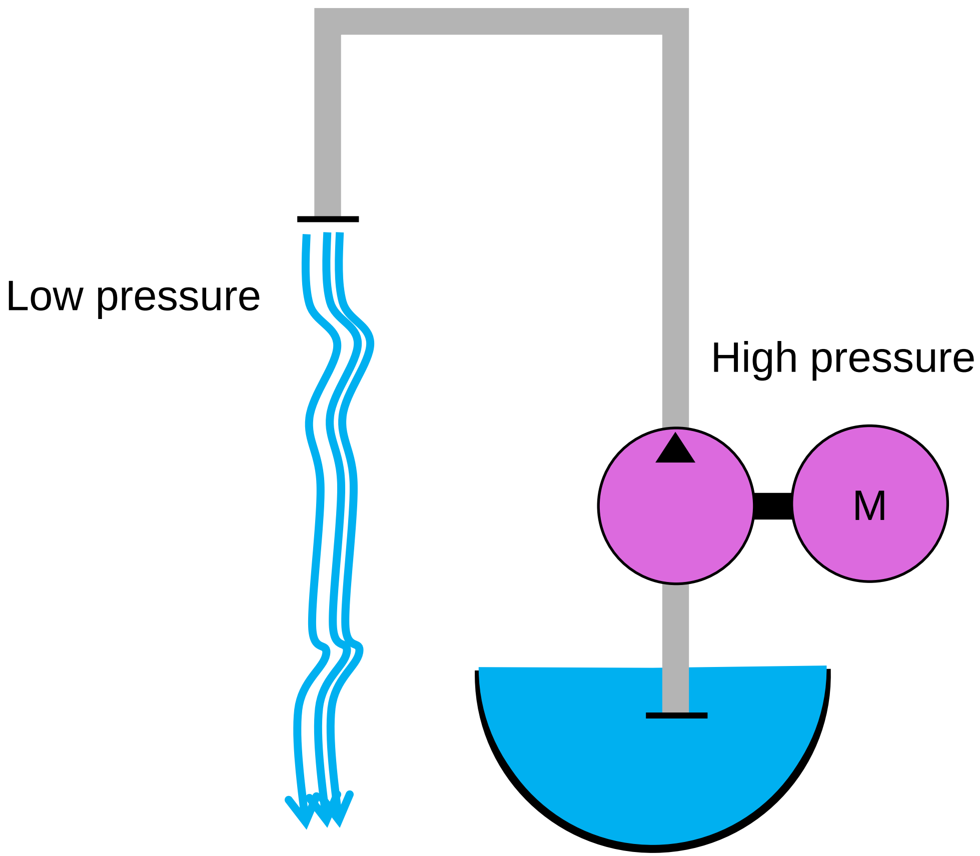


No pressure – no motion

Pressure difference causes flow.

Without pressure, there is no flow.

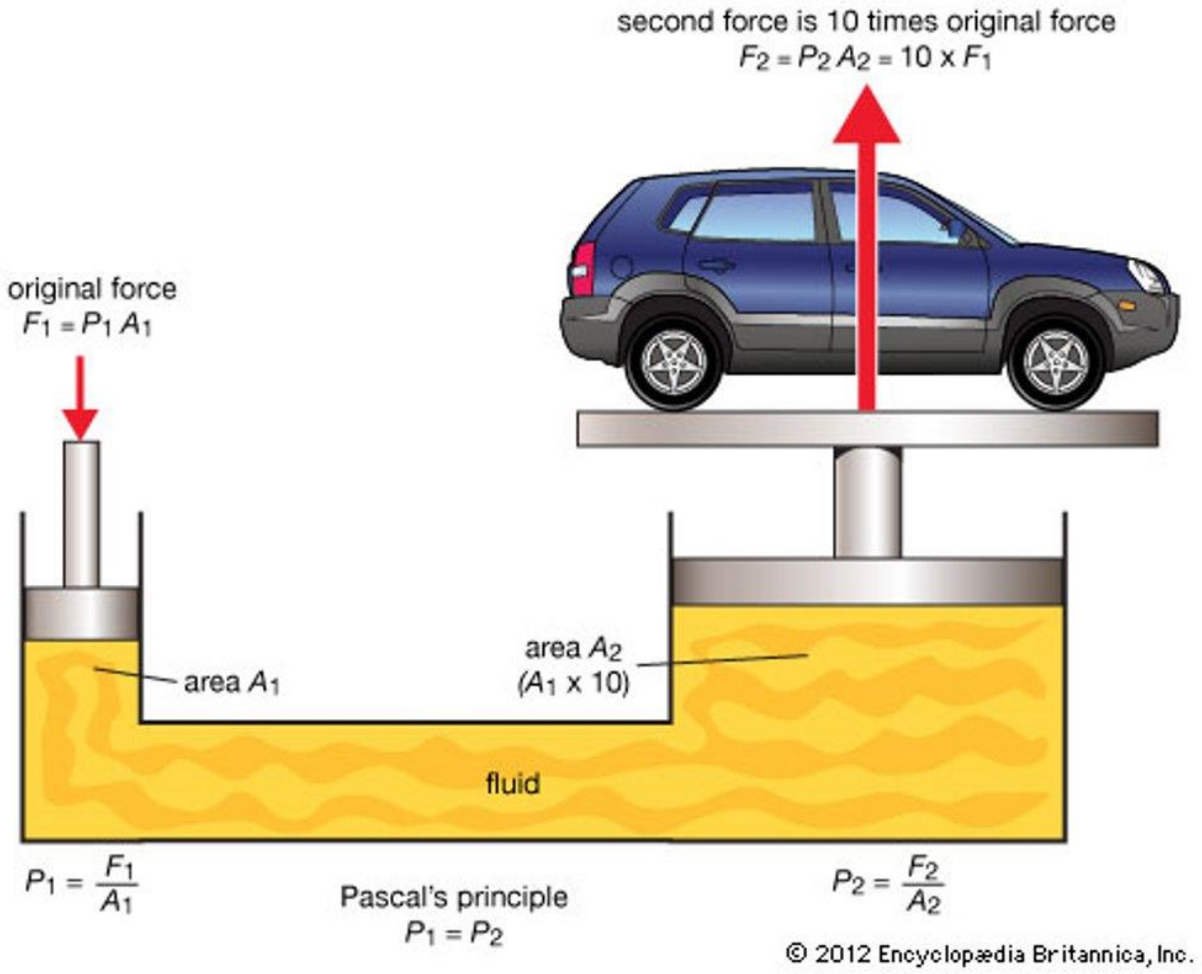
Why this doesn't work?



Hydraulic force conversion

Two cylinders

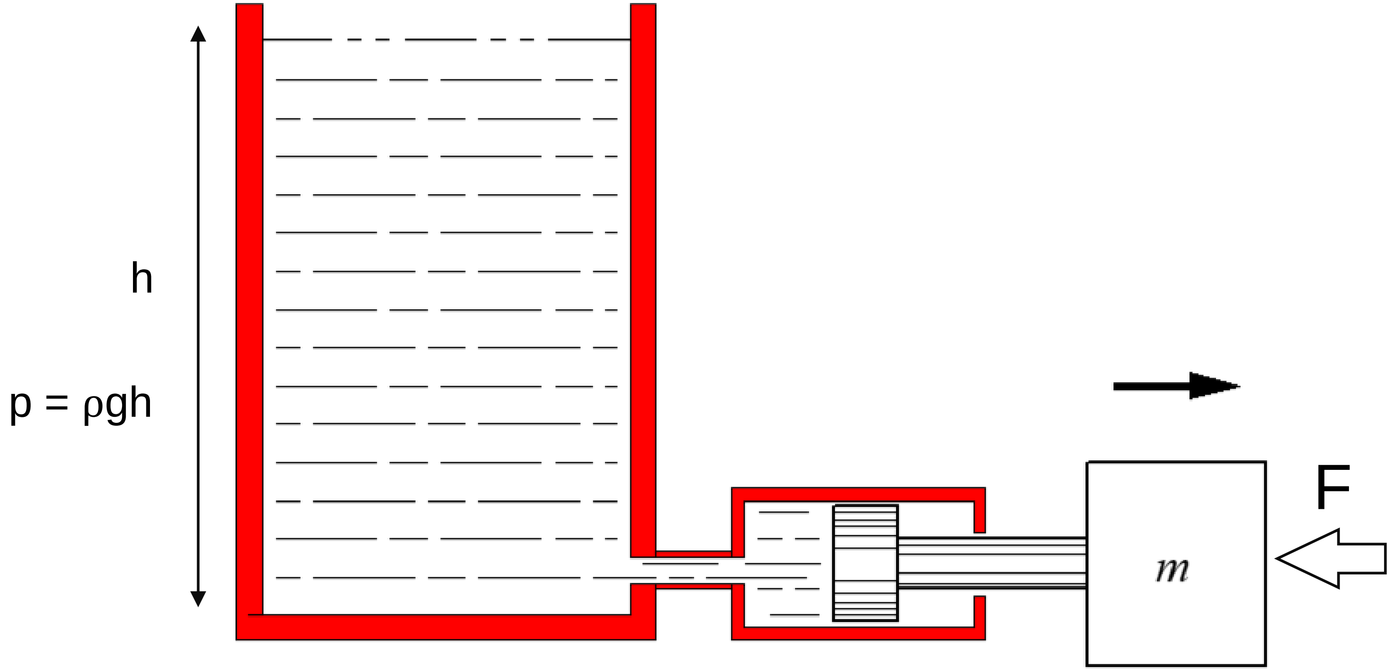
- **Same pressure, bigger area for lift**
- **Higher force, lower speed**
- **Power transmission**



System types

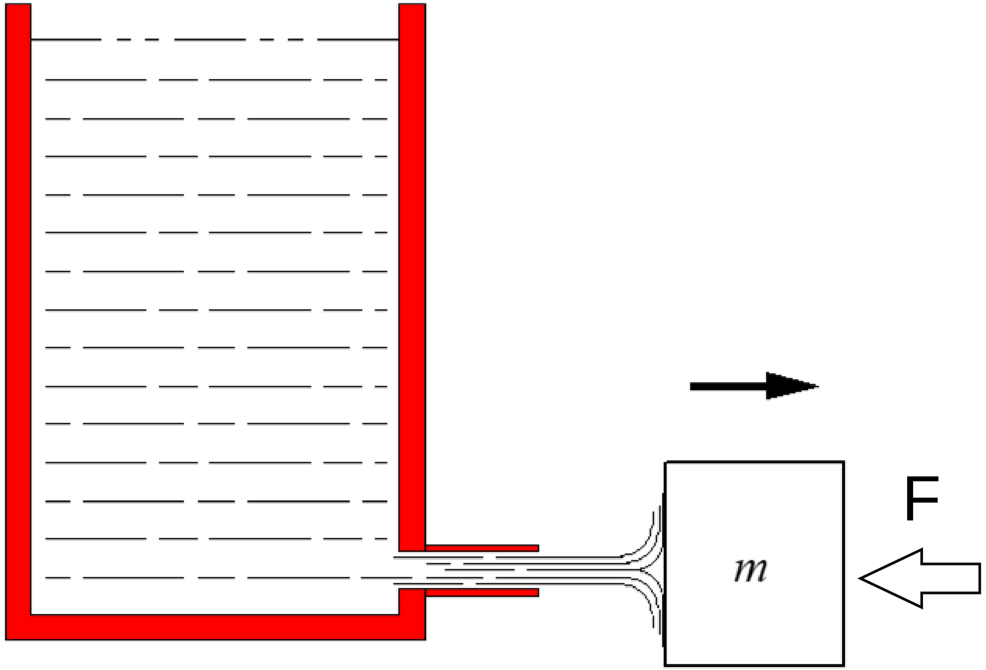
Hydrostatic system

Force mostly linked to pressure *p*



Hydrodynamic system

Force mostly linked to flow q_V



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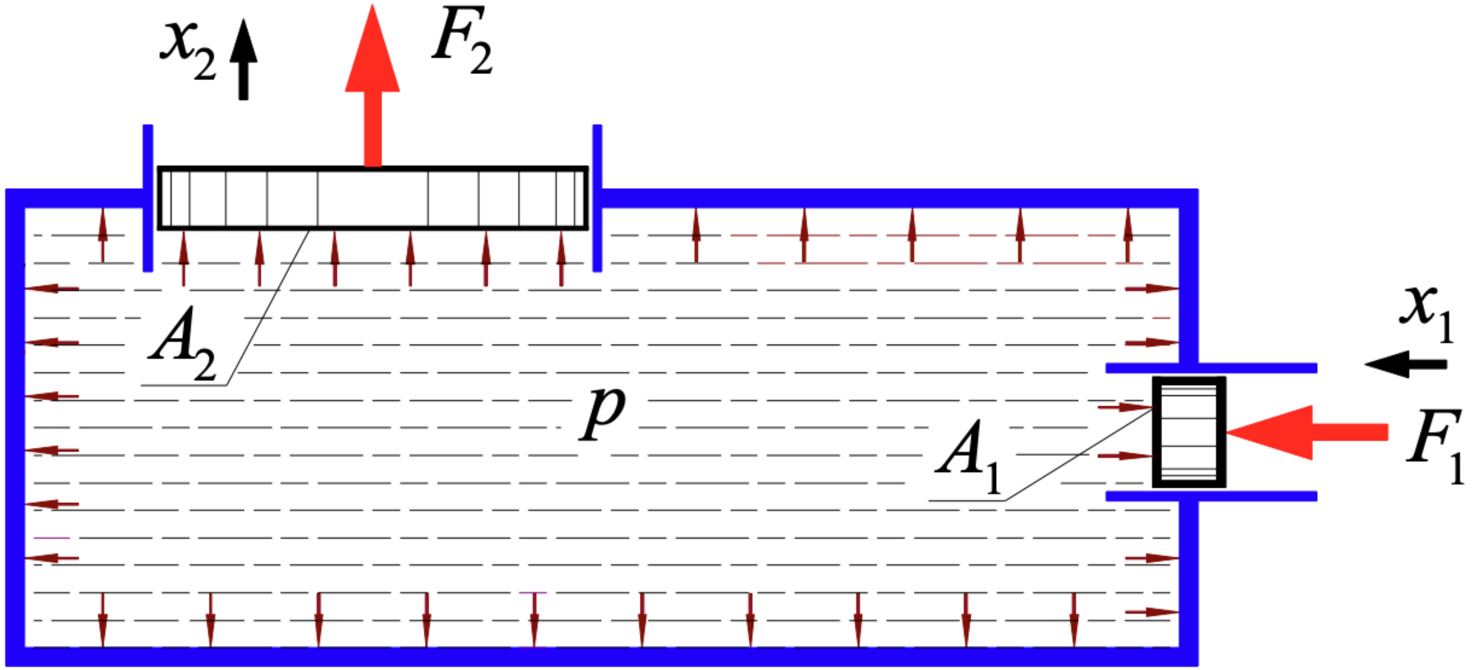
Pressure affects perpendicularly

Pressure is the same
everywhere in the same volume



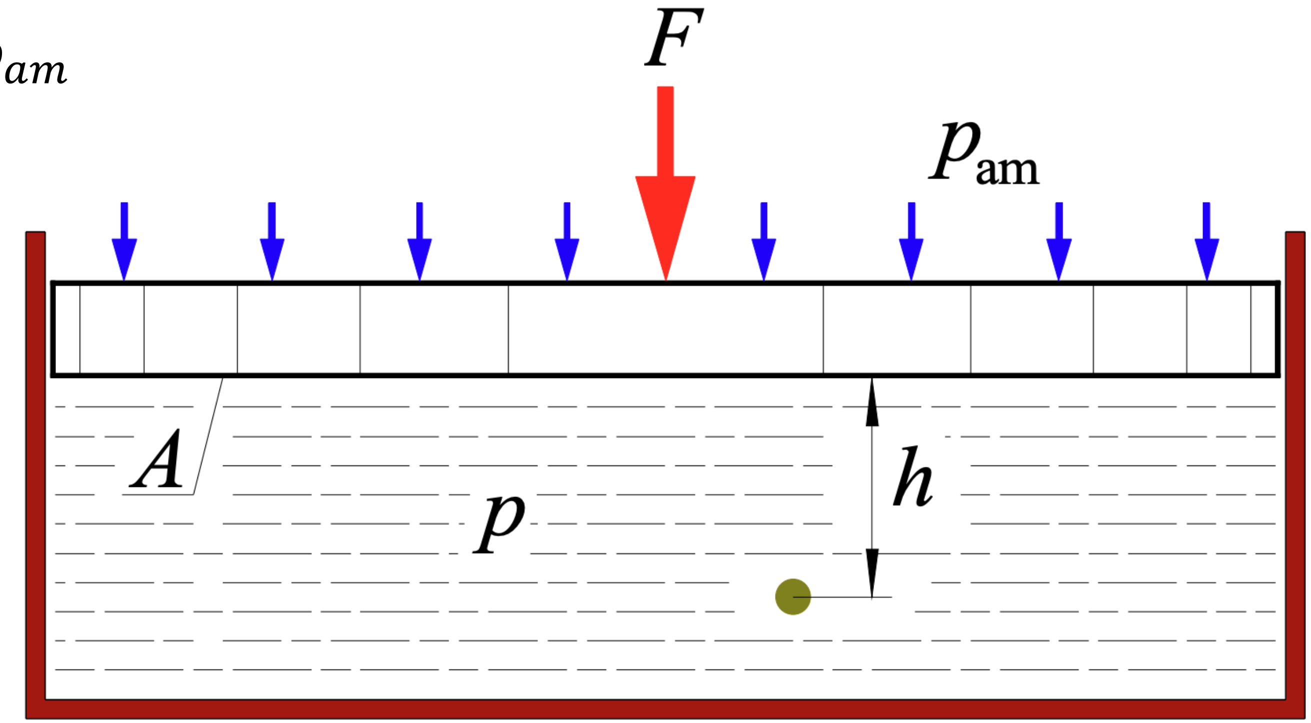
Absolute pressure

Units
SI Unit Pascal: 1 Pa = 1 N/m^2

105 Pa = 1 bar (engineering unit)

Based on Bernoulli's equation

$$p = \frac{F}{A} + \rho g h + p_{am}$$



Gauge pressure

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

Flow

a) **Laminar flow**

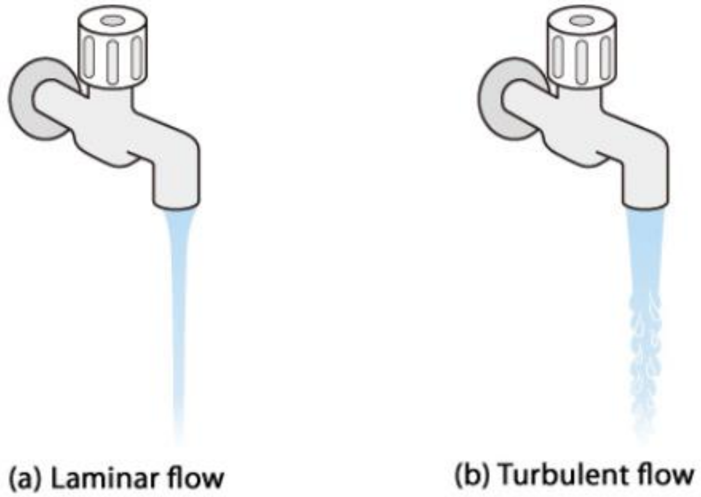
Smooth and streamlined, low internal resistance

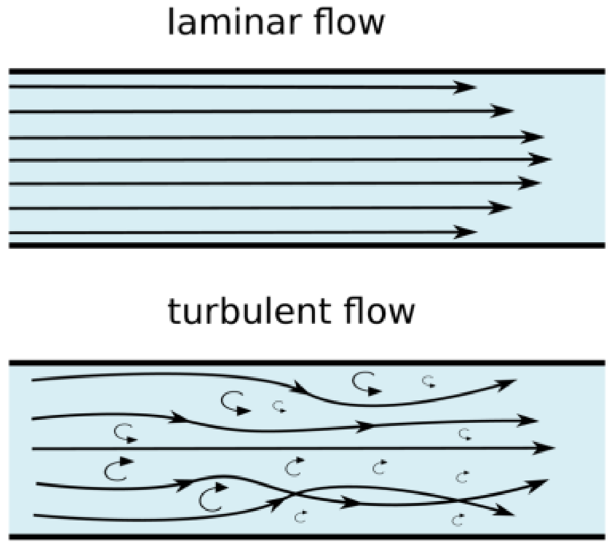
b) **Turbulent flow**

Chaotic and irregular -> Energy loss

Depends on

- Pipe size
- Fluid viscosity
- Speed



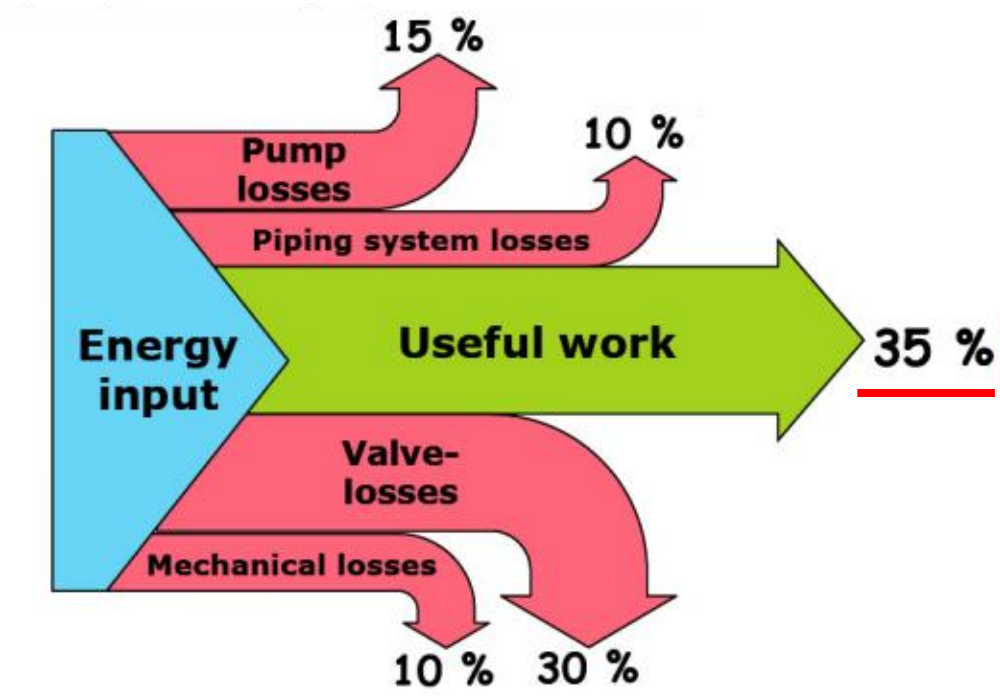


2. Fluid Power Systems

System Components

- **Power source**
  - Electric motor or engine + pump
- **Actuators** to convey movement
  - Cylinders and motors
- **Valves** for logic & control
- **Fluid** to convey power
  - Oil or water
- **Utilities**
  - Pressure accumulator, heat exchanger, filters, tank

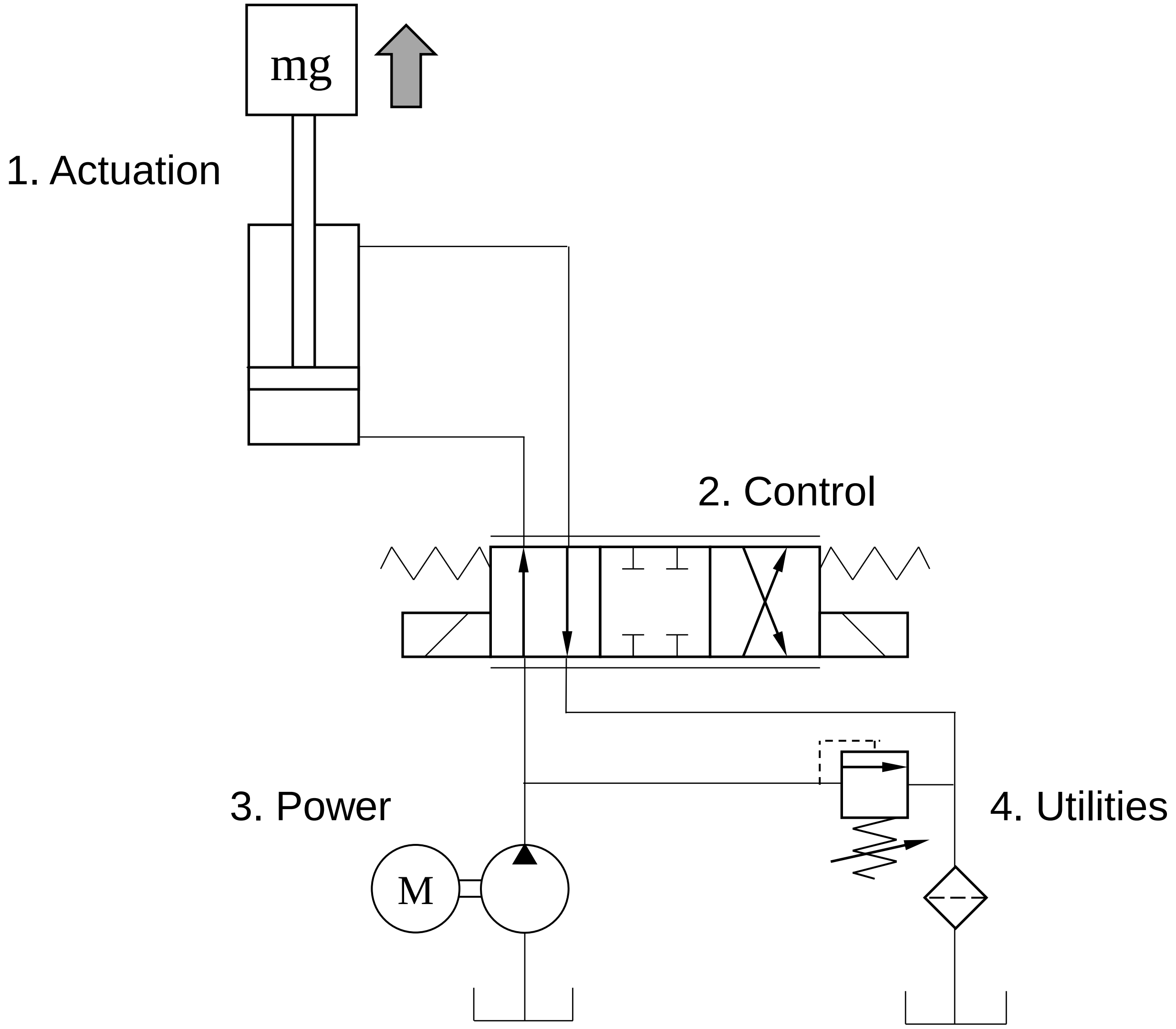
Energy losses



If idling is taken into account, average efficiency can drop to 20 %

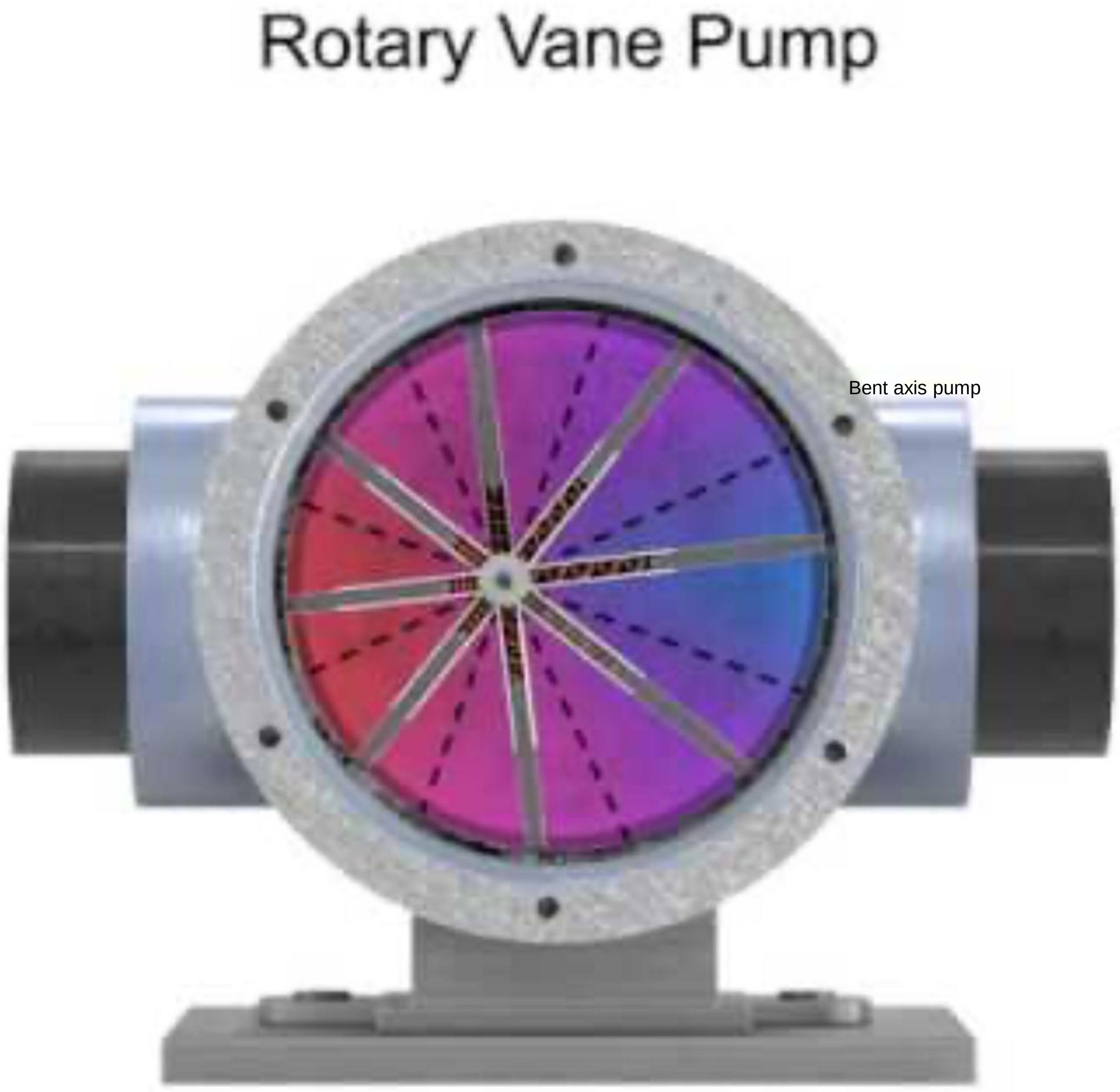
K.-E. Rydberg, "Energy Efficient Hydraulics – System Solutions for Minimizing Losses," in *National Conference on Fluid Power, "Hydraulikdagar'15"*, Linköping, Sweden, 2015.

Basic Hydraulic system



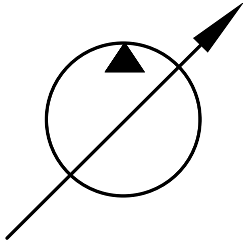
“Powerpack”: eMotor/Engine + Pump

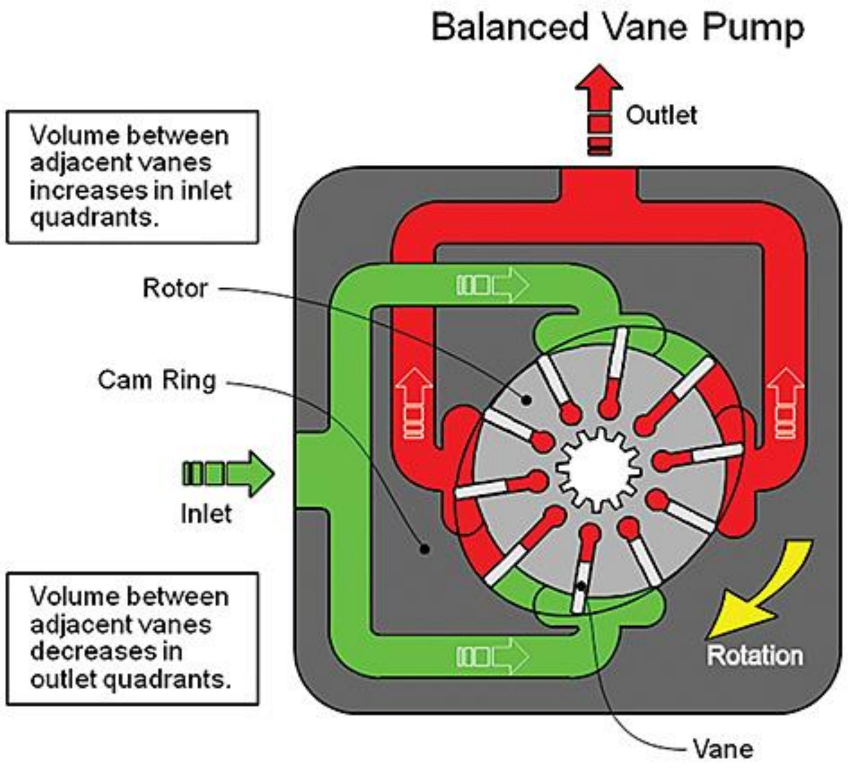
Video (8 min)

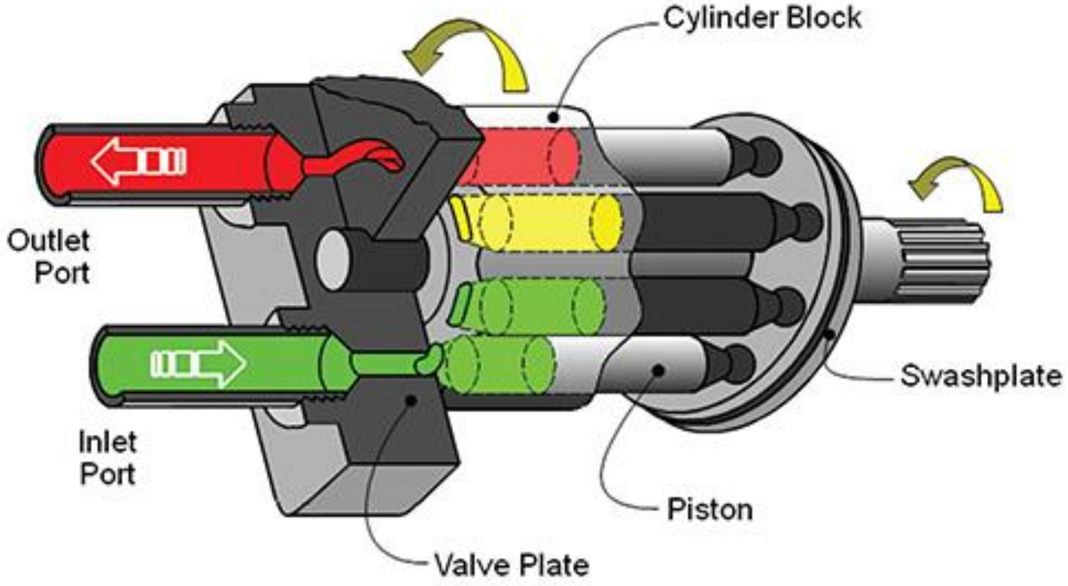


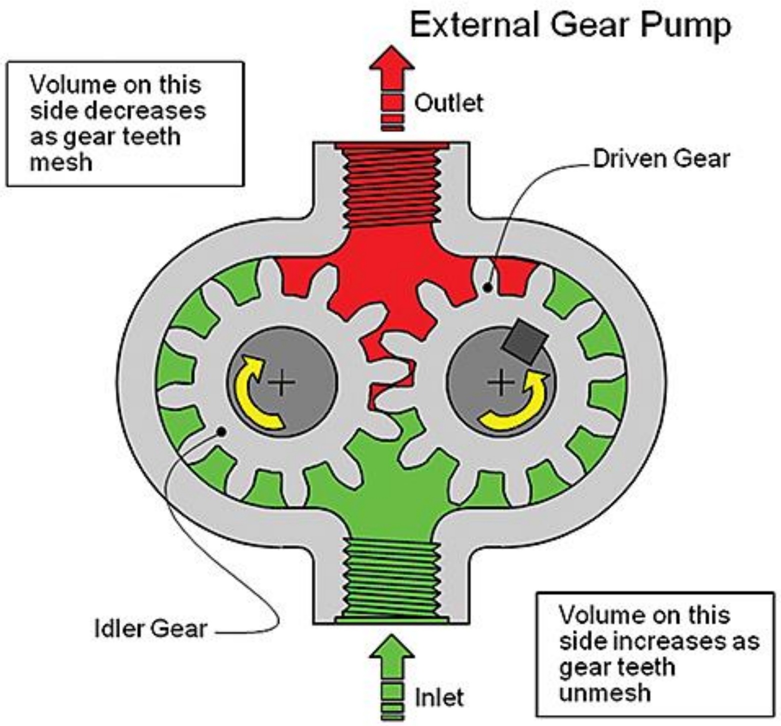
Bent axis pump

Pumps









http://www.designworldonline.com/a-quick-and-easy-guide-to-hydraulic-pump-technology-and-selection/#_

Pump equations

Ideal and real values for flow, torque and power

Produced flow rate $q_v = nV_r\eta_v$

Required torque $T = \frac{\Delta p V_r}{2\pi\eta_{hm}}$

Required power $P = \frac{q_v\Delta p}{\eta_{tot}}$

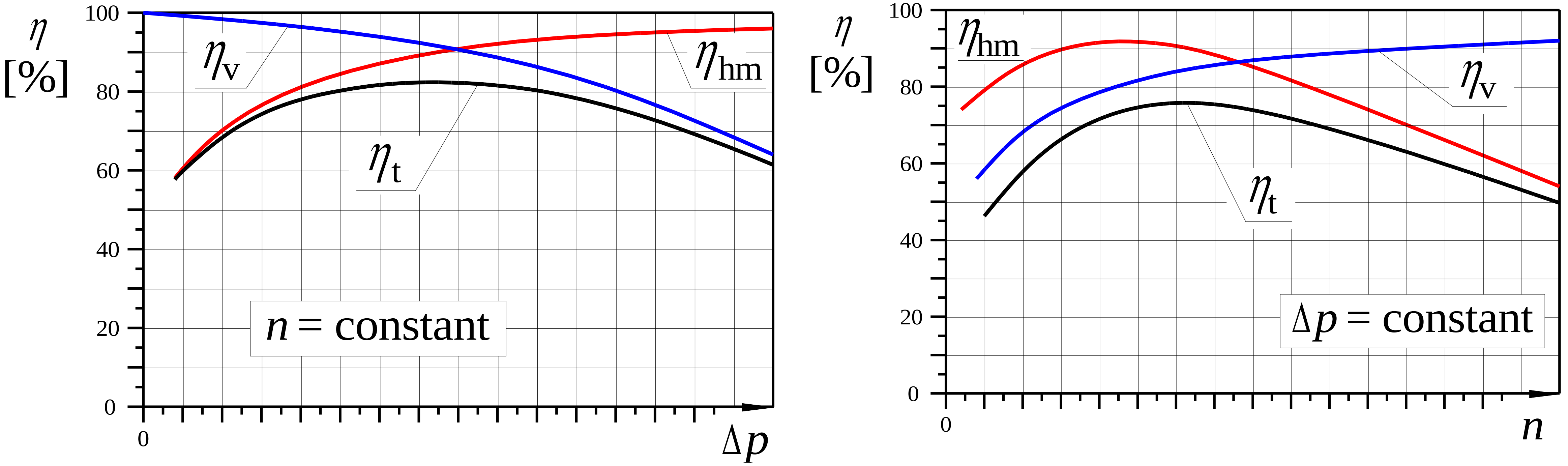
n = Rotational speed [r/s]
V_r = Displacement [m^3/r]
Δp = Pressure difference between inlet and outlet [Pa]
q_V = Flow rate [m^3/s]
η_v = Volumetric efficiency []
η_{hm} = Hydromechanical efficiency []
η_t = Overall efficiency []
$= \eta_v \cdot \eta_{hm}$

More torque and rotational speed $\Rightarrow$ input power needed because of

- Friction (hydromechanical efficiency)
- Leakages (volumetric efficiency)

than in ideal pumps

Pump efficiency



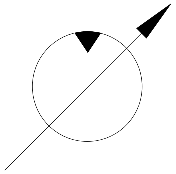
η_v : volumetric efficiency (leaks)

η_{hm} : hydromechanical efficiency (flow and mechanical frictions)

η_t : overall efficiency

Actuation: Rotational and Linear

Motors



Often exactly the same structure as in a pump

Types

- Axial piston
  - Bent axis
- Radial piston
- Gear
- Vane

Motor equations

Efficiency is taken into account inversly compared to pumps

Flow rate in $$q_v = \frac{nV_r}{\eta_v}$$

Produced torque $$\mathbf{T} = \frac{\Delta \mathbf{p} \mathbf{V}_r \eta_{hm}}{2\pi}$$

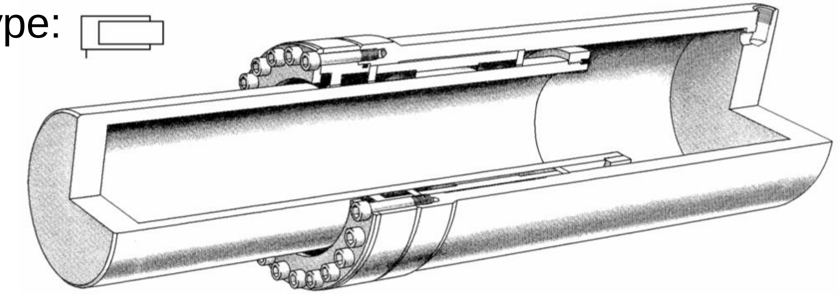
Power in $$P = q_v \Delta \mathbf{p} = \frac{\mathbf{T}\omega}{\eta_t}$$

n = rotational speed [r/s]
ω = angular velocity [rad/s]
V_r = swept volume [m^3/r]
T = load torque [Nm]
Δp = pressure difference between in- and outlet [Pa]
q_V = flow rate [m^3/s]
η_v = volumetric efficiency []
η_{hm} = hydromechanical efficiency []
η_t = overall efficiency [] $= \eta_v \cdot \eta_{hm}$

Cylinder Types

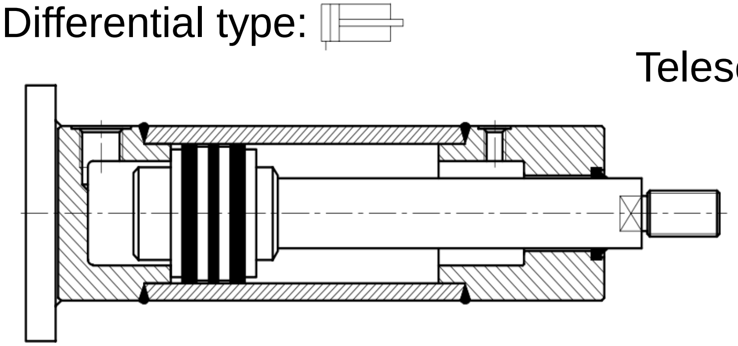
Single acting

Plunger type:

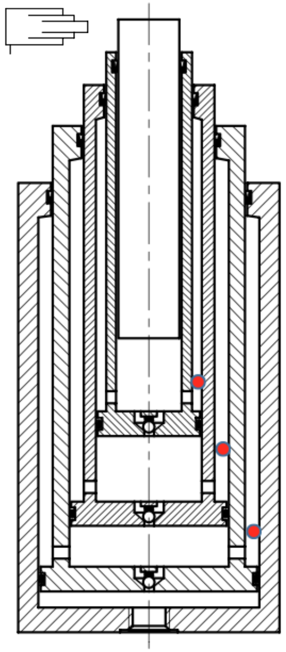


Single or Double acting

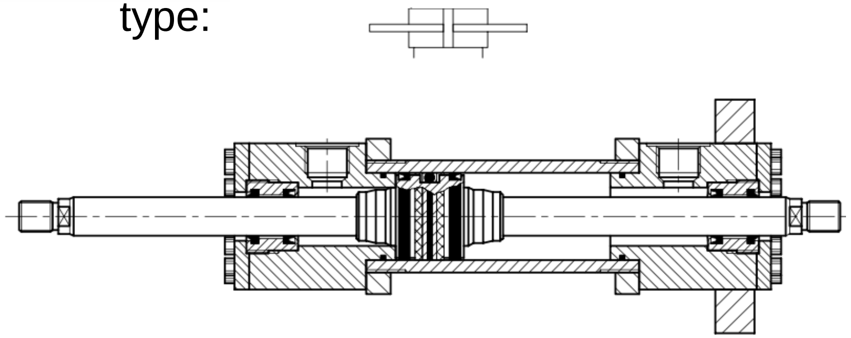
Differential type:



Telescopic type:



Non-differential (symmetric) type:



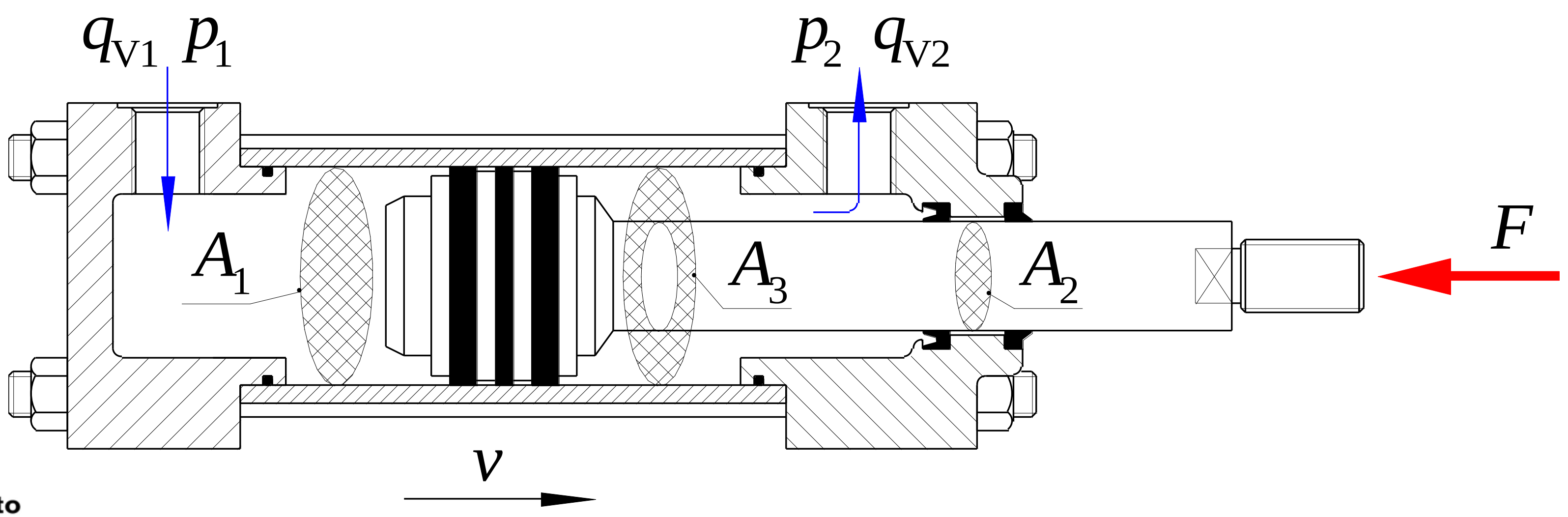
Cylinder equations

Flow rate $$q_{v1} = \frac{A_1 v}{\eta_v}$$

Force balance $$p_1 A_1 = \frac{F}{\eta_{hm}} + p_2 A_3$$

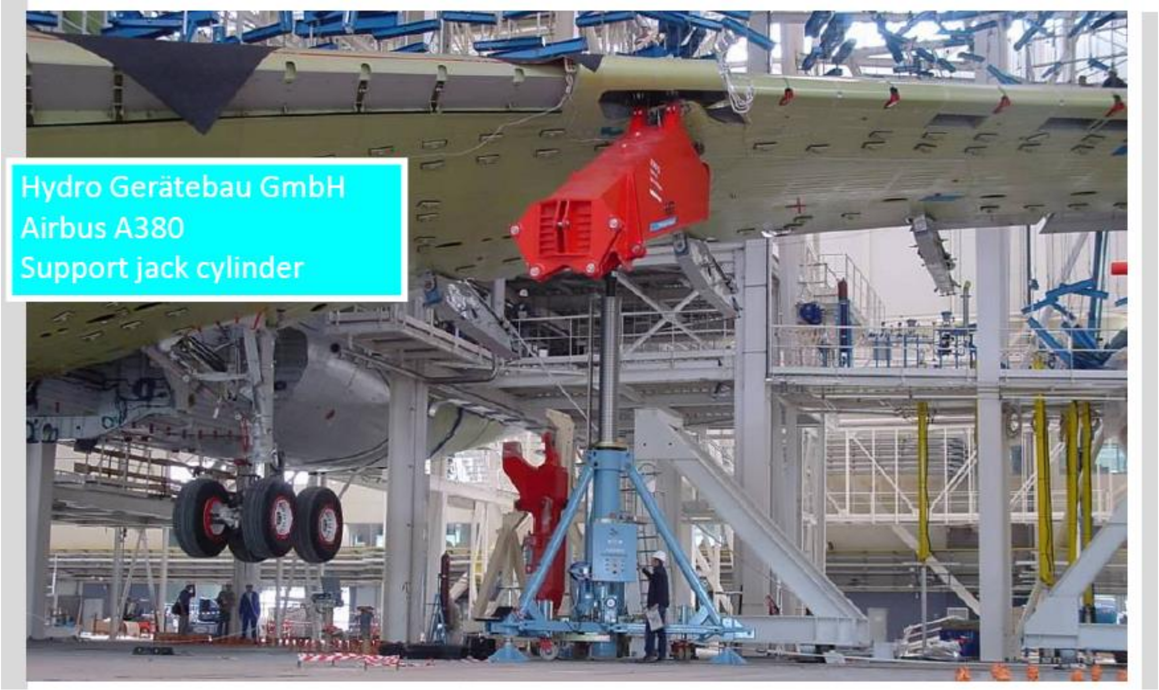
Required power $$P = q_{v1}\left(\mathbf{p_1} - \frac{\mathbf{A_3}}{\mathbf{A_1}}\mathbf{p_2}\right) = \frac{\mathbf{F_{net}v}}{\eta_t}$$

A_1	= piston area on the working chamber [m^2]
A_3	= piston area on the opposing chamber [m^2]
v	= piston speed [m/s]
F	= external load force [N]
p_{out}	= pressure on the opposing chamber [Pa]
η_v	= volumetric efficiency []
η_{hm}	= hydromechanical efficiency []
η_t	= overall efficiency []



Cylinder size

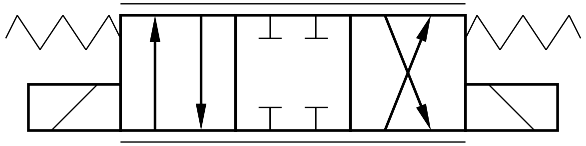
D= 500 mm
@ 400 bar
⇒ 7.7 MN
⇒ Lift 800 tons

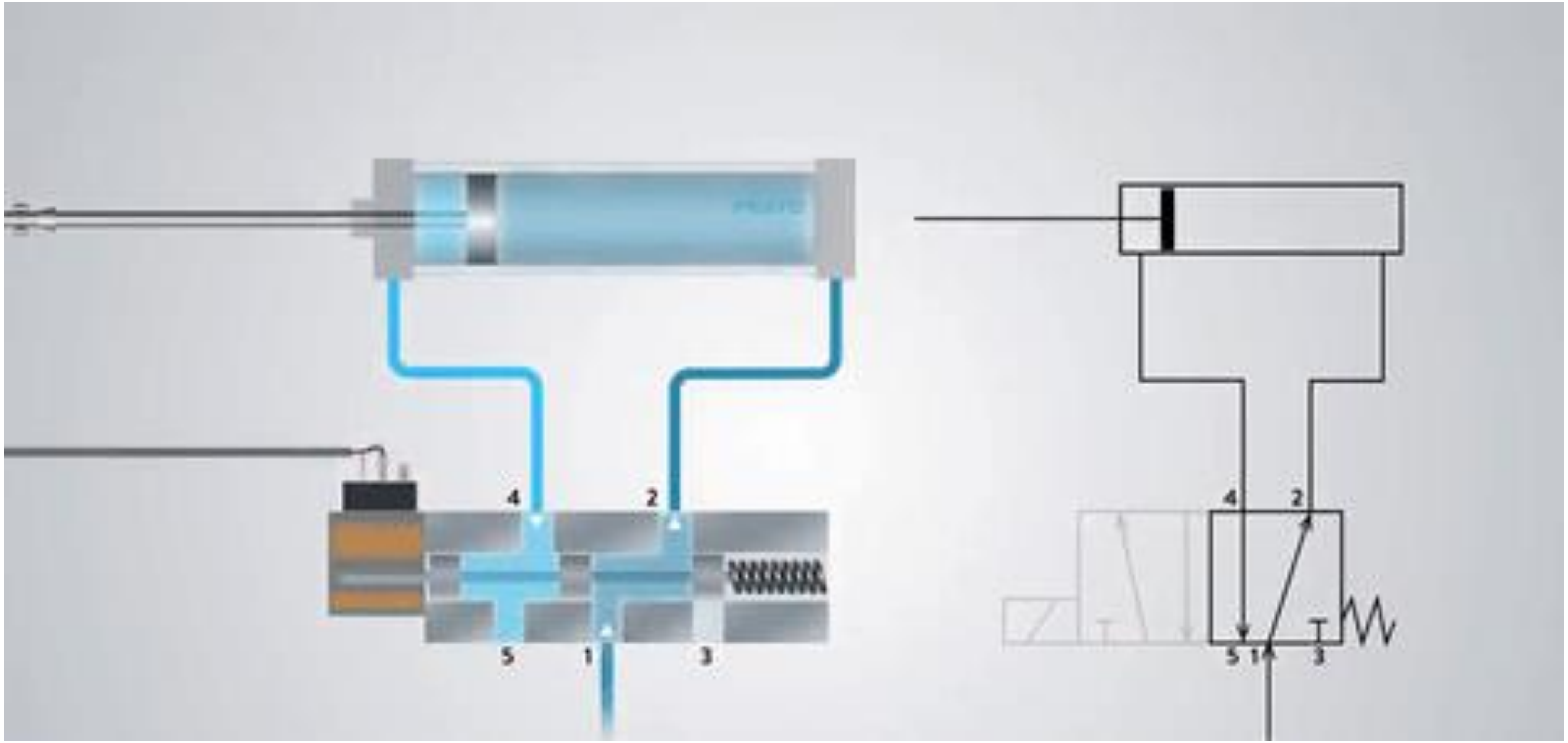


AIRBUS A380 - Superjumbo
- 3 jacks
- Cylinders made in Finland
- Empty mass 277 000 kg

Control: Valves

Directional Control Valves





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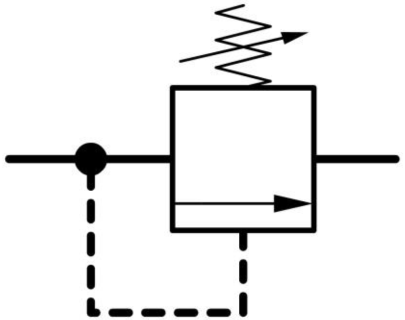
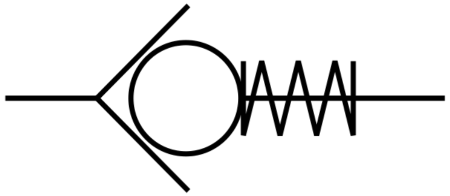
Other valves

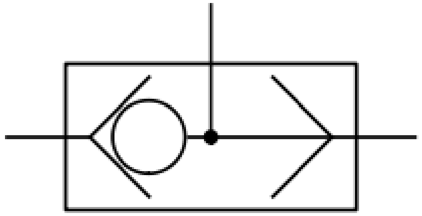
Presure Relief Valve (PRV)
To protect from over pressure
Usually connects the protected line to tank
Necessary component in practice



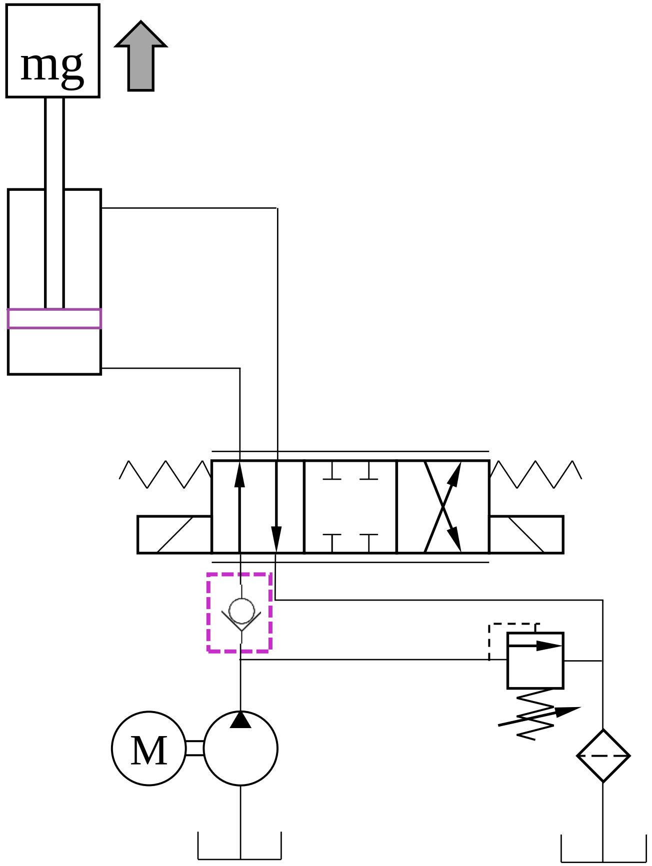
Check valve
Block reverse flow direction

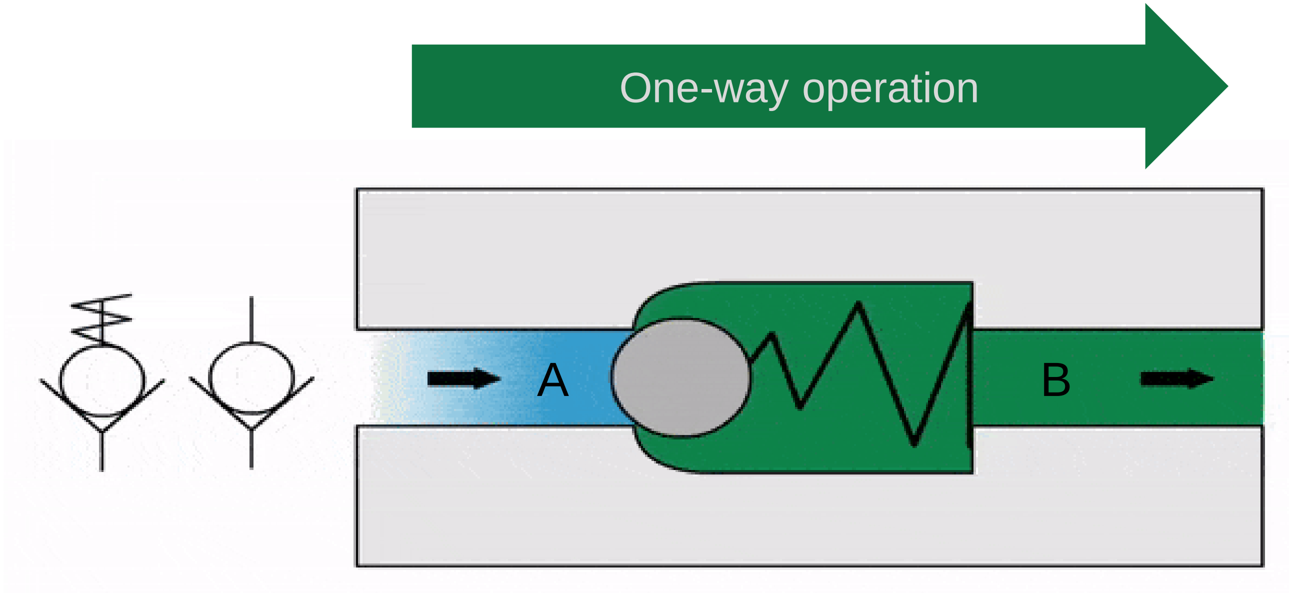


Shuttle valve
Choose the larger pressure level

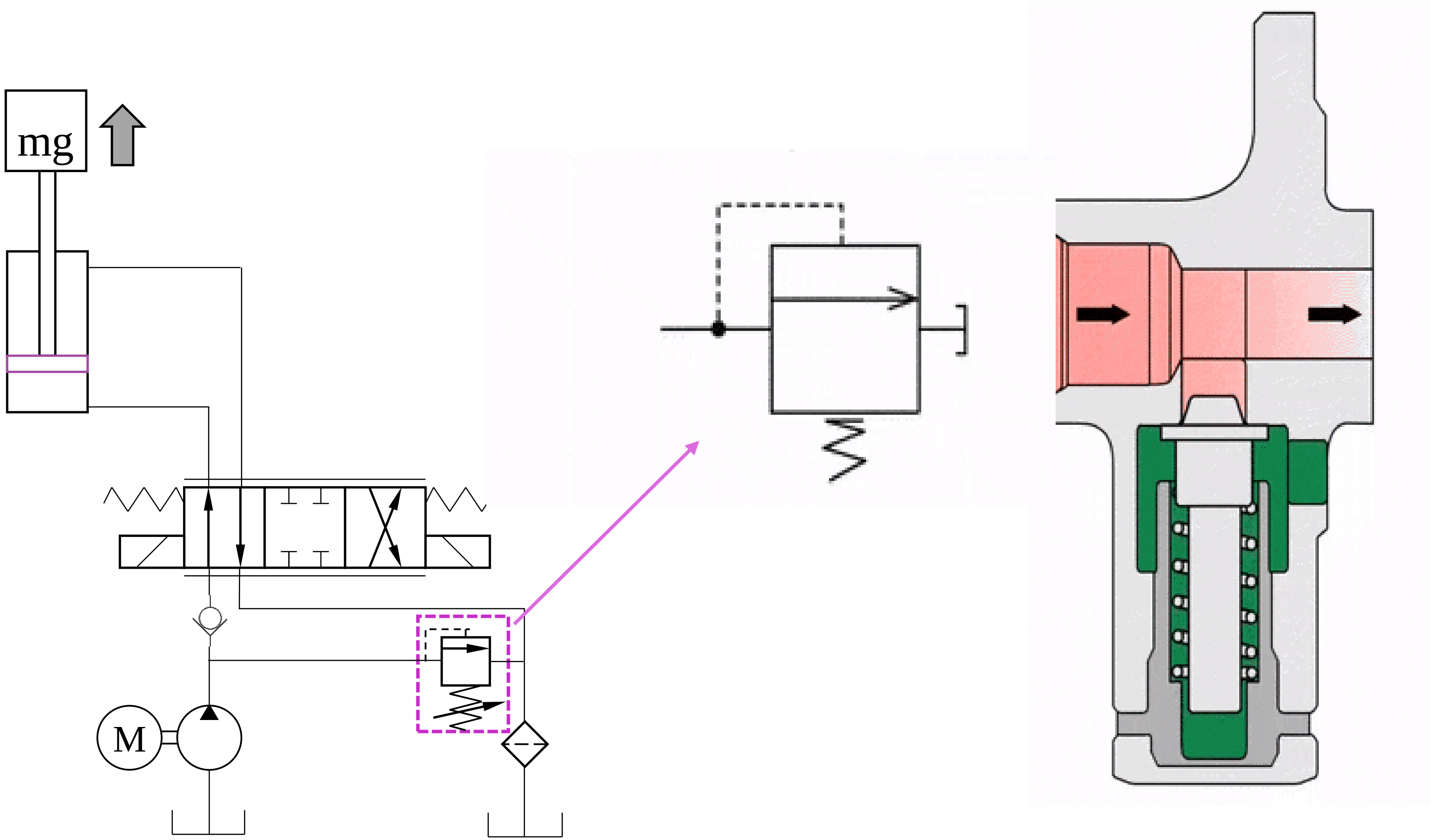


Check valve



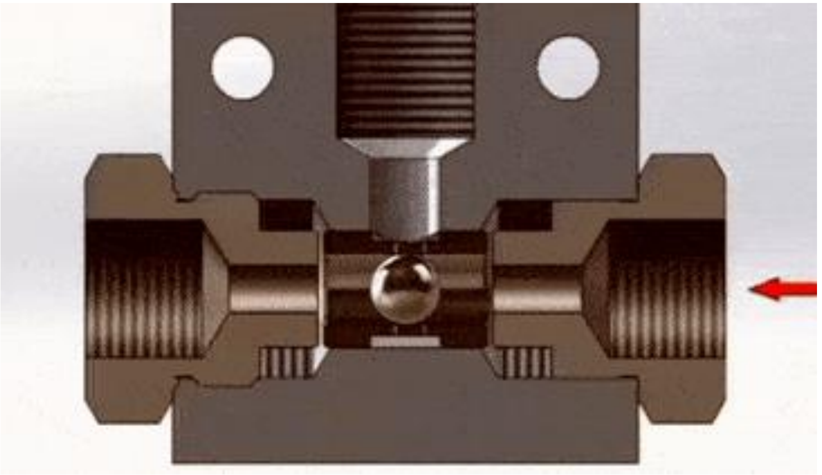


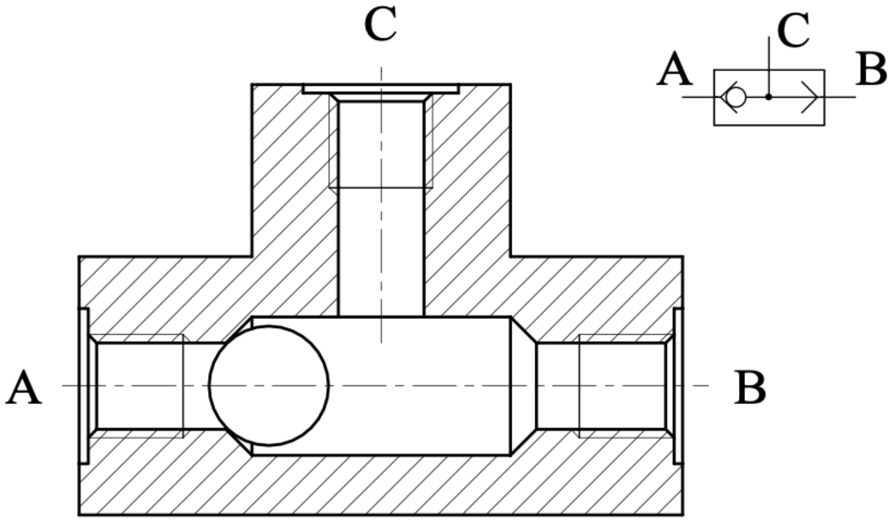
Pressure Relief Valve (PRV)



Shuttle valve

- Pressure passes from higher pressure
- Comparison between ports A and B



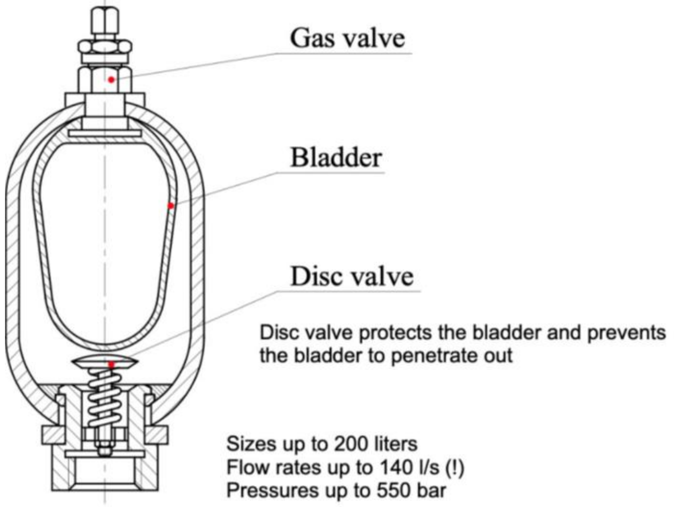


Energy Storage: Pressure Accumulator

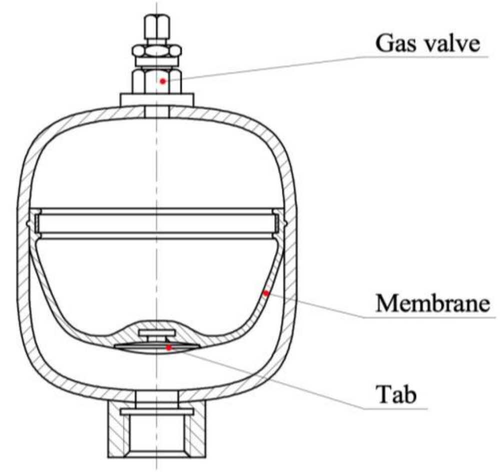
Pressure Accumulator

- Energy storage
- Fluid compresses nitrogen gas
- Pressure depends on loading condition

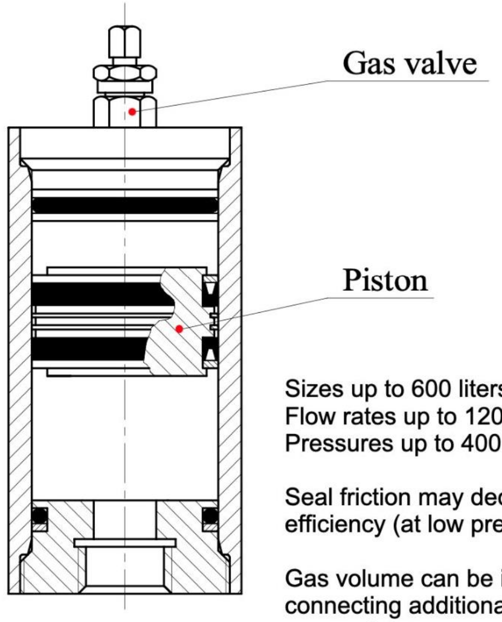
Bladder



Membrane



Piston



Sizes up to 600 liters
Flow rates up to 120 l/s (!)
Pressures up to 400 bar

Seal friction may decrease the efficiency (at low pressures)

Gas volume can be increased by connecting additional gas bottles to accumulators

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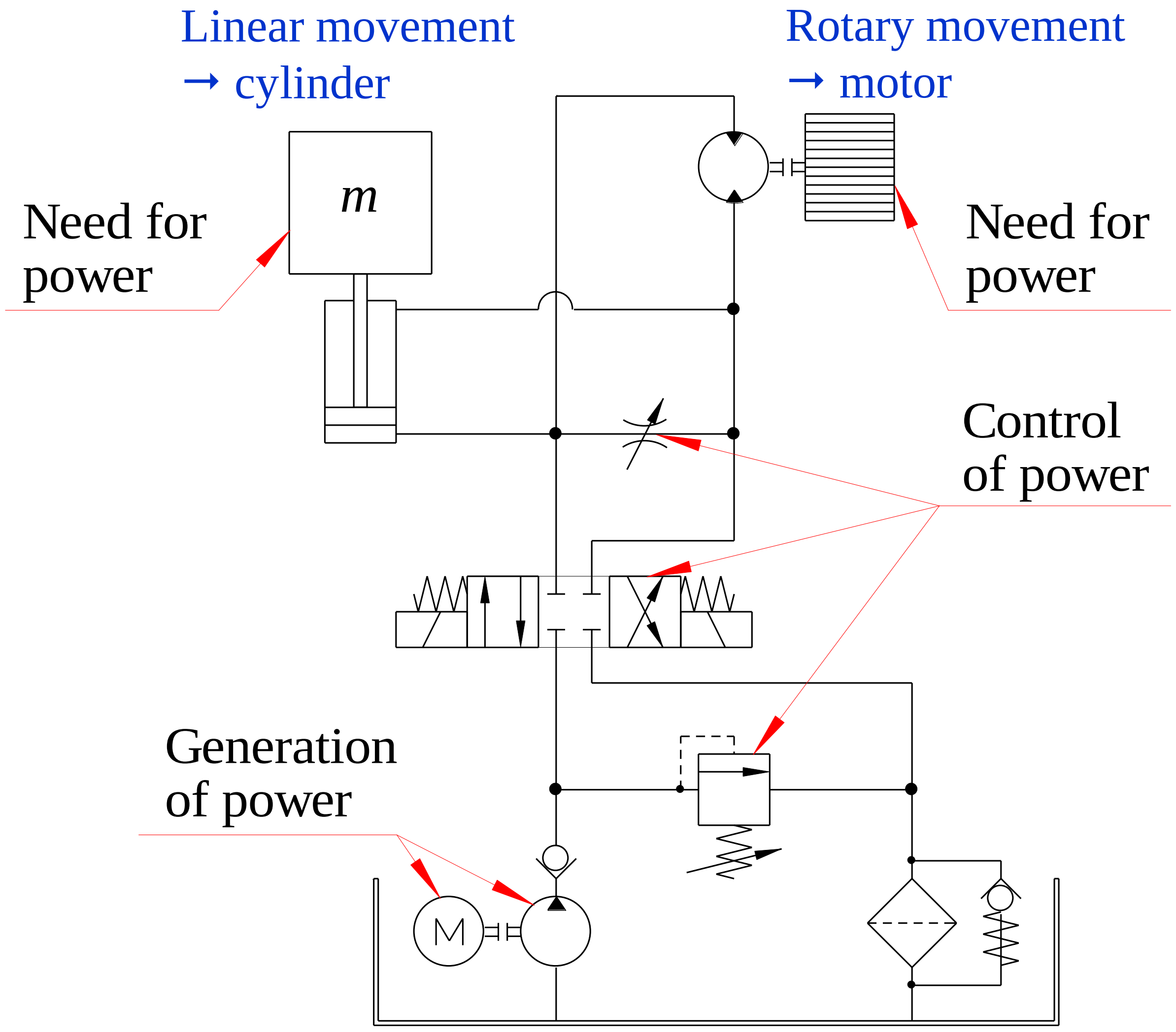
System Architectures: Throttling vs. Pump control

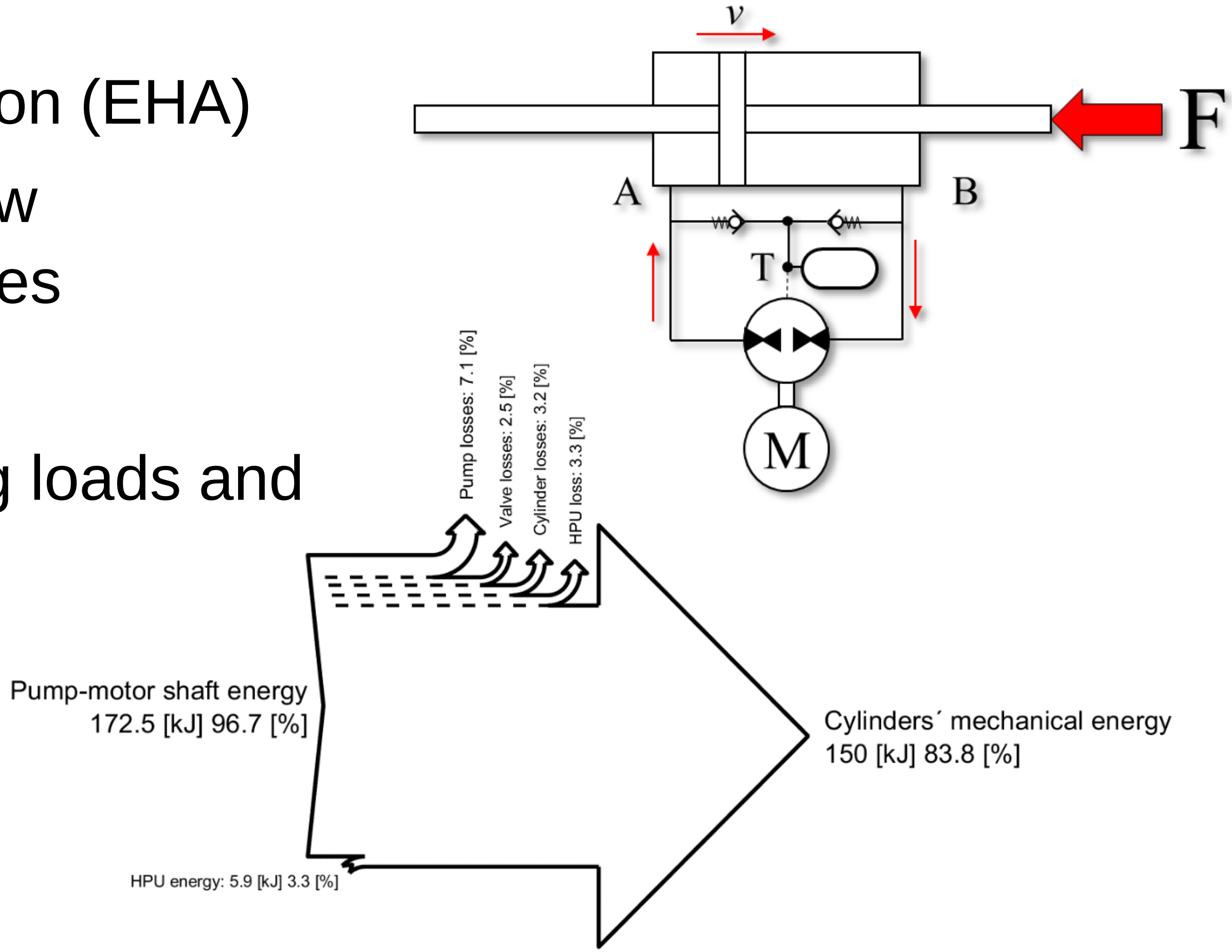
Throttle control

- ”Traditional system”
- Constant Flow
  - Engine on one speed
  - Fixed displacement pump
- <u>< 40 % efficiency</u>
- Easy to control



Pump Contro

- Aka Electro-Hydraulic Actuation (EHA)
- Electric motor controls the flow
  - No need for control valves
- <u>> 80 % efficiency</u>
- Difficult to control with varying loads and speeds



Hermansson, R. (2021). Testing and simulation of energy efficiency of direct drive hydraulic system. Master’s thesis.

Hydraulic fluids

Oil

- Good lubricant
- Environmental hazard
- Health risk
  - Food industry
- Expensive
- Fire hazard
- Viscosity index

Water

- Needs additives to lubricate
- ”Clean”
- Expensive components
- Can freeze
- Corrosion
  - Stainless steel must be used (or even plastics for low pressures)

Filtering

- Metal chips, water, air

Fluid power systems

Pros

- **High power/weight –ratio**
- **Linear and rotational motion**
- **Robust control**
  - Compliant if needed
  - Overload prevention
- **Freedom of system layout**
  - Distributed power

Cons

- **Energy efficiency**
  - 22 % on avg.
    - New tech even over 80%
- **Characteristics of pressure medium**
  - Leaks
  - Impurities

3. Applications and Research

Workmachines

Harvester

Excavator

Mining loader

Wheel loader

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Boston dynamics: Atlas

28 hydraulic joints

Telescopic crane

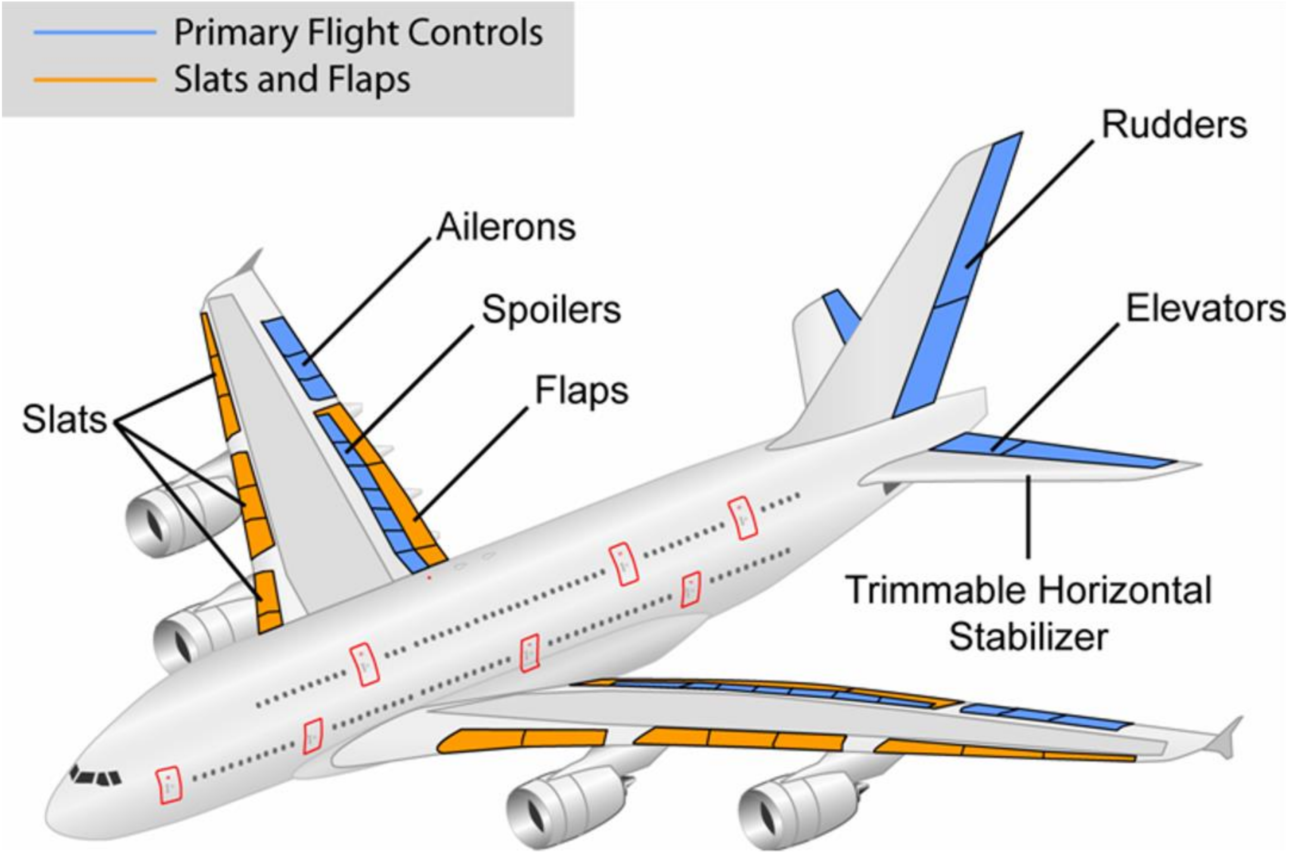
Airplanes

Elevator, rudder

Landing gear

Brakes

Cargo doors, stairs



Hydraulic press

Forming sheets by pressing them into a mold with a huge force

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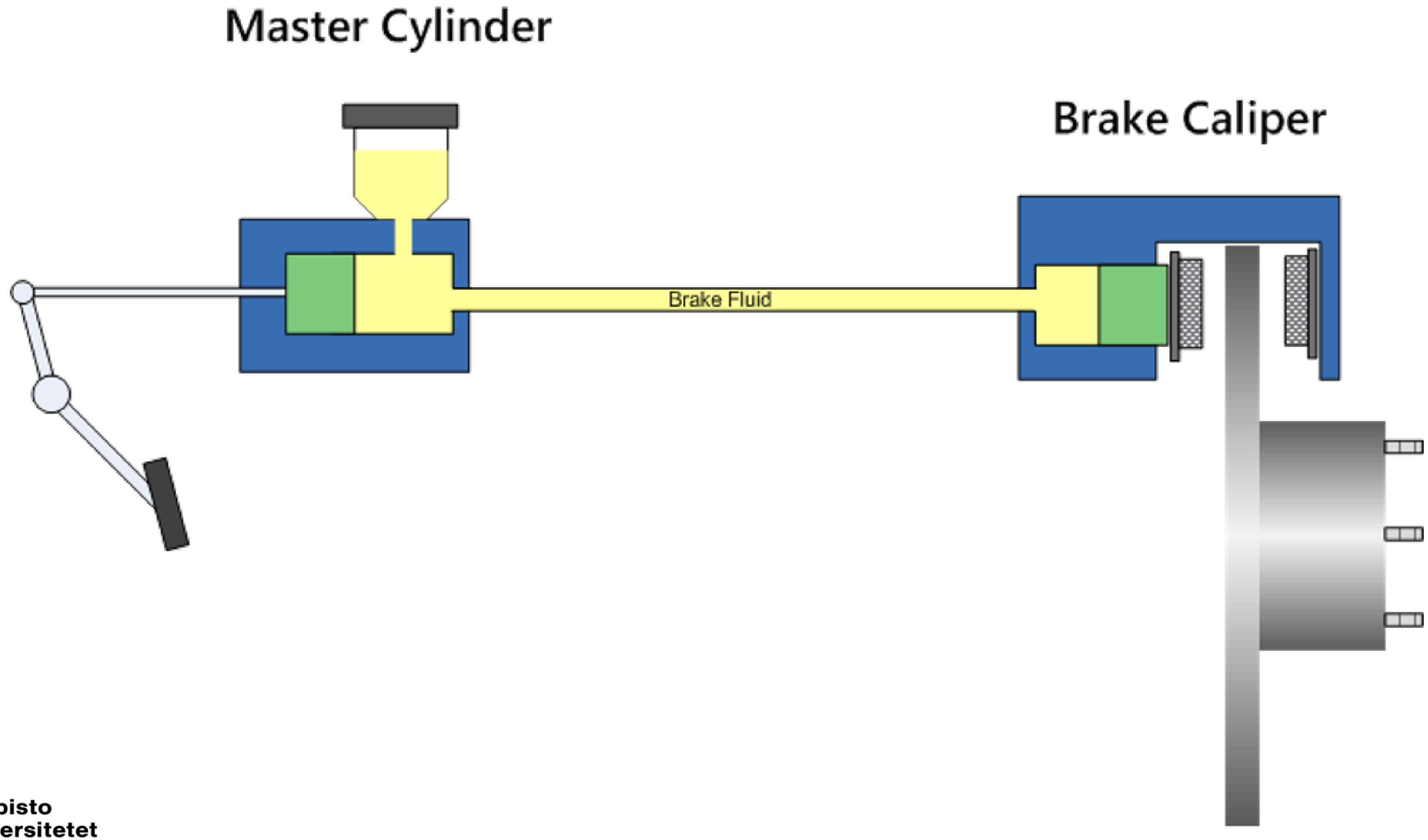
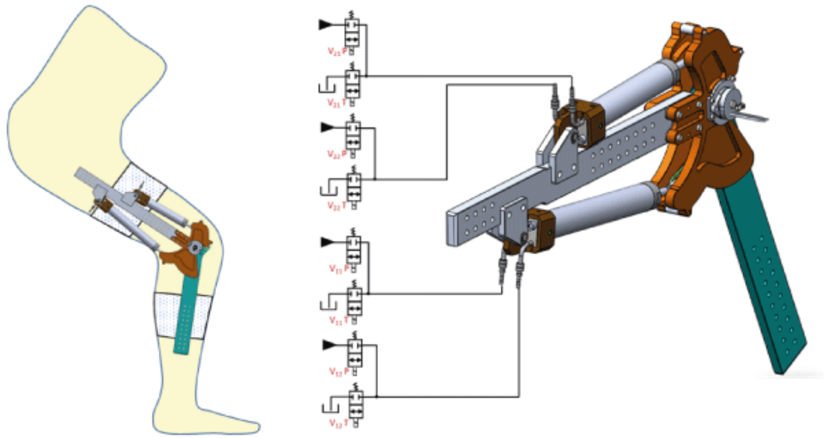
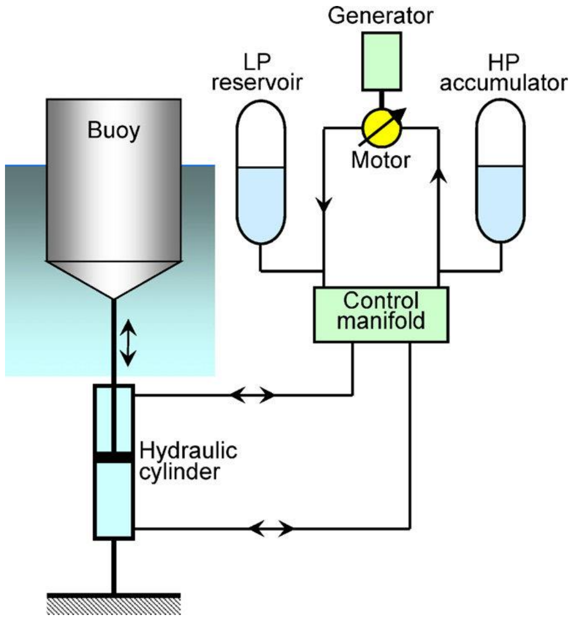
Hydraulic brakes



Emerging Technologies

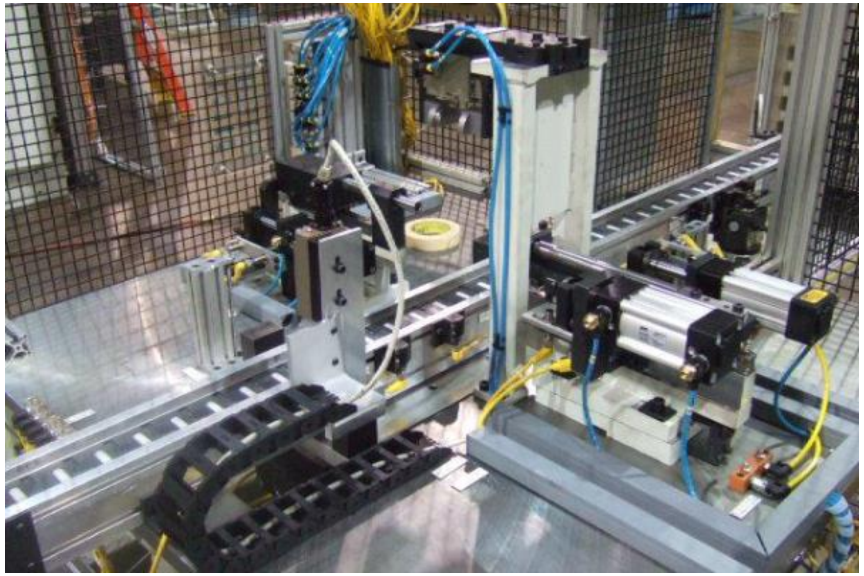




Exoskeletons
Aging population

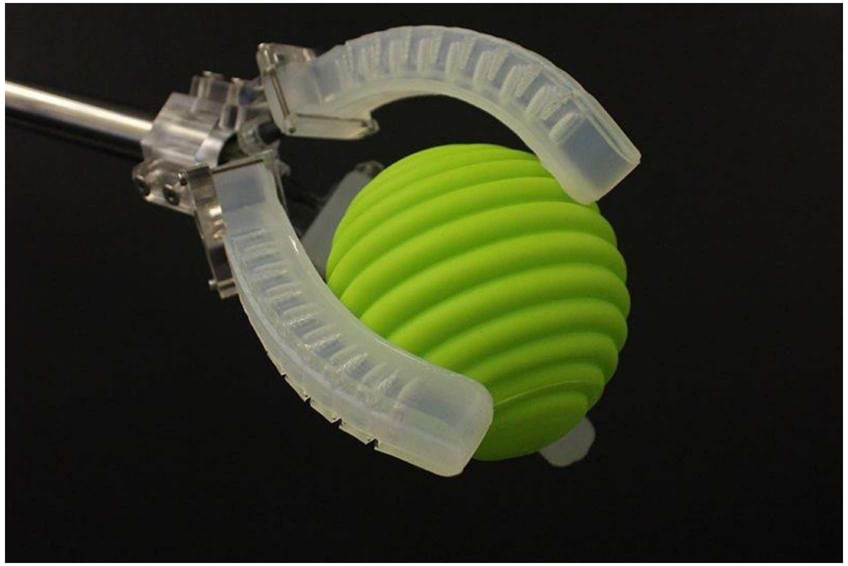
Wave Energy Converters
Climate crisis

Pneumatics

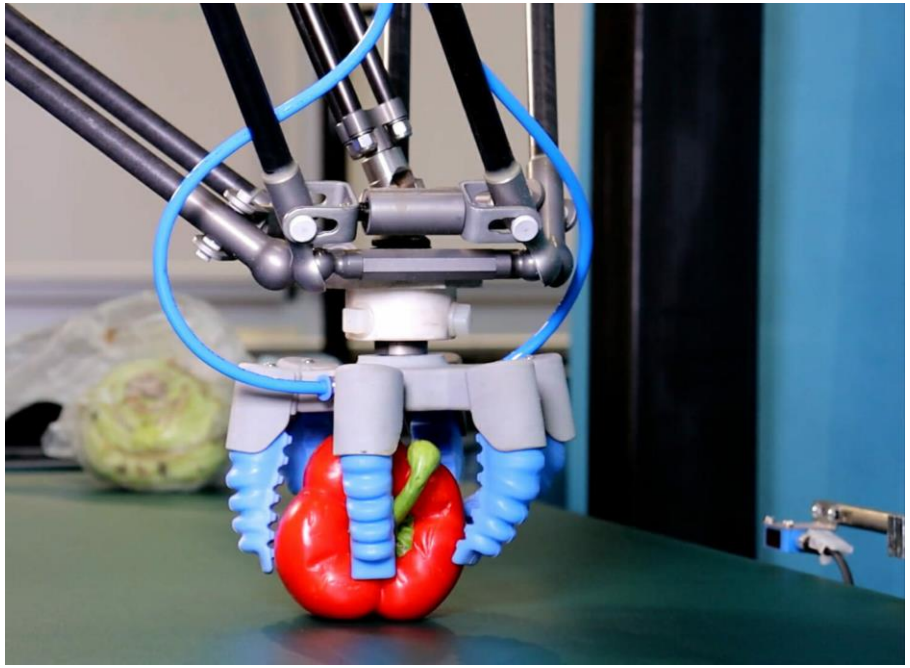


Production Line automation
- fast actuation

Soft grippers



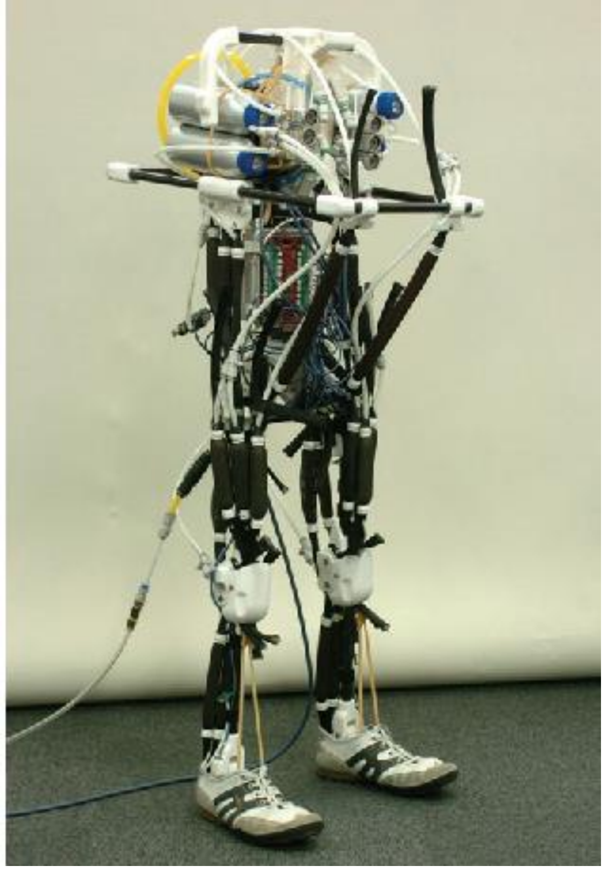
- Compliant grip
- Usually coupled with force sensing or haptic sensing

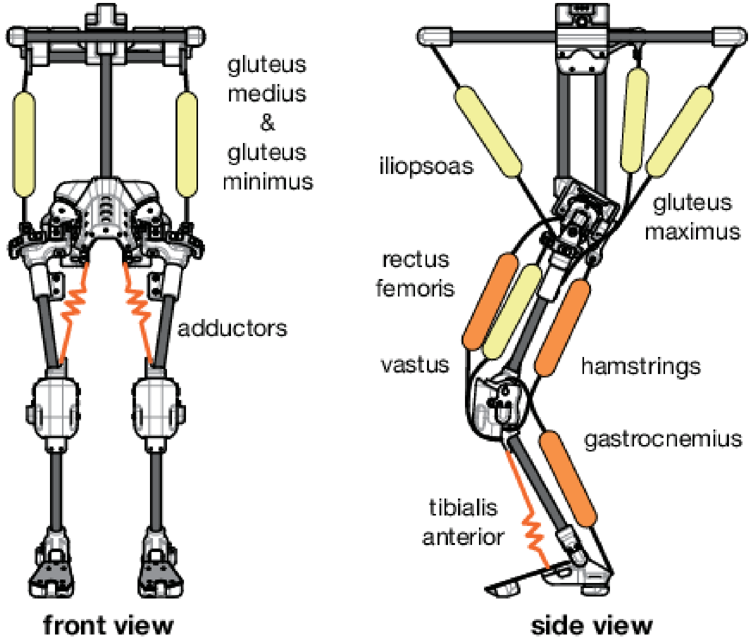


Soft gripper

Pneumatic muscles

- **Very light weigth**
- **Inherently compliant**
- **Biomimetic**





Research focus: Non-Road Mobile Machinery

There is a need for electrification to reduce emissions and improve efficency. High power requires large batteries and motors. Challeges:

- Cost
- Weight
- Space
- Heat

Challenge: Industry is very conservative, hard to introduce new solutions

Research Topics Breakdown

- Non-Road Mobile Machines
  - System Design
    - Improved Performance
      - Energy Recuperation
      - Optimizing Components
    - Increasing Longevity
      - Vibration Damping
      - Predictive Maintenance
  - Thermal Design
    - Waste Heat Utilization
      - Adsorption Materials
    - Managing Peak Loads
      - Phase Change Materials
      - Cooling Dimensioning

Summary

Hydraulics is a power transmission method

- Pressure differences required to create flow
- High forces and power from compact actuators
- Good efficiency actuators, often bad efficiency systems

Hydraulic system consists of

- Powerpack: eMotor/Engine + Pump
- Actuators: Cylinders and motors
- Valves: Directional and Control
- Sensors: pressure, flow, position, force, temperature
- Fluid: oil, water
- Utilities: Pressure accumulator, heat exchanger, filters, tank

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