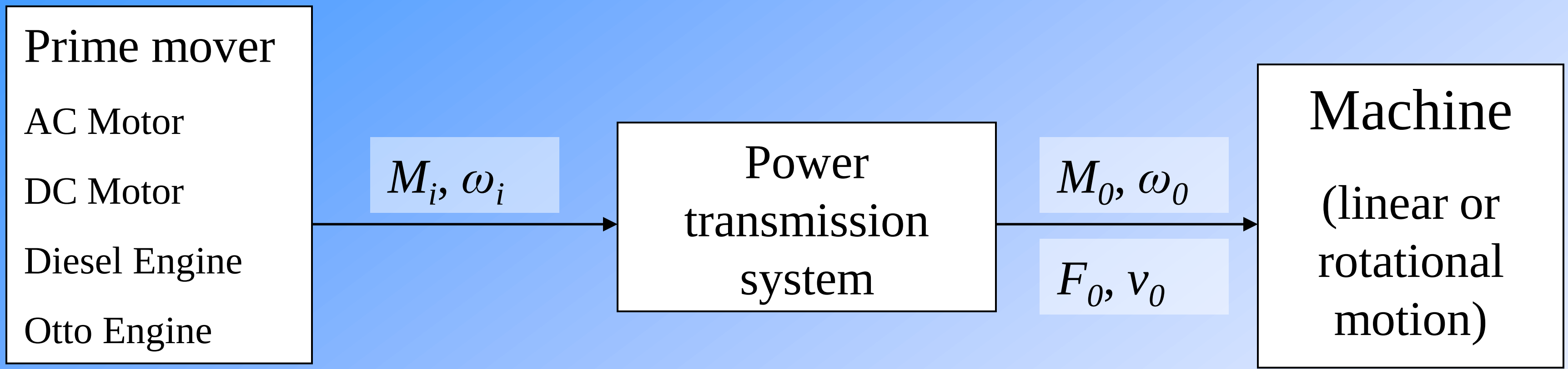
Hydraulic and Pneumatic Systems

Power train



- Mechanical power transmission:
  - Gears
  - Belt drive
  - Friction drive
  - Rigid couplings
  - Clutches

Properties:

- Continuously variable drive is difficult
- The relative spatial position of prime mover is fixed
- If the motor is electrical (DC motor or AC motor with variable frequency), then the rotational speed can be continuously changed but they are expensive

Hydraulic power transmission

- Hydraulic power transmission:

Hydro = water, aulos = pipe

The means of power transmission is a liquid (pneumatic → gas)

Hydrodynamic power transmission:

- Turbo pump and turbine
- Power transmission by kinetic energy of the fluid
- Still the relative spatial position is fixed
- Compact units

Hydrostatic power transmission:

- Positive displacement pump
- Creates high pressure and through a transmission line and control elements this pressure drives an actuator (linear or rotational)
- The relative spatial position is arbitrary but should not be very large because of losses (< 50 m)

✓ A continuously variable transmission is possible

Most of this lecture will be about hydrostatic systems (in common language it is also called simply hydraulics)

Hydrostatic vs hydrodynamic systems

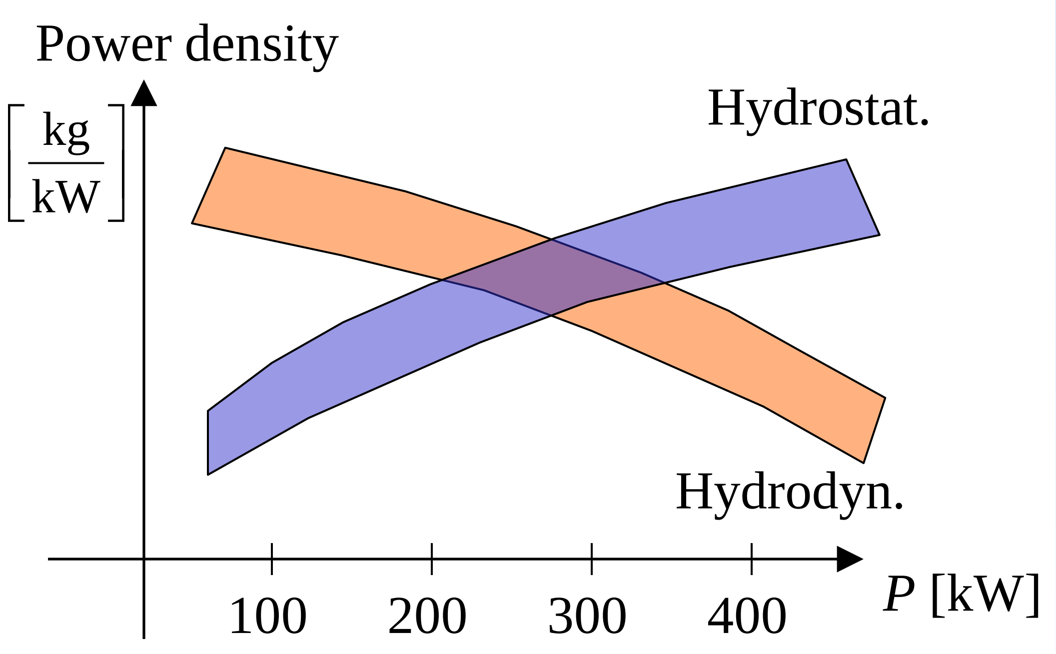
Roughly speaking:

$P = \Delta p \cdot Q$

Large Q, small Δp → **hydrodynamic** transmission

Large Δp, small Q → **hydrostatic** transmission.

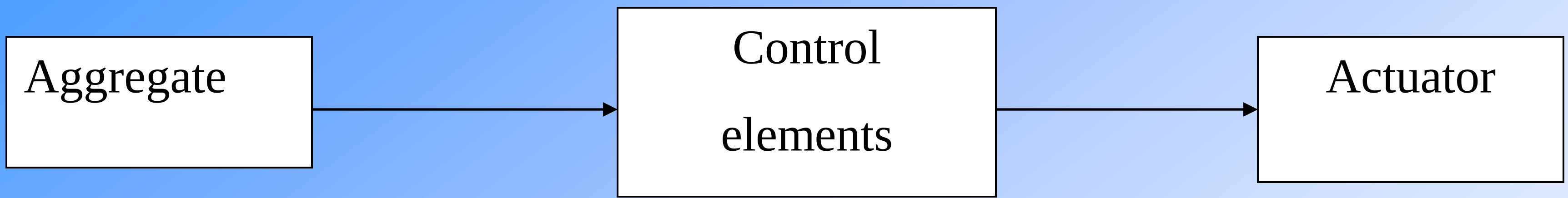
But there is no general rule, depends on the task.



- Generally larger than 300 kW power hydrodynamic is more favourable.
- But for soft operation (starting of large masses) hydrodynamic is used for smaller powers either.

- ❑ Linear movement against large forces: hydrostatic
- ❑ Linear movement and stopping in exact position: also hydrostatic

Structure of a hydrostatic drive



Pump, motor

Fluid reservoir

Pressure relief valve

Filter

Piping

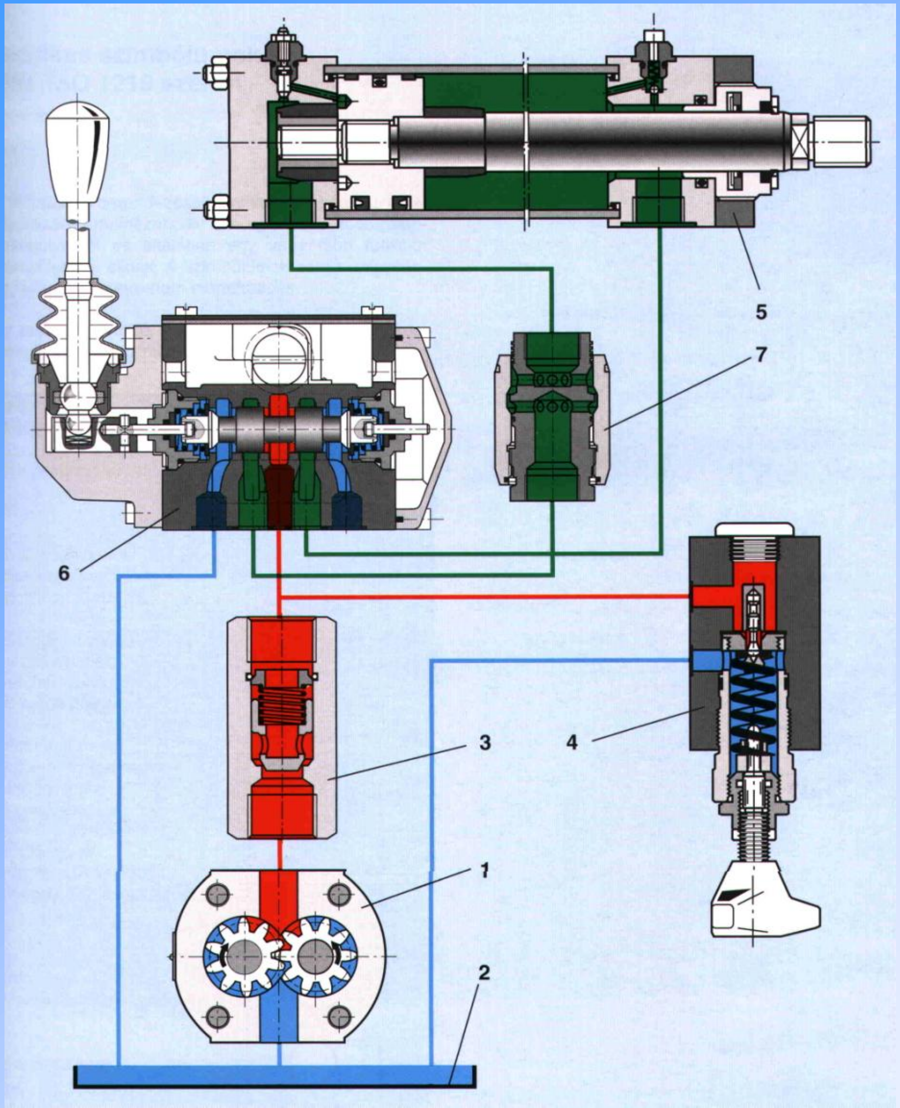
Valves, determining the path, pressure, flow rate of the working fluid

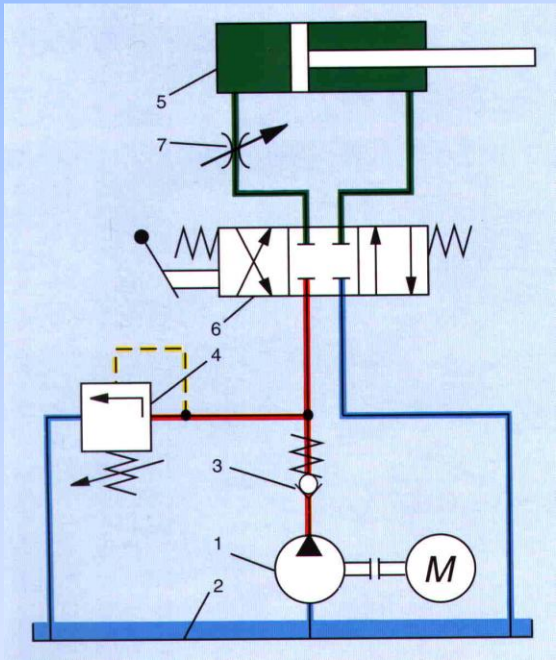
Elements doing work

- Linear
- Rotational
- Swinging

These components and their interaction is the subject of this semester

A typical hydraulic system





1 – pump

2 – oil tank

3 – flow control valve

4 – pressure relief valve

5 – hydraulic cylinder

6 – directional control valve

7 – throttle valve

Advantages of hydrostatic drives

- Simple method to create linear movements
- Creation of large forces and torques, high energy density
- Continuously variable movement of the actuator
- Simple turnaround of the direction of the movement, starting possible under full load from rest
- Low delay, small time constant because of low inertia
- Simple overload protection (no damage in case of overload)
- Simple monitoring of load by measuring pressure
- Arbitrary positioning of prime mover and actuator
- Large power density (relatively small mass for a given power compared to electrical and mechanical drives)
- Robust (insensitive against environmental influences)

Disadvantages of hydrostatic drives

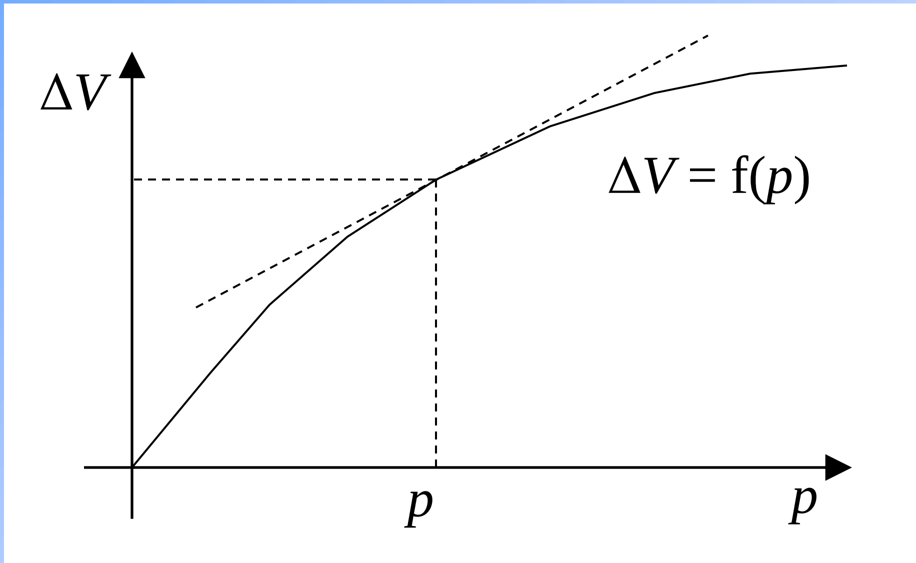
- Working fluid is necessary (leakage problems, filtering, etc.)
- It is not economic for large distances

Hydraulic capacity and inductivity

Hydraulic capacity:

All the things discussed so far referred to steady processes. In practice, however, very often unsteady processes are encountered: starting, stopping, change of load, change of direction of motion, etc.

In these cases the compressibility of the fluid and the pipes, and the inertia of the fluid have to be taken into consideration.



Nonlinear function.

It can be locally linearized and:

$$\frac{\mathrm{d}\Delta V}{\mathrm{d}p} = C_h, \text{ hydraulic capacity.}$$

Hydraulic capacity and inductivity

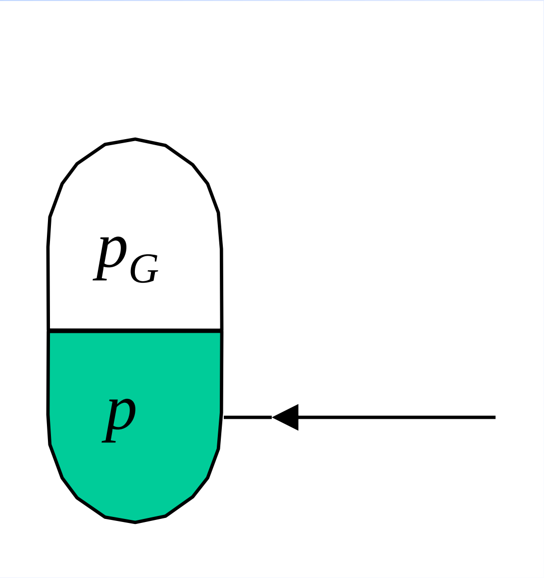
Hydraulic capacity:

The capacity has three parts:

$$C_h = C_{fl} + C_{pipe} + C_{accumulator}$$

The capacitive flow rate:

$$Q_c = \Delta\dot{V}_c = C_h \cdot \dot{p} \Rightarrow p = \frac{1}{C_h} \cdot \int Q_c \mathrm{d}t$$



$$C_{fl} = \frac{V_0}{K}$$ K compression module

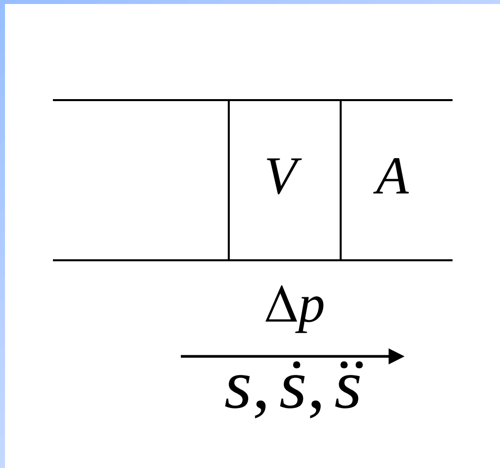
C_{pipe} is negligible if the pipe is made of metal

C_{pipe} is not negligible if the pipe is flexible.

$$C_{accumulator} = \frac{V_1}{n \cdot p} \cdot \left(\frac{p_G}{p}\right)^{\frac{1}{n}},$$ n is the polytropic exponent.

Hydraulic capacity and inductivity

Hydraulic inductivity:



$$\Delta p \cdot A = \rho \cdot V \cdot \ddot{s}, \quad \ddot{s} = \frac{\dot{Q}}{A}$$

$$\Delta p = \frac{V \cdot \rho}{A^2} \dot{Q}$$

$$\Delta p = L_h \cdot \dot{Q}_{in} \Rightarrow Q_{in} = \frac{1}{L_h} \int \Delta p \, \mathrm{d}t$$

$L_{total} = L_h + L_{sol}$, where L_{sol} is the inertia of solid parts.

Hydraulic Accumulators

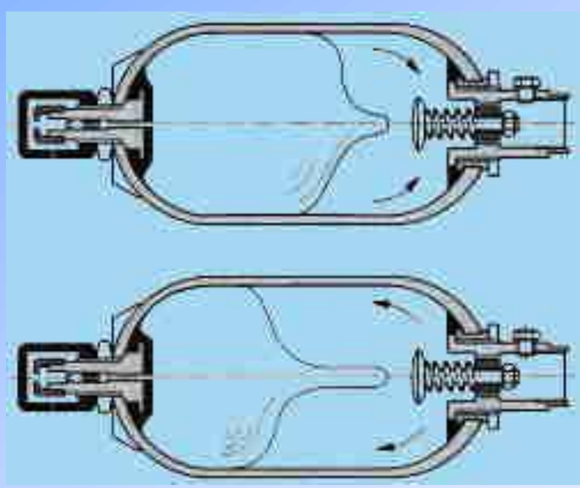
Working states of hydroaccumulators with bladder:

This installation is practically a bladder filled with gas and placed in a tank made out of steal. The bladder is filled with carbon dioxide (gas pressure). At the starting of the pump the fluid flows in the tank and compresses the gas. When required (if there is a high enough pressure difference) the fluid flows very quickly back in the system.

Requirements on the system side:

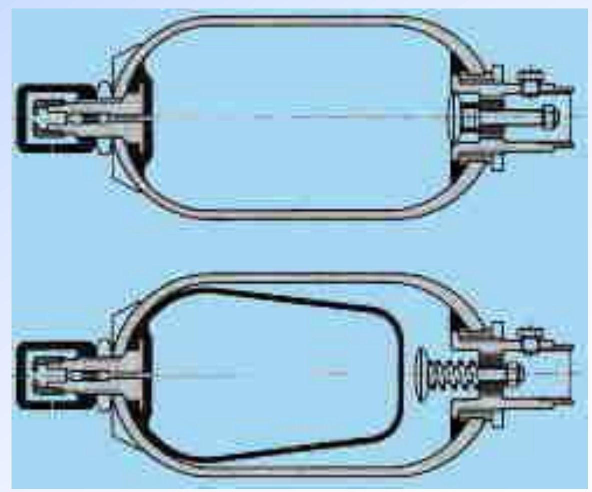
- locks both in the T and P lines,
- controlled release valves,
- juncture for pressure manometer (mostly built with the hydroaccumulator together),
- throw back valve in the P line.

Fluid flows out



Fluid flows in

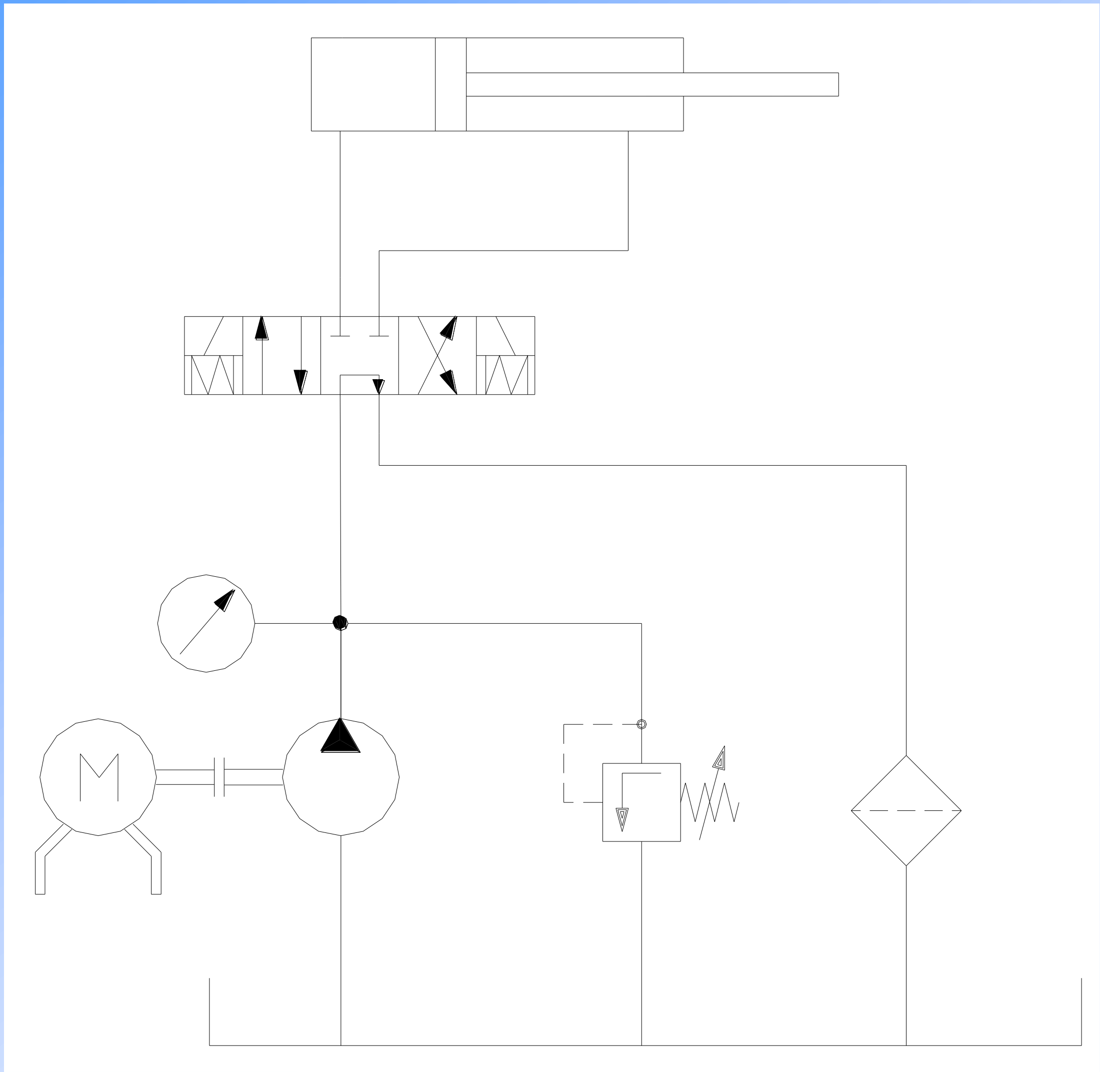
Hydroaccumulator with pre-stressed bladder



pressureless, without pre-stress

Hydraulic Systems

Typical hydraulic system:



Hydraulic Systems

Pressure reservoirs = Accumulators

Serve three purposes:

- damping of pressure and volumetric flow rate oscillations,
- supplying the flow rate at variable demand,
- hydropneumatic spring.

They use the compressibility of a gas but the gas and liquid surface may not touch because then the gas will be dissolved in the liquid.

Three constructions:

a. Piston

b. Bladder (bag)

c. Membrane