Aalto University
School of Engineering

MEC-E5003

FLUID POWER BASICS

Study Year 2019 - 2020

Introduction
Graphic symbols
Hydromechanics

Aalto University
School of Engineering

Lecture themes

Hydraulics – What is it actually? Why and where to use hydraulics? Pressure – What and Why?

Is pressure any good for something?

FLUID

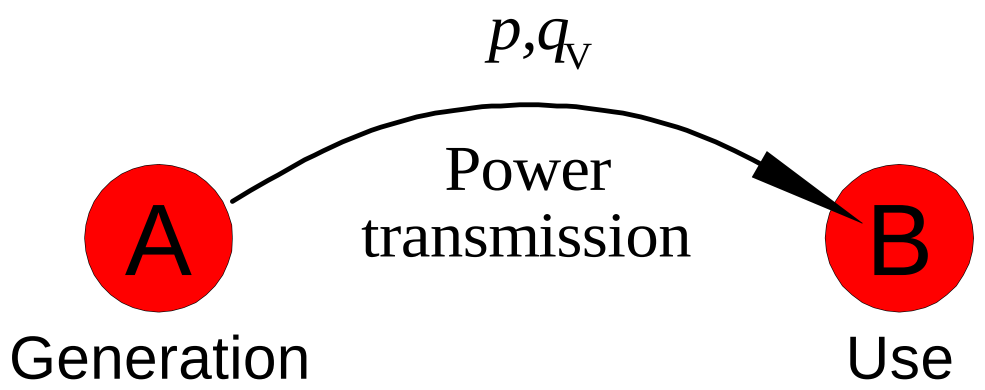
” Fluid, any liquid or gas or generally any material that cannot sustain a tangential, or shearing, force when at rest and that undergoes a continuous change in shape when subjected to such a stress”

Reference: Encyclopædia Britannica

”FLUID POWER” covers both hydraulics (liquids, oil/water hydraulics) and pneumatics (gas, air).

Power transmission
Technology of converting power to a more useable form and distributing it to where it is needed. (by NFPA)
https://www.nfpa.com/home/AboutNFPA/What-is-Fluid-Power.htm

Hydraulic systems



Pros

High power/weight -ratio
Linear and rotational motion
Ease of control
Overload prevention
Freedom of system layout

Cons

Mediocre efficiency
Characteristics of pressure medium

Application examples

Mobile hydraulics
Industrial hydraulics

U.S. manufacturing of fluid power components reached a record-high $21.7 billion in 2017











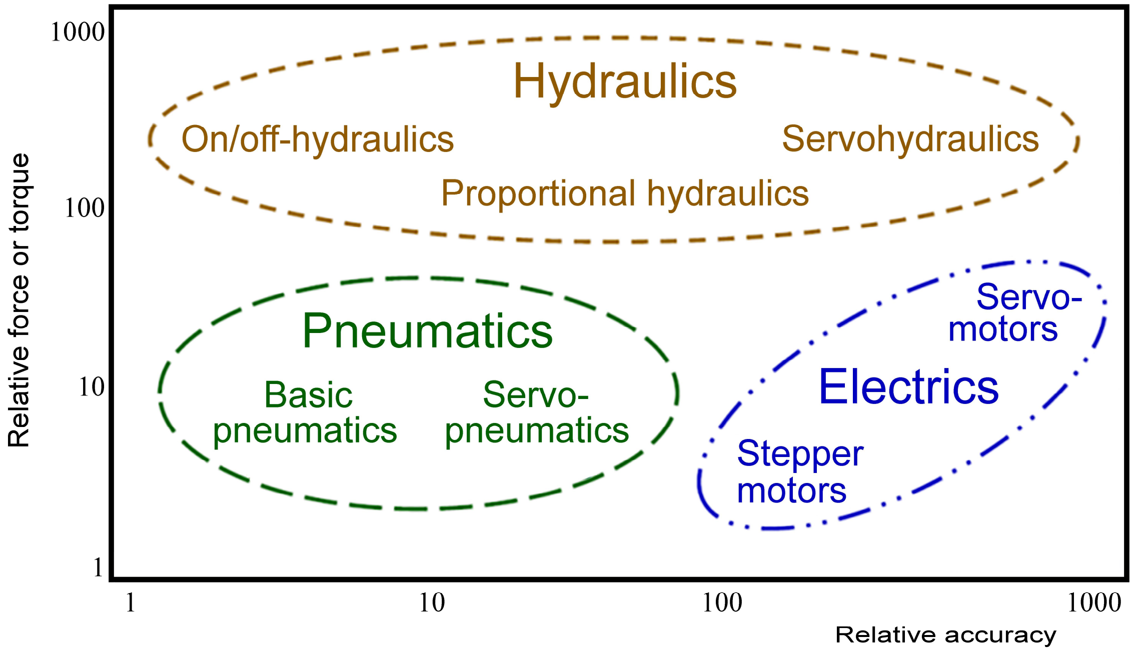

https://www.nfpa.com/home/industry-stats/Annual-Report-on-US-Fluid-Power-Industry.htm

Application areas of hydraulics

Accuracy of
- Position
- Velocity
- Force

etc.

Force or torque D accuracy

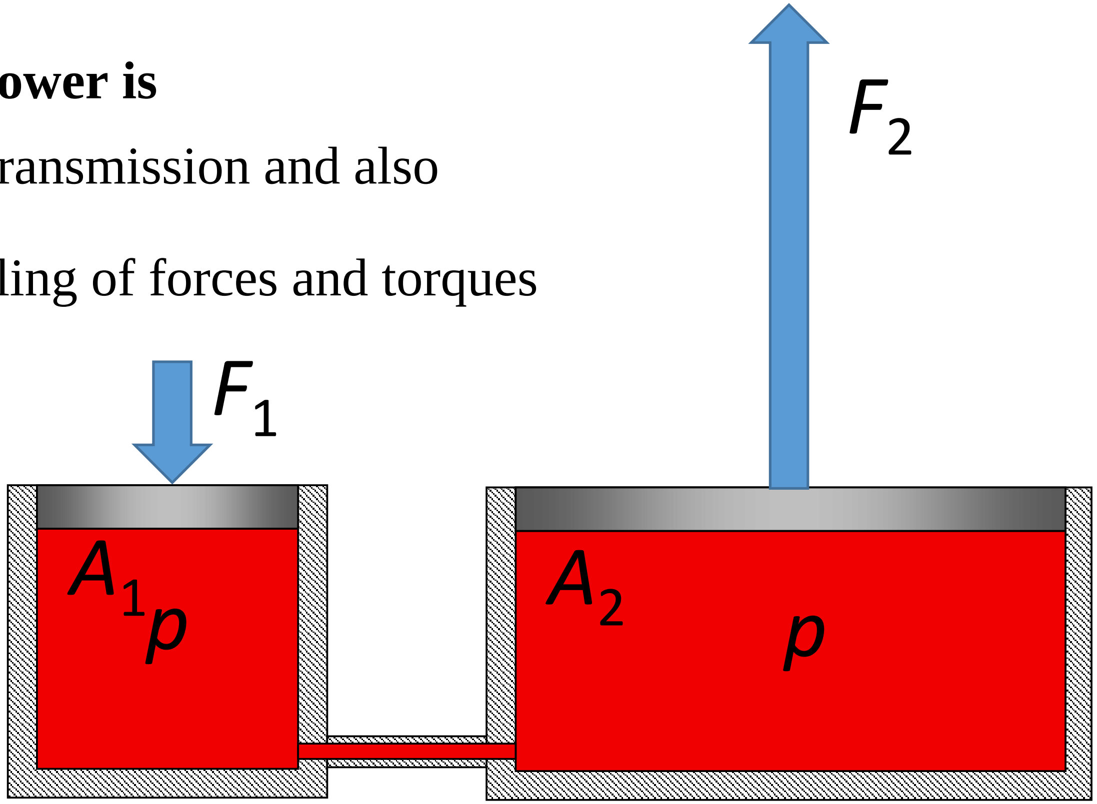


Pressure and Force

Fluid power is

Power transmission and also

Controlling of forces and torques



Unit [Pa] =[N/m^2]

10^5 Pa = 1 bar

Typical pressures

100 - 350 bar $\Rightarrow$ 10 - 35·10^6 N/m^2

Forces are easily very high!

$$F = pA$$

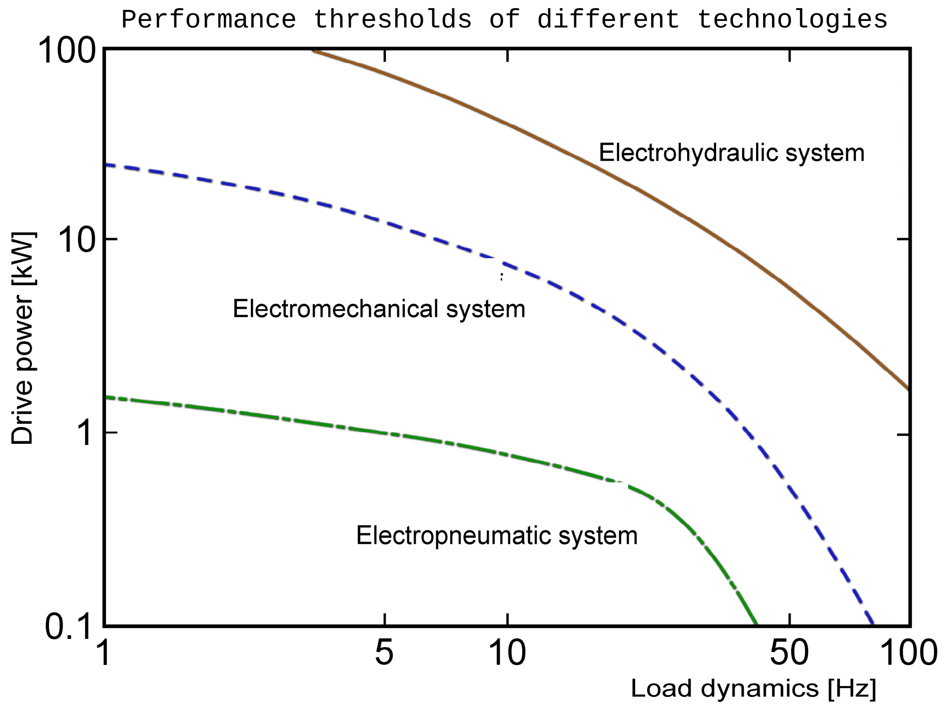
Stationary case:

$p_1 = p_2$

Pascal's Principle

Application areas of hydraulics

Power D dynamics



System characteristics

Range of pressures and ambient temperatures is large.

Traditional rough division
- Mobile hydraulics
- Industrial hydraulics

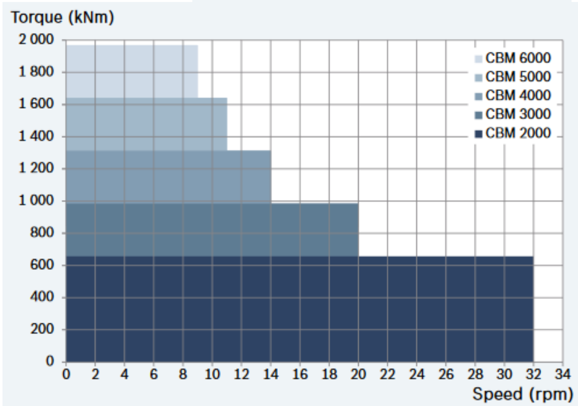
Application area	p_{max} [bar]	q_{am} [°C]
Theaters	160	+18 ® +30
Machine tools	200	+18 ® +40
Steelworks	220	-40 ® +60
Cars	250	-40 ® +60
Power plants	250	-10 ® +60
Agricultural and forestry machines	250	-40 ® +50
Aeroplanes	280	-65 ® +60
Earthmoving machines	315	-40 ® +60
Ships	315	-60 ® +60
Rolling mills and foundries	315	+10 ® +150
Presses	630	+18 ® +40
Mining industry	1000	-40 ® +60
Simulation and testing equipment	1000	+18 ® +150

Hydraulic motor

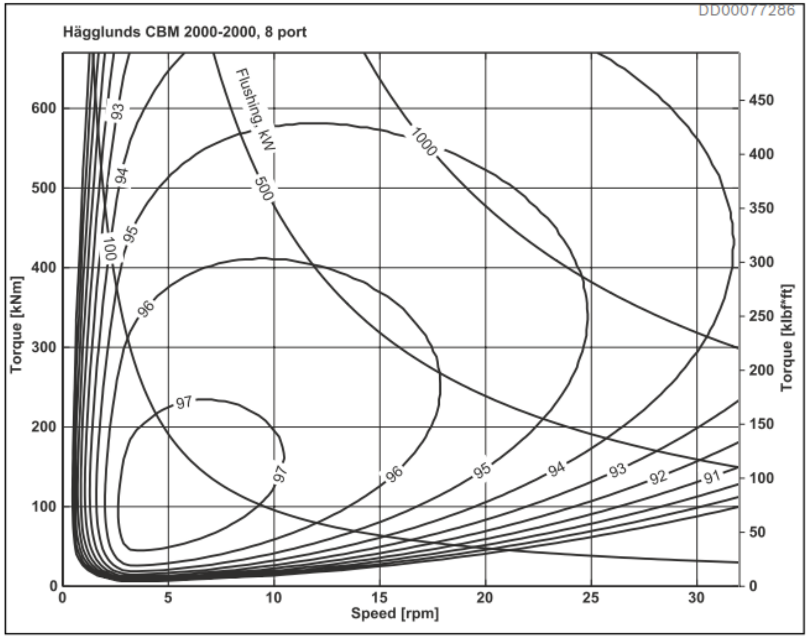
Bosch - Rexroth

Hägglunds CBm radial piston motor

Diameter 1.46 m
Height 1.3 m
Weight 7500 kg



Maximum torque 1.97 MNm



Total efficiency exceeds 97%

Hydraulic pump/motor

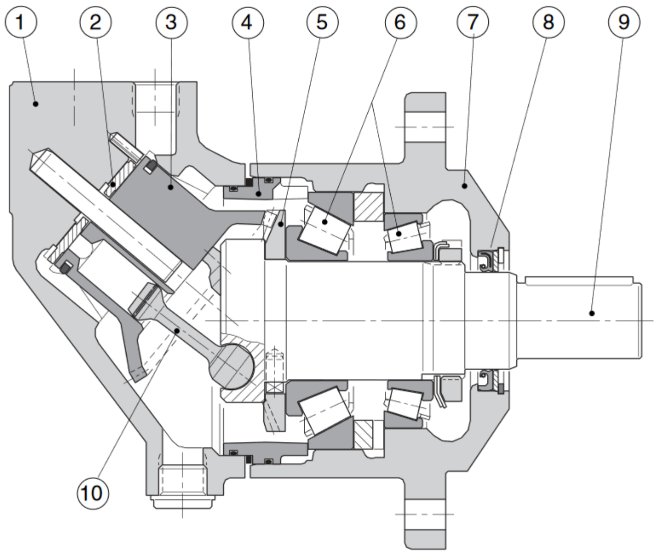
Displacement	4.9 cm^3/rev
Weight	5 kg
Max. rotational speed	12 000 rpm
Max. pressure	420 bar
Peak power (theoretical)	41 kW

Parker F11 and F12 pump/motors

⇐ Smallest model

F11 cross section

1. Barrel housing
2. Valve plate
3. Cylinder barrel
4. Guide spacer with O-rings
5. Timing gear
6. Roller bearing
7. Bearing housing
8. Shaft seal
9. Output/input shaft
10. Piston with laminated piston ring

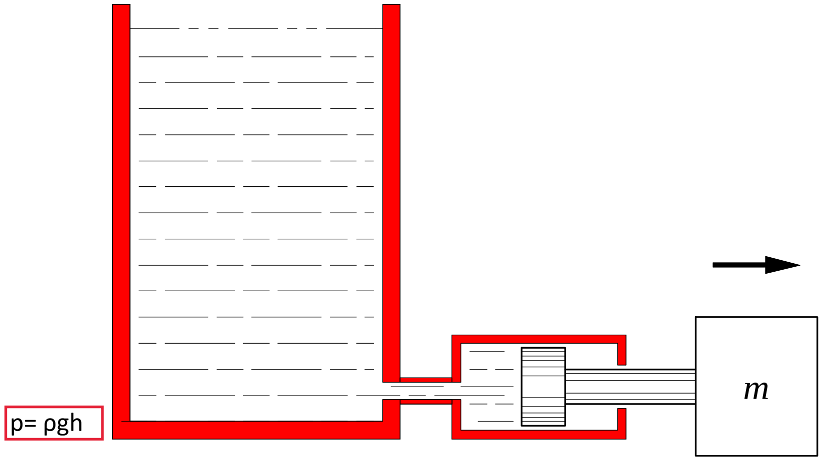


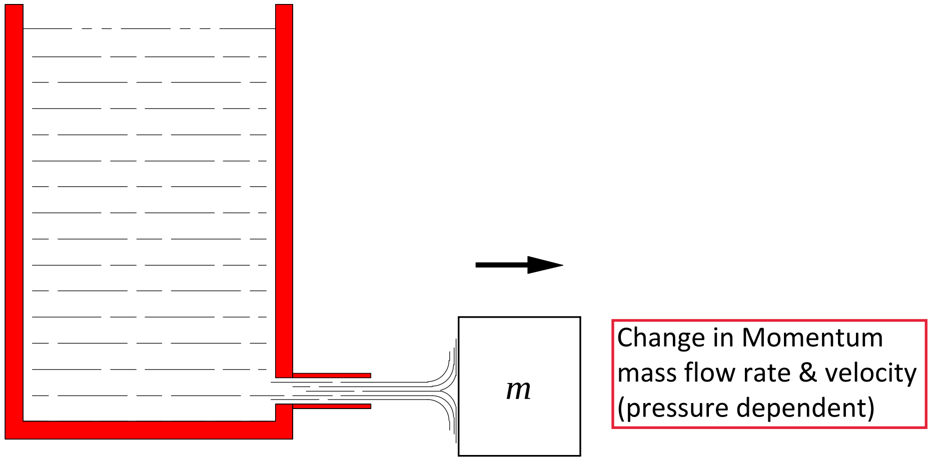
Bent axis type axial piston pump/motor

https://www.parker.com/literature/Literature%20Files/hydraulicpump/cat/english/F11-F12_HY17-8249-US.pdf

System types

Components of hydraulic power: p and q_V





Hydrostatic system

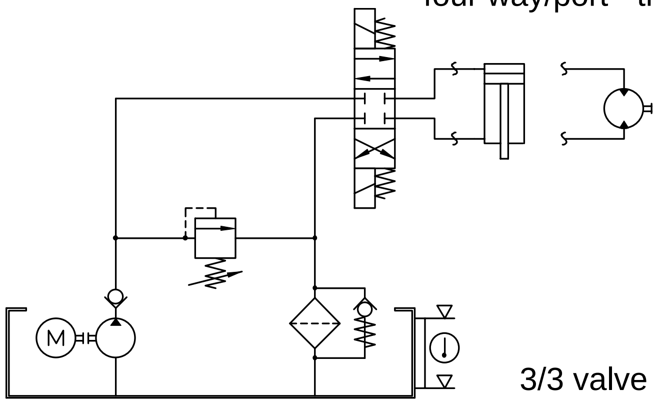
Power transmission mainly linked to the pressure p

Hydrodynamic system

Power transmission mainly linked to the flow q_V

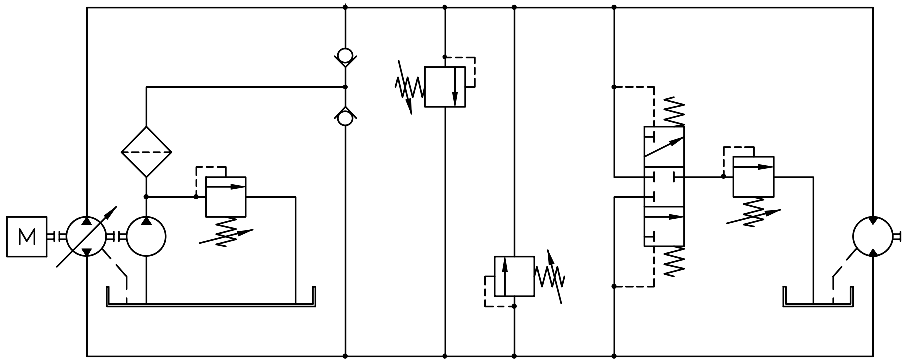
Hydrostatic systems

4/3 valve
four way/port - three position



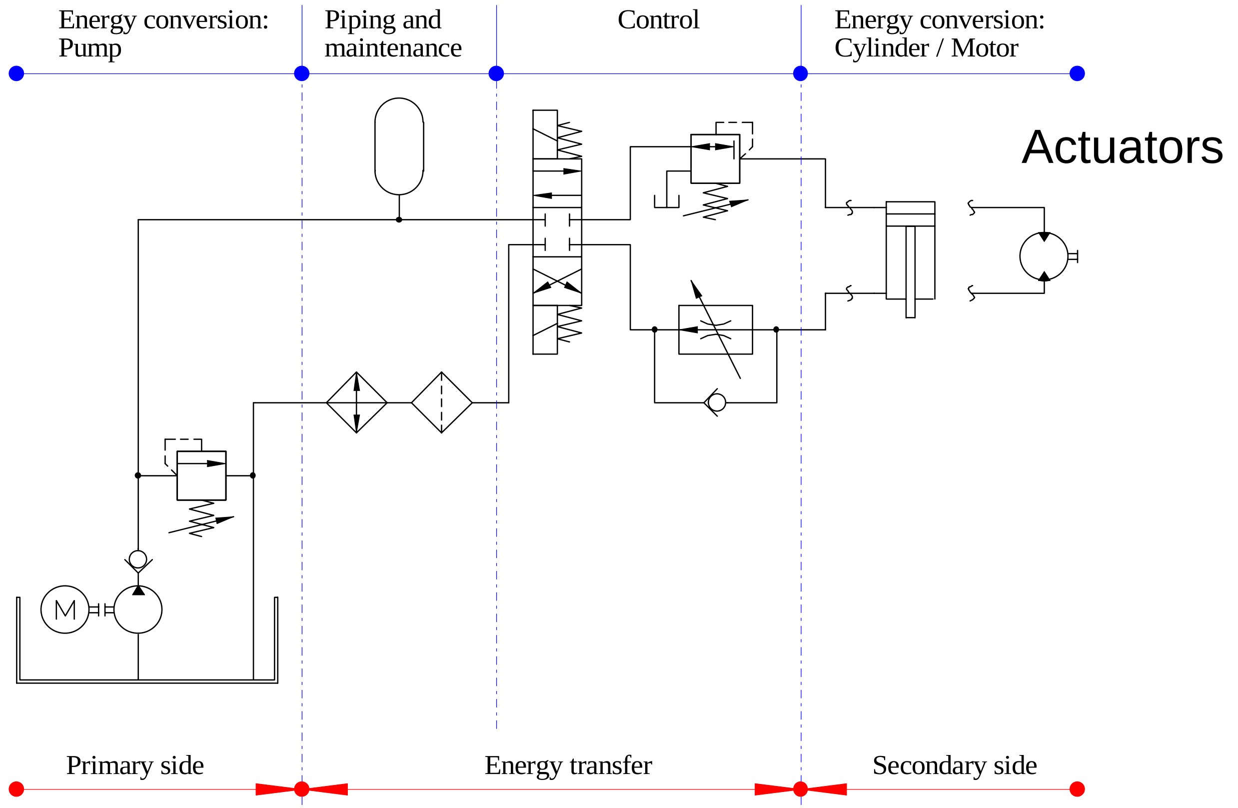
Open system

3/3 valve
3 way - three position



Closed system

Structure of hydrostatic system



For e-learning, you can test pages:
https://www.e4training.com/hyd_princip/hydraulic_symbols1.php

Graphic symbols and diagrams

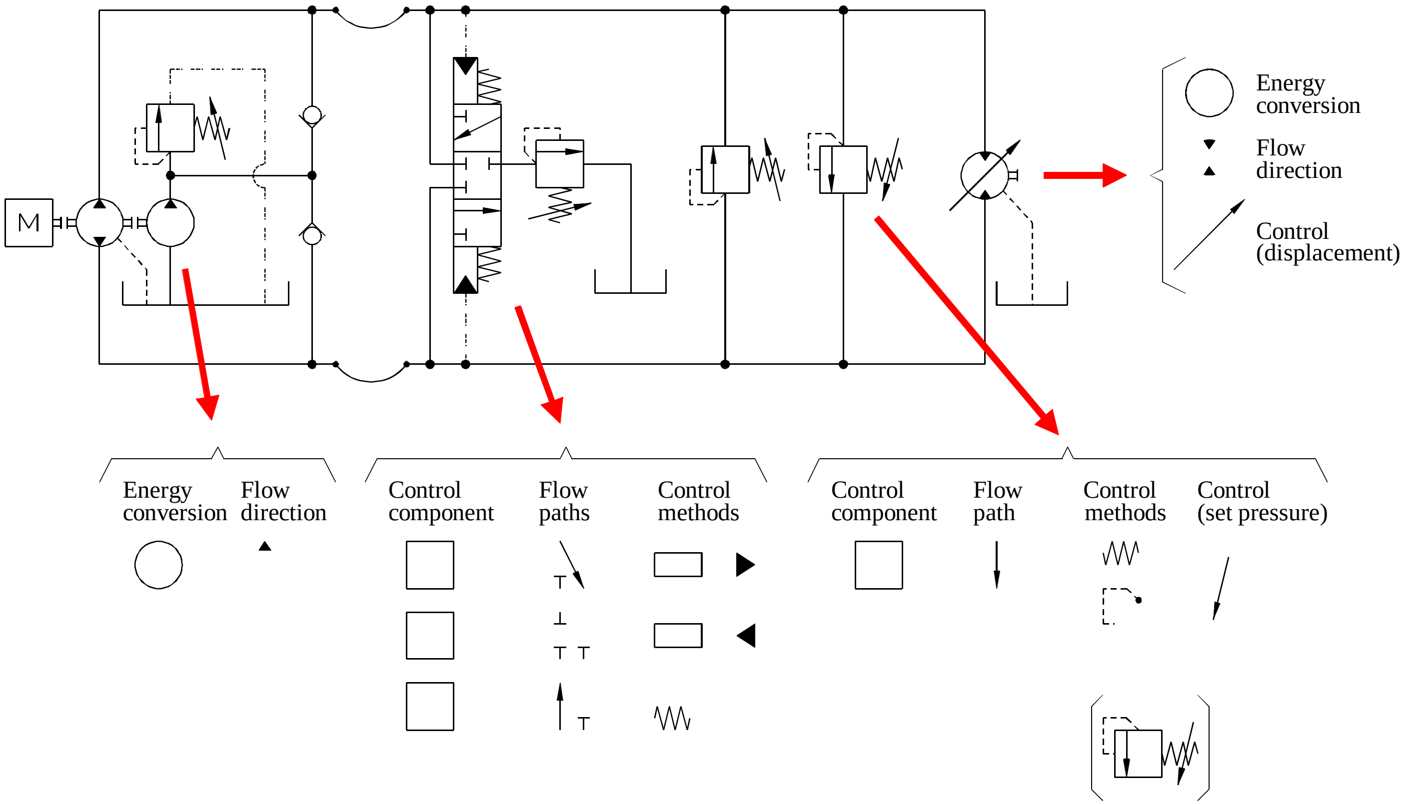
® Symbols are defined in standards
- w DIN-ISO 1219 ® ISO 1219 (2 volumes)
- w DIN 24342
- w SFS 2247

® Symbols are constructed from basic symbols and functional elements

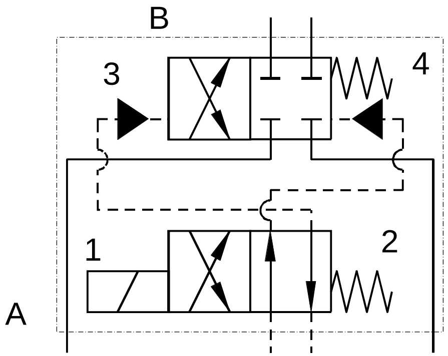
® Symbols depict component’s external connections, not the construction or the functional principle of it

® Symbols enable illustrating the hydraulic signal structure of the hydraulic system

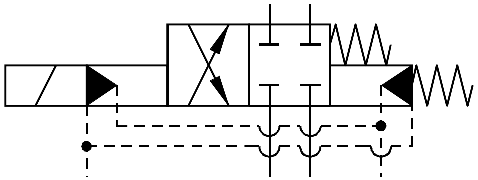
Structure of graphic symbols



Detailed - Simplified

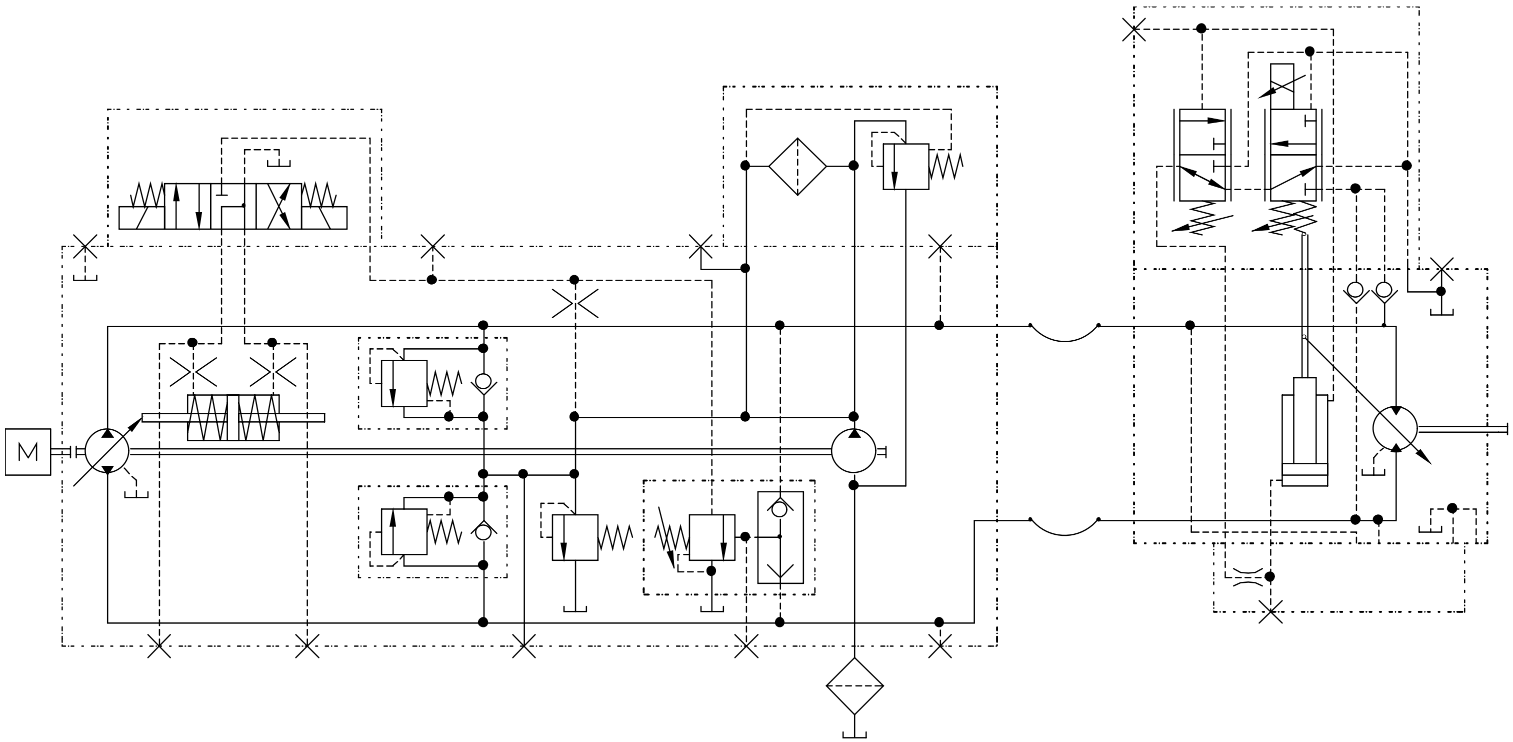


Pilot controlled 4/2 directional control valve,
where an electric control device (1) (solenoid, torque motor) and a spring (2) control the pilot valve (A), which in turn with hydraulic pilot operation (3) and a spring (4) controls the main valve (B) .
A pilot valve
B main valve



Same as above but drawn in a simplified form.

Hydraulic diagrams



Hydromechanics

® HYDROSTATICS

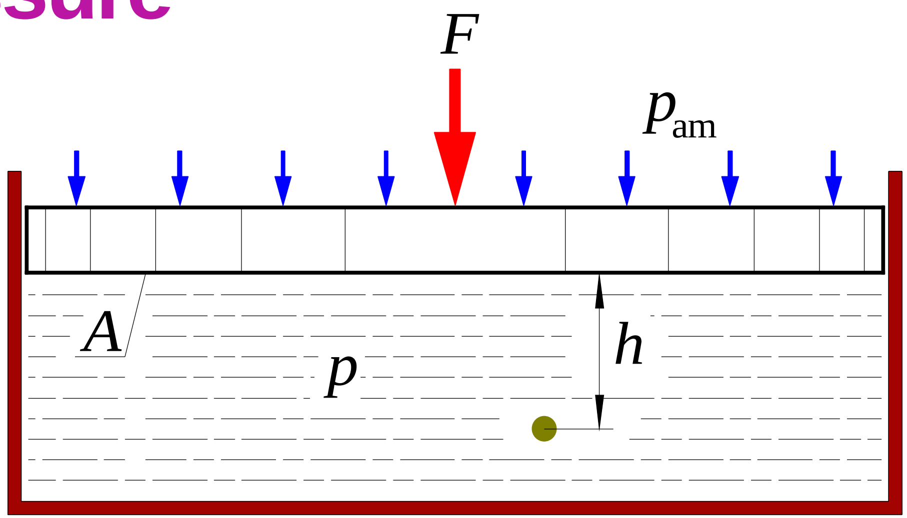
® HYDRODYNAMICS

Hydrostatics

Stationary ideal fluid under external load

Properties of ideal fluid
- no mass
- no internal or external friction
- incompressible

Pressure



Unit [Pa] (SI unit)

1 Pa = 1 N/m²

10^5 Pa = 1 bar (engineering unit)

1 MPa = 10 bar

Also in use (US)

psi (pounds per square inch, lbf/in²)

1 bar = 14.503773773 psi

In line with Bernoulli's equation $\quad p_{st} = \frac{F}{A} + \rho \cdot g \cdot h + p_{am} \quad \rightarrow \quad p = \frac{F}{A}$ (in simplified form)

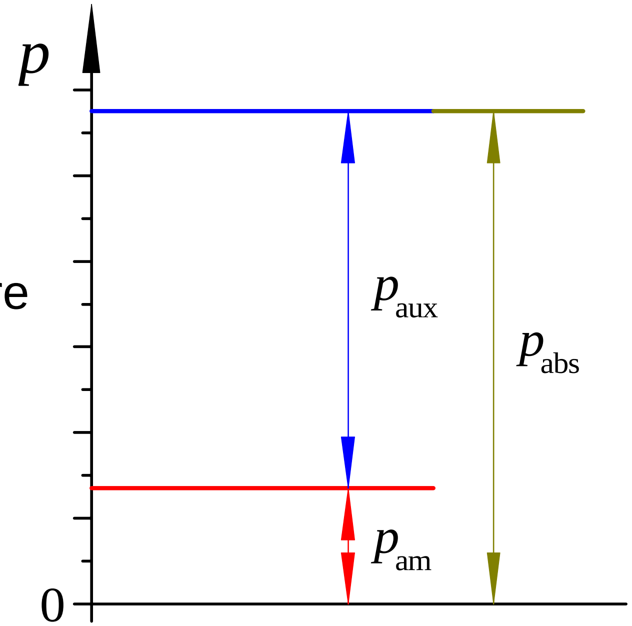
- absolute pressure
- gauge pressure

Note: $p_{abs} = p_{am} + p_{aux}$ above $p_{aux} = p_F = \frac{F}{A}$

Absolute pressure

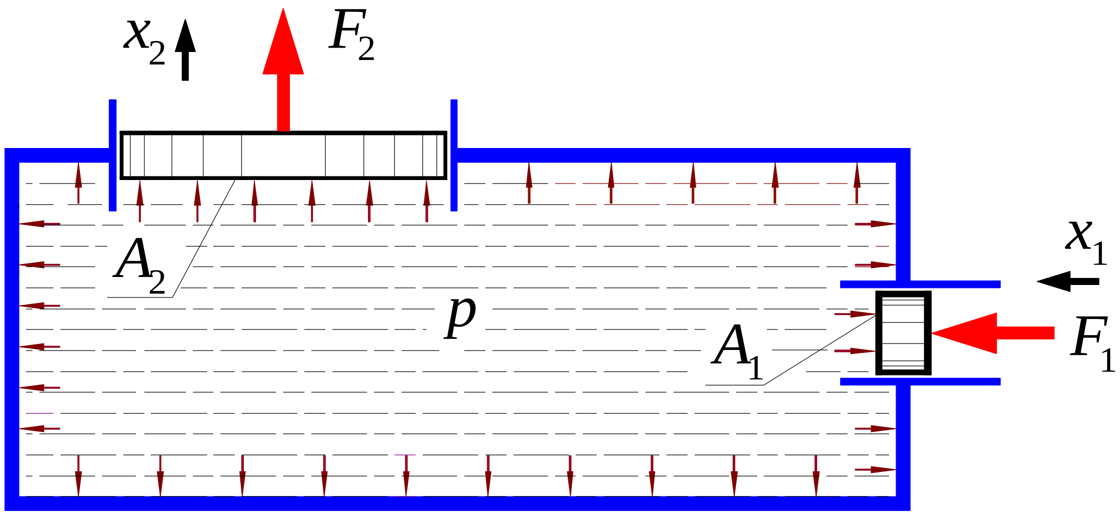
= atmospheric/ambient pressure + pressure

Gauge pressure



$$p_{abs} = p_{am} + p_{aux}$$

Pressure affects perpendicularly against surfaces



Speed of sound

$$\sqrt{\frac{K_f}{\rho}}$$

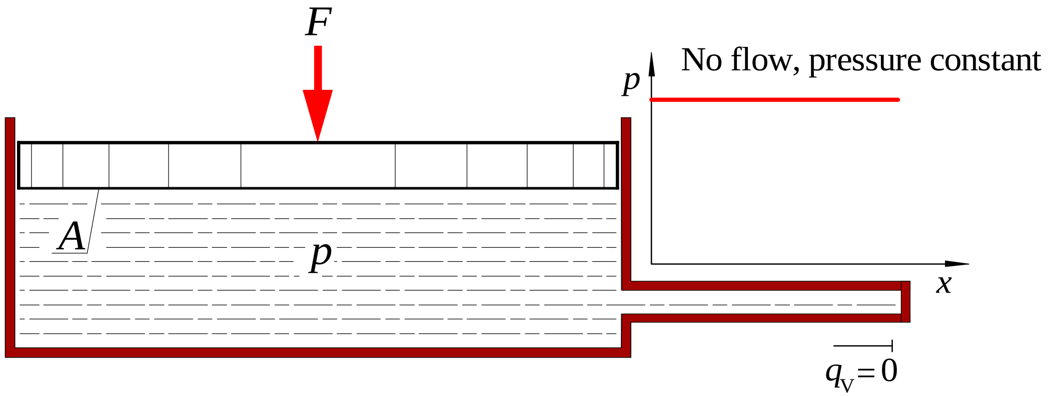
Bulk modulus K_f

Density ρ

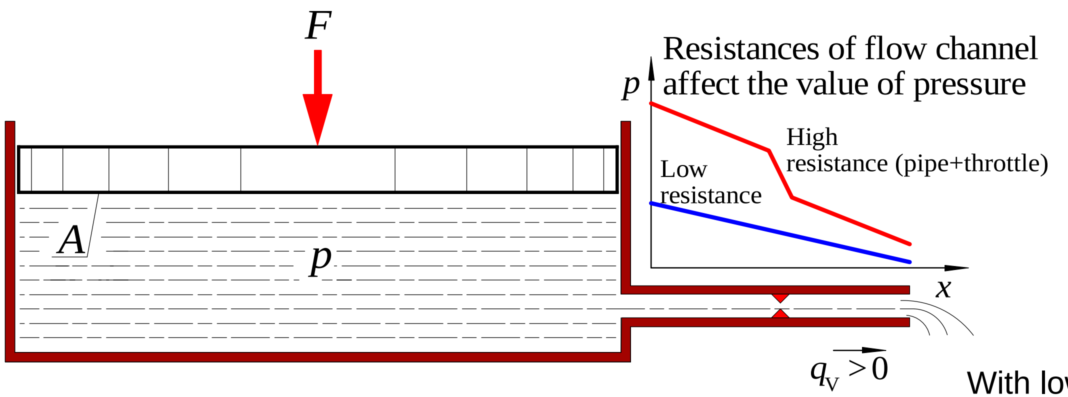
Pressure's spreading speed in pure hydraulic fluid ~ 1200–1400 m/s

Pressure's spreading speed in hydraulic system ~ 800–1000 m/s

Flow and pressure



No flow
®
Equal pressure
everywhere

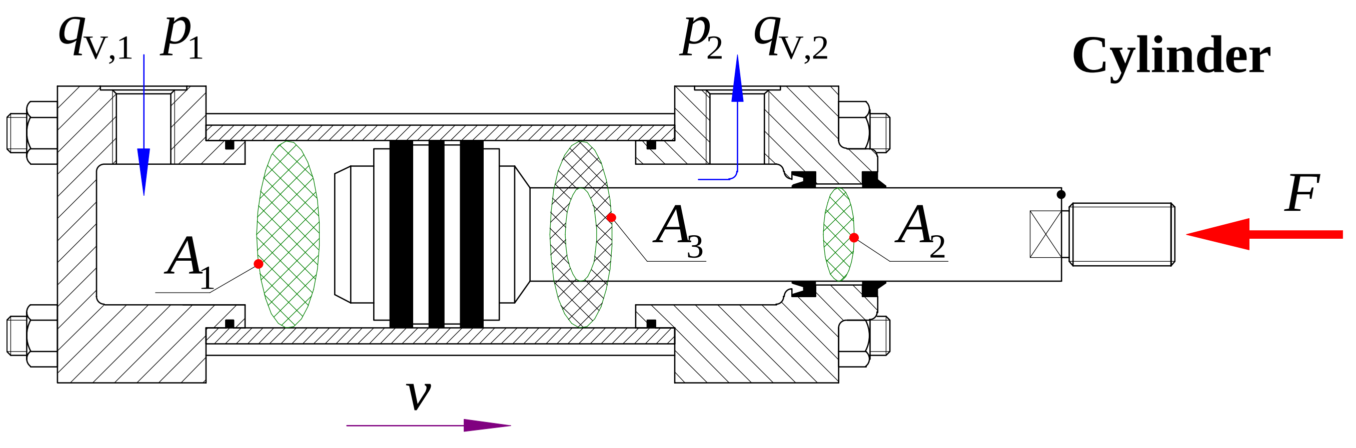


Flow
®
Pressure decreases
in the flow direction
(in principle)

With low resistance higher flow rate and piston velocity.

Pressure: An application example

Annulus area



Cylinder

A_3 annulus area

Force equation ® Pressure demand

$$p_1 A_1 - p_2 A_3 = F$$

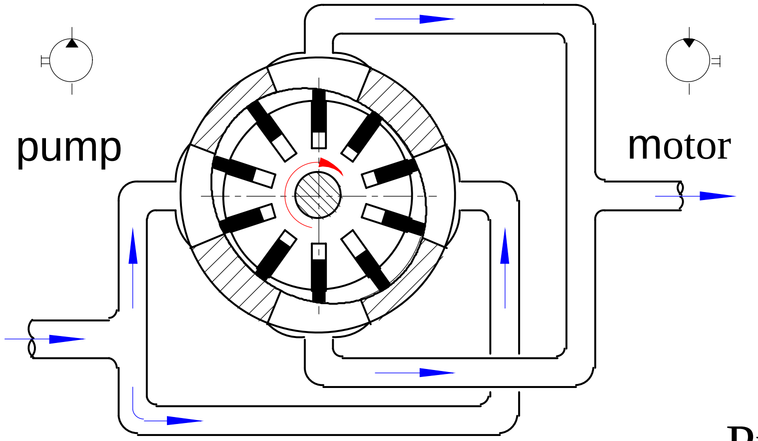
$$p_1 = \frac{F + p_2 A_3}{A_1}$$

Hydraulic component
Differential cylinder

Pressure: An application example

vane pump OR vane motor

Ideal torque and ideal pressure demands
- no friction (mechanical, flow)
- no leakage



Pump

Torque demand

$$T_{\mathrm{p}} = \frac{\Delta p \cdot V_{\mathrm{g,p}}}{2\pi}$$

Motor

Pressure demand

$$\Delta p = \frac{2\pi \cdot T_{\mathrm{m}}}{V_{\mathrm{g,m}}}$$

V_{g} swept volume or displacement (per revolution)

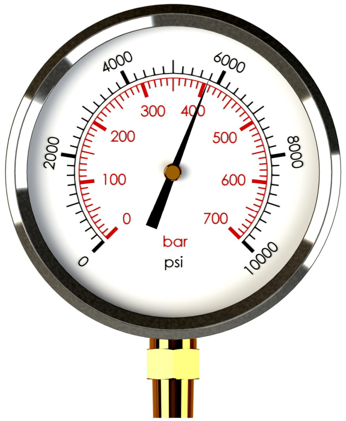
Lecture themes - Recap

Hydraulics – What was it?

Where an why to use hydraulics?

Pressure – What and Why?

Is there any use for pressure?



EXECUTIVE SUMMARY

Fluid power (hydraulic and pneumatic actuation) is the generation, control, and application of pumped or compressed fluids when this power is used to provide force and motion to mechanisms. This form of mechanical power is an integral part of United States (U.S.) manufacturing and transportation. In 2008, according to the U.S. Census Bureau, sales of fluid power components exceeded $17.7B, sales of systems using fluid power exceeded $226B. As large as the industry is, it has had little fundamental research that could lead to improved efficiency since the late 1960s (prior to the 1970 energy crisis).[1] While there have been some attempts to replace fluid powered components with electric systems, its performance and rugged operating condition limit the impact of simple part replacement. Oak Ridge National Laboratory and the National Fluid Power Association (NFPA) collaborated with 31 industrial partners to collect and consolidate energy specific measurements (consumption, emissions, efficiency) of deployed fluid power systems. The objective of this study was to establish a rudimentary order of magnitude estimate of the energy consumed by fluid powered systems. The analysis conducted in this study shows that fluid powered systems consumed between 2.0 and 2.9 Quadrillion (10^{15}) Btus (Quads) of energy per year; producing between 310 and 380 million metric tons (MMT) of Carbon Dioxide (CO_2). In terms of efficiency, the study indicates that, across all industries, fluid power system efficiencies range from less than 9% to as high as 60% (depending upon the application), with an average efficiency of 22%. A review of case studies shows that there are many opportunities to impact energy savings in both the manufacturing and transportation sectors by the development and deployment of energy efficient fluid power components and systems.

Estimating the Impact (Energy, Emissions and Economics) of the U.S.Fluid Power Industry
https://info.ornl.gov/sites/publications/Files/Pub28014.pdf