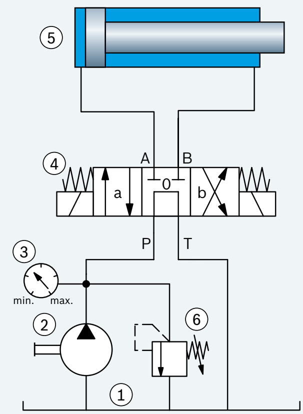
The Drive & Control Company

Rexroth
Bosch Group

Compact knowledge

Hydraulics – Basic principles



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1 General information

1.1 Introduction to hydraulics

Definition

Hydraulics is the science of stationary and flowing fluids. In technical practice, hydraulics is generally understood as the generation of forces and motion by hydraulic fluids. The term is derived from the ancient Greek words "hydor" (water) and "aulos" (pipe).

Historical development

As far back as the ancient world people were utilizing the energy of flowing water. For example, there is evidence to suggest that the first water wheels were built around 200 B.C. They are still being used today in watermills and their technical advancement can still be seen in the water turbines of power stations.

approx. 5000 B.C.	People utilize the energy of flowing water.
approx. 200 B.C.	The first water wheels are developed.
as of approx. 1600	Utilization of water pressure as drive power
1653	French physician Pascal (1623-1662) illustrates the hydrostatic principle using the hydraulic press as an example.
1795	British engineer Joseph Bramah (1749-1814) produces a hydraulic press using water as a hydraulic fluid for generating large forces. He is thus considered to be the first to use hydraulics in industry.
1851	British industrialist William G. Armstrong (1810-1900) develops an accumulator ("weight accumulator") with which large flows can be generated.
1905	Beginning of oil hydraulics: Williams and Janney use mineral oil as a transmission medium for hydrostatic transmissions for the first time.
1922	Engineer Hans Thoma uses a radial piston pump operated with mineral oil in an industrial application.
since 1950	Oil hydraulics becomes prevalent in all fields of industrial hydraulics.

Tab. 1: History of hydraulics

Fields of application of hydraulics

Hydraulic systems are used in the fields of power transmission and in both open and closed-loop control technology. In order to classify the diversity of possible fields of application, a distinction is generally made between **industrial hydraulics** (or stationary hydraulics) and **mobile hydraulics**.

Applications in industrial hydraulics

The term industrial hydraulics comprises applications in which hydraulic components are used in fixed installations. Application examples include machine tools, plastics processing machines and presses in the rolling mill industry.

Plastic injection molding machine	**Tower Bridge**
	
Wind turbine	**Continuous casting plant with rolling mill**
	

Tab. 2: Applications in industrial hydraulics

Applications in mobile hydraulics

Mobile hydraulics comprises applications in which hydraulic components are installed in mobile machines. For example, here hydraulics is used in hydraulic excavators, wheel loaders, road rollers, snow groomers, tractors, lift trucks, or municipal vehicles.

Mobile excavator

Mobile crane

Wheel loaders

Tractor hitch control

Tab. 3: Applications in mobile hydraulics

1.2 Comparison of drive technologies

Drive technologies

Solutions from the technological fields of hydraulics, pneumatics, electrics and mechanics come into play when designing drives:

- In hydraulic drives, motion is generated by means of hydraulic fluid, which displaces solid bodies. Hydraulic drives are used in many industrial fields as well as in mobile machines such as excavators.
- In pneumatic drives, motion is generated by means of compressed air. Well-established applications include pneumatic assembly tools for screws and nuts in vehicle garages and the transportation of lightweight goods on production lines.
- Electric drive technology works mostly with electric motors, which are being increasingly controlled electronically. Electric drives are used in high-precision machine tools and printing presses.
- Mechanical drives can generate linear or rotatory motion or curves by means of either crank drives, transmissions with a fixed transmission ratio, stepless transmissions or cam gears.

Different requirements are placed on drive technology, depending on application and use. Specific differences emerge between drive technologies with regard to energy supply, energy distribution, properties of the transmission medium used and characteristics (type of motion) of the drive itself.

Comparison of drive technologies

The following table contains a comparison of drive technologies according to their most important technical criteria.

Criterion	**Hydraulics**	**Pneumatics**	**Electrics**	**Mechanics**
Energy carrier	hydraulic fluid	air	electrons	motion, position, deformation
Energy transmission	pipes, hoses, bores	pipes, hoses, bores	electrically conductive material	shafts, rods, belts, chains, wheels etc.
Conversion from / into mechanical energy	hydraulic pump, hydraulic motor, hydraulic cylinder	compressor, pneumatic cylinder, pneumatic motor	generator, battery, solenoid, electric motor	–
Most important characteristics	Pressure p, flow q_V	Pressure p, flow q_V	Voltage U, electric current I	Force F, torque M, velocity v, speed n
Storage	bladder-type accumulator, piston-type accumulator, diaphragm-type accumulator	compressed air reservoir	capacitor	weight

Criterion	Hydraulics	Pneumatics	Electrics	Mechanics
Power density	very good (high working pressure)	good (limited by max. working pressure)	not very good (power-weight ratio of electric motors approx. 10 times higher than that of hydraulic motors)	good (energy conversion not required; limited where high degree of controllability required)
Efficiency	dependent on leakage and friction during energy conversion; losses during valve control (open and closed loop)	dependent on leakage and friction during energy conversion; losses during valve control (open and closed loop)	dependent on availability of electricity as primary energy source	dependent on size of frictional losses
Generation of linear motion	very easy (by means of cylinders; start-up and reversal of motion at full load possible)	very easy (by means of cylinders)	not very easy (by means of linear electric motor, threaded spindle etc.)	easy (by means of crank drives, spindle etc.)
Generation of rotational motion	easy (by means of hydraulic motor)	easy (by means of compressed air motor)	very easy (by means rotary electric motor)	very easy (by means of transmission)
Generation of curves	not very good	not very good	not very good	very good for certain applications (bending technology)
Path accuracy	very good (fluid is hardy compressible)	not very good (air is compressible)	varies: not very good with asynchronous motors very good at synchronous and stepping motors	very good (by means of form and force fit)
Controllability (open and closed loop), signal processing	very good (by means of valves and variable displacement pumps; use of servo valves in control technology; further improvements by combining with electric systems)	very good (by means of valves)	very good (by means of switches, relays, semiconductors, variable speed motors, variable resistors etc.)	good (by means of transmissions, lever systems etc.)

Tab. 4: Technical criteria of drive technologies

Conclusion

The following conclusions can be drawn from the comparison of the various drive technologies:

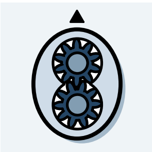
- Hydraulic drives offer the advantage of generating high forces yet with a very compact design. The disadvantage of this drive technology is the effort required to prevent hydraulic fluid from leaking into the environment.
- Pneumatic drives can generally be used if fast motion and little force are required. Further advantages include comparatively low capital costs and good environmental compatibility. One disadvantage of this technology is the high level of noise development.
- Electric drives feature high control dynamics and flexibility. On the other hand, capital costs are comparatively high.
- Mechanical drives are straightforward to construct and are easily able to generate linear and rotational motion. However, one disadvantage is less effective controllability.

By combining various drive technologies, e.g. the combination of hydraulics and electrical engineering in variable-speed pump drives (Sytronix), the advantages of the respective technology can be optimally utilized and the disadvantages compensated as required.

3.2 Hydraulic pumps

3.2.1 External gear pumps

Short description



External gear pumps are displacement machines in which the displacement chambers are comprised of externally geared toothed wheels.
In the housing bores of external gear pumps, two gears engage, one of which is driven (e.g. by electric motor). This driven gear drives the second gear in the opposite direction. The hydraulic fluid is delivered in the tooth clearances.

Characteristics

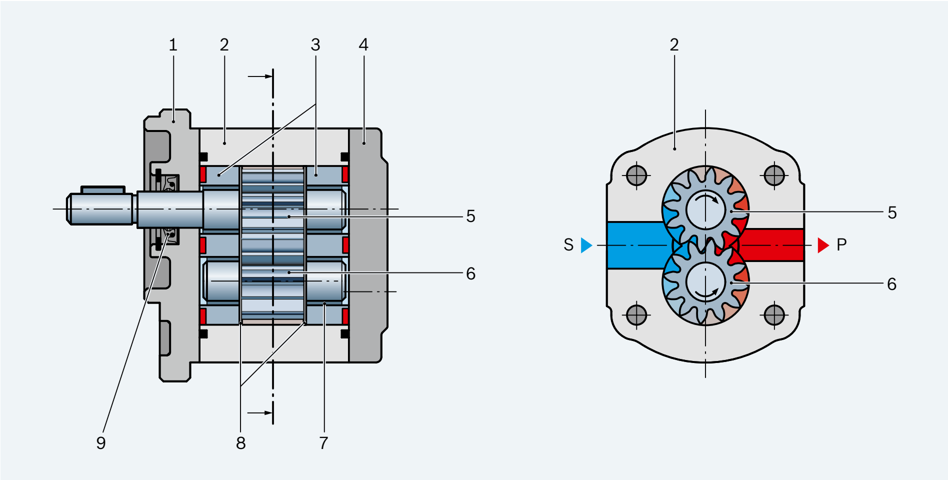
External gear pumps are fixed displacement pumps. They feature a compact design and high power density. They offer good emergency operation properties so that any temporarily lack of lubrication, e.g. during start-up, does not cause any damage to the pump.
External gear pumps consist of few components, whereas the housing can be produced with little production expenses from one extruded aluminum profile.

Disadvantages include leakage and frictional losses, combined with considerable noise development, which can vary depending on the pump design.

External gear pumps can be used across a broad speed range and operated with hydraulic fluids within a large viscosity range. This results in numerous possible applications, particularly in mobile hydraulics (tractors and forklifts) and industrial applications.

Design

The figure illustrates the general design of an external gear pump in longitudinal and cross-section.



1	Flange (front cover)	7	Bearing
2	Housing	8	Sealing surface between bearing blocks and gears
3	Bearing blocks	9	Shaft seal
4	Housing cover (end cover)	P	Pressure port
5	Drive shaft with drive gear	S	Suction port
6	Driven gear		

Fig. 9: Longitudinal and cross-section of an external gear pump

Construction types and variants

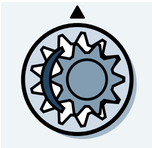
External gear pump with helical gearing

The most efficient reduction of noise development of external gear pumps is achieved in "Bosch Rexroth SILENCE PLUS" helical gear pumps.
Due to the helical gearing of a round tooth profile, the delivering displacement chambers overlap to ensure even flow with minimal flow pulsation. The round tooth profile guarantees that both gear wheels mesh without clearance, thus ensuring that the hydraulic fluid is completely displaced from the tooth clearance. This ensures that, no hydraulic fluid, i.e. compressed oil, remains in the displacement chambers, which would otherwise lead to abrupt unloading on transition from pressure to the suction area.
At low and medium pressures, the noise of the "SILENCE PLUS" external gear pump is drowned by the operating noise of the driving electric motor and is barely audible.

Fig. 10: External gear pumps with helical gearing

3.2.2 Internal gear pumps

Short description



Internal gear pumps are displacement machines in which the displacement chambers are comprised of a pinion and an eccentrically mounted internal gear. Pressure and suction area are separated by a crescent shaped element.

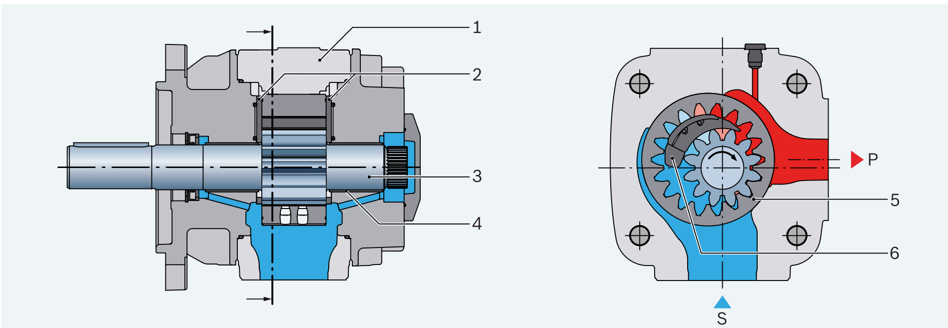
Characteristics

Internal gear pumps are fixed displacement pumps. They are characterized by a broad speed range and can be operated with hydraulic fluids within a large viscosity range. By means of clearance compensation, internal gear pumps achieve higher efficiencies.

Due to their low noise level, internal gear pumps have many fields of application. In stationary hydraulics, they are used in such applications as machine tools, presses and plastics processing machines. In mobile hydraulics, internal gear pumps are particularly used for vehicles working in closed rooms (e.g. electric forklifts).

Design

The figure illustrates the general design of an internal gear pump in longitudinal and cross-section.

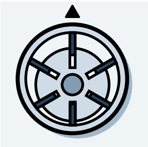


1	Housing	5	Internal gear
2	Axial washers	6	Crescent shaped element
3	Pinion shaft	P	Pressure port
4	Bearing	S	Suction port

Fig. 11: Longitudinal and cross-section of an internal gear pump

3.2.3 Vane pumps

Short description



Vane pumps are displacement machines in which the displacement chambers are formed between cam ring, rotor and vane.

The rotor of a vane pump comprises sliding metal plates, known as vanes. The vanes are guided into slots which are installed radially to the drive shaft in the rotor. On rotation of the rotor, these vanes are pressed onto the inner surface of the cam ring by centrifugal force. Thus, the vanes divide the space between cam ring and rotor in the displacement chamber. Due to the eccentric position of the cam ring, the displacement chambers, which in these pumps are also referred to as cells, change their size during rotation of the rotor.

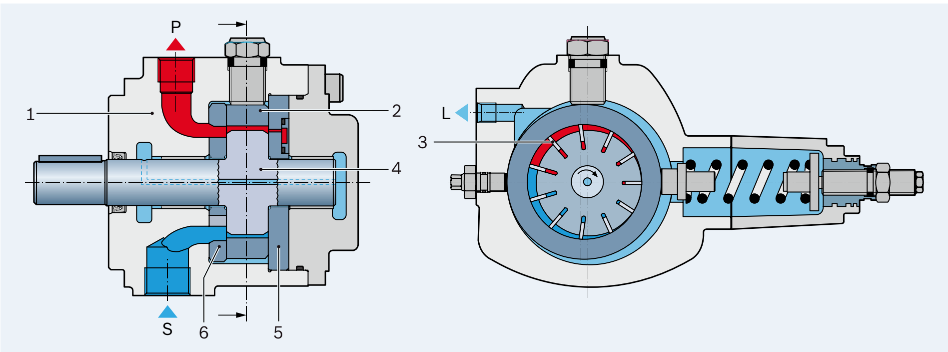
Characteristics

Vane pumps can be either fixed or variable displacement pumps. They are characterized by low pulsation and low noise development. Due to their design, the displacement is easily adjustable.

The properties of vane pumps make them very versatile. In industry, they are often used in machine tools and packaging applications.

Design

The figure illustrates the general design of a vane pump in longitudinal and cross-section.



1	Housing	6	Lens plate
2	Cam ring	L	Drain port
3	Vane, can be moved radially	P	Pressure port
4	Rotor with drive shaft	S	Suction port
5	Loading plate		

Fig. 12: Longitudinal and cross-section of a vane pump

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Bosch Rexroth is one of the worldwide leading specialists in drive and control technology with unique technological know-how. This knowledge is passed on by the Drive & Control Academy to support customized basic and advanced training as well as qualification of technical personnel.

For everybody interested in a general overview and basic understanding of the technological know-how of Bosch Rexroth, the book series "Compact knowledge" was developed. In this series, "Hydraulics – Basic principles" offers an overview of the basic principles and components of hydraulic systems such as on/off valves, hydraulic pumps, hydraulic motors and hydraulic cylinders. These topics are illustrated by means of graphics and circuit diagrams.

This book may be used as reference in addition to formal training at Bosch Rexroth or for independent learning.

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