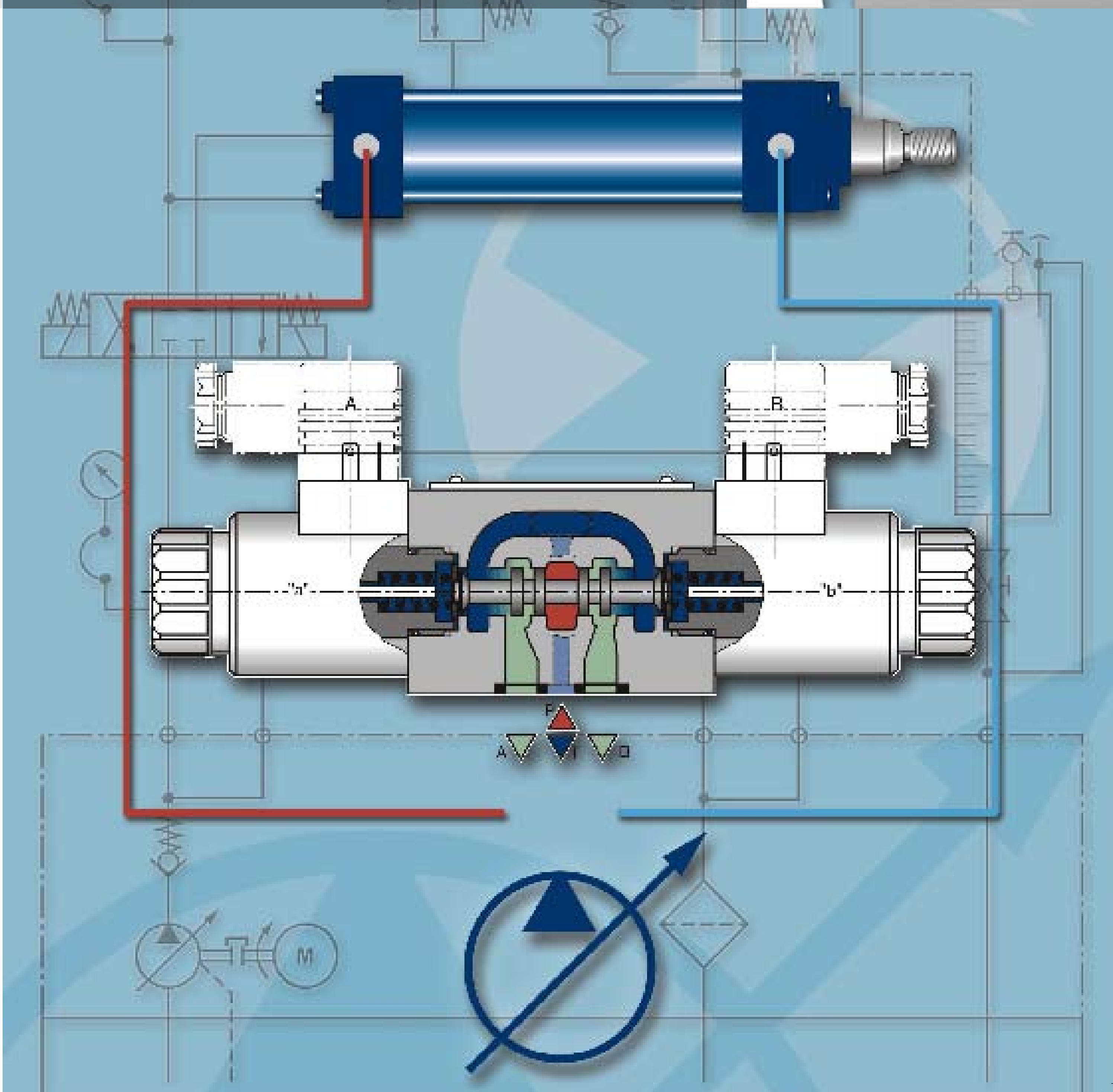
Rexroth
Bosch Group

RE 00845/04.07

Project Manual
Industrial Hydraulics

Trainer‘s manual



A

Introduction

Imparting knowledge through project work • Project designation with short description of the industrial application • Comparison of project exercises Bosch Rexroth AG/BIBB • Component matrix • Overview of components • Safety aspects

B

Basic principles of hydraulics

System technologies/energy conversion • Simple hydraulic circuit • Symbols according to DIN ISO 1219-1 • Circuit systems in the field of hydraulics • Demands placed on drive elements • Physical basic principles • Hydraulic fluids • Filtration

C

Project tasks

Fundamental safety notes • 01 Hydraulic power unit • 02 Hydraulic pump/variable displacement pump characteristic curve • 03 Single-rod cylinder/pressure intensification • 04 Single-rod cylinder/flow • 05 Hydraulic motor • 06 4/3 directional valve • 07 Check valve • 08 Check valve, pilot operated • 09 Throttle valve, adjustable • 10 Throttle check valve • 11 Flow control valve • 12 Pressure relief valve, direct operated • 13 Pressure relief valve controls • 14 Pressure reducing valve • 15 Pressure switch • 16 Pressure switch/ hysteresis • 17 Hydraulic accumulator • 18 Regenerative circuit • 19 Rapid speed/creep speed control • 20 Valve circulation control • 21 Commissioning, inspection, maintenance, troubleshooting, repair

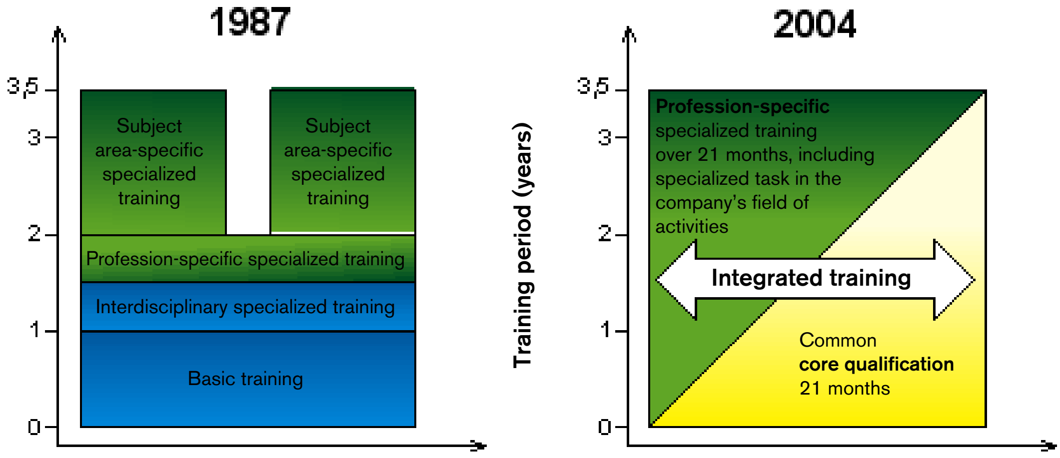
D

Annex

RE 07008 General product information about hydraulic products from Bosch Rexroth AG

Restructuring of industrial metalworking and electrical professions

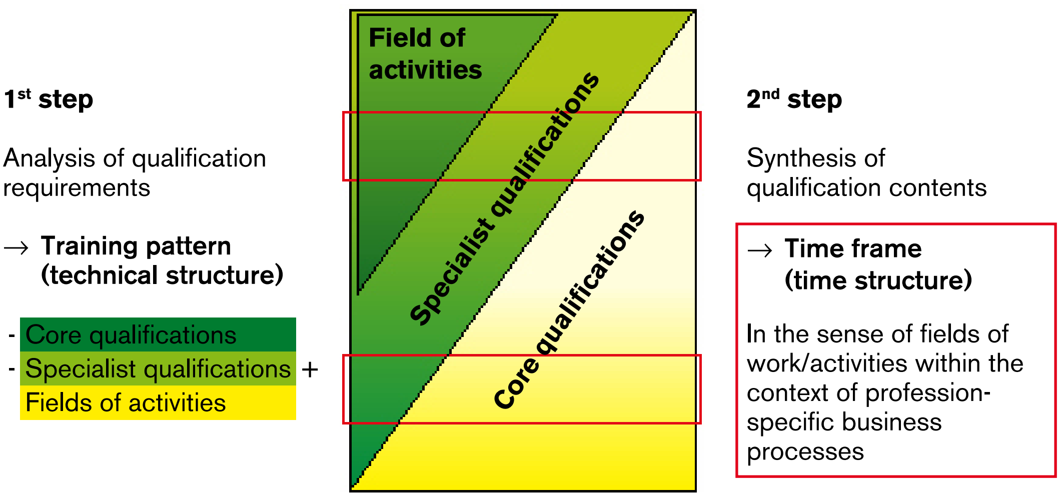
The increasing importance of process-oriented working procedures, the growing complexity and networking of new technologies as well as comprehensive, customer-oriented services have resulted in the necessity to restructure industrial metalworking professions, which was laid down in regulations in 1987.



Restructuring of industrial metalworking professions (source: DIHK 06/2004)

Qualification requirements

The requirements for core qualification are met by solving tasks set in the form of project steps, which involve informing, planning, decision-making, executing, checking and assessing. Mastering and internalizing the multitude of qualifications finally results in the professional competence to act.



Time frame - method (source: DIHT 06/2004)

Imparting knowledge through project work

The present *Project Manual Industrial Hydraulics* is intended for imparting the required specialist knowledge in the field of hydraulic control technology in practice-oriented applications. Through the logically structured project work the trainee:

Training contents

- is to understand the physical laws and technical interrelationships (area, pressure, force, work and power),
- is to become able to explain the function, structure, practical operating principle and possible applications of hydraulic equipment,
- is to become able to read and understand symbols and circuit diagrams,
- is to get to know basic controls of hydraulics and assemble units according to prepared circuit diagrams,
- is to be made familiar with types, properties, requirements and application of hydraulic fluids.

Framework curriculum

The project tasks and project work described in the *Project Manual Industrial Hydraulics* provide trainers and trainees with information and instruments that will help them comply with the demands made on the transfer of specialist know-how in the field of hydraulics.

The sub-objectives listed below, which are taken from the framework curriculum for vocational training of industrial mechanics, are matched with the regulations for vocational training in industrial metalworking professions dated 09.07.2004 (BGBl. I. S. 1502). The sub-objectives listed refer to training objectives given for hydraulic control technology.

Industrial mechanics

- plan and organize work sequences, check and assess work results,
- verify mechanical and physical variables,
- assemble and disassemble machines, equipment, fixtures and systems,
- commission systems and plants, including open and closed-loop control equipment, and instruct customers,
- carry out maintenance work and ensure the operability of technical systems,
- prepare technical documentation,
- apply standards and regulations for safeguarding the process and product quality and contribute to continuing improvements in the work sequences in the company.

Fields of activities

Industrial mechanics are mainly assigned to professional activities in the field of production, assembly, maintenance and automation of technical systems. The fields of activities mentioned before are dealt with in individual training sections. Within the fields of activities, the training sections of the individual training years are based on each other.

Training sections

In training section-oriented lessons the solutions required for project handling are not imparted like in conventional lessons. The solution of the task set is worked out alternately in systematic, technical and situation- or case-related training. In the course of the project work it should be envisaged that the trainee can handle the projects on his/her own and under his/her own responsibility and, whenever possible, in a team.
This brings the training contents closer to the trainee's real world of experience, which enables and simplifies imparting the professional competence to act in the lessons.
To solve a more complex project task, it may be required to impart the basic principles for this project in systematic technical training.

Training section 6, which is geared to hydraulic control technology, is described below.
(Training framework curriculum § 10 section 1 No. 10/Control technology)

Training section 6:	**Installing and commissioning control systems**	**2nd year of training Recommended time: 60 hours**
The trainees are to install and commission control systems. They determine the control components to be used and the functional sequence for controls on the basis of circuit diagrams and other documentation for various component technologies. For this, they use manufacturers's documents. The trainees plan and realize the set-up of the control. They commission the control system observing rules for safety at work. They develop strategies for troubleshooting and optimization of the control systems and apply them. They document and present their results utilizing suitable user programs.		
Contents: • Technology diagram • Hydraulic power part • Supply unit • Sensors • Flow of material, energy, information • Electrical circuit diagrams • Pressure fluids • Pressures, forces, velocity, flow • Operating modes • Plant safety		

Training schedule

The starting point of didactic-methodical structuring of the training situation in the individual training sections is to be the business and work process in the vocational field of activities. This is reflected in the formulation of objectives in the individual training sections. The objectives of the training sections are the decisive factors for the structuring of the lessons and represent the minimum scope together with supplementary contents.
The technical contents of the individual training sections are formulated generally and are not listed in a differentiated way. The individual contents of the training sections are coordinated with the training curriculum for in-company training.
According to § 7 of the regulations for vocational training in industrial metalworking professions deviations from the training curriculum are permitted in terms of technical contents and time schedule, in particular, where practical requirements necessitate this deviation.

The project tasks described in the *Project Manual Hydraulics* are structured so that the trainee achieves the training objectives described in the project definition in 6 project steps:

- Informing,
- Planning,
- Deciding,
- Executing,
- Checking,
- Evaluating.

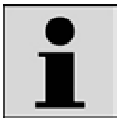
Specialist competence

The objectives described are geared to the development of competence to act. The trainee will develop his or her competence to act from the capability and willingness to solve tasks and problems and evaluate results in a target-oriented manner, skillfully, methodically and independently on the basis of technical knowledge and skills.

Professional competence to act

The projects described in the project definition are oriented towards practical needs and are characterized by a high level of conformity with customer orders from industry and trade. Customer orders represent complete activities and develop and promote the trainee's professional competence.

As mentioned before, the trainee is to work off the project task or the project order in 6 steps.



1. Informing

Based on the project definition, the trainee is to get a clear idea of the finished solution, including any required details. This is achieved through a systematic analysis of the project documentation and, if required, by asking questions.

Possible questions:

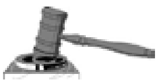
- What is to be done?
- Have I understood the task completely?
- Which hydraulic component/system is to be dealt with?

2. Planning

Planning means the theoretical preparation and anticipation of the concrete execution. In detail, planning requires competence to handle the project order and to organize the project handling steps.

Possible questions:

- How to proceed?
- What knowledge is required?
- Which aids are available?
- Are there comparable applications in my company?

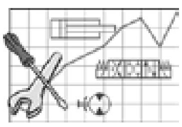


3. Decision-making

After the planning stage, the trainee determines the aids to be used, e.g. which data sheets are required for coping with the project task. He/she decides on the sequence and the interrelationships of the individual project steps. Moreover, a decision should be made as to whether it would be easier to solve the project task in a team.

Possible questions:

- Which hydraulic components will be used?
- How can you know that technical data sheets are up to date?
- Have I utilized all available sources of information?
- Are the prescribed safety instructions at hand?



4. Executing:

The order is to be executed according to the work instructions given in the chapter "order execution", taking all safety notes into account. After a thorough preparatory phase, the trainee is to carry out the project order largely on his/her own. After the solution was worked out in writing, it should be verified or questioned, whether the right attempt at a solution was selected.
Depending on the project order, the possibilities of execution may be limited. This is valid, for example, in the case of costly work in the field of information technology.

Possible questions:

- Have I chosen the correct sequence?

5. Checking:

The trainee must check intermediate results as early as during the execution stage, and finally the result of the customer requirement. In some cases, the result can be compared with the manufacturer's documents. In the case of measuring exercises, it must be checked, whether the measured results are realistic. The documentation should also be finally corrected, improved and completed. This also includes the preparation of a final report. After completion, the trainer makes a final check.

Possible questions:

- Was the control properly installed?
- Has the project objective been complied with?
- Is the customer satisfied with the project result?
- Which documentation is required?
- Is the result completely documented in the correct order?

6. Evaluating:
In the final evaluation phase, an external or self-evaluation is to be carried out on the basis of a comparison of project order documents, the installed control and results of measurements and checks.
Faults, if any, and their causes must be analyzed and possibilities discussed as to how faults can be avoided in the future.
The trainee must learn to assess his/her strengths and weaknesses and develop objective quality standards for his/her acting, which ultimately leads to personal competence. The evaluation can be finalized in a technical discussion, possibly also in a discussion with the customer.

General notes:

For didactic reasons, we refer exclusively to trainees and trainers in the present manual. We expressly point out that these terms include all persons involved in the basic and advanced training: Instructors, teachers, project managers, etc., whether male or female.

Procedural knowledge

In this manual, we do not give notes on procedural knowledge (explanatory knowledge). It is the knowledge of how to achieve a certain result with which measures, procedures or processes - in this case, how the learning target can be reached.
The present manual must be understood as a tool for providing the required core and specialist qualification that must be imparted in an integrated form through independent planning, executing and checking according to the regulations for vocational training in industrial metalworking professions.

Pictogram

The pictograms, which are used as recurrent symbols, are to transfer important information as quickly as possible in the form of a simplified graphical representation and independently of languages.

Basic principles of hydraulics

Introduction

Hydraulics, derived from the Greek word hydro = water, refers, in a scientific sense, to the science of still and moving fluids (hydrostatics and hydrodynamics).
If we speak of hydraulics in mechanical, vehicle and aircraft engineering, we understand by this the practical application of this discipline of physics in the fields of power transmission and open and closed-loop control technology.

Comparison of systems

System technologies such as hydraulics, pneumatics, electrics/electronics and mechanics compete with each other as means for the transmission of power; on the other hand, they complement each other and are also combined.
The decision in favor of a certain system, or a combination, requires detailed knowledge of the features and also of the pros and cons.

	Hydraulics	**Pneumatics**	**Electrics**	**Mechanics**
Source of energy (drive)	El. motor Combustion engine	El. motor Combustion engine Pressure vessel	Mains Battery	El. motor Combustion engine Weight Tension force by spring
Energy transmission elements	Pipes and hoses	Pipes and hoses	Electric cables Magnetic field	Mechanical parts: Levers, shafts, etc.
Energy carriers	Fluids	Air	Electrons	Rigid and elastic bodies
Force density (power density)	High High pressures Large forces Small installation space requirement	Relatively low Low pressures	Low cf. power/weight ratio of el. motor to hydraulic motor 1:10	High Volume and assignment of required installation space is often less favorable than with hydraulics
Smooth control (accelerating, decelerating)	Excellent via pressure and flow	Good via pressure and flow	Good to excellent Electrical open and closed-loop control	Poor
Motion types of drives	Linear and rotary movements can easily be achieved with hydraulic cylinders and hydraulic motors	Linear and rotary movements can easily be achieved with pneumatic cylinders and pneumatic motors	Mainly rotary movements	Linear and rotary movements

Comparison of system technologies

System planning

The specific advantages of hydraulic technology over other technologies such as pneumatics, electrics and mechanics, can only be utilized to the full extent, if the system planner knows the typical features offered by hydraulic control technology.

Features of hydraulic systems

- Transmission of large forces within a minimum of space;
- High energy density
- Storing of energy is possible
- Stepless changes in motion variables such as velocities, forces and moments
- Good monitorability of occurring forces
- Swift reversing operation due to small masses (low moments of inertia) of the drive elements
- High switching dynamics
- Good transmission ratio
- Simple conversion of rotary movements into linear movements or vice versa
- Constructive flexibility in the arrangement of components
- Physical separation of input and output through pipes and hoses
- Possibility of automating all types of movements and auxiliary movements by means of pilot control valves and electronic command transmission
- Usability of standard components and assemblies
- Simple overload protection
- Low wear, since hydraulic components are lubricated by the operating medium
- Long service life
- Possibility of energy recovery

- Pressure and flow losses (fluidic friction) in line systems and control elements
- Dependence of viscosity of the hydraulic fluid on temperature and pressure
- Leakage problems; therefore risk of accidents and risk of fire
- Compressibility of the hydraulic fluid

Energy conversion

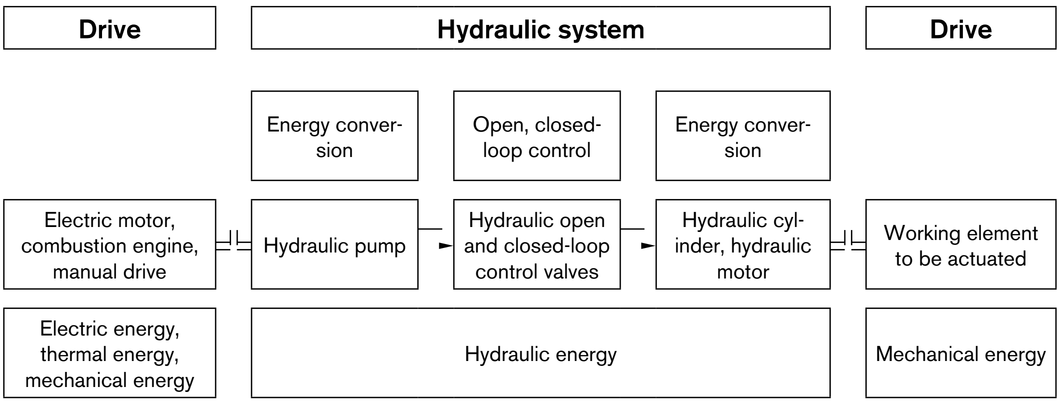
Hydraulic systems convert mechanical energy into hydraulic energy, transport it in this form in an open or closed-loop controlled way and then re-convert it into mechanical energy.

For the conversion of energy, hydraulic pumps are used on the primary side, and hydraulic cylinders and hydraulic motors on the secondary side.

Hydraulic energy and hence the transmitted power can be influenced in pressure and flow by hydraulic pumps, and in its magnitude and direction of action by open and closed-loop control valves.

The hydraulic fluid that is directed via pipes, hoses and bores in control blocks or manifolds assumes, among others, the energy transport.

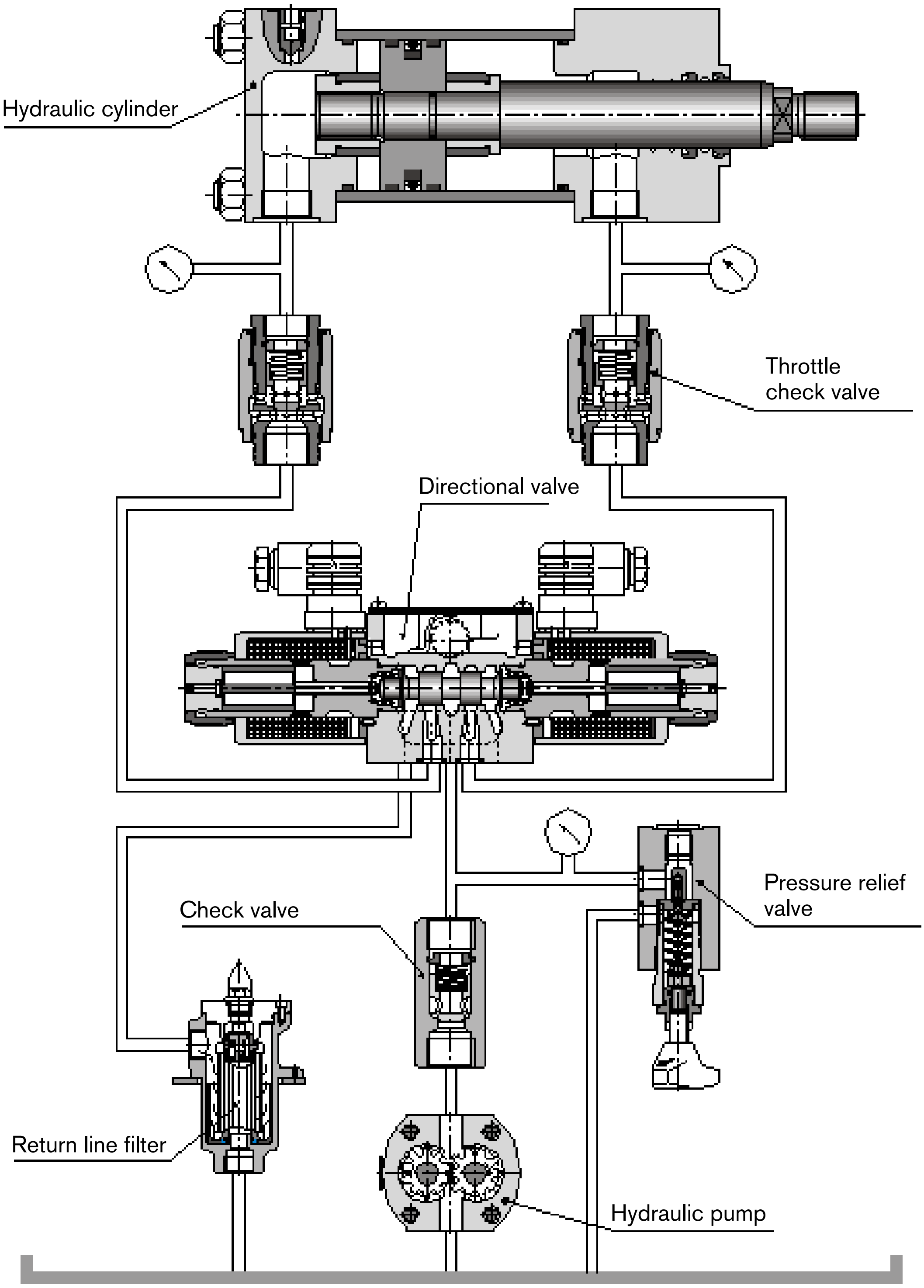
For storing and maintaining the hydraulic fluid, additional equipment such as reservoirs, filters, coolers, heaters, measuring and testing instruments are required.



Energy conversion in a hydraulic system

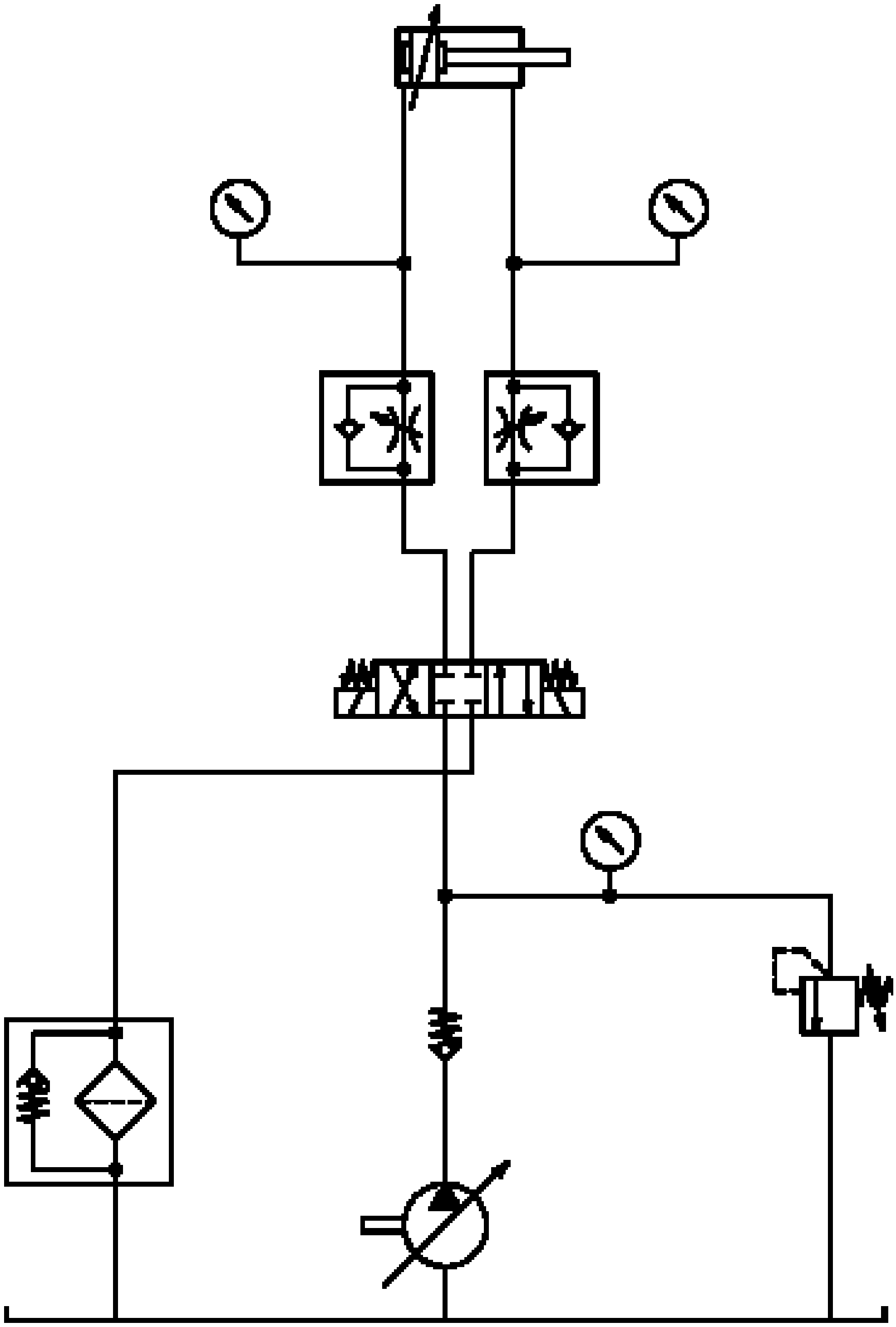
As illustrated in the schematic above, an oil-hydraulic system firstly converts mechanical energy into hydraulic energy, transports it in an open or closed-loop controlled way, and then converts it into mechanical work. The components used in hydraulics can be classified according to their function.

The figure below schematically shows the components of a simple hydraulic system.



Section circuit diagram of a hydraulic system

Instead of sectional drawings, standardized symbols according to DIN ISO 1219 part 1 are used in hydraulic circuit diagrams. More detailed information is provided in the next chapter "Symbols".



Symbol circuit diagram of a hydraulic circuit

Symbols according to DIN ISO 1219-1

In fluid power systems, energy is transported within a circuit by a pressurized medium (liquid or gaseous) and open or closed-loop controlled.

Graphical symbols help to identify the function in circuit diagrams of fluid power technology. They can also be attached to the components themselves for this purpose.

DIN ISO 1219-1

The symbols included in standard DIN ISO 1219 should preferably be used, but their use does in no way rule out the use of symbols commonly applied in other technical areas for identifying pipes and hoses.

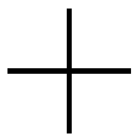
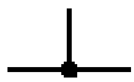
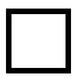
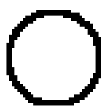
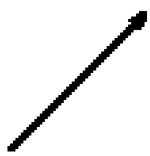
The followings lists are not complete, but must be regarded as working aid for the preparation or completion of project-related circuit diagrams.

The graphical symbols used in the manual comply with DIN ISO 1219 - fluid power technology; graphical symbols and circuit diagrams; part 1: Graphical symbols.

DIN ISO 1219-2

The basic rules for the preparation of hydraulic circuit diagrams are determined in part 2 of standard DIN ISO 1219. Circuit diagrams are a tool to simplify the planning and description of a hydraulic system in order to prevent - through a standardized representation - uncertainties and faults at the planning stage, during production, installation, and servicing.

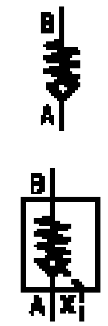
Basic symbols

	Supply line, return flow line, frames for components and symbols
	Internal and external pilot line, leakage line, flushing line, venting line
	The crossing of two lines without connection point indicates that there is no connection
	The connection of two lines is represented by means of a connection point.
	Hose
	Function unit for valves having a maximum of four service ports
	Frame for energy conversion unit (pump, compressor, motor)
	Adjustability of a pump/motor
	Direction of action of the hydraulic force

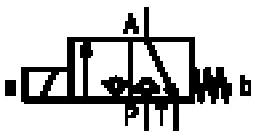
Overview of symbols

Directional valves

Check valve



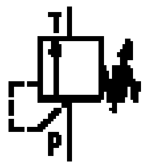
Directional poppet valve



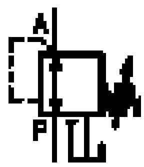
Directional spool valve

Pressure control valves

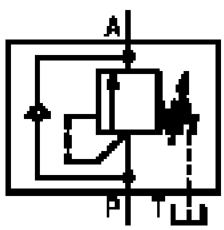
Pressure relief valve



Pressure reducing valve



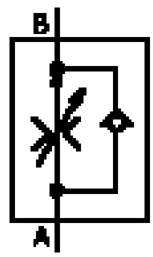
Sequencing valve



Flow control valves

Throttle valve/orifice

Two-way flow control valve



Overview of symbols according to DIN ISO 1219, part 1 (excerpt)

Hydraulic circuit systems

In the field of hydraulics, we differentiate between three circuit systems:

- Open circuit,
- closed circuit,
- semi-closed circuit.

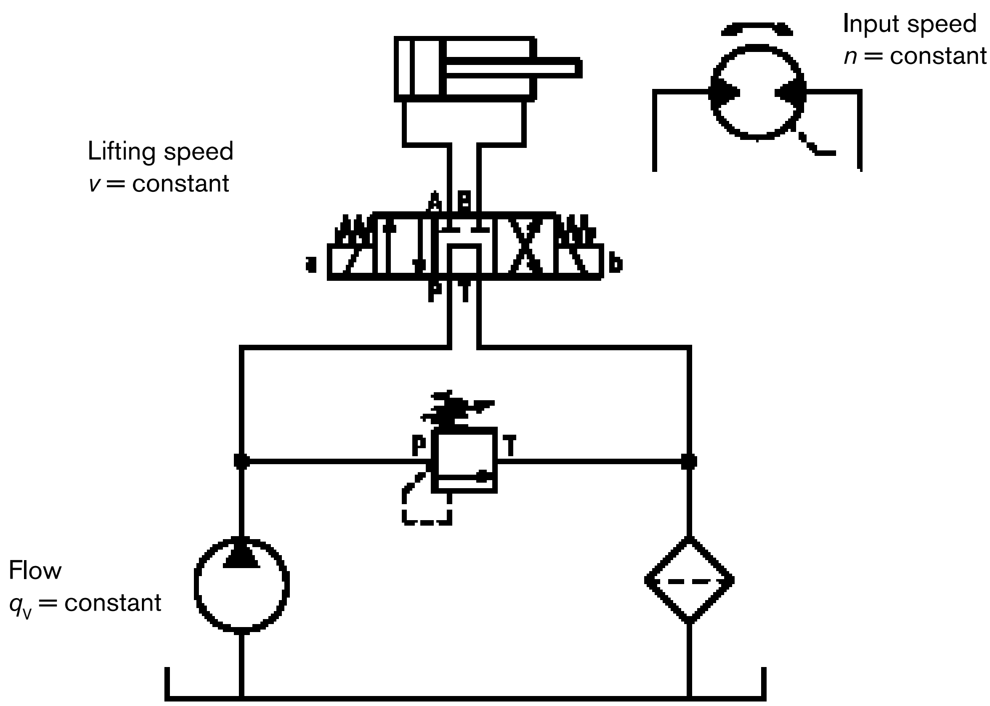
Open circuit

In an open circuit, the hydraulic pumps usually aspires hydraulic fluid through the suction pipe, which is installed below fluid level. The hydraulic fluid is directed by directional valves to the actuator and fed back to the storage reservoir; this means, there is no connection between the suction pipe of the hydraulic pump and the hydraulic fluid returning from the actuator.

Typical features of the open circuit:

- The hydraulic pump aspires oil directly from the hydraulic tank,
- the hydraulic fluid flows via control elements to the actuator,
- the hydraulic fluid flows from the actuator back to the hydraulic tank,
- simple structure,
- better cooling,
- contamination can settle in the hydraulic tank,
- large amount of fluid,
- large hydraulic tank required,
- large space requirement,
- unfavorable volumetric efficiency

Schematic diagram



The open circuit is employed, for example, in machine tools, handling systems, press controls, winch drives, and gears for mobile applications. The actuators can be hydraulic cylinders and hydraulic motors.

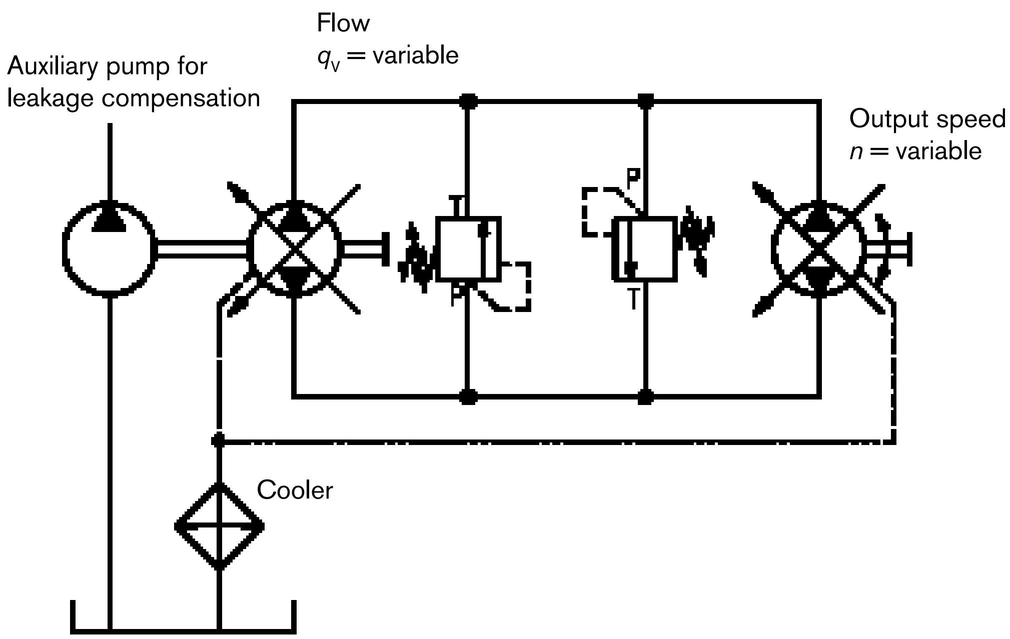
Closed circuit

In a closed circuit, the hydraulic fluid returning from the actuator is directly re-fed to the hydraulic pump. The high-pressure side of the system is protected by a pressure relief valve. The pressure is unloaded to the low-pressure side, that is, the hydraulic fluid remains in the circuit.
The design-inherent permanent, internal leakage of the hydraulic pump and the hydraulic motor is compensated for by a separate auxiliary pump, which is flange-mounted to the hydraulic pump in most of the cases.

Typical features of the closed circuit are:

- The hydraulic fluid is fed by the pump to the actuator,
- the hydraulic fluid flows from the actuator directly back to the pump,
- compact design,
- silent, smooth running,
- good controllability,
- good volumetric efficiency,
- complicated structure,
- greater stressing of the oil,
- sensitive to contamination

Schematic diagram



The closed circuit is used almost exclusively in mobile applications, e.g. for powering a wheel loader travel drive. The hydraulic pumps and hydraulic motors used are in most of the cases axial piston units.

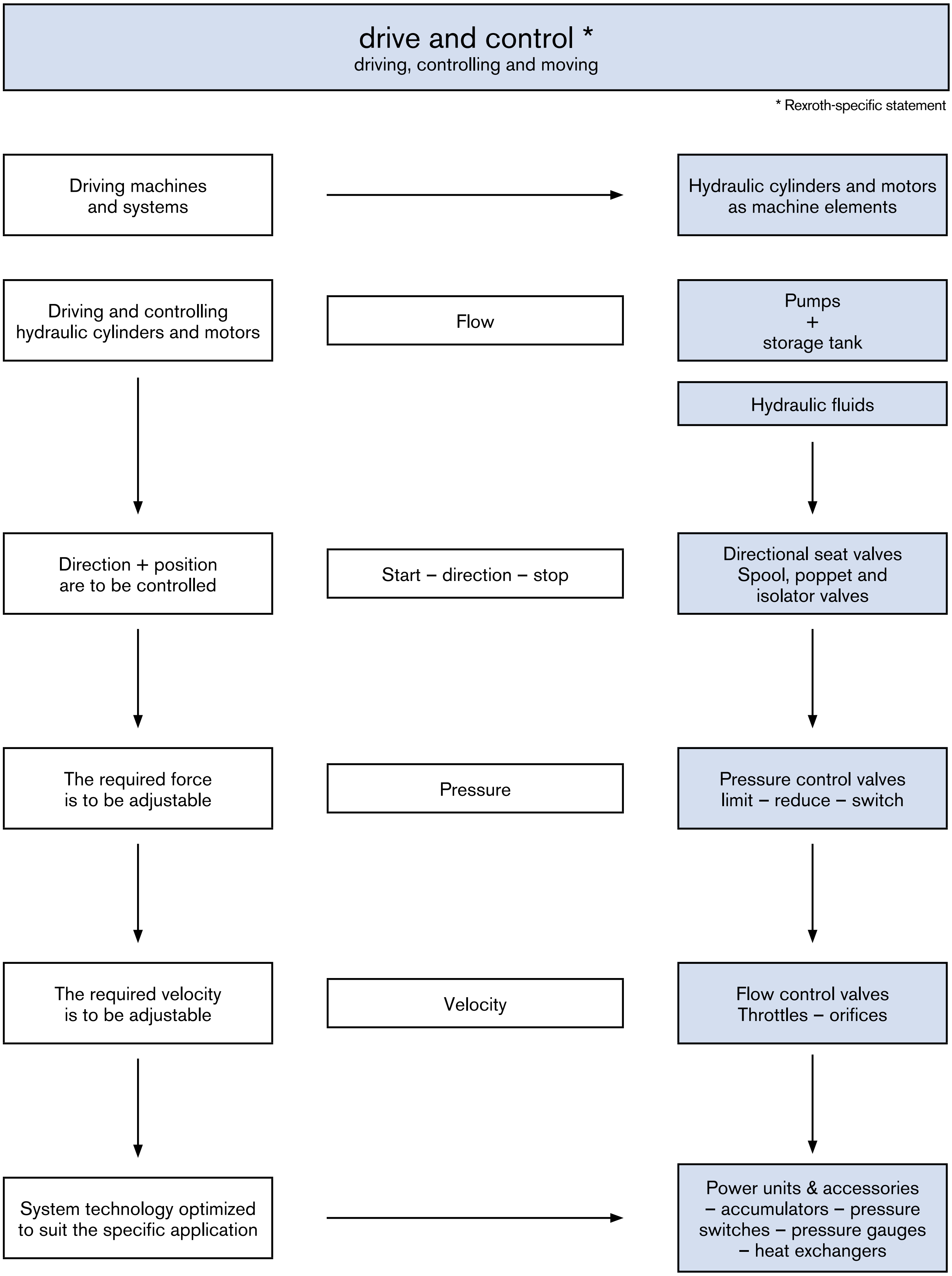
Semi-closed circuit

The semi-closed circuit is a combination of the open and the closed circuit and is used, if the volume must be balanced by means of anti-cavitation valves, for example, when a single-rod cylinder is employed in a mobile machine.

drive and control

The schematic illustration "drive and control / driving - controlling - and moving" on the next page shows the task set to a hydraulic cylinder or hydraulic motor as machine element.

- The travel speed of the actuator is realized by the hydraulic pump flow.
- The direction, start and stop are controlled by directional valves.
- The required force can be varied by adjustable pressure control valves.
- The specified travel speed of the actuator can be influenced by means of a flow control valve.
- Optimized system technology includes monitoring elements such as pressure switches and pressure gauges. Hydraulic accumulators can be provided for realizing faster movements. Heat exchangers optimize the oil quality and hence the availability of the system.



Demands made on hydraulic cylinders / motors as drive elements

Physical basic principles

Pascal's law

Pressure (p) in the vessel results from force (F), which acts on the piston. This means that a greater force (load) generates a higher pressure, whereas with decreasing force (load), the pressure falls.

The second relationship lies in the size of the area (A), onto which the force acts.
The smaller the area, the higher the pressure; and, of course, vice versa, the greater the area, the smaller the pressure.

Consequently, the pressure is dependent on the amount of the effective force (F) and the size of the area (A) onto which this force acts.

Pascal's law:

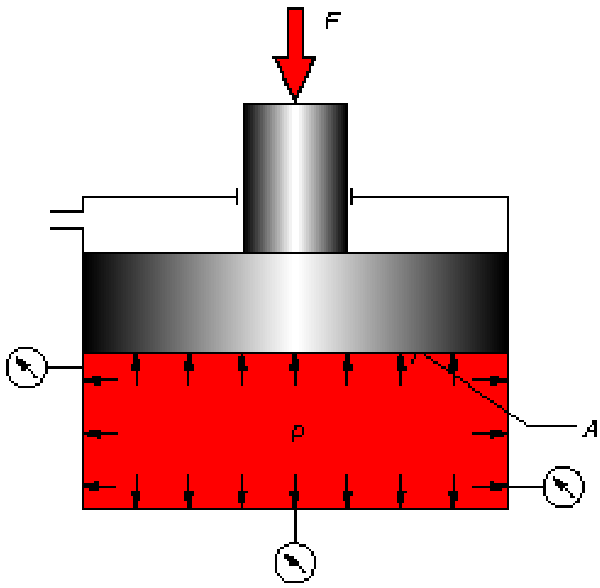
$$p = \frac{F}{A}$$

or:

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

$$F = p \cdot A$$

Force = pressure • area



Pascal is the SI unit of pressure. It was named after Blaise Pascal.

$$1\ \text{Pa} = \frac{1\ \text{kg}}{m \cdot s^2} = 1\ \text{N/m}^2$$

The force in Newton per surface area of one square meter, where:

1 bar = 100,000 Pascal (10^5 Pa)
1 bar = 10 N/cm^2

In pressure calculations, the unit Dekapascal (daPa) is often used, where one Dekapascal corresponds to 0.1 mbar.

100 Pa = 10 daPa = 1 haPa = 1 mbar
100,000 Pa = 0.1 MPa = 1 bar = 1,000 mbar
1.000.000 Pa = 1 MPa = 10 bar = 1 N/m^2

Force transmission

In a closed system with two cylinders of different size, only one pressure (p) can prevail. If both cylinders are to be held in balance and the areas (A1 - A2) have different sizes, the loads (F) acting on the areas must consequently be different.

Cylinder 1 means: $p = \frac{F_1}{A_1}$

Cylinder 2 means: $p = \frac{F_2}{A_2}$

If p is identical in both cylinders, this means: $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

Rearranged by force: $F_1 \cdot \frac{A_2}{A_1} = F_2$

$\frac{A_2}{A_1}$ is the area ratio of the cylinders and is identified by letter φ.

Consequently: $F_1 \cdot \varphi = F_2$

Example:

Area A_1 = 50 cm²
Area A_2 = 750 cm²
Weight force F_1 = 1.000 daN
Weight force F_2 = ?

Solution: $F_1 \cdot \frac{A_2}{A_1} = F_2$

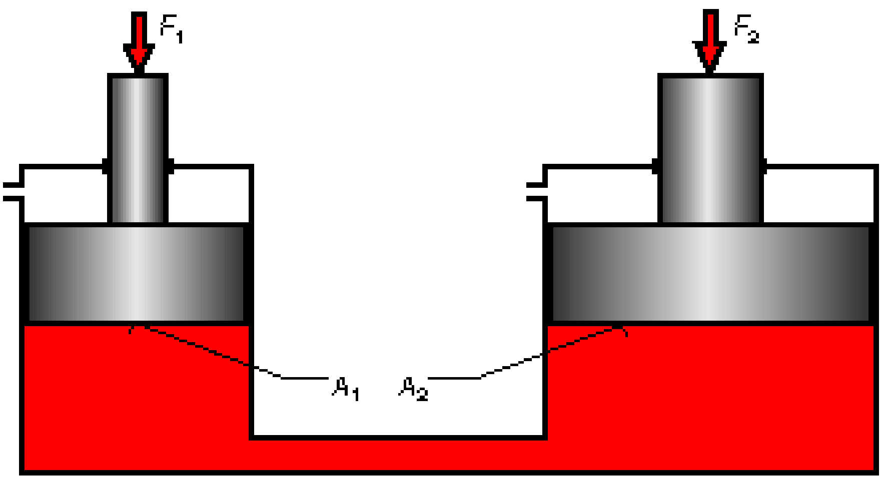
$$1.000 \text{ daN} \cdot \frac{750 \text{ cm}^2}{50 \text{ cm}^2} = 15.000 \text{ daN}$$

$$\text{or with } \varphi = \frac{A_2}{A_1} = \frac{750}{50} = 15$$

$$F_1 \cdot \varphi = F_2$$

$$1.000 \text{ daN} \cdot 15 = \underline{15.000 \text{ daN}}$$

This means that cylinder 1 with a force of 1,000 daN, which corresponds to a mass of 1,000 kg, can hold cylinder 2 with a load of 15,000 kg or 15 t.



Pressure intensification

The extending speed of a piston is to be adjustable by means of a meter-out throttle.

Which **risk** arises, when the throttle is completely closed, e.g. due to dirt?

Example:

$p_K = 100$ bar

$\varphi = 2:1$

$$\varphi = \frac{A_K}{A_R}$$

Solution:

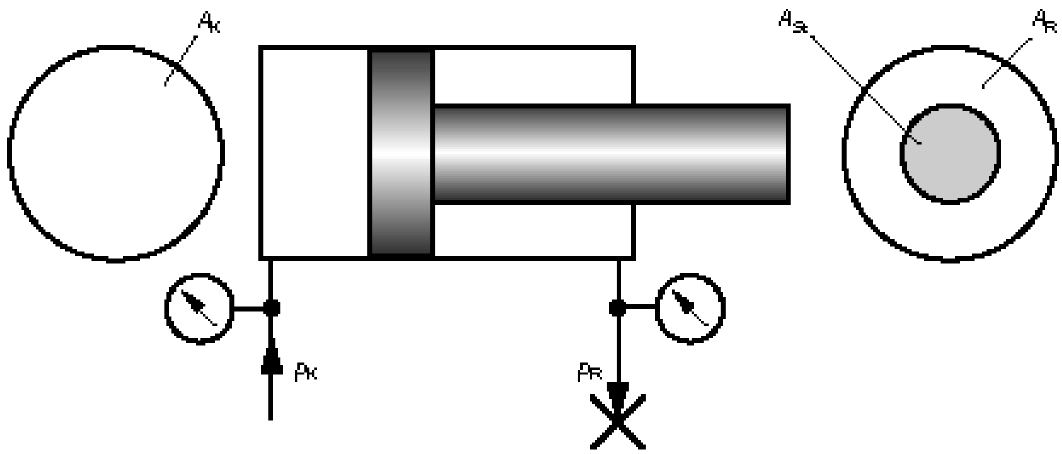
$$p_K \cdot \varphi = p_R$$

$$100 \text{ bar} \cdot \frac{2}{1} = 200 \text{ bar}$$

$$p_R = 200 \text{ bar}$$

Conclusion:

Meter-out throttling involves the risk of **pressure intensification**!



Flow

The flow is the amount of fluid (nominal volume) that moves in a hydraulic systems within a certain time.

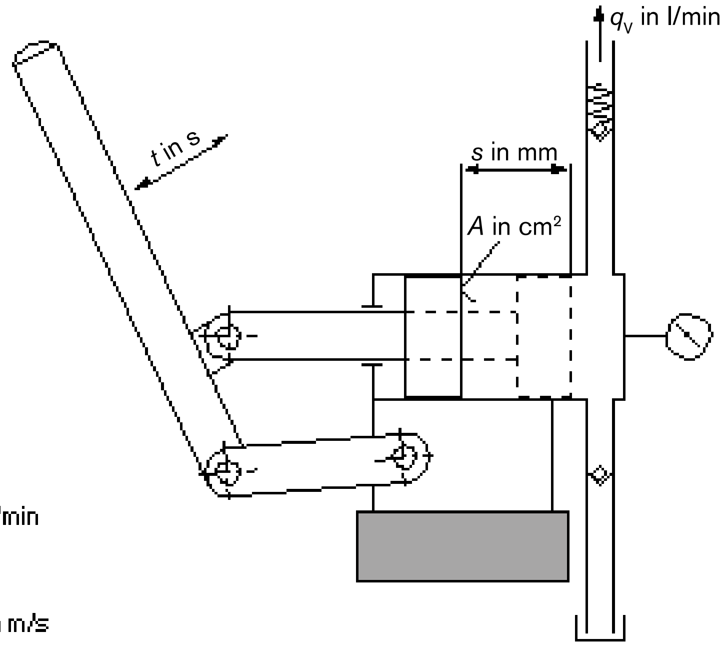
In conjunction with pumps, we also speak of displacement.

The unit commonly used in industrial hydraulics is l/min.

If in the schematic diagram below the lever of the pump is shifted to the right, the piston displaces fluid into the system. If there is no counterforce (counterpressure), almost no pressure will consequently build up in the pump. The fluid is fed to the system at zero pressure.

Only when the displacement is opposed by a resistance (directional valve, throttle, cylinder piston or similar elements), can a counterforce be generated. The pump continues to displace fluid and compresses the fluid. Pressure builds up, which depends on the resistance not generated by the pump.

The pump only displaces fluid into the system.



q_v in l/min

$$q_v = \frac{V}{t} = \frac{A \cdot s}{t}$$

$$\boxed{q_v = A \cdot v \cdot 6} \text{ in l/min}$$

A in cm²

$$v = \frac{s}{t} = \text{Velocity in m/s}$$

s in mm

A in cm²

v in m/s

In technical data sheets, the size of the pump is given in cm³/revolution. The following formula is applied for determining the power:

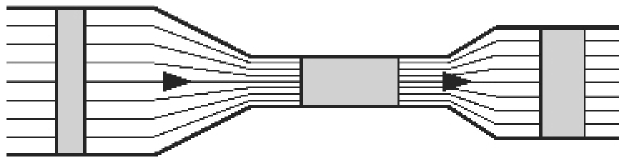
$$q_V = \frac{V_g \cdot n}{1.000} \text{ in l/min}$$

V_g = displacement in cm³/rev
n = speed of the pump shaft in min^{-1}

(rule of thumb without consideration of the volumetric efficiency).

Flow law

The identical volumes flow through a pipe with different cross-sections within the same time. This means that the flow velocity of the fluid must increase at the narrow point.



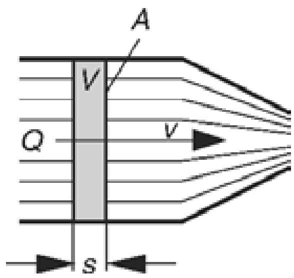
Flow q is fluid volume V divided by time t $\quad q_V = \frac{V}{t}$

Fluid volume V is the product from area A times distance s $\quad V = A \cdot s$

If $A \cdot s$ is subsituted for V, q is then given by $\quad q_V = \frac{A \cdot s}{t}$

Distance s divided by time t provides velocity v $\quad v = \frac{s}{t}$

Flow q hence equals the product from the cross-sectional area of pipe A multiplied by the velocity of the fluid v $\quad q_v = A \cdot v$.



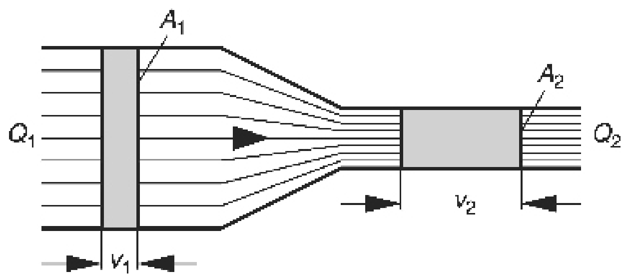
Flow

Flow q in L/min is the same at any point in a pipe. If the pipe has two cross-sections A_1 and A_2, corresponding velocities must occur at the two cross-sections.

$$q_1 = q_2$$
$$q_1 = A_1 \cdot v_1$$
$$q_2 = A_2 \cdot v_2$$

This results in the following continuity equation $A_1 \cdot v_1 = A_2 \cdot v_2$

$$v_2 = v_1 \frac{A_1}{A_2} > v_1$$



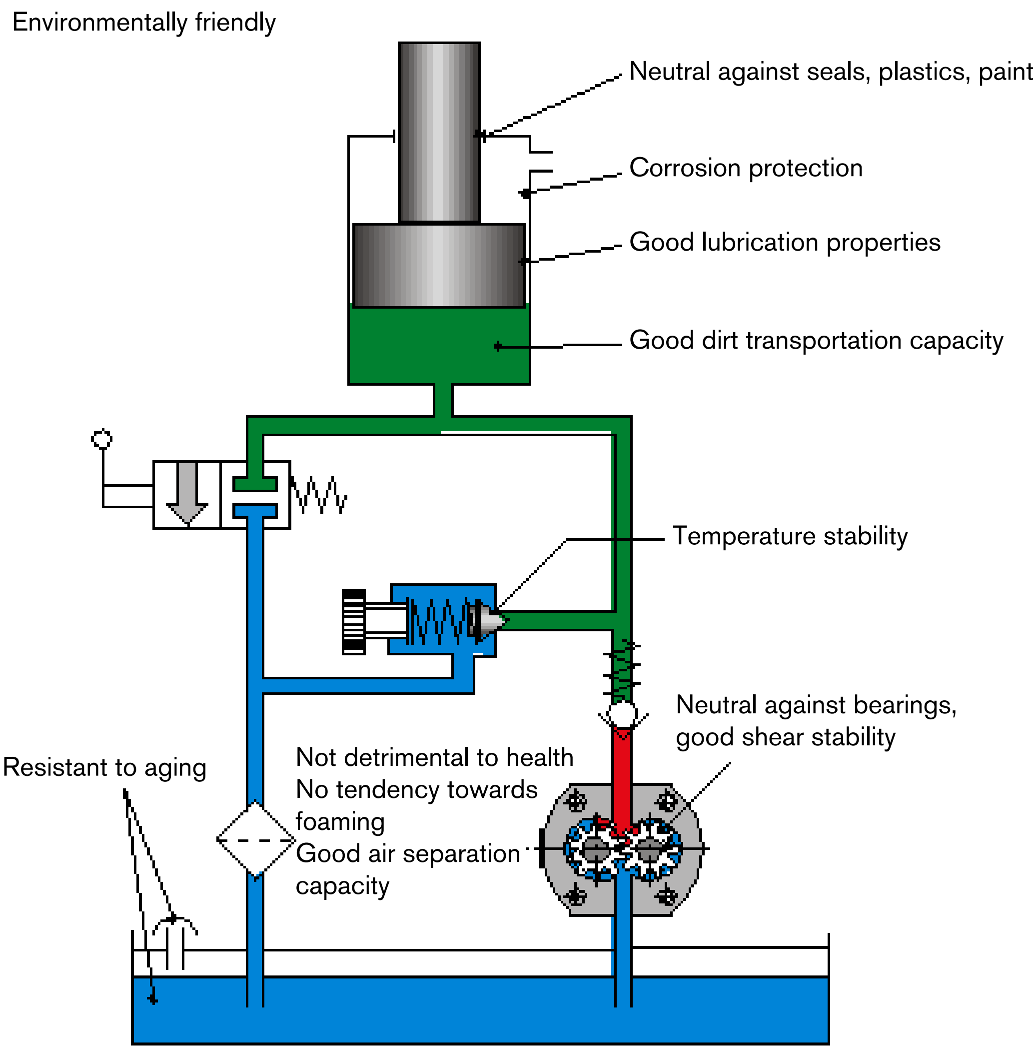
Hydraulic fluids

General

In a hydraulic system, the fluid assumes the task of force transmission. This means that certain demands must be placed on the fluid.

The fluid should:

- be incompressible for the transmission of forces
- dissipate heat that is generated
- not change its viscosity at different temperatures
- carry away abrasion from hydraulic components
- be easy to filter
- be neutral against metal guides, seals and paints
- feature good lubrication properties
- be resistant to aging
- not be detrimental to health
- be easy to dispose of after use



Demands made on hydraulic fluids

Requirements of the market

None of the fluids offered on the market today can meet all of the requirements listed on the previous page. Even in view of ongoing discussions about environmental compatibility of hydraulic fluids and in spite of all concerns, mineral oil is still the most common hydraulic fluid used in hydraulic systems.

Selection criteria

Being an important design element and machine element, the hydraulic fluid must be taken into account at the planning stage, and during engineering and commissioning of hydraulic systems.

The hydraulic fluid to be used is selected according to the prevailing operating conditions such as:

- Operating temperature range
- Concept of the hydraulic system
- Hydraulic pump type
- Working pressure and environmental requirements
- Operating time and availability
- Economic and ecological factors

Viscosity

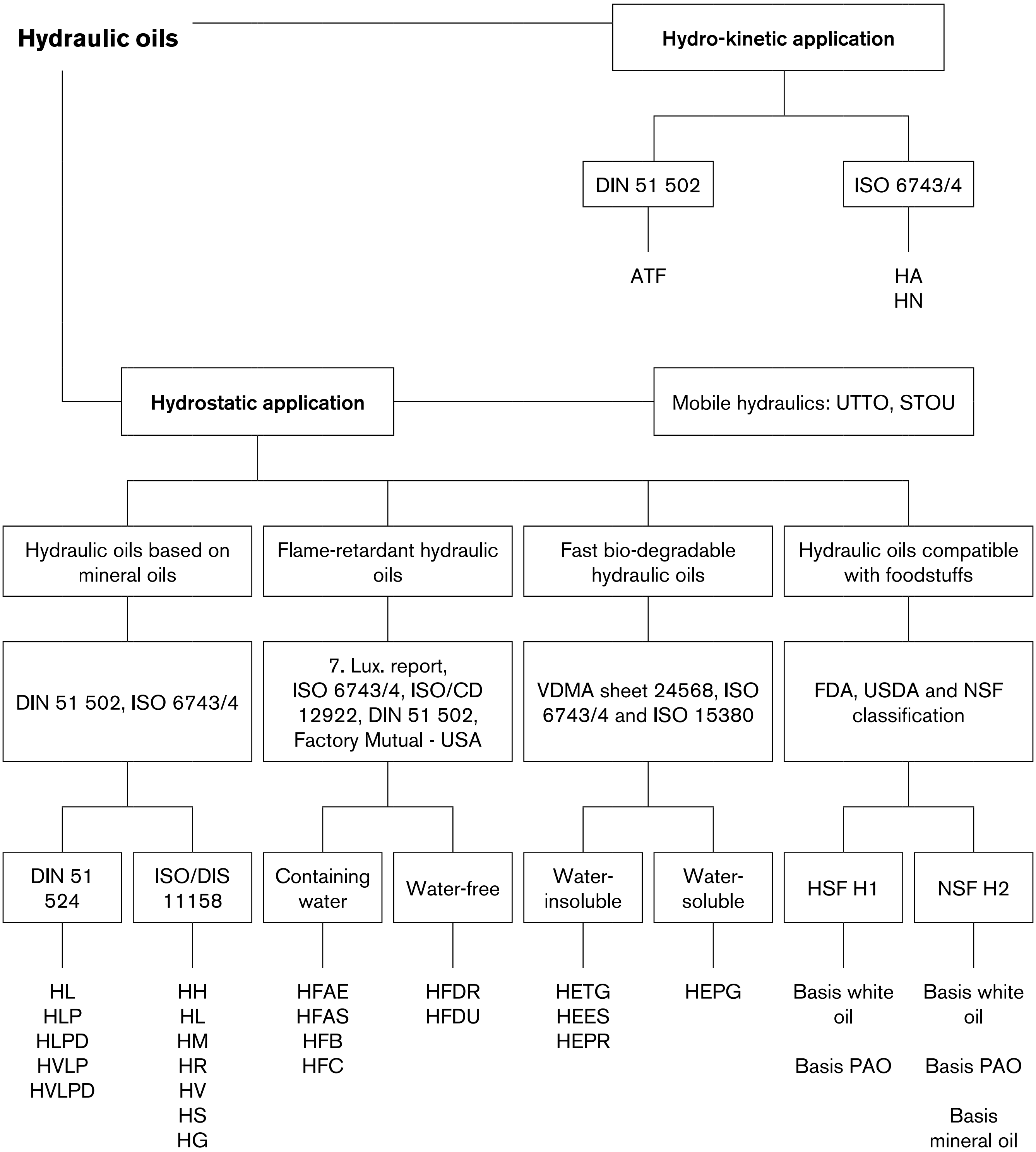
Viscosity is the most important criterion for the selection of the hydraulic fluid. Viscosity data indicate whether a pressure medium is light or viscous at a certain temperature and hence whether friction between the fluid layers is smaller or greater.
The viscosity is measured in the SI unit mm^2/sec. It changes as temperature changes. In a diagram with a double logarithmic scale for the viscosity axis, the representation in the change in viscosity in dependence upon *temperature T* shows a straight line.

Manufacturer's data

For determining the application limits of a hydraulic system and consequently for the selection of the hydraulic fluid, it is important to take minimum and maximum viscosity values into account that are given by the manufacturer in his documentation for the hydraulic components used.

The component manufacturer Rexroth, for example, indicates the data for the selection of the hydraulic fluid in the technical data sheet of the component - RE data sheet - in the section *Technical data, hydraulic*. Here, you can find details about the hydraulic fluid, hydraulic fluid temperature and viscosity range.

Classification of hydraulic oils



Source: Specialist magazine 0 + P

Classification of hydraulic fluids based on mineral oil

Code letter according to DIN 51 502 and ISO 6743/4 **Class L:** Lubricants, industrial oils and related products; **Class H:** Hydraulic systems			
Code letter (symbol) **DIN**	**Code letter** (symbol) **ISO-L**	**Composition** Typical properties	**Field of application** Operating temperature
--	HH	Mineral oils without active additives (base oils)	Hydraulic systems without specific requirements (only in rare applications today) -10 to 90 °C
HL	HL	Mineral oils with active additives to increase the resistance to aging and to improve corrosion protection	Hydrostatic drives with high thermal stress, good water separation capacity -10 to 90 °C
HLP	HM	Mineral oils of type HL with active additives to improve wear protection in the mixed friction area	Hydrostatic drives with high thermal stress, which require additives for the reduction of wear, good water separation capacity -20 to 90 °C
--	HR	Mineral oils of type HL with active additives to improve viscosity / temperature characteristics	Extended operating temperature range when compared with HL oils -35 to 120 °C
HVLP	HV	Mineral oils of type HM with active additives to improve viscosity / temperature characteristics	Among others, hydrostatic drives in mobile hydraulics -35 to 120 °C
--	HS	Synthetic fluids without specific flame-retardant properties	Special applications in hydrostatic systems -35 to 120 °C
(HLPD)	HG	Mineral oils of type HM with active additives to improve stick-slip characteristics	Hydrostatic systems with plain bearings at intermittent, low velocities -30 to 120 °C
HLPD	--	Mineral oils of type HM with detergent / dispersive (DD) additives; DD additives reduce friction values	Hydrostatic drives with high thermal stress, which require EP/AW additives; DD additives hold contaminations in balance, e.g. in machine tools and mobile systems.

Source: Specialist magazine 0 + P

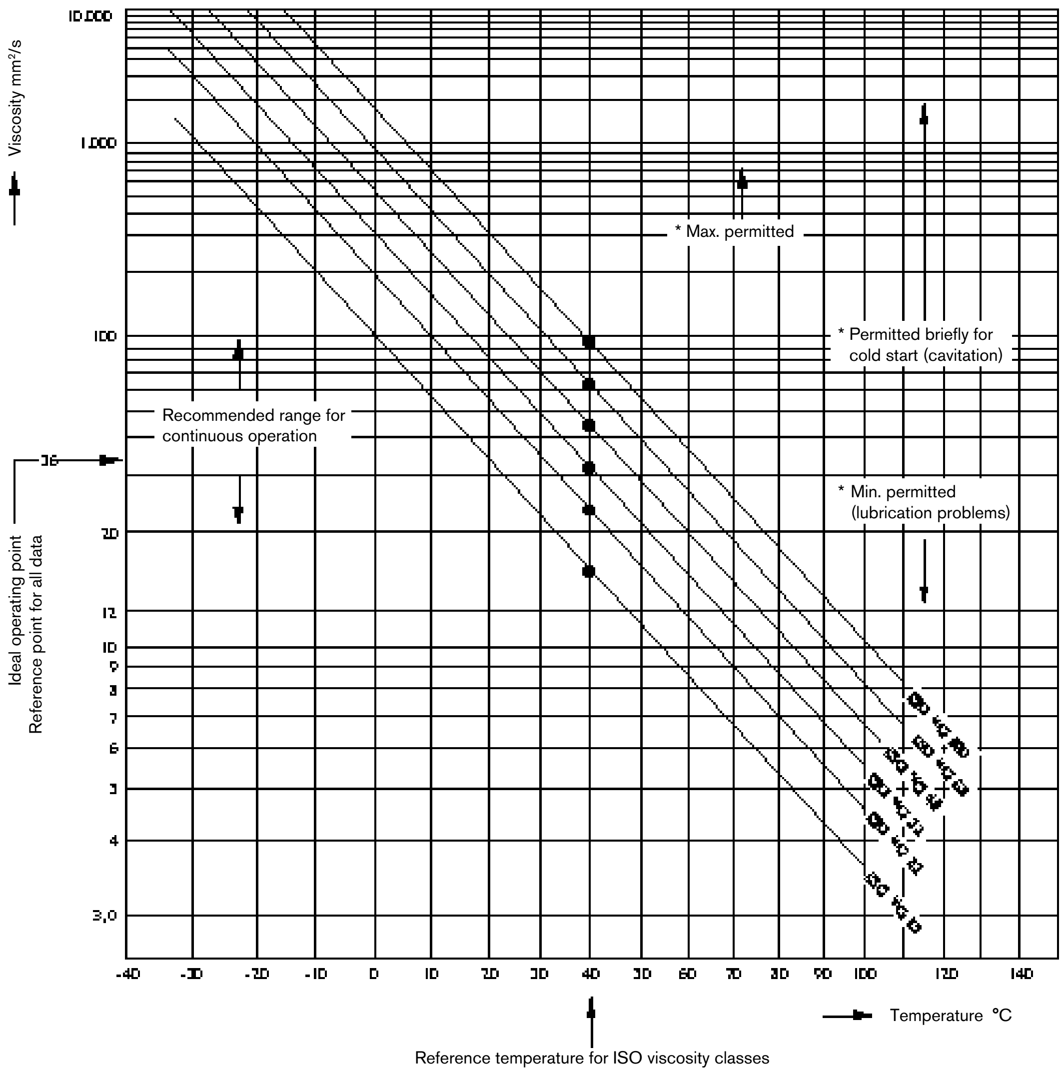
Classification of flame-retardant hydraulic fluids and water-free, fast bio-degradable hydraulic fluids

Code letter according to 7th Luxemb. report, DIN 51 502 and DIN EN ISO 6743/4: April 2002	Composition Typical properties	Field of application Operating temperatures (Notes)
Flame-retardant, water-containing hydraulic fluids		
HFA-E	Oil-in-water emulsions, mineral oil / synth. esters Concentrate share < 20 %	Power hydraulics of about 300 bar, for example in shield tunneling in the field of mining
HFA-S	Mineral oil-free watery solutions of chemicals Concentrate share < 20 %	Hydrostatic drives - working pressures < 160 bar 5 to < 55 °C
HFB	Water-in-oil emulsion Share of mineral oil 60 %	For example in British mining 5 to 60 °C
HFC	Watery polymeric solution Water share > 35 %	Hydrostatic drives, industrial and mining hydraulics -20 to 60 °C
Water-free, synthetic, flame-retardant hydraulic fluids		
HFD-R	Synthetic fluids based on phosphate esters, water-free	Lubrication and control of steam turbines, industrial hydraulics -20 to 150 °C in hydrostatic systems often 10 to 70 °C
HFD-U	Synthetic fluids of other composition (mostly carboxylic acid, polyesters) water-free	Hydrostatic drives, industrial hydraulics -35 to 90 °C

Code letter according to VDMA 24568 and ISO 15380	Composition Typical properties	Field of application Operating temperatures (Notes)
Water-free, fast bio-degradable hydraulic fluids		
HEPG	Polyalkylene glycol Water-soluble	Hydrostatic drives, e.g. ship lock hydraulics -30 to < 90 °C
HETG	Triglycerides (vegetable oils) Not water-soluble	Hydrostatic drives, mobile hydraulics -20 to 70 °C
HEES	Synthetic esters Not water-soluble	Hydrostatic drives, mobile and industrial hydraulics -35 to 90 °C
HEPR	Polyalpha olefins (synth. hydrocarbons) Not water-soluble	Hydrostatic drives, mobile and industrial hydraulics -35 to < 80 °C

Source: Specialist magazine 0 + P

Viscosity/ temperature diagram



Viscosity/temperature diagram with application limits for hydraulic systems

Viscosity

Viscosity is the reference for internal friction of the fluid.
It is the resistance that material particles put up to the force during mutual shifting.

Comparison of different viscosity classes

SAE classes	ISO - VG (DIN 51519)	SAE classes
30	100	68
		49
20, 20 W	68	36
	46	25
10 W	32	
5 W	22	16
	(15)	
		9
	10	

Additives

No hydraulic fluid can meet all requirements. Thanks to additives, certain properties of the hydraulic fluid can be optimized to suit the requirements of specific applications.

For example:

- for improving:
  - corrosion protection
  - pressure resistance
  - resistance to aging
  - viscosity/temperature behavior

- for reducing:
  - the pour-point
  - foaming
  - wear

Practical notes

Effects of air in the oil

Air can be present in hydraulic oils in the following forms: as dissolved air (invisible), as surface foam (visible), and as undissolved, dispersed air (visible). While dissolved air and minor surface foam hardly show any adverse effects, dispersed air can cause severe problems. Since the oil contains very small air bubbles, which are finely dispersed and can rise to the surface only very slowly, the following troubles can occur:

- Uneven or jerky movements of hydraulic spools, vibration in the system due to increased compressibility, changed actuating times of servo-valves
- Pump noise
- Damage to pumps, lines and seals caused by cavitation
- Accelerated aging of the oil
- Micro-diesel effect, a form of thermal cracking due to high temperatures in compressed air bubbles

Environmental aspects

Hydraulic systems are closed systems. When hydraulic systems are used properly, hydraulic fluid does therefore not get into the environment. Care must be taken that power units are leak-free and maintenance/repairs are carried out in due time. Especially hydraulic hoses and hose connections must be intensively observed and inspected. Oil changes must be made properly and thoroughly; waste oil must be disposed of in accordance with all relevant legal stipulations.

Safety aspects

Danger

Hydraulic fluids based on mineral oil are water-endangering and inflammable. Pressure fluids may only be used, if the corresponding safety data sheet of the manufacturer is at hand and all precautions prescribed therein are observed.

If leakage on the hydraulic product can lead to the contamination of water and soil, the hydraulic product must be placed in a suitable oil drip tray.

Filters

Causes of contamination

One of the preconditions for the trouble-free operation of a hydraulic system is filtration of the hydraulic fluid and the ambient air connected to the tank.
The contamination to be removed by means of filters enters the hydraulic system from the surroundings via the filling connection or past the seals.
This type of contamination is termed **external** contamination or contamination that enters the system from outside.
The contamination ingression rate to be expected depends exclusively on the contamination of the surroundings and the design of systems and components.
Moving parts in the hydraulic system such as pumps, spools and valves also generate particles (abrasion). This type of contamination is termed internal contamination.
Especially during commissioning of the system, there is a risk that the individual components are damaged or destroyed by solid particles that were transported into the system already during assembly.
The majority of malfunctions in hydraulic systems are caused by strongly contaminated hydraulic fluids. Fresh pressure fluid, with which the hydraulic fluid is to be filled, is often contaminated to an impermissibly high level.

– **Contamination during the production of components**
 (component contamination)

 Due to the often highly complicated internal contours of housings and internal parts of components, the latter cannot in every case be sufficiently cleaned. When the hydraulic system is flushed, the contaminants get into the hydraulic fluid.
 Components are often preserved for intermediate storage. The preservatives bind dirt and dust. This dirt also gets into the hydraulic fluid when the system is commissioned.
 Typical contaminants are:
 Chips, sand, dust, fibres, paint flakes, water or preservatives.

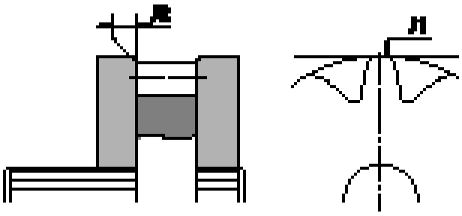
– **Contamination during the assembly of systems**
 (assembly contamination)

 When individual parts are joined, e.g. installation of fittings, solid particles may be produced.
 Typical contaminants are:
 Seal material, scales, welding beads, rubber parts from hoses, residues of pickling and flushing fluids, cutting and grinding dust.

– **Contamination during operation of the hydraulic systems**
 (production contamination)

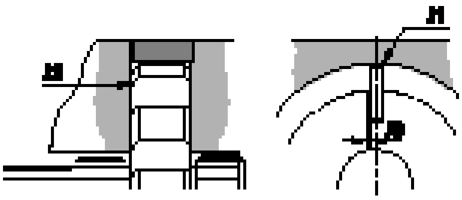
 Abrasion in components results in the formation of particles. Particles smaller than 15 μm are particularly wear-promoting.
 Aging residues in hydraulic fluids, which are in most of the cases caused by high operating temperatures, change the tribological properties of the hydraulic fluid.

Critical tolerances for hydraulic components



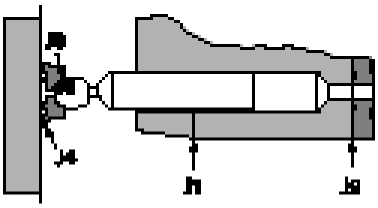
Gear pump

J1	from	0.5	to	5 µm
J2	from	0.5	to	5 µm



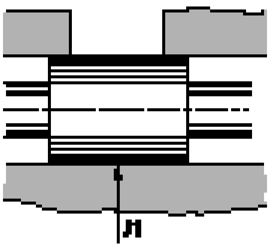
Vane pump

J1	from	0.5	to	5 µm
J2	from	5	to	20 µm
J3	from	30	to	40 µm



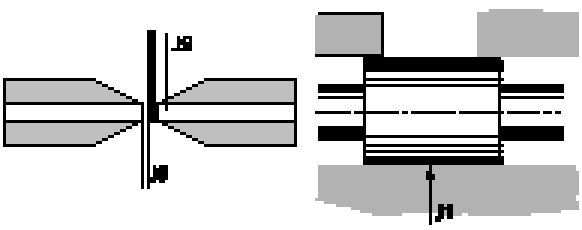
Piston pump

J1	from	5	to	40 µm
J2	from	0.5	to	1 µm
J3	from	20	to	40 µm
J4	from	1	to	25 µm



Valve

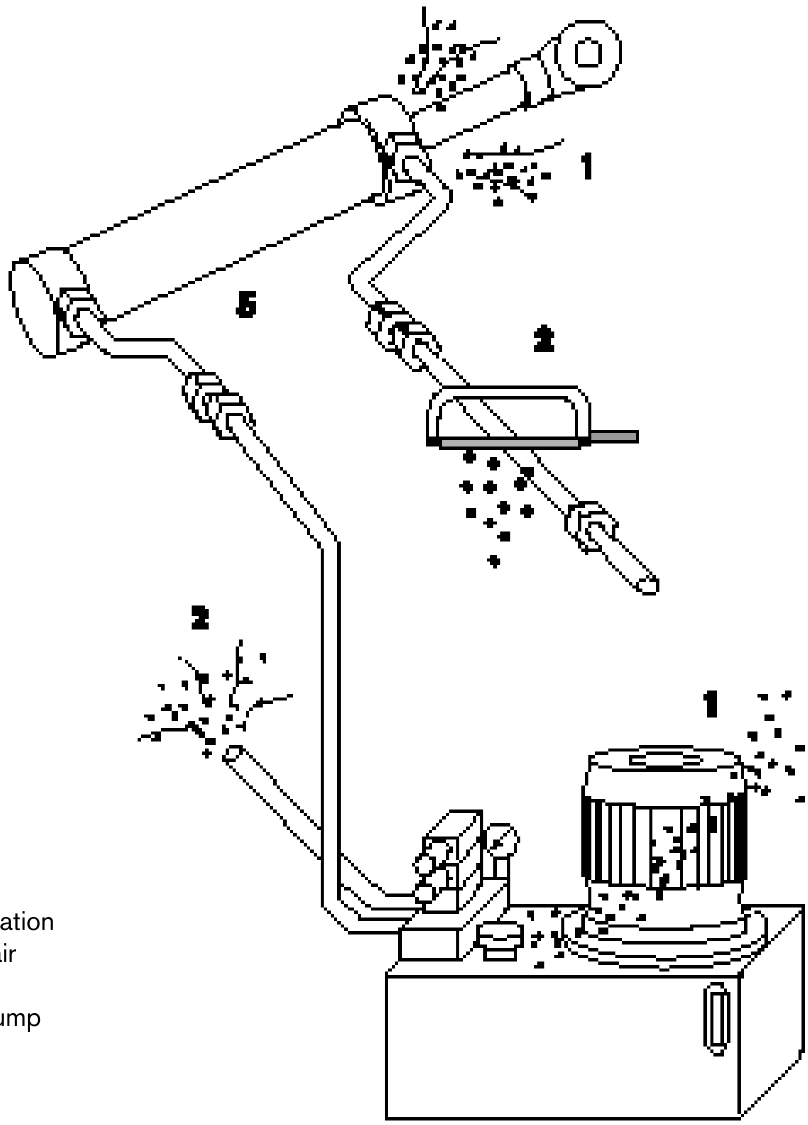
J1	from	5	to	25 µm



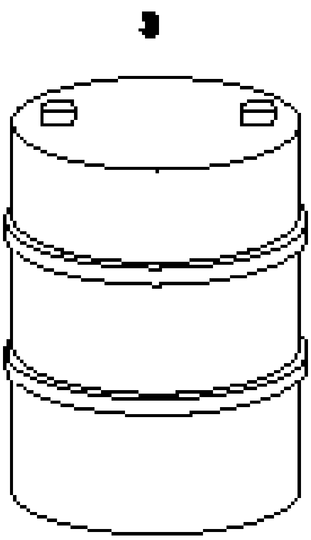
Servo-valve

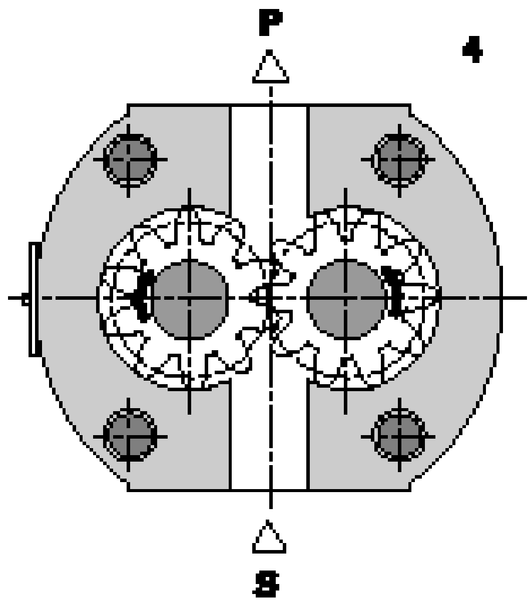
J1	from	0.5	to	8 µm
J2	from	100	to	450 µm
J3	from	20	to	80 µm

Causes and sources of contamination



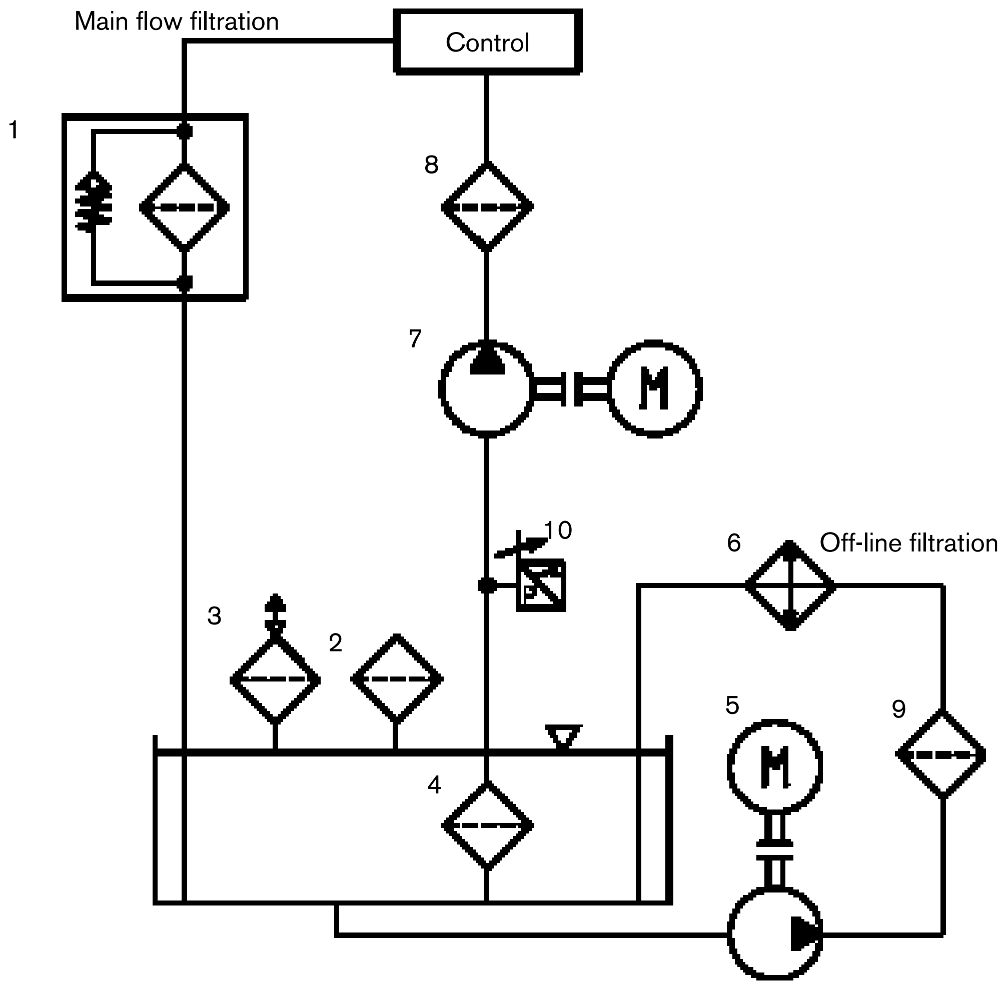
1 External contamination
2 Installation + repair
3 Fresh oil
4 Abrasion in the pump
5 Abrasion of seals





Arrangement of filters in the open circuit

The task of filters is directly related to their arrangement in the system. Filters perform certain tasks depending on their location in the system.



1 Built-on return flow filter
2 Filling filter
3 Breather filter
4 Suction filter
5 Hydraulic pump
6 Cooler
7 Hydraulic pump
8 High-pressure filter
9 Off-line filter
10 Underpressure switch

Filter types

Return flow filter

These filters are located at the end of the return flow line and are designed mostly as filters for tank mounting. This means that the hydraulic fluid coming from the system is filtered before being fed back to the tank. Thus, the major part of dirt particles, which entered the system or are produced in the system, are filtered out of the hydraulic fluid.

The maximum flow must be taken into account for the selection of the filter size.

Advantages

- Low cost
- Ease of maintenance
- Can be fitted with clogging indicator
- Provides fine filtration
- No pump cavitation

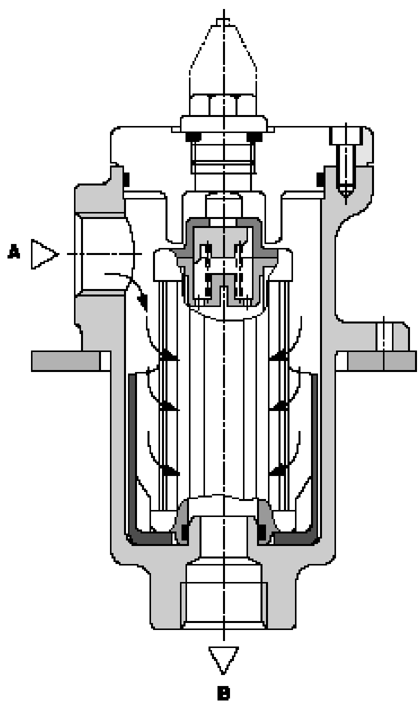
Disadvantages

- A by-pass valve is required
- Lets dirt particles through the open by-pass valve in the case of pressure peaks and cold start conditions

The filter shown below is mounted to the tank cover using a mounting flange. The housing with the filter connection protrudes directly into the tank. A great advantage of this filter design is good accessibility and consequently maintenance-friendliness.

The filter element can be quickly and easily taken out by removing the cover.

An important feature is that a strainer encloses the filter element. When the filter element is taken out, the strainer is pulled out as well, thus preventing dirt already settled from flowing into the hydraulic tank. The filters are generally provided with a connection for a clogging indicator.



In-line filter (pressure filter)

This filter type ensures that the function of downstream hydraulic components is maintained. For this reason, these filters must be installed as closely as possible to the components to be protected.

The following aspects are decisive for the use of pressure filters:

- Components are particularly susceptible to dirt (e.g. servo-valves or high-response valves) or decisive for the operation of a system.
- Components are particularly expensive (e.g. large cylinders, servo-valves, hydraulic motors) and of extreme importance for the safety of a machine.
- Downtime costs of a system are extraordinarily high.

Pressure filters should generally be fitted with a clogging indicator.

Upstream of particularly critical components, only pressure filters without by-pass valve should be used. This type of filter must be provided with a filter element that withstands also higher pressure differential loads without any damage.

The filter housings must withstand the max. system pressure.

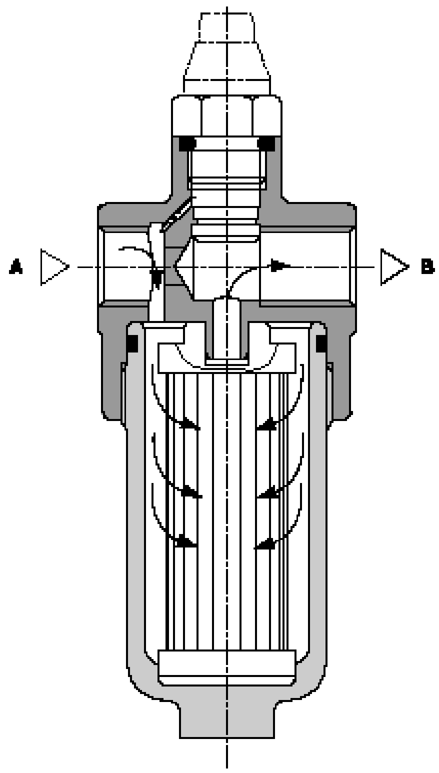
The filter basically consists of a filter head with a screw-in filter housing and a filter element. The standard variant is designed without by-pass valve and without pressure unloading screw. A connection for a clogging indicator is generally provided.

Advantages

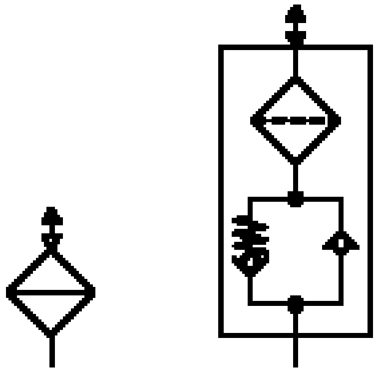
- Can be installed directly upstream of sensitive components
- No pump cavitation

Disadvantages

- Element must be provided for a high differential pressure

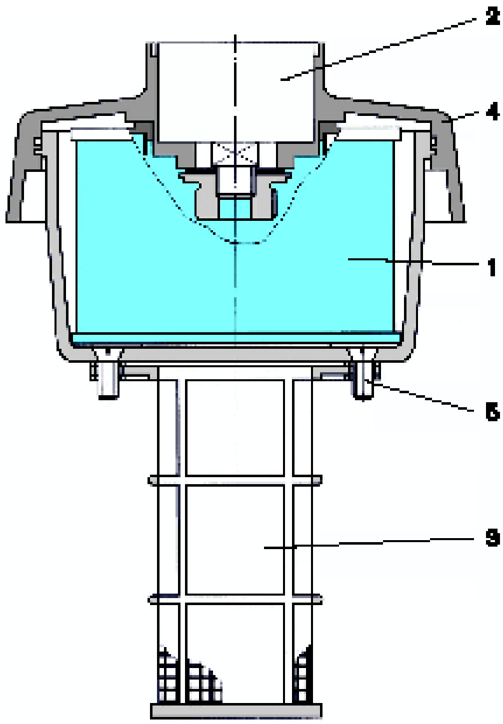


Filler and breather filter



Symbol for filler and breather filter without (on the left-hand side) and with by-pass valve (on the right-hand side)

Filler and breather filter with and without filling filter



Filler and breather filter with filling strainer

In the past minor importance had been attached to these filters in hydraulic systems. However, according to latest findings, they are one of the most important elements for the filtration of hydraulic fluids in hydraulic systems. A significant part of contaminants gets into hydraulic systems through unsuitable venting equipment. Design measures such as pressurization of oil tanks are often uneconomical when compared with the highly efficient breather filters offered on the market today.

Depending on the required cleanliness class, breather filters are equipped with replaceable elements of different filtration ratings. The filters should be fitted with a connection for clogging indicators (2).
Filler and breather filters basically consist of an air filter (1) for filtering the air flowing into the tank and a filling strainer (3) for retaining coarse particles when the system is filled with fluid. The air filters are available with different filtration ratings so that CETOP standard RP 70 can be complied with, which prescribes the same filtration rating for system filters and air filters.

The requirements for this filter type are laid down in DIN 24557.

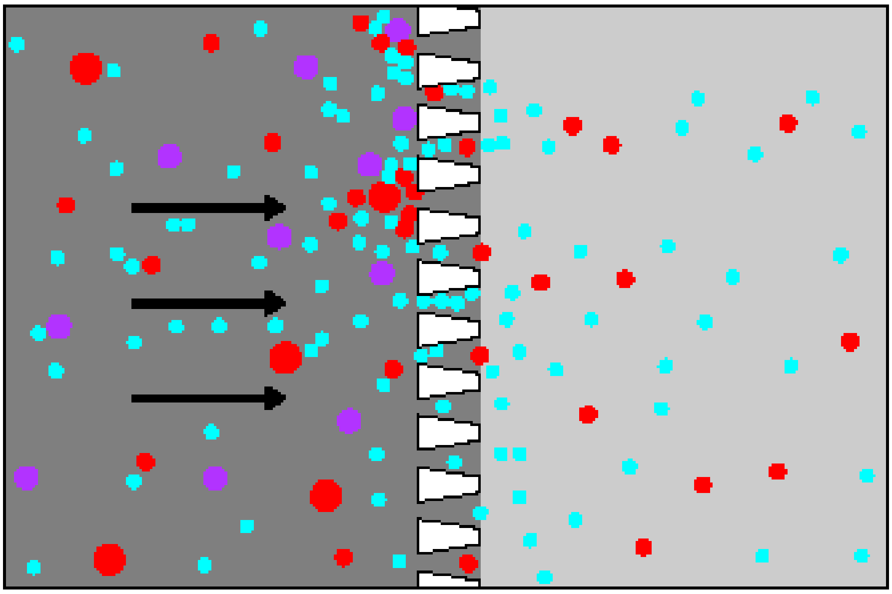
Filtration media

For the filtration methods described, various filter media or a combination of filter media are used.

a) Surface filtration

With surface filters, the particles are separated directly at the surface of the filter media. Particles that get into the filter medium due to their small diameter can pass through the filter without any hindrance. However, the filter resistance increases as the surface is clogged. The filter cake built up on the surface can result in a reduction in the filtration rating.

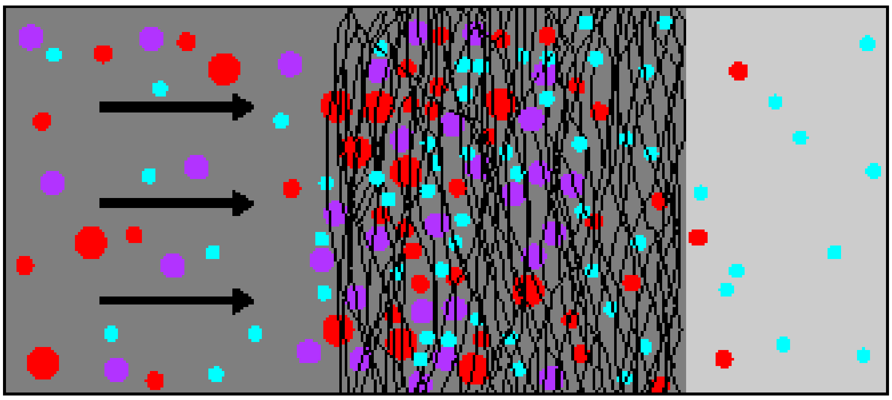
For surface filtration, diaphragm filters of filter materials made of wire mesh, metal edges or Dutch weave are used.



b) Deep filtration

The fluid to be filtered penetrates the filter structure. The particles to be removed are also retained in the deeper layers of the filter. As more and more particles are retained by the filter, the flow resistance increases so that the filter element has to be replaced. For these filters, filter media are used, which are made of

- impregnated cellulose materials (organic filter material),
- glass fiber material (inorganic filter material),
- sintered metal meshpacks,
- porous, sintered metal.



Particle size and filtration rating

Finest particle contamination	Fine particle contamination	Coarse particle contamination
Finest particles (3 to 5 μm) cause an impairment of function and reduction in the performance due to: – the erosive effect of finest particles (often erosion on control lands) – fine sedimentation in narrow gaps (through edge filtration effect - risk of clogging) – Changes of the operating medium (oil aging) as a result of chemical reactions on the particle surface	Fine particles (5 to 20 μm) cause cratering mainly in narrow fits. The consequences are: – Increase in clearance due to abrasion (increased internal leakage) – Temporary failure (brief seizing effect on sliding spool valves or leakage on valve seats) – Total failure due to severe abrasion	Coarse particles > 20 μm often cause a sudden total failure due to clogging and blocking effects or direct destruction. Typical: – Blocking of nozzles – Jamming or seizing of spools – Material breakouts due to effect of large forces
Finest filtration	**Fine filtration**	**Coarse filtration**
Effective separation of finest-dispersed particles ($\beta_{3\ \text{to}\ 5} \rightarrow 100$) High differential pressure-stable finest filters safeguard the function – They minimize the formation and further development of erosion – They prevent clogging of narrow gaps – They provide protection against aging of oil – They prevent system malfunction	Partial separation of fine particle contamination and complete separation of coarse-grain contamination ($\beta_{5\ \text{to}\ 20} \rightarrow 100$) Fine filters reliably control the acceptable degree of contamination of the system – They protect components optimally against contamination – They reduce cratering – They prevent sudden failures of components	Separation of mainly coarse particles ($\beta_X \rightarrow 100$) X = μm particle size, which can cause a sudden failure on the component to be protected. Coarse filters protect the system against coarse particle contamination They reduce the risk of a sudden failure or total loss.

Classification systems for the degree of contamination of the hydraulic fluid

The solid particle content in the hydraulic fluid is determined with the help of classification systems (standardized cleanliness classes).

The most common standards today are NAS 1638 (National Aerospace Standard) and DIN ISO 4406.

Classification according to NAS 1638

14 cleanliness classes are available for the classification of the hydraulic fluid. For each class, a certain number of particles (in 100 ml) is specified for each of the 5 sizes.

Contamination class	Particle size in µm				
	5 - 15	15 - 25	25 - 50	50 - 100	> 100
00	125	22	4	1	0
0	250	44	8	2	0
1	500	89	16	3	1
2	1000	178	32	6	1
3	2000	356	63	11	2
4	4000	712	126	22	4
5	8000	1425	253	45	8
6	16000	2850	506	90	16
7	32000	5700	1012	180	32
8	64000	11400	2025	360	64
9	128000	22800	4050	720	128
10	256000	45600	8100	1440	256
11	512000	91200	16200	2880	512
12	1024000	182400	32400	5760	1024

Contamination classes to NAS 1638
Maximum number of dirt particles in 100 ml hydraulic fluid

Classification according to ISO DIS 4406 Assignment of scale numbers

Number of particles per milliliter		Scale number
more than	up to and including	
2500000		> 28
1300000	2500000	28
640000	1300000	27
320000	640000	26
160000	320000	25
80000	160000	24
40000	80000	23
20000	40000	22
10000	20000	21
5000	10000	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1
0.00	0.01	0

Filter clogging indicators

Inside the clogging indicators, each change in pressure is recorded as change in travel by means of metering pistons or diaphragms. A piston with attached magnet is moved against the force of a spring inside the clogging indicator. On visual clogging indicators, a unipolar magnet is mounted in the indicator head. The closer the poles come to each other, the greater becomes the repulsive force between the magnets, until finally the red indictor button pops out.

With the electrical variant, a switching contact picks up.

For a permanent indication of the element contamination electronic clogging indicators were developed. Through the use of these indicators, maintenance intervals become foreseeable.

With these fully electronic clogging indicators, the differential pressure building up as a result of contamination of the element is converted contact-free into an analog electrical output signal with the help of a sensor. A pressure peak suppression and cold start suppression are additionally integrated.

Backpressure clogging indicators

Differential pressure clogging indicators

Project 01: Hydraulic power unit

Project/trainer information

Hydraulics as technology can be assigned to **drive technology**. The task of drive engineering is to provide a drive for a machine or system that ensures optimum performance of the technological function. This is equally valid for the engine of a passenger car as for the drive of the projects described in this project manual such as the drive of:

- feed equipment for the vertical transport of workpieces,
- rope winches for lifting loads,
- lifting gear for the horizontal transport of loads,
- conveyor belts for transporting loads,
- feed carriages for tool transport,
- punching equipment for punching perforated metal sheets,
- rotary drives for relocating workpieces, and
- pressing equipment for workpiece pressing.

The drive power is made available by an electric motor or combustion engine. The output torque of the motor or engine is converted by a convertor into a rotary or linear movement as required by the machine. This task is assumed by a transmission - in this case, the hydraulic component such as a hydraulic cylinder or a hydraulic motor. The power is transmitted by the hydraulic fluid.

The basic **components of a hydraulic system** are:

- Fluid flow generator/pump,
- fluid flow consumers/hydraulic cylinders and motors,
- open and closed-loop control equipment/valves,
- accessories.

The components of a hydraulic system listed above can be designed as individual components or, to form a compact assembly, combined in a **hydraulic power unit** (without consumers). The valves such as directional, pressure and flow control valves are in most of the cases installed separately into a machine.

A simple hydraulic power unit consists of:

- Hydraulic pump with drive motor,
- reservoir for storing the fluid,
- instruments for monitoring the fluid level, temperature and pressure,
- equipment for fluid care such as filters, coolers and heaters,
- valves for pressure relief functions and, if required,
- hydraulic accumulators as energy accumulators.

In the following *Project 01* you can impart knowledge of the general structure of a hydraulic power unit.
In the project order, the trainee sets up the required components on the basis of the given requirements. In this project task, he or she is to understand the following:

- A hydraulic system consists of a fluid flow generator and a fluid flow consumer (actuator), open and closed-loop control devices and accessories.
- In a hydraulic power unit, hydraulic components are grouped to form a compact assembly.

- The required drive elements and the accessories such as control and monitoring devices as well as maintenance equipment can be mounted on top or to the hydraulic fluid reservoir.
- The size of the power unit, e.g. the capacity of the reservoir, depends on the given conditions and customer requirements.

In this project task, the trainee is to set up a power unit on the basis of the conditions listed below and draw a sketch of a schematic diagram:

- Hydraulic pump in the form of a pilot operated, variable vane pump with a displacement of $\boldsymbol{q_V}$ **= 20 l/min**;
- electric motor for a maximum system pressure of $\boldsymbol{p}$ **= 80 bar**,
- reservoir according to the displacement (3 - 5 times q_V),
- carrier components,
- hydraulic filter with visual, mechanical clogging indicator,
- filler and breather filter,
- level monitor and
- drain valve for changing the hydraulic fluid.

A hydraulic accumulator is not provided.

Notes on the detailed technical information about hydraulic power units:

- *The Hydraulic Trainer Volume 1/Bosch Rexroth AG*
  Basic principles and components, chapter 17
- *The Hydraulic Trainer Volume 3/Bosch Rexroth AG*
  Planning and design of hydraulic systems
- *Technical data sheet RE 51098*
  Modular standard power units
- *Technical data sheet RE 10515*
  Variable vane pump, pilot operated

Project definition

In a hydraulic system for driving lifting equipment for heavy loads, a hydraulic power unit with a variable displacement pump powered by an electric motor and associated accessories is to be used.

The customer wishes to get information about the structure of a hydraulic power unit with pilot operated vane pump. In the list of the hydraulic power unit components he requests the provision of short information about the selected components, including a schematic diagram of the hydraulic system and a parts list.

Fig. 01.1 Practical example: Hydraulic power unit with hydraulic pump/el. motor and accessories

Project tasks

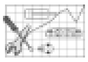
- Independent **understanding** of the task and its putting into practice using hydraulic control technology
- **Planning** and organizing the customer requirement (core qualification)
- **Analyzing** the technical data sheet for a standard power unit with pilot operated vane pump (technical qualification)
- **Handling** of hydraulic components in line with functional needs

Project steps

- **Informing:** Accepting and understanding the order, among others, through discussions with the customer.

- **Planning:** Planning and organizing the execution of the customer order; among others, through the selection of power unit construction parts from a technical data sheet (RE 91098 / modular standard power units).

- **Deciding:** Hydraulic design and dimensioning of the power unit.



- **Executing::** Preparation of a schematic circuit diagram and selection of the required drive elements and accessories with short description.

- **Checking:** Are all customer requirements met?

- **Evaluating:** Are there further possibilities of meeting the customer requirement or simpler ways of project execution? Have unforeseeable problems occurred?

Notes

Hydraulic schematic diagram

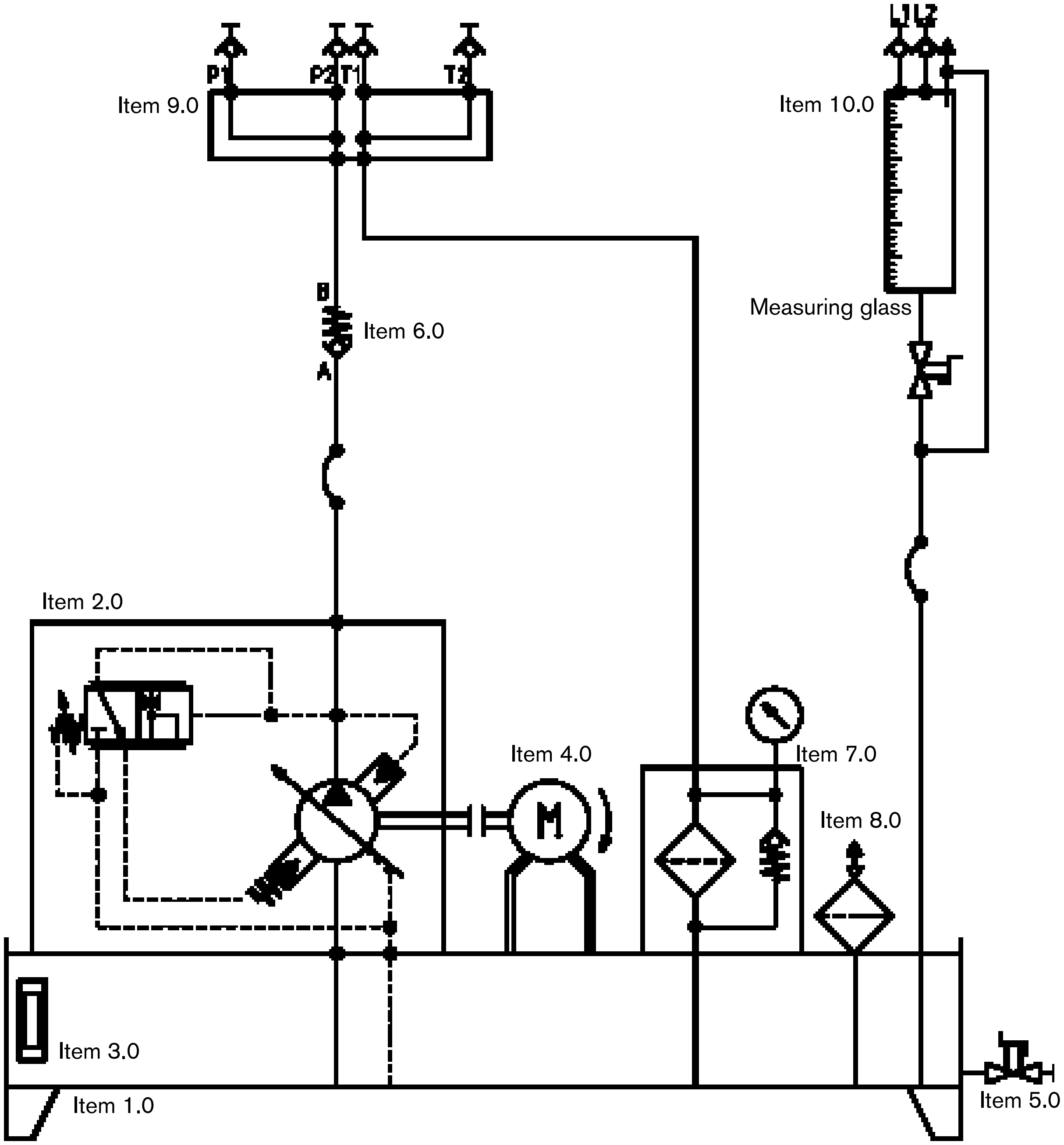


Fig. 01.2 Hydraulic schematic diagram: Drive power unit

Component selection with parts list

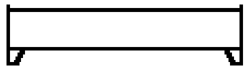
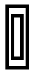
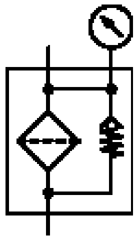
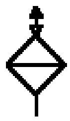
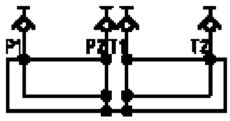
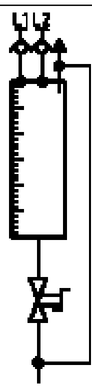
Item	Qty	Component designation	Type designation	Symbol
1.0	1	Reservoir with cover	**100 L/steel**	
2.0	1	Variable displacement pump, pilot operated	**PV7-1X/16-30...**	
3.0	1	Level control	**FSK**	
4.0	1	Electric motor	**4 KW/1450 rev/ min.**	
5.0	1	Shut-off valve, operated by turning		
6.0	1	Check valve with spring, flow enabled in only one direction; closed at rest position	**S6-1X/...**	
7.0	1	Filter with by-pass valve and pressure measuring device	**RF 060...**	
8.0	1	Tank breather filter		
9.0	1	Connection block with 1/4" coupler plug		
10.0	1	Measuring glass		

Table 01.1 Parts list for hydraulic circuit diagram Fig. 01.2

Notes for the trainer:

Items 9.0 and 10.0 listed in the parts list are accessory components for a training system and are not part of a hydraulic power unit in real industrial applications.

Safety notes

To ensure the operability of plant and machinery, and consequently to allow the recognition of potential risks, safety regulations must be observed before and during the execution of the order. Relevant sources of regulations are given in the introduction of the present manual.

Warning

If work on electrohydraulic components is carried out improperly, risks of injury and a safety risk can arise during operation of the system, including danger to life.

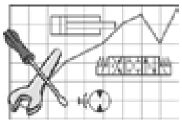
Caution

Before starting work on the training stand, make sure that electrical ON/OFF switches on the hydraulic power unit are pressed in, that is, that the system is switched off. Check on the system pressure gauge that the system is depressurized.

Hydraulic systems can store pressure energy at rest. This can cause injury when the system is opened.

Notes

Execution of the order



Dimensioning of a hydraulic power unit requires fundamental knowledge of hydraulic control technology. This also includes knowledge of the design of hydraulic systems inclusive of the drive power unit. The listing on the next page shows influencing factors that have to be taken into account when rating a hydraulic power unit.

In the project order, only **simple rules** for the rating of power units can be applied. For this, formulas from physical basic principles can be applied (see Fig. 01.3). Any power losses are not considered.

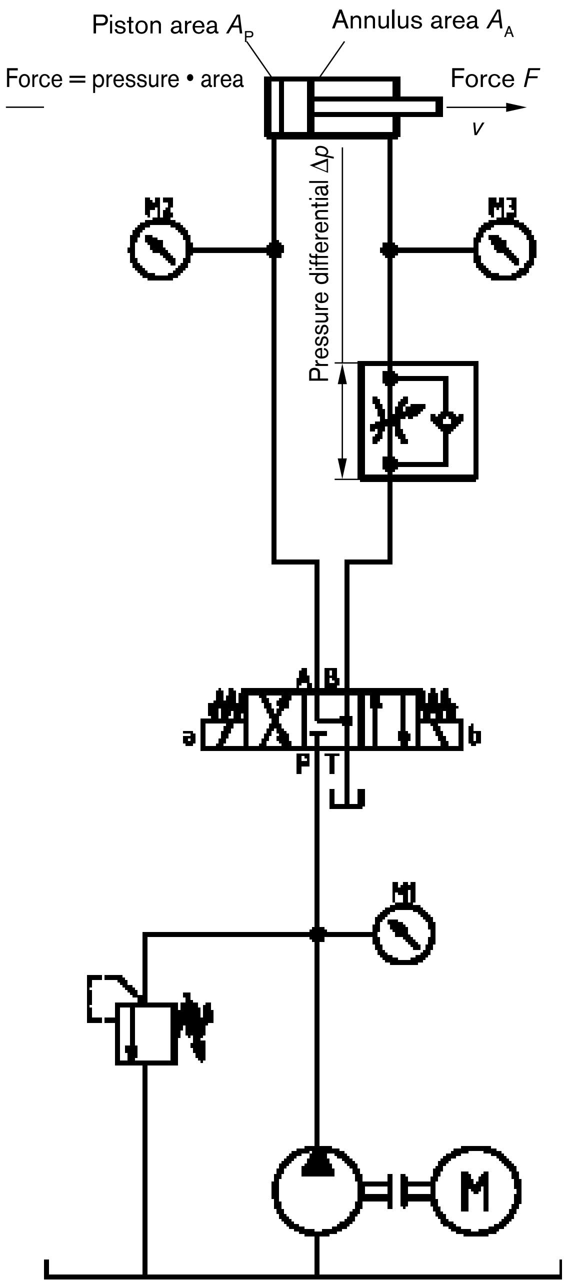
Energy converter
e.g. cylinder

Flow control valve
Change in velocity

Directional valve
Start, direction, stop

Pressure control valve
Force / pressure limitation

Energy converter
e.g. fixed displacement pump



Force

$$F = \frac{p \cdot A}{10}$$

F = force in N
p = pressure in bar
A = area in mm²

Velocity

$$v = \frac{s}{t}$$

v = velocity in $\frac{m}{s}$
s = travel in m
t = time in s

Displacement/flow

$$q_V = \frac{V_g \cdot n \cdot \eta_{vol}}{1000}$$

q_V = flow in $\frac{l}{min}$
V_g = geometric displacement in $\frac{cm^3}{rev}$
n = Speed of the pump shaft in $\frac{rev}{min}$
η = volumetric efficiency in %

Motor power

$$P_M = \frac{p \cdot q_V}{600 \cdot \eta_{total,P}}$$

P_M = power in kW
p = pressure in bar
q_V = flow in $\frac{l}{min}$
$\eta_{total,P}$ = overall efficiency in %

Fig. 01.3 Physical basic principles with formulas

Factors that have an influence on the rating of a power unit

- Environment, surroundings - climate
- Pipe length to the consumer
- Place of installation: integrated - separate
- Duty cycle
- Expected drive power
- Volume fluctuation
- Ambient temperatures
  – Heat dissipated by the reservoir
  – Cooling (air, water)
  – Heating
- Noise - transmitted by pipes and air ducts
- Acoustic insulation
  – Hoses
  – Compensators
  – Anti-vibration mounts
  – Low flow velocity
  – Pump selection
  – Encapsulation
  – Hydraulic accumulator
  – Silencers
  etc.
- Assembly - disassembly - maintenance

Factors that have an influence on the rating of a return flow filter

- Field of application, environment
- Susceptibility of components (the component with the most stringent requirement determines the filter rating for the entire system!)
- The required cleanliness class and filter rating must be adhered to. Both must be specified by the component manufacturer. State of art with regard to minimum requirements is, for example, NAS class 9 and a minimum retention rate of $\beta 10 \geq 100$; ISO 4406 (c) class 20/18/15.
- A reliable calculation of cleanliness is impossible, because the ingress of dirt in relation to the β value cannot be determined.
- Arrangement of filters
- Type, viscosity and operating temperature of the fluid
- Operating pressure
- The flow rate determines the selection of the filter size
- Permissible Δp across the clean element (Bosch Rexroth selection series: Rated Δp for a pressure filter - 1 bar, return line filter = 0.4 bar)
- By-pass valve - determined by the filter series, not provided for pressure filters
- Clogging indicator - a MUST in modern hydraulic systems - visual and/or electrical
- The tank breather filter must have the same filter rating as the fluid filters.

Hydraulic pump:

The following must be known for **rating** the hydraulic pump:

q_V = ? l/min., i.e. which volume is the pump to provide within which time.

Since manufacturers usually indicate only the **sizes** in technical data sheets (how much is displaced during one revolution of the pump?), the speed of the drive/electric motor must be known. In industrial applications, motors of approx. 1,500 rev/min. are employed. For converting the displacement into **power per unit of displacement** the following formula can be applied:

$$q_V = \frac{V_g \cdot n}{1.000} \text{ in l/min}$$

Because no manufacturer will be able to offer a hydraulic pump with exactly the requested power, the next larger size is usually selected.

Electric motor:

For **rating** the electric motor, the possible maximum system pressure must be known apart from the displacement of the hydraulic pump in l/min.

Calculation formula for the selection of the hydraulic motor:

$$P = \frac{p \cdot q_V}{600} \text{ in kW}$$

p in bar
q_V in l/min

Also here, the next larger frame size of the manufacturer's electric motor is selected. Typical frame sizes are, e.g. 3 kW, 4 kW, 5.5 kW, 7.5 kW, etc.
The selection of the required **carrier components** such as coupling, pump mounting bracket and damping elements will not be considered here and are not part of the order execution.

Hydraulic fluid reservoir:

Hydraulic fluid reservoirs are selected on the basis of practical experience such as:

Reservoir size = displacement of the hydraulic pump • 5

Whenever possible, standard reservoirs of standardized sizes should be used. The topic of cooling is not dealt with in this simple engineering task. The provision of a drain valve is always recommended for changing the hydraulic fluid.

Accessories:

In this project task, required accessories for a hydraulic fluid reservoir are a return flow filter, a filler/breather filter and a level control device. For the selection, please refer to technical data sheets of the manufacturers.

When **selecting the return flow filter,** the actual flow required for operating a single-rod cylinder must in any case be taken into account, i.e. how much oil returns from the hydraulic cylinder to the filter (see *Project 04*).
The factors that have an influence on the selection of a return flow filter are listed on the previous page.

As additional aid for rating a hydraulic power unit we recommend the use of a hydraulic slide rule.

For the simplified rating of a return flow filter, see technical data sheet RE 50081.

Detailed notes on the engineering and design of hydraulic systems can be found in The Hydraulic Trainer Volume 3/Bosch Rexroth AG.

General note:

In contrast to the following project tasks, this order execution does not involve any practical work on the training system.
A component arrangement drawing and a general layout of the training system are therefore not provided.

Evaluating the work results in relation to the customer requirement

- A hydraulic system consists of a fluid flow generator and a fluid flow consumer, valves and accessories.
- A hydraulic power unit accommodates the hydraulic components to form a compact unit.
- The required drive elements and reservoir accessories such as control and monitoring and maintenance devices can be mounted to or on top of the reservoir.
- The size and design of the hydraulic power unit depends on the given conditions and the requirements of the customer.

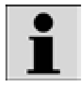
Notes

Project schedule: Project 01

Q. Public, John
Last name, first name

Hydraulic power unit
Customer requirement:
– Hydraulic circuit diagram
– Parts list
– Information about components
– System rating/calculation

Project handler



Project designation

Informing
from the project definition.

Understand the circuit diagram
Identifiy components
Supplement parts lists
Rate components
Evaluate the result

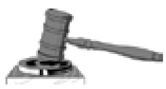
Planning steps

Planning
of the project objective and the proceeding.

Sources of information

DIN ISO 1219
The Hydraulic Trainer Volume 1
Project manager
Data sheets
Internet
Hydraulics supplier

Select components from data sheets
Make calculations

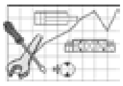


Decision-making

Deciding on
and selecting components; complementing the circuit diagram and parts list.

(Overleaf)

Summarize the information obtained



Execution of the order

Execution
Set-up of the electrohydraulic control and acquisition of required data.

Special points?

Pump data sheet RE 10515 is very complex

Comparison of summary with customer requirements

Quality check

Checking
Are all customer requirements met?

Evaluating
Optimize project steps

(If required, add supplementary sheet)

Assign individual project steps to team members → faster results

Project 01

Note of completion by confirmation of the project manager/place, date, signature