Chapter 1

Basic Principles

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1. Introduction

As this chapter describes basic principles, certain terms from Physics must also be mentioned. It must be noted that even though Physics used to be thought of as a completely separate subject to Chemistry, it is now realised that there is no clear dividing line between the two subjects. Chemistry also determines processes which occur in life. A link between the two subjects is the effect of electrical or electronic actions.

Processes mentioned may very slightly from recent common hydraulics practice, however we hope that what we describe is acceptable. Deviations from practice will be mentioned in footnotes. Physical processes in all technical fields will be described uniformly, due to the way we describe the processes.

1.1 Fluid power

This field was until recently described as "oil hydraulics and pneumatics". This was not only corrected in DIN, but the industry has also adopted the subject designation of "fluid power". When the title "oil hydraulics" appeared many years ago, mineral oil manufacturers became interested in it, as this subject would probably deal with the problems in pipelines, since hydraulics was supposed to be the science of fluid flow laws.

In fact, this subject area deals with the transfer of energy and, when the fluid is stationary, with the transfer of pressure. However, in the transfer of pressure, for example, at the same time as a hydraulic cylinder or motor operates, the pump may generate a flow, and hence the flow laws need to be considered as well. Because of this, the term "hydraulics" has been retained in fluid power to describe the hydraulic characteristic, as opposed to the "mechanical" or "pneumatic" characteristics. However, wherever possible, a phrase such as "some hydraulics is built into the system" should be avoided.

Care should be taken that the mechanical characteristics of a pressure fluid, (i.e the ability to transfer pressure) are made use of in fluid power systems. This is not only true for the hydraulics in fluid power, but also for pneumatics.

The term fluid includes liquid, steam or gases, i.e. air is also a fluid when considered as a mixture of gases. As fluid power is concerned with the mechanical characteristics of fluids, we use the term hydro-mechanics when we are dealing with liquids and aero-mechanics when we are dealing with air.

1.2 Hydro-mechanics

In "hydraulic" fluid power the laws of hydro-mechanics are used. Pressure, or energy, or signals in the form of pressure are transferred, and the laws of hydro-statics (mechanics of still fluids) and of hydro-kinetics [1)] (mechanics of moving fluids) apply.

1.2.1 Hydro-statics

The term hydro-static pressure is common in Physics. It is the pressure which acts on the base of an open container filled with fluid, and which is dependent on the height of the head of liquid inside the container. A hydraulic paradox occurs here, which is that the shape of the container is irrelevant, and only the height of the head of liquid determines the pressure. Hence, this also means that the pressure at the bottom of the container is higher than at the top of the container. This fact is well-known, if you consider the pressure of water deep down in the open sea. The behaviour is the same in a "sea of air".

In statics, care must be taken that the forces are balanced. This is also true for analogue forces in hydro-statics. At the base of a container, at the bottom of the sea, or at a particular height in the place to be measured, the pressure present does not create any changes in the existing relationships.

If the fluid is enclosed in a closed container, as for example, in a hydraulic cylinder in fluid power, and if much higher pressures are needed than exist due to gravity at a certain height in a fluid, then these pressures are created via appropriate technical measures, e.g. by a hydraulic pump. Fluid is pumped into the closed container at a pressure produced by the hydraulic pump, and this

[1)] This field is still widely known as "hydro-dynamics".In reference english books, it used only to be called hydro-kinetics, but recently, especially from American sources, hydro-dynamics has been used instead. Here is however recommended that hydro-dynamics be used to cover both hydro-statics and hydro-kinetics, as stated in DIN 13317. In this standard, dynamics covers both statics and kinetics, as dynamics deals in general with forces, and not only with the forces which are generated from kinetic energy.

pressure exerts itself equally on all sides of the container. This fact may be made use of, by making the base of the container movable. The base then moves, when pressure is applied, and providing that the hydraulic pump continues to supply fluid under pressure, a head of liquid is moved.

If the hydraulic cylinder (also under pressure) is at rest, e.g. in clamping hydraulics the forces are in equilibrium. This effect may be described as hydro-static. However, if the piston in the cylinder is moved by a supply of flow under pressure, then not only is the pressure produced from potential energy effective, but a boost pressure is also effective which is created by the kinetic energy. This pressure must be and is taken into account in fluid power systems. The relationships in this process or system may not really be described wholly as hydro-static, but the hydro-static relationships predominate.

Systems of this type, where hydro-static relationships are predominant and the transfer of pressure is most important, operate at relatively high pressures and low flow velocities in order to keep the influence of hydro-kinetics[1] as low as possible.

1.2.2 Hydro-kinetics

Systems in which the kinetic energy of moving fluids is used to transfer power are not usually considered to be part of fluid power, even though there is no physical reason for them not to be included. These often so-called "hydro-dynamic drives" are the ones which as already mentioned should really be called "hydro-kinetic drives". In this type of drive, as in fluid power the laws of hydro-statics must be considered as well as those of hydro-kinetics, but in this case the laws of hydro-kinetics are the predominant ones.

Considering the fact that both types of energy are active in "hydro-dynamic drives" they must also both be active in systems where hydro-statics is predominant. Hence these systems are also "hydro-dynamic" systems, and so to form sub-groups of hydro-statics and hydro-dynamics would be incorrect.

The still so-called "hydro-dynamic drives" operate according to their designation with high flow velocities and relatively small pressures.

1.3 Types of energy transfer (choice)

	Hydraulics[2]	Pneumatics[3]	Electrics	Mechanics
Energy source (Drive)	Electric motor Combustion engine Accumulator	Electric motor Combustion engine Pressure tank	Power supply Battery	Electric motor Combustion engine Weight force Tension force (spring)
Energy transfer elements	Pipes and hoses	Pipes and hoses	Electrical cable, magnetic field	Mechancal parts Levers, shafts, etc.
Energy carriers	Fluids	Air	Electrons	Rigid and elastic objects
Force density (Power density)	Large, high pressures, large forces, small flow	Relatively small, low pressures	Small, with respect to power weight Electric motor with hydraulic motor 1 : 10	Large, selection and distribution of required flow is often not as good as in hydraulics
Smooth control (acceleration, deceleration)	Very good via pressure and flow	Good via pressure and flow	Good to very good electrical open loop and closed loop control	Good
Types of movement ≙ of outputs	Linear and rotary movements via hydraulic cylinders and hydraulic motors easily attainable	Linear and rotary movements via pneumatic cylinders and pneumatic motors easily attainable	Primarily rotary movement, linear movement: solenoid → small forces → short strokes, poss. linear motor	Linear and rotary movements

Table 1: *Features of types of energy transfer*

[1] see footnote on page 23
[2] as part of fluid power, even though hydraulics deals with far more than just fluid power.
[3] as part of fluid power, even though pneunatics deals with far more than just fluid power.

1.4 Quantities, symbols, units

(see DIN 1301 part 1 and DIN 1304 part 1)

Quantity	Symbol	SI unit	Dimension	Conversion to other accepatable units	Relationship
Length Distance	l s	Metre	m	1 m = 100 cm = 1000 mm	
Area	A	Metre squared	m^2	$1\ m^2 = 10\,000\ cm^2 = 1\,000\,000\ mm^2$ $= 10^6\ mm^2$	$A = l \bullet l$
Volume	V	Metre cubed	m^3	$1\ m^3 = 1000\ dm^3$ $1\ dm^3 = 1\ L$	$V = A \bullet h$
Time	t	Seconds	s	$1\ s = \frac{1}{60}\ min$	
Velocity	v	Metre per second	$\frac{m}{s}$	$1\ \frac{m}{s} = \frac{60\ m}{min}$	$v = \frac{s}{t}$
Acceleration	a	Metre per second squared	$\frac{m}{s^2}$	Acceleration due to gravity (rounded off) $g = 9{,}81\ \frac{m}{s^2}$	$a = \frac{s}{t^2}$
Flow	q_V, Q	Metre cubed per second	$\frac{m^3}{s}$	Litre per minute $\frac{L}{min}$ $1\ \frac{m^3}{s} = 60\,000\ \frac{L}{min}$	$Q = \frac{V}{t}$ $Q = v \bullet A$
Speed	n	Revolutions per second Revolutions per minute	$\frac{1}{s}$ $\frac{1}{min}$ (rpm)	$\frac{1}{s} = \frac{60}{min}$	$n = \frac{1}{t}$
Mass	m	Kilogram	kg	1 kg = 1000 g	$m = V \bullet \rho$
Density	ρ	Kilogram per metre cubed	$\frac{kg}{m^3}$	Kilogram per decimetre cubed $\frac{kg}{dm^3}$ $1\ \frac{kg}{m^3} = 0{,}001\ \frac{kg}{dm^3}$	$\rho = \frac{m}{V}$
Force	F	Newton	N	$1\ N = 1\ \frac{kg \bullet m}{s^2}$	$F = m \bullet a$ $F_G = m \bullet g$
Pressure	p	Newton per metre squared Pascal	$\frac{N}{m^2}$ Pa	$1\ \frac{N}{m^2} = 1\ Pa = 0{,}00\,001\ bar$ $1\ bar = 10\ \frac{N}{cm^2} = 10^5\ \frac{N}{m^2}$ $10^{-5}\ bar = 1\ Pa$	$p = \frac{F}{A}$
Work	W	Joule	J	1 J = 1 Ws = 1 Nm $1\ kWh = 3{,}6\ MJ = 3{,}6 \bullet 10^6\ WS$	
Power	P	Watt	W	$1\ W = 1\ \frac{J}{s} = 1\ \frac{Nm}{s}$	$P = Q \bullet p$
Temperature Temperature in Celsius	T, Θ t, ϑ	Kelvin	K	Celsius °C	$0\ °C \triangleq 273\ K$ $0\ K \triangleq -273\ °C$

Table 2: *Quantities, symbols and units*

The following analogies are relevant for linear movements (hydraulic cylinders) and rotations (hydraulic motors):

Hydraulic cylinders			**Hydraulic motor**		
Parameter	Symbol	SI unit	Parameter	Symbol	SI unit
Distance	s	m	Angle	α	rad
			Frequency of rotation (Speed)	f	$\frac{1}{s}$
Velocity	v	$\frac{m}{s}$	Angular velocity	ω	$\omega = \frac{\alpha}{t}$ $\frac{rad}{s}$
Acceleration	a	$\frac{m}{s^2}$	Angular acceleration	φ	$\varphi = \frac{\omega}{t}$ $\frac{rad}{s^2}$
Force	F	N	Torque	T	$T = \frac{V_g \cdot \Delta p \cdot \eta_{mh}}{20 \cdot \pi}$ Nm
Power	P	W	Power	P	$P = T \cdot \omega$ $\frac{Nm}{s}$
Mass	m	kg	Moment of inertia	J	kgm^2

Table 3: *Analogies*

2. Physics Terms

2.1 Mass, Force, Pressure

2.1.1 Mass *m*

A weight force is created by a mass on the ground due to gravity.

2.1.2 Force *F*

According to Newton's law:

Force = mass • acceleration
$F = m \cdot a$.

If the general acceleration a is replaced by the acceleration due to gravity g (g = 9.81 m/s^2), the following is obtained:

Weight force = mass • acceleration due to gravity
$F = m \cdot g$.

For a mass of 1 kg, this results in a weight force of
F = 1 kg • 9.81 m/s^2 = 9.81 kg m/s^2.

The SI unit for force is the Newton

$$1\ N = \frac{kg\ m}{s^2}.$$

A mass of 1 kg creates a force of 9.81 N on the ground.

In practice, it is generally adequate to use 10 N or 1 daN instead of 9.81 N for a weight force of 1 kg.

2.1.3 Pressure *p*

In descriptions of processes involving fluids, pressure is one of the most important quantities.

If a force acts perpendicularly to a surface and acts on the whole surface, then the force F divided by the area of the surface A is the pressure p

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

The derived SI unit for pressure is the Pascal

$$\frac{1\ N}{m^2} = 1\ \text{Pascal (1 Pa)}.$$

In practice, it is more common to use the bar unit

$$1\ \text{bar} = 10^5\ \text{Pa}.$$

In fluid power, pressure is indicated by *p*. If positive or negative is not indicated, *p* is taken as pressure above atmospheric (gauge) pressure (*Diagram 1*).

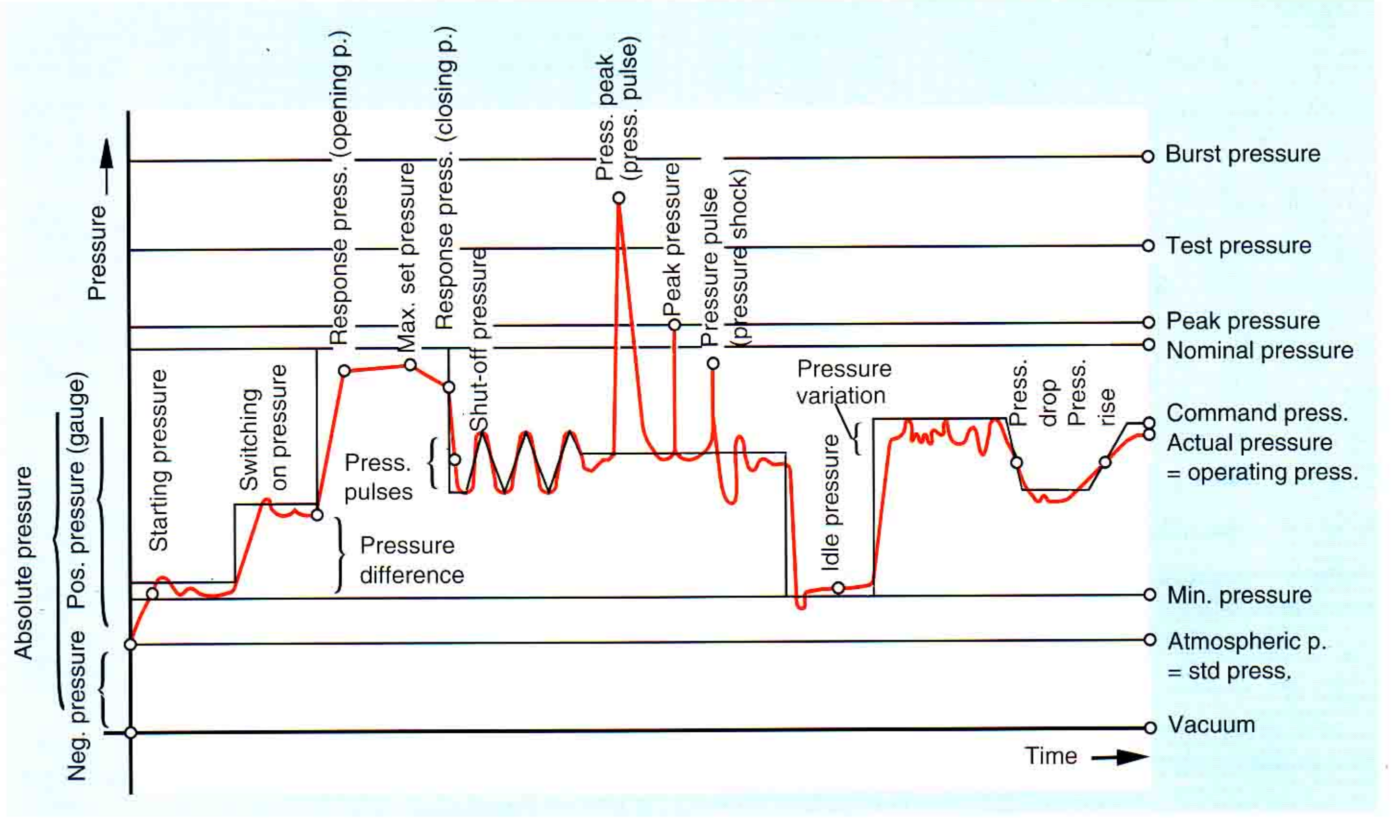

Diagram 1: *Pressures to DIN 24312*

2.2 Work, Energy, Power

2.2.1 Work

If an object is moved by a force *F* over a certain distance *s*, the force has then done work *W*.

Work is a product of distance covered *s* and the force *F* which acts in the direction of the displacement

$$W = F \cdot s .$$

The SI unit for work is the Joule

1 J = 1 Nm = 1 Ws.

2.2.2 Energy

If an object is capable of work, it has "stored work".

This type of "stored work" is known as energy.

Work and energy hence have the same unit.

Depending on the type of "stored work", there are two types of energy:

- Potential energy (energy due to position, E_p) and
- Kinetic energy (energy due to movement, E_k).

2.2.2.1 Potential energy

An object may sink to a particular level due to its high initial position and it hence carries out work.

The amount of work stored is dependent on the weight force $m \cdot g$ of the object and on the height *h*

$$E_p = (m \cdot g) \cdot h.$$

2.2.2.2 Kinetic energy

If a moving object meets an object at rest, the moving object performs work on the body at rest (e.g. deformation work).

The work stored is contained in the movement of the object in this case.

The amount of energy is dependent on the mass *m* and the velocity *v* of the object

$$E_k = \frac{(m \cdot v^2)}{2} .$$

2.2.3 Power

Power is given by work divided by time

$$P = \frac{W}{t} .$$

The SI unit for power is the Watt

$$1\text{W} = 1\ \frac{\text{J}}{\text{s}} .$$

2.3 Velocity, acceleration

2.3.1 Velocity

Velocity *v* is the distance *s* divided by time *t* taken to cover this distance

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

The SI unit for velocity is the metre per second.

2.3.2 Acceleration

If an object does not move at constant velocity, it experiences an acceleration *a*.

The change in velocity may be positive (increase in velocity/acceleration) or negative (decrease in acceleration/deceleration).

The linear acceleration *a* is given by velocity *v* divided by time *t*

$$a = \frac{v}{t} .$$

The SI unit for acceleration (deceleration) is metre per second squared.

2.4 Hydro- mechanics

Hydro-mechanics deals with physical characteristics and behaviour of fluids in stationary (hydro-statics) and moving (hydro-kinetics [1]) states.

The difference between liquids and solid particles is that the particles in liquids are easily moved within the mass of liquids. Hence, liquids do not assume a specific shape, but instead, they assume the form of the container surrounding them.

In comparison with gases, liquids are not as compressible.

2.4.1 Hydro-statics

The laws of hydro-statics strictly apply only to an ideal liquid, which is considered to be without mass, without friction and incompressible.

With these relationships, it is possible to deduce the behaviour of ideal, that is, loss-free circuits. However, losses of one form or another do appear in all components in fluid systems. In components, which operate according to the throttling principle, the losses which arise are indeed a pre-requisite for them to function.

2.4.2 Pressure

If pressure is applied, as shown in *Fig. 1*, on surfaces of the same area (A_1=A_2=A_3), the forces which are produced are the same size ($F_1 = F_2 = F_3$).

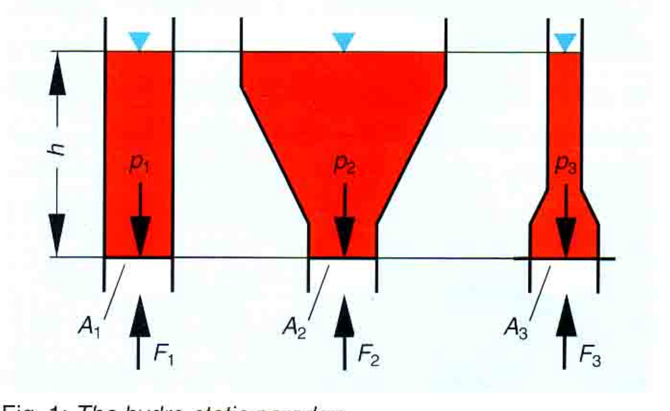

Fig. 1: *The hydro-static paradox*

[1] see footnote[1] on page 23

2.4.2.1 Pressure due to external forces

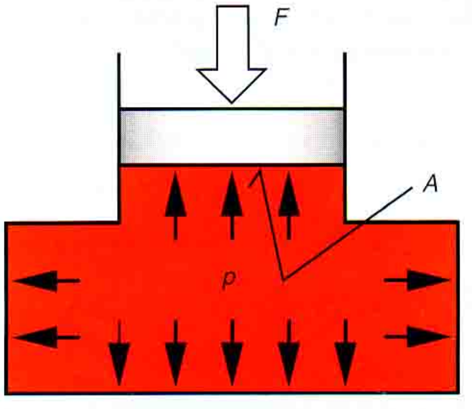

Fig. 2: *Pascal's law*

The basic principle in hydro-statics is Pascal's law:

"The effect of a force acting on a stationary liquid spreads in all directions within the liquid. The amount of pressure in the liquid is equal to the weight force, with respect to the area being acted upon. The pressure always acts at right angles to the limiting surfaces of the container."

In addition, the pressure acts equally on all sides. Neglecting pressure due to gravity, pressure is equal at all points (*Fig. 2*).

Because of the pressures used in modern hydraulic circuits, the pressure due to gravity may usually be neglected.

Example: 10 m water column ≈ 1 bar.

2.4.2.2 Force Transmission

As pressure acts equally in all directions, the shape of the container is irrelevant.

The following example (*Fig. 3*) will demonstrate how the hydro-static pressure may be used.

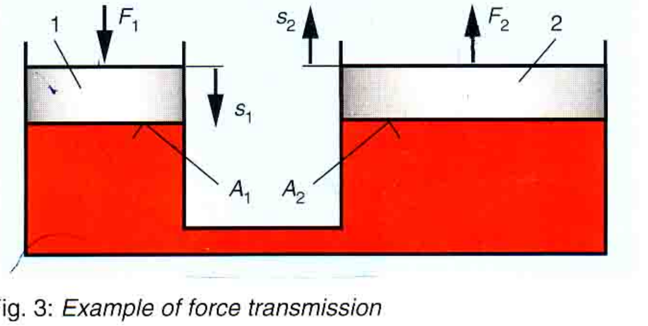

Fig. 3: *Example of force transmission*

When force F_1 acts on area A_1, a pressure is produced of

$$p = \frac{F_1}{A_1}.$$

Pressure p acts at every point in the system, which includes surface A_2. The attainable force F_2 (equivalent to a load to be lifted) is given by

$$F_2 = p \bullet A_2.$$

Hence

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

or

$$\frac{F_2}{F_1} = \frac{A_2}{A_1}.$$

The forces are in the same ratio as the areas.

Pressure p in such a system always depends on the size of the force F and the effective area A. This means, that the pressure keeps increasing, until it can overcome the resistance to the liquid movement.

If it is possible, by means of force F_1 and area A_1, to reach the pressure required to overcome load F_2 (via area A_2), the load F_2 may be lifted. (Frictional losses may be neglected.)

The displacements s_1 and s_2 of the pistons vary in inverse proportion to the areas

$$\frac{s_1}{s_2} = \frac{A_2}{A_1}.$$

The work done by the force piston (1) W_1 is equal to the work done by the load piston (2) W_2

$$W_1 = F_1 \bullet s_1,$$
$$W_2 = F_2 \bullet s_2.$$

2.4.2.3 Pressure transmission

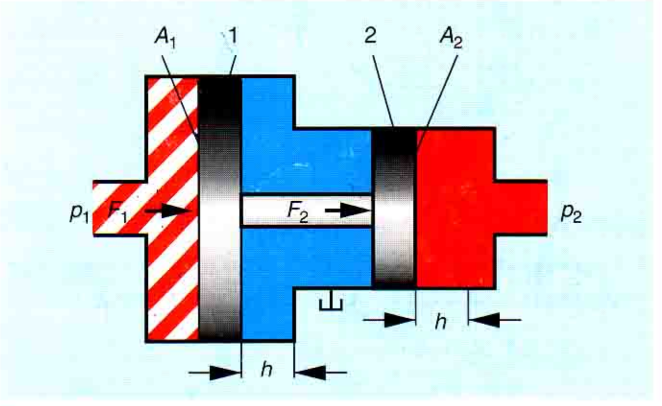

Fig. 4: *Pressure transmission*

Two pistons of different sizes (*Fig. 4: 1 and 2*) are fixed together by means of a rod. If area A_1 is pressurised with pressure p_1, a force F_1 is produced at piston (1). Force F_1 is transferred via the rod to area A_2 of piston (2) and hence pressure p_2 is obtained there.

Ignoring losses due to friction:

$$F_1 = F_2 \quad \text{and} \quad p_1 \cdot A_1 = p_2 \cdot A_2 .$$

Hence $p_1 \cdot A_1 = F_1$ and $p_2 \cdot A_2 = F_2$

or

$$\frac{p_1}{p_2} = \frac{A_2}{A_1} .$$

In pressure transfer the pressures vary in inverse proportion to the areas.

2.4.3 Hydro-kinetics

Hydro-kinetics[1] is concerned with the liquid flow laws and the effective forces which result. Hydro-kinetics may also be used to partially explain the types of losses which occur in hydro-statics.

If the frictional forces at limiting surfaces of objects and liquids are ignored and those between the individual liquid layers are also ignored, it may be assumed that the flow is free or ideal.

The important results and conformity to the natural laws for ideal flows may be adequately described and are dealt with in the following sections.

[1] see footnote[1] on page 23

2.4.3.1 Flow Law

If liquid flows through a pipe of varying diameters, at any particular time the same volume flows at all points. This means, that the velocity of liquid flow must increase at a narrow point (*Fig. 5*).

Flow Q is given by the volume of fluid V divided by time t

$$Q = V/t .$$

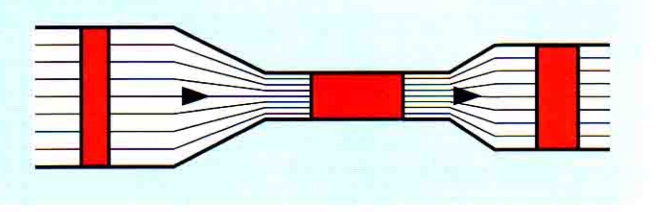

Fig. 5: *Flow*

Liquid volume V is itself given by area A times length s (*Fig. 6a*)

$$V = A \cdot s .$$

If $A \cdot s$ is substituted for V (*Fig. 6b*), Q is then given by

$$Q = \frac{A \cdot s}{t} .$$

Distance s divided by time t is velocity v

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

Flow Q hence equals the cross-sectional area of the pipe A multiplied by the velocity of the liquid v (*Fig. 6c*)

$$Q = A \cdot v .$$

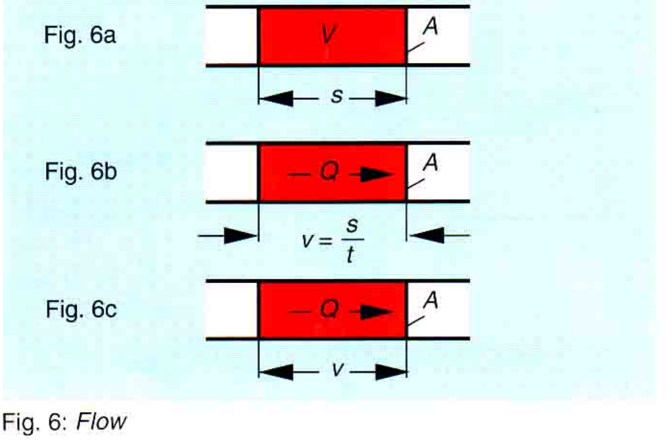

Fig. 6: *Flow*

The same flow Q in L/min occurs at any point in the pipe. If a pipe has cross-sectional areas A_1 and A_2, corresponding velocities must occur at the cross-sections (*Fig. 7*)

$$Q_1 = Q_2,$$
$$Q_1 = A_1 \cdot v_1,$$
$$Q_2 = A_2 \cdot v_2.$$

Hence the continuity equation is produced

$$A_1 \cdot v_1 = A_2 \cdot v_2.$$

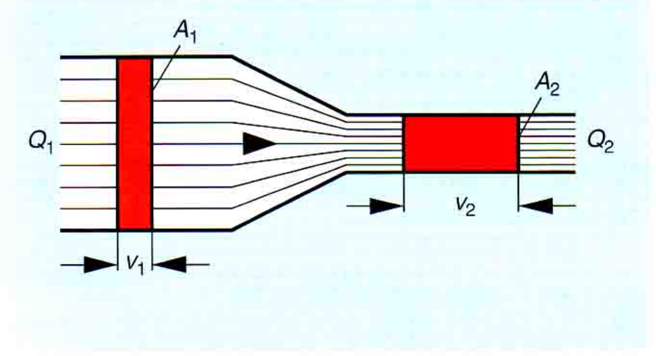

Fig. 7: *Velocity of flow*

2.4.3.2 Law of conservation of energy

The law of conservation of energy, with respect to a flowing fluid, states that the total energy of a flow of liquid does not change, as long as energy is not supplied from the outside or drained to the outside.

Neglecting the types of energy which do not change during flow, the total energy is made up of:

- Potential energy
  → positional energy, dependent on the height of head of liquid and on static pressure

and

- Kinetic energy
  → movement energy, dependent on the velocity of flow and on back pressure.

Hence Bernoulli's equation is produced

$$g \cdot h + \frac{p}{\rho} + \frac{v^2}{2} = \text{constant.}$$

With respect to pressure energy, this means

$$p_{tot} = p_{st} + \rho \cdot g \cdot h + \frac{\rho}{2} \cdot v^2$$

whereby
p_{st} = static pressure,
$\rho \cdot g \cdot h$ = pressure due to height of head of liquid,
$(\rho/2) \cdot v^2$ = back pressure.

Let's now consider both the continuity equation and the Bernoulli equation. The following may be deduced:

If the velocity increases as the cross-section decreases, movement energy increases. As the total energy remains constant, potential energy and/or pressure must become smaller as the cross-section decreases.

There is no measurable change in potential energy. However, the static pressure changes, dependent upon the back pressure, i.e. dependent on the velocity of flow. (*Fig. 8*: The height of the head of liquid is a measure of the pressure present at each head.)

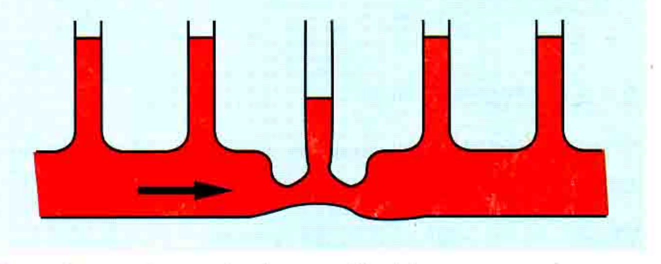

Fig. 8: *Dependence of columns of liquid on pressure*

It is mainly the static pressure which is of importance in "hydro-static systems", as the height of head of liquid and velocity of flow are usually too small.

2.4.3.3 Friction and pressure losses

So far in looking at conformity to natural laws for liquid flow, we have assumed that there is no friction between liquid layers as they move against each other and also that there is no friction as liquids move against an object.

However, hydraulic energy cannot be transferred through pipes without losses. Friction occurs at the pipe surface and within the liquid, which generates heat. Hence hydraulic energy is transformed to heat. The loss created in this way in hydraulic energy actually means that a pressure loss occurs within the hydraulic circuit.

The pressure loss - differential pressure - is indicated by Δp (*Fig. 9*). The larger the friction between the liquid layers (internal friction), the larger the viscosity (tenacity) of the liquid becomes.

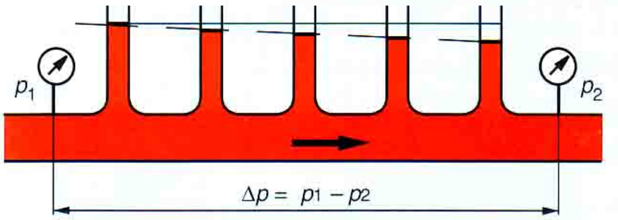

Fig. 9: *Viscosity*

Frictional losses are mainly dependent upon:

- Length of pipe,
- Cross-sectional area of pipe,
- Roughness of pipe surface,
- Number of pipe bends,
- Velocity of flow and
- Viscosity of the liquid.

2.4.3.4 Types of flow

The type of flow is also an important factor when considering energy loss within a hydraulic circuit.

There are two different types of flow:

- Laminar flow and
- Turbulent flow.

Up to a certain velocity, liquids move along pipes in layers (laminar). The inner-most liquid layer travels at the highest speed. The outer-most liquid layer at the pipe surface does not move (*Fig. 10*). If the velocity of flow is increased, at the critical velocity the type of flow changes and becomes whirling (turbulent, *Fig. 11*).

Hence the flow resistance increases and thus the hydraulic losses increase. Therefore turbulent flow is not usually desirable.

The critical velocity is not a fixed quantity. It is dependent on the viscosity of a liquid and on the cross-sectional area through which flow occurs. The critical velocity may be calculated and should not be exceeded in hydraulic circuits.

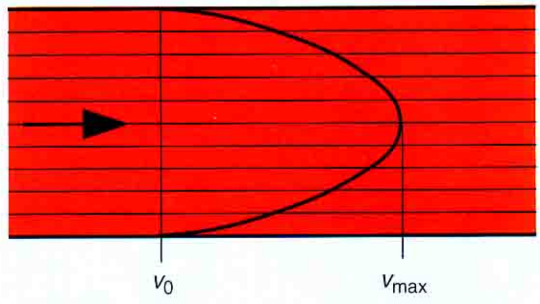

Fig. 10: *Laminar flow*

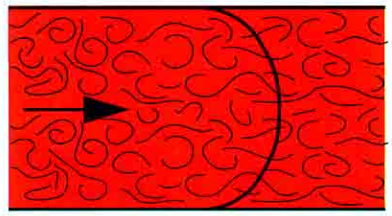

Fig. 11: *Turbulent flow*

2.4.3.4.1 Reynold's number *Re*

The type of flow may be roughly determined using Reynold's number

$$Re = \frac{v \cdot d_h}{\nu}$$

whereby

v = velocity of flow in m/s,
d_h = hydraulic diameter in m, with circular cross-sections equal to the pipe internal diameter, and otherwise calculated as $d_h = 4 \cdot A/U$,
A = cross-sectional area,
U = circumference,
ν = kinetic viscosity in m^2/s and
Re_{crit} ≈ 2300.

This value only applies for round, technically smooth, straight pipes.

At Re_{crit} the type of flow changes from laminar to turbulent and vice versa.

Laminar flow occurs for $Re < Re_{crit}$, and turbulent flow occurs for $Re > Re_{crit}$.

3. Hydraulic circuits

3.1 Important characteristics of hydraulic circuits

- Transfer of large forces (torques) at relatively small volumes.
- Operation may commence from rest under full load.
- Smooth adjustment (open loop or closed loop control) of the following is easily achieved:
  - speed
  - torque
  - force
- Simple protection against over-loading.
- Suitable for both quick and very slow controlled sequences of movements.
- Storage of energy with gases.
- Simple central drive system is available.
- Decentralised transformation of hydraulic into mechanical energy is possible.

3.2 Design of a hydraulic circuit

Mechanical energy is converted to hydraulic energy in hydraulic circuits. This energy is then transferred as hydraulic energy, processed either in an open loop or closed loop circuit, and then converted back to mechanical energy.

3.2.1 Energy conversion

Hydraulic pumps are primarily used to convert energy and next hydraulic cylinders and motors do so.

3.2.2 Control of energy

Hydraulic energy and its associated transfer of power exist in a hydraulic circuit in the form of pressure and flow. In this form, their size and direction of action are effected by variable displacement pumps and open loop and closed loop control valves.

3.2.3 Transport of energy

The pressure fluid, which is fed through pipes, hoses and bores within a manifold, transports the energy or only transfers the pressure.

3.2.4 Further information

In order to store and take care of the pressure fluid, a series of additional devices are necessary, such as tank, filter, cooler, heating element and measurement and testing devices.

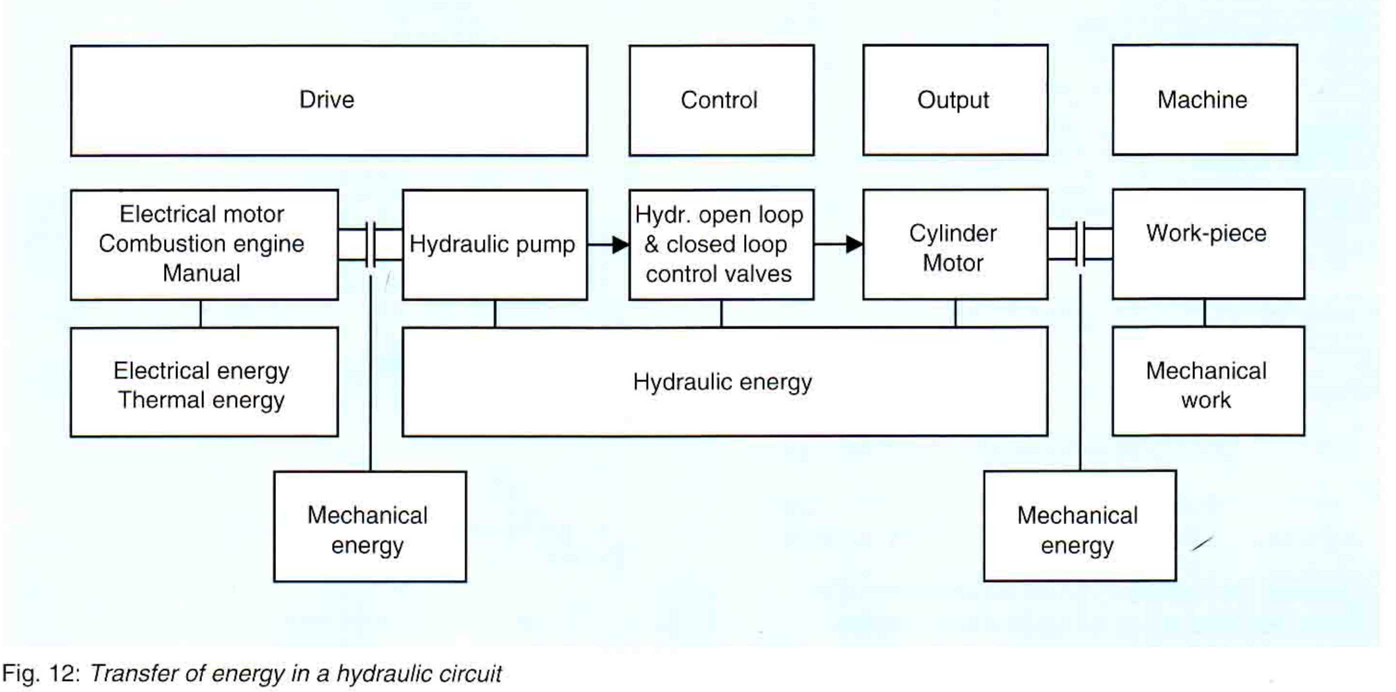

Fig. 12: *Transfer of energy in a hydraulic circuit*

3.3 Design of a simple hydraulic circuit

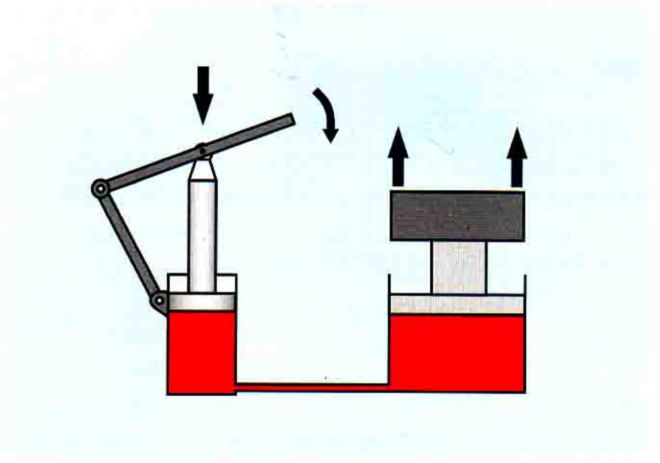

Fig. 13: *Principle of a hydraulic circuit*

The piston of a hand pump is loaded with a force (*Fig. 13*). This force divided by the piston area results in the attainable pressure ($p = F/A$).

The more the piston is pressed on, i.e. the greater the force on the piston is, the higher the pressure rises. However, the pressure only rises until, with respect to the cylinder area, it is in a position to overcome the load ($F = p \cdot A$).

If the load remains constant, pressure does not increase any further. Consequently, it acts according to the resistance, which is opposed to the flow of the liquid.

The load can therefore be moved, if the necessary pressure can be built up. The speed, at which the load moves, is dependent on the flow which is fed to the cylinder. With reference to *Fig. 13*, this means that the faster the piston of the hand pump is lowered, the more liquid per unit time is supplied to the cylinder, and the faster the load will lift.

In the illustrations shown in *Figs. 14 to 19*, this principle (*Fig. 13*) is extended to further devices, which

- control the direction of movement of the cylinder (directional valve),
- effect the speed of the cylinder (flow control valve),
- limit the load of the cylinder (pressure relief valve),
- prevent the system at rest from being completely drained via the hydraulic pump (check valve) and
- supply the hydraulic circuit continuously with pressure liquid (via an electric motor driven hydraulic pump)

In the following sections, a simple circuit will be designed and illustrated via sectional diagrams and symbols to DIN ISO 1219.

3.3.1 Step 1 (*Figs. 14 and 15*)

Hydraulic pump (1) is driven by a motor (electric motor or combustion engine). It sucks fluid from tank (2) and pushes it into the lines of the hydraulic circuit through various hydraulic devices up to the hydraulic cylinder (5). As long as there is no resistance to flow, the fluid is merely pushed further.

Cylinder (5) at the end of the line represents a resistance to flow. Pressure therefore increases until it is in a position to overcome this resistance, i.e. until the piston in the cylinder (5) moves. The direction of movement of the piston in the cylinder (5) is controlled via directional valve (6).

At rest, the hydraulic circuit is prevented from being drained via the hydraulic pump (1) by check valve (3).

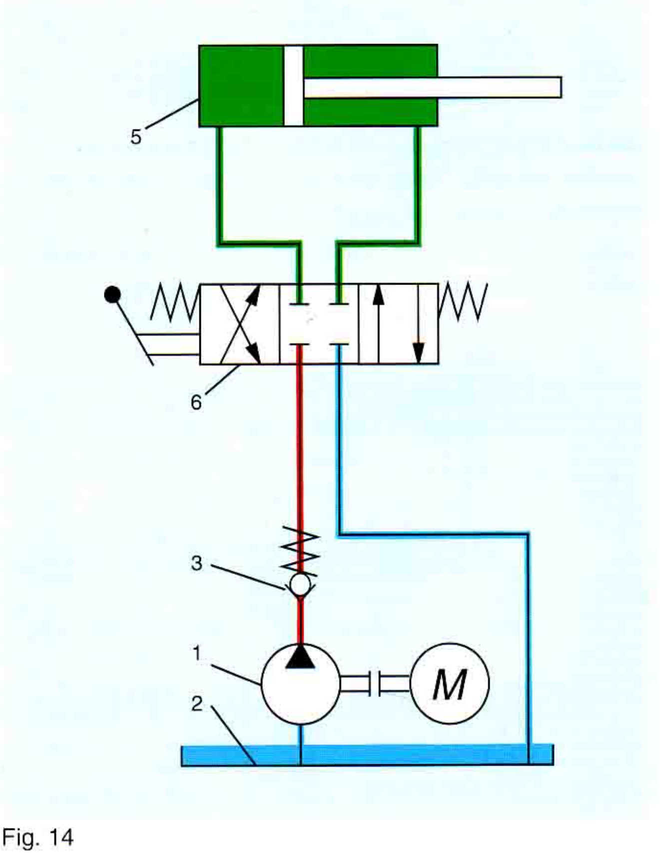

Fig. 14

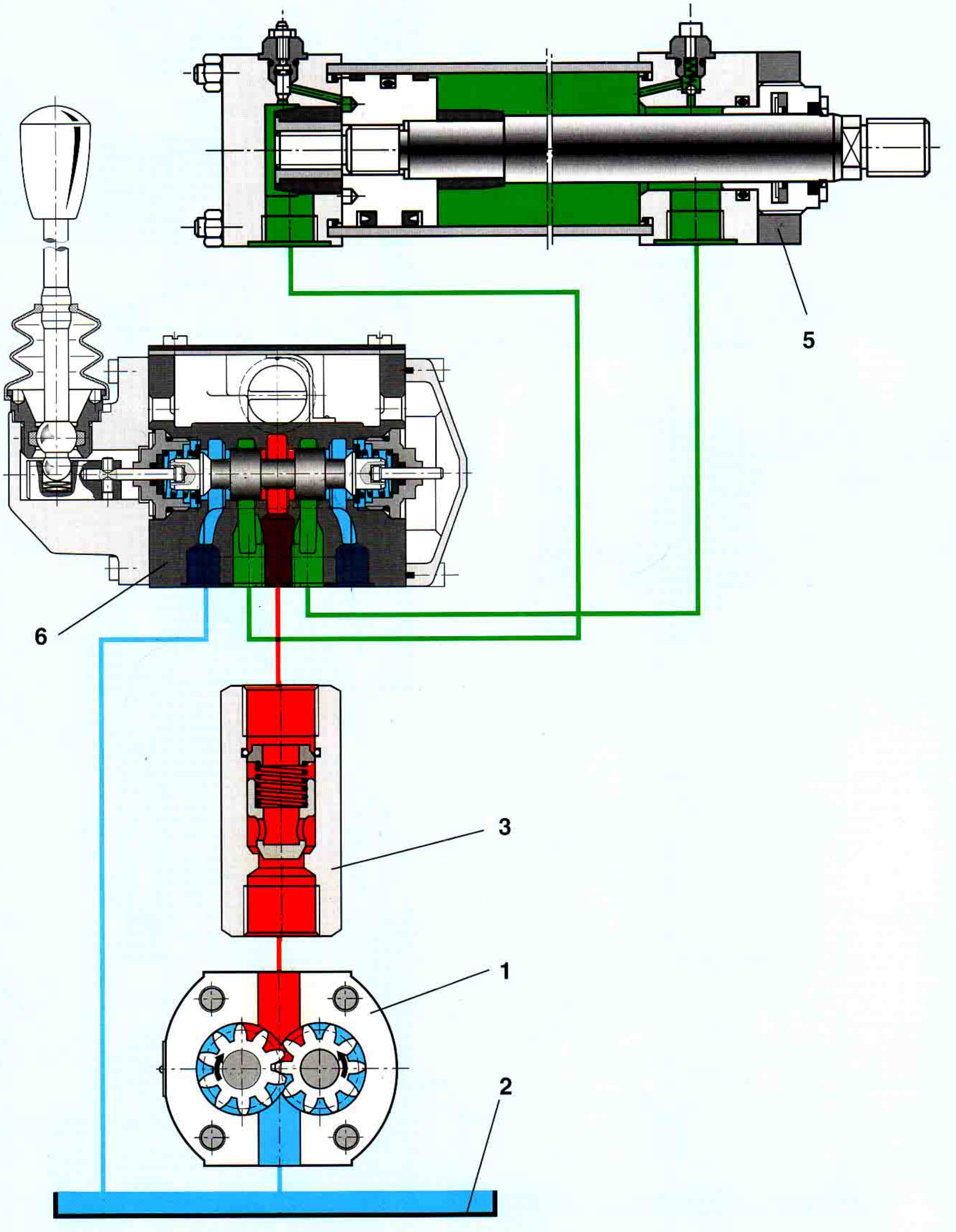

Fig. 15

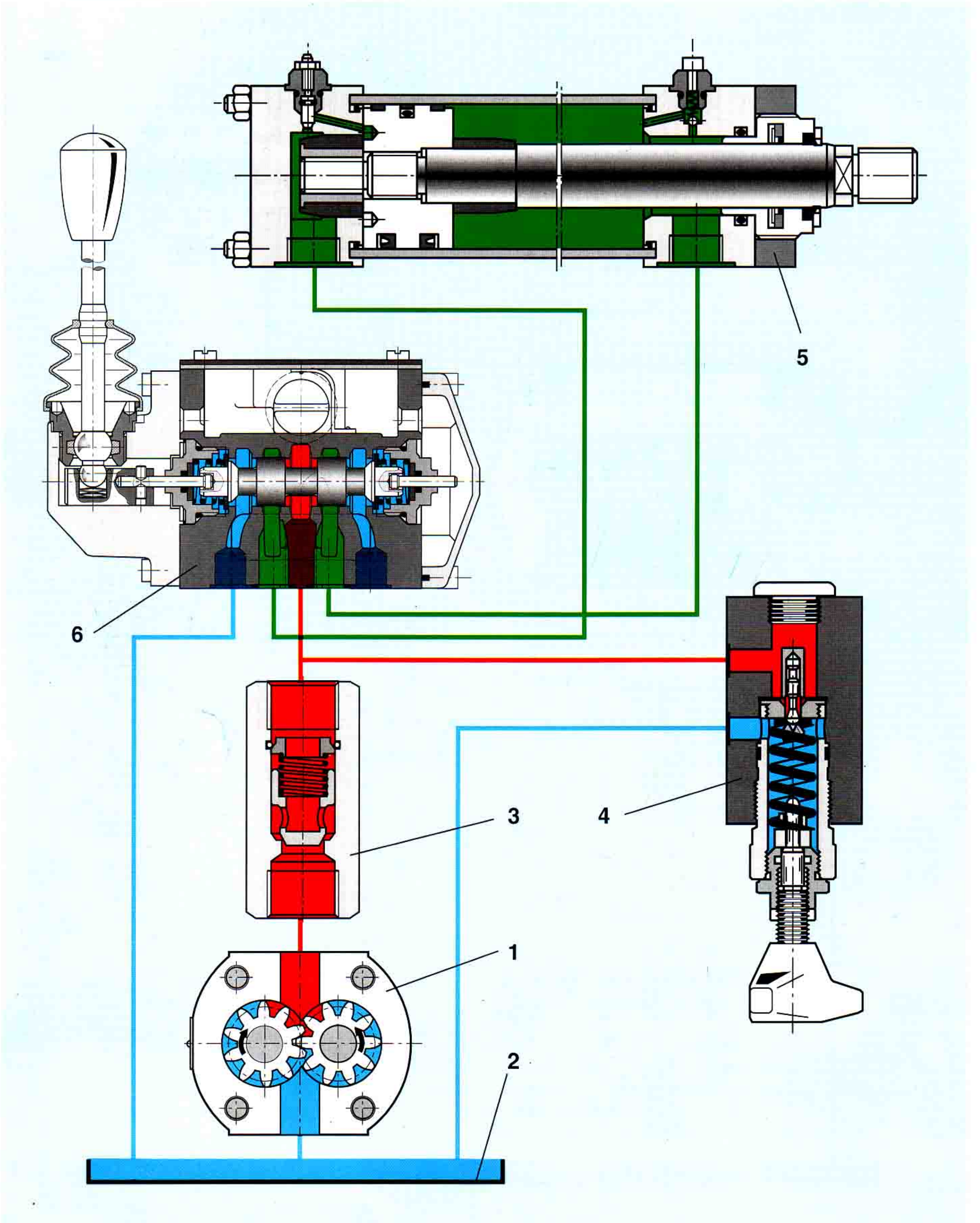

Fig. 17

3.3.2 Step 2 (*Figs. 16 and 17*)

So that the hydraulic circuit is protected from excess pressures and hence from overloading, the maximum pressure must be limited.

This is achieved using a pressure relief valve (4).

A spring as mechanical force, presses a poppet onto the seat of the valve. Pressure in the line acts on the surface of the seat. In accordance with the equation, $F = p \bullet A$, the poppet is lifted from its seat when the force from pressure • area exceeds the spring force. Pressure now no longer rises. The flow still delivered by the hydraulic pump (1) flows via pressure relief valve (4) directly back to the tank.

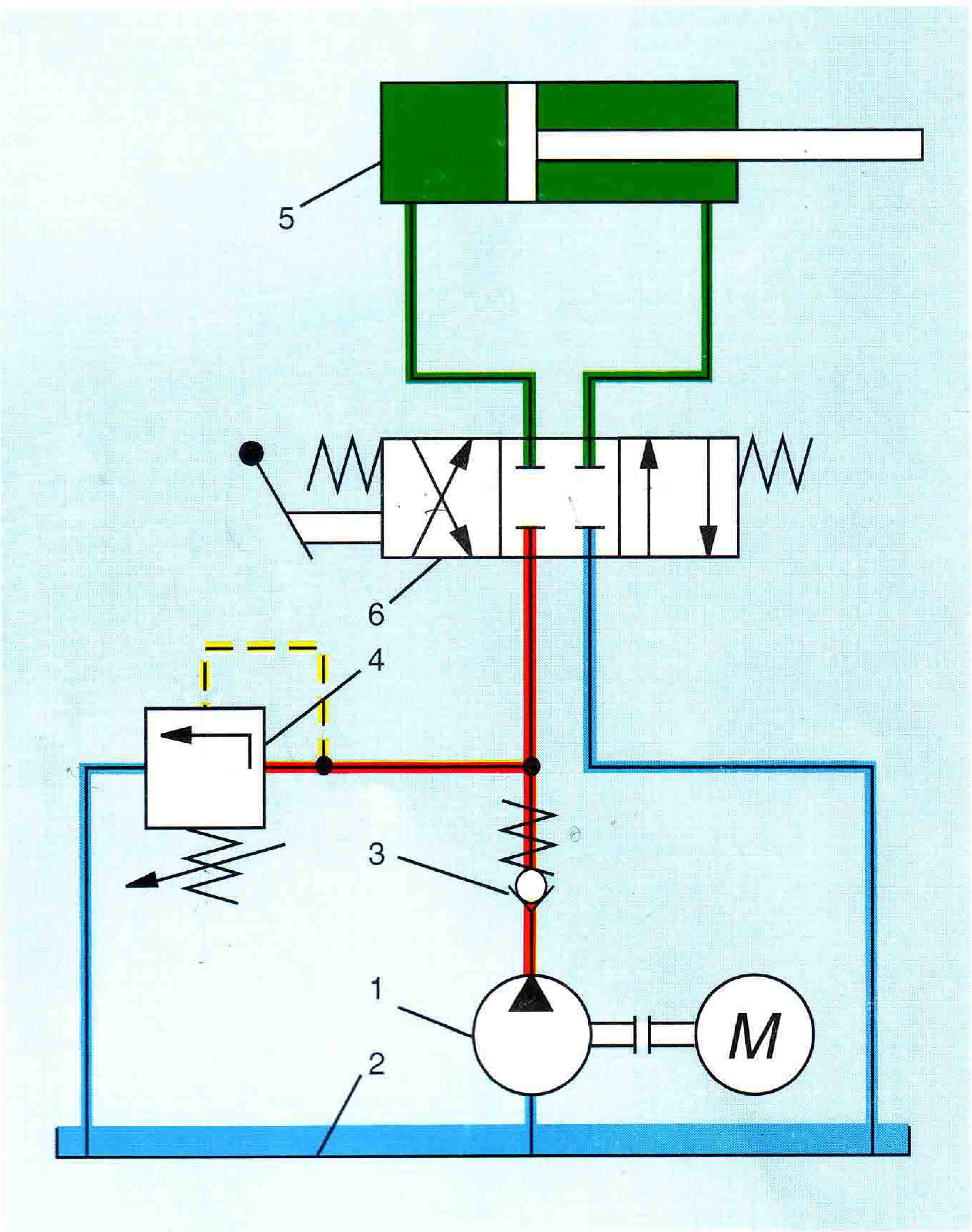

Fig. 16

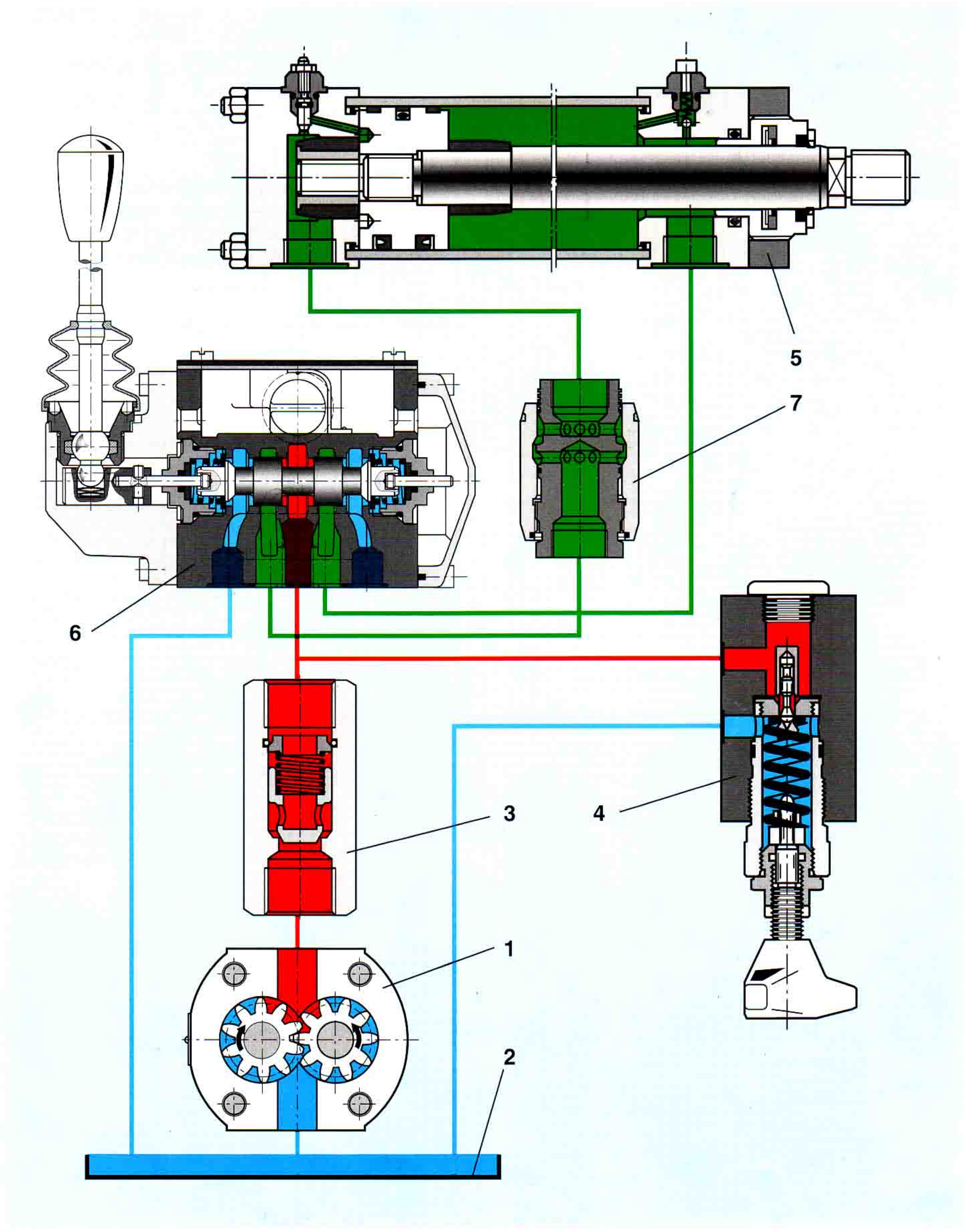

Fig. 18

3.3.3 Step 3 (*Figs. 18 and 19*)

In order to change the speed of movement of the piston in the hydraulic cylinder (5), the amount of flow to the cylinder must be controlled. This may be achieved, using a flow control valve (7).

The cross-sectional area of a pipe may be changed, using a flow control valve. If the area is decreased, less liquid per unit time reaches cylinder (5). The piston in cylinder (5) hence moves slower. The excess liquid, which is now delivered by pump (1), is drained to tank (2) via pressure relief valve (4).

The following pressures occur in a hydraulic circuit:

- pressure set at pressure relief valve (4) acts between hydraulic pump (1) and flow control valve (7)

  and

- pressure dependent on load acts between flow control valve (7) and cylinder (5).

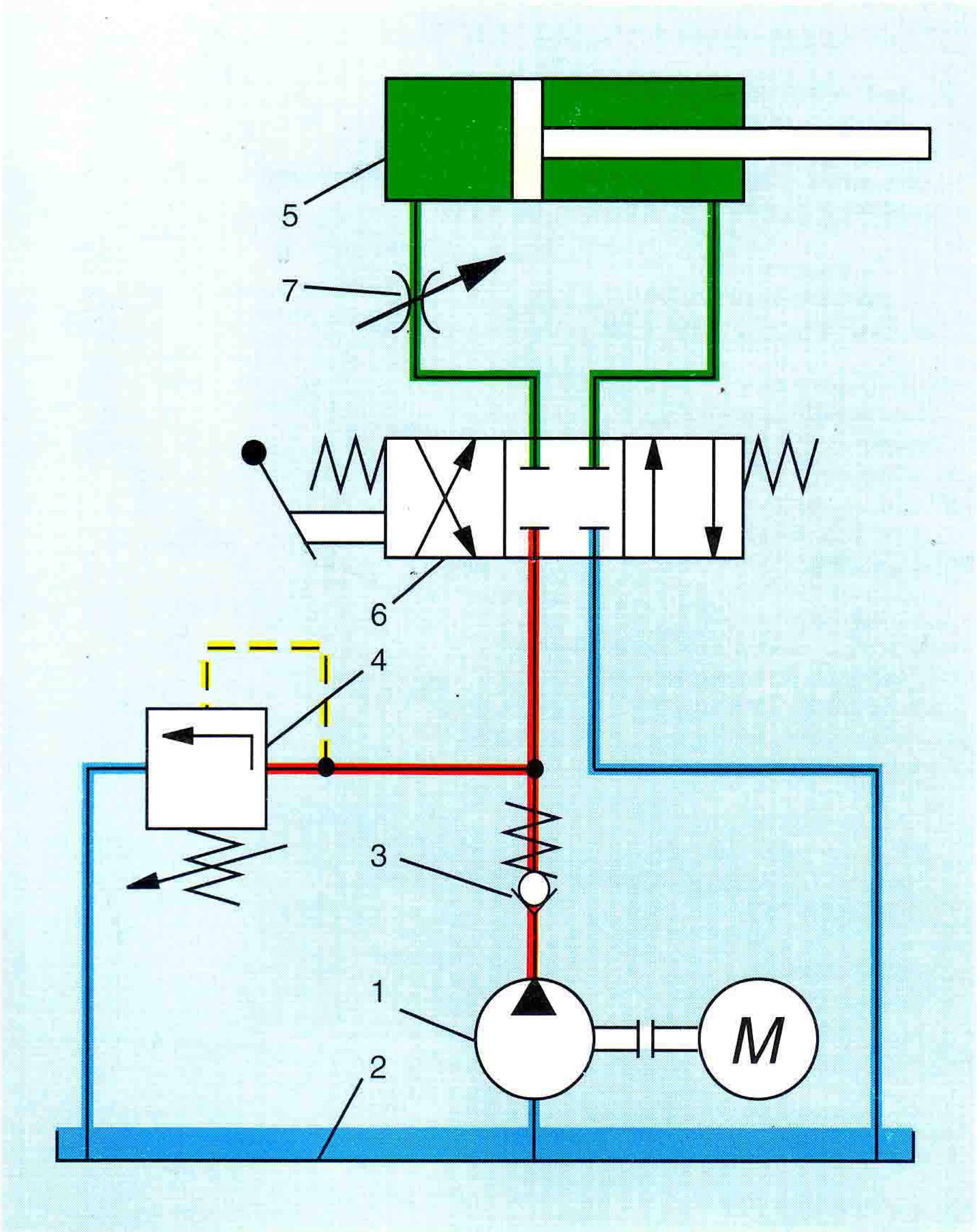

Fig. 19