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"Hydraulic Drives for Bridges Considering the New DIN Standard 19704"

by

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Hydraulic Drives for Bridges Considering the New DIN Standard 19704

Deffiné Bridge

Rexroth Hydraulics

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In July 1991 the working commitee NAW AA 114 "Hydraulic steel structures" was set up within the Water resources standard commitee. Its objective was the first revision of the standard DIN 19704 and 19705 that was first issued in 1976. The chairman was Professor Dr.-Eng. Gerhard Schmaußer. Under his competent chairmanship the working commitee was able to pass the present revision of DIN 19704 in Spring 1997 after only 10 working sessions. Five working groups, into which the working commitee had been subdivided, contributed to this success.

The DIN 19704 and 19705 has been completely revised according to the latest developments and now consists of three parts:

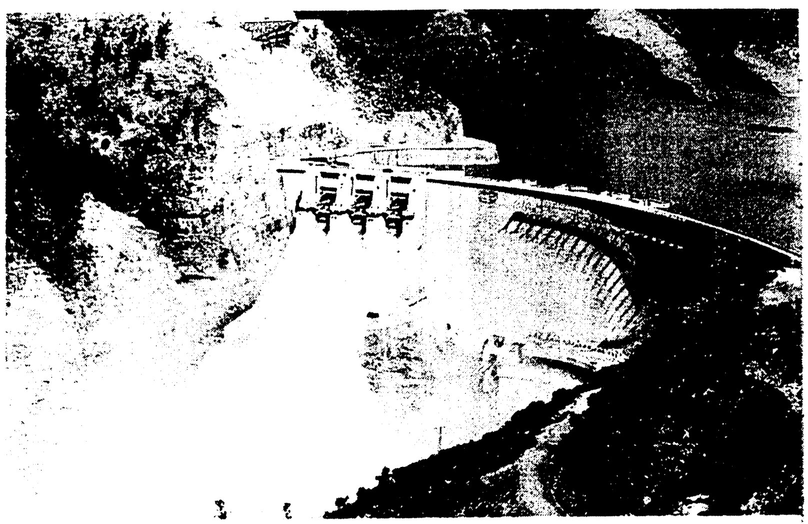
Part 1: Hydraulic steel structures, criteria for design and calculation

Part 2: Hydraulic steel structures, design and manufacturing

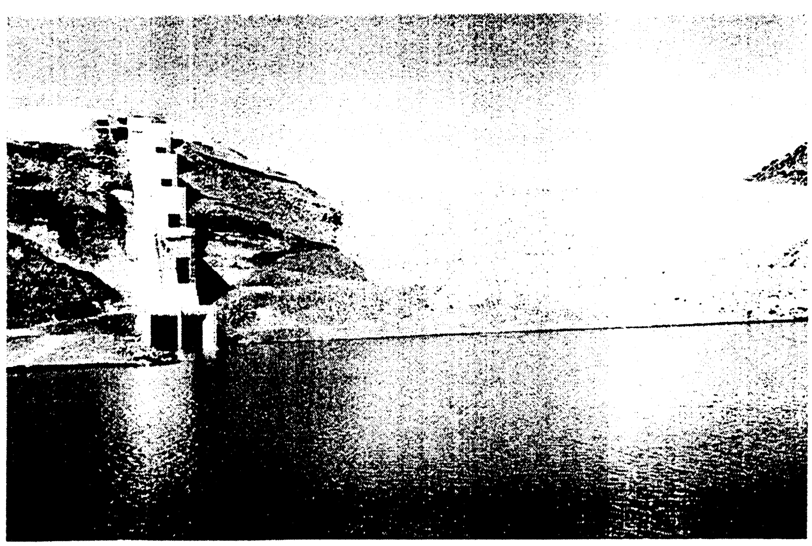
Part 3: Hydraulic steel structures, electrical equipment

DIN 19704 is valid for hydraulic steel structures in:

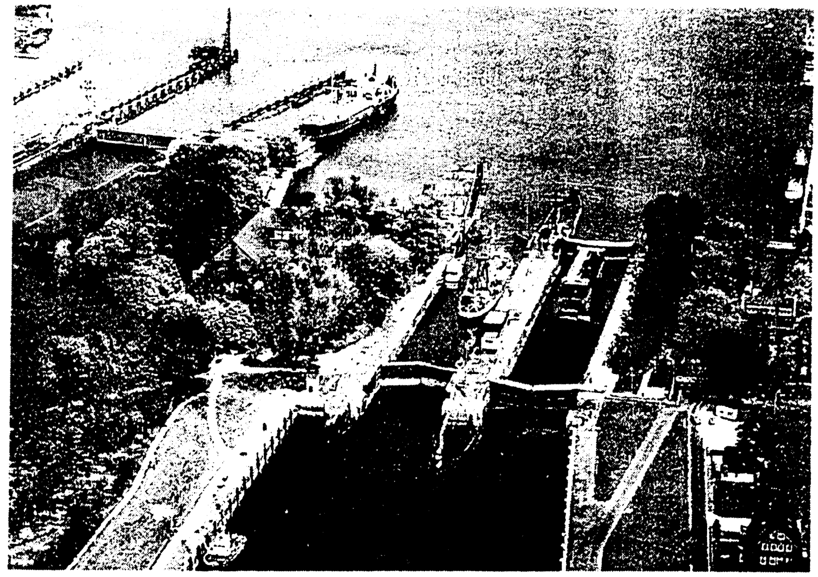
– hydro power plants



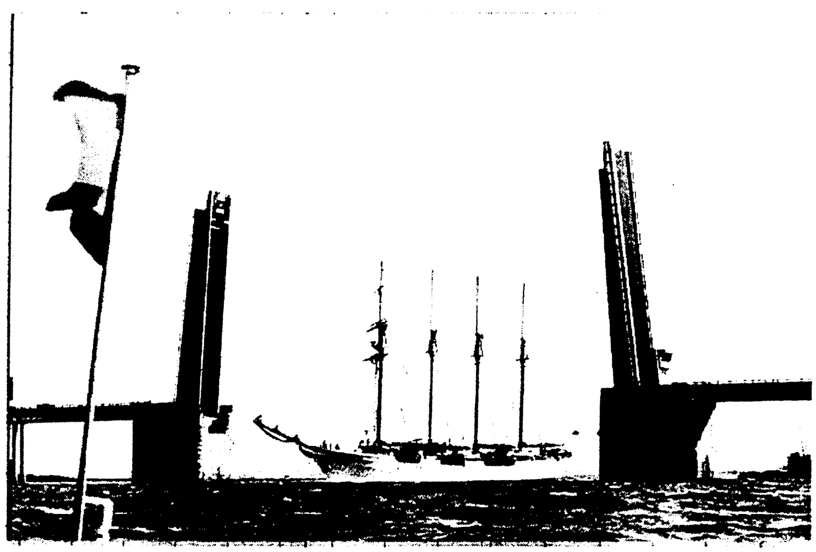
– irrigation systems and high water storage systems



– constructions for river control and installations for inland navigation



– movable bridges



Partial safety factors γ_F and combination values ψ for ultimate limit state analysis (except for fatigue strength proof) of steel structures

No	Type of action	Actions	Acc. to	Basic combinations Case 1 [1)3)]	Basic combinations Case 2 [1)3)]	Exceptional combinations Case 3 [1)2)3)]
1	Permanent	Permanent actions	5.1		γ_F = 1.35, ψ = 1.0	
2		Hydrostatic actions	5.2.1			
3		Hydrodynamic actions	5.2.2	γ_F = 1.35		
4		Water load	5.2.3	ψ = 1.0		
5		Ice load	5.2.4		γ_F = 1.35	
6	Variable	Live load	5.2.6		ψ = 0.9	
7		Forces due to inertia	5.2.7			γ_F = 1.35
8		Changes in conditions of support	5.2.8			ψ = 0.8
9		Ice pressure, ice impact	5.2.5			
10		Temperature influences	5.2.9			
11		Ship friction	5.2.10			
12		Leaking of air chambers	5.3.1			
13	Exceptional	Actions under transport, installation and repair conditions	5.3.2			
14		Actions of the drive in the case of a fault	5.5			γ_F see table 5, ψ = 1.0

NOTES:
1) Variable actions only have to be taken into account as present at the same time as specified by the purchaser, if their coincidence is possible.
2) For the exceptional actions no. 12 to 14, only one has to be considered at a time.
3) For other actions, which are to be specified by the purchaser, see 5.4

The most substantial changes as against previous issues of the standard are:

a) The calculation of the steel structure and -as far as possible - also of the machinery construction is based on the concept of limit state design using partial safety factors and combination factors.

b) Steel structures and machinery constructions are generally not regarded as being constructions under static load. Therefore, fatigue strength proofs are required.

c) The (computational) service life of steel structures, machinery elements and electrical equipment is given.

d) For the first time, manufacturing tolerances are given for the steel structures of firmly installed parts and hydrogates. The objective of this is to ensure that the calculation assumptions, e.g. bearing conditions, comply with the design to a sufficient degree. In addition, the aspects of serviceability have been taken into account for the manufacturing tolerances.

e) In view of their importance hydraulic drives are dealt with in detail. The technical progress in the field of hydraulic drives has been significantly promoted by Mannesmann REXROTH. It was therefore possible to consider the basic principles for design and matters of operational safety, reliability and fatigue strength in a comprehensive form in the new regulations.

Considering their function, hydraulic steel structures must be designed simple, robust and operationally safe. For steel structures a service life of 70 years has to be assumed, for machine elements, including their electrical equipment for 35 years. This does not refer to wear parts.

Apart from some fundamental determinations, the standards DIN 19704 and 19705, issue 1976, contained only a few regulations regarding the design of oil hydraulic drives.

The new revision of DIN 19704-1, -2 and -3, issue 1997, which replace the old standards 19704 and 19705, therefore took into account the new developments in the field of oil hydraulics, so that this standard now reflects state of the art.

In the previously valid standards DIN 19704, issue 1976, the following load cases were relevant for the calculation and rating of the drives:

Normal operational case "NB"
Specific operational case "BB"
Exceptional load case "AL"

Investigations have shown that for approximately 80 % of all supplied systems, the specific operational case **"BB"** are relevant for the calculation and design of the drives. For this reason the new standard norm DIN 19704-1 provides only the operational case "moving" for the drives.

If "Exceptional actions" have to be additionally taken into account (e. g. double-sided drive of a closing-off structure - failure of drive), the drive must be automatically shut down when these actions occur. At that moment, only a single traversing to one of the two end positions **"closing-off structure open"** or **"closing-off structure closed"** will be permitted or, if required, moving into a repair position. For this purpose the client must make unmistakable determinations which comprise both operational measures.

In the previously valid standard DIN 19704 the following maximum operating pressures were determined:

Normal operational case	**"NB"** = 220 bar
Specific operational case	**"BB"** = 250 bar
Exceptional load case	**"AL"** = 300 bar

It must be noted that these determinations have proven useful over the last 20 years since the DIN 19704 - issue 1976 was published. For this reason, in the new DIN the orders of the maximum operating pressures were in principle maintained.

The new standard DIN 19704 - 1 now provides only one operational case **"moving"**, with the permissible maximum operating pressure being 250 bar. If **"exceptional actions"** have to be taken into account, during the presence of which operating movements do not occur, the permissible static pressure in the cylinder or hydraulic motor must not exceed 300 bar. (The pressures mentioned here are the set values of the pressure relief valves, see chapter "Determination of computational operating pressures").

If the operating pressures are considerably lower than 250 bar, components with lower continuous operating pressures/nominal pressures can also be selected. This is also permitted within a hydraulic system, e. g. for auxiliary drives.

The actions of drives such as the stalling torque of the motor, the braking torque or the setting values of pressure relief valves (which have to be secured by sealing) in oil hydraulic systems are considered as controlled, variable actions. Their values have to be included in the calculation as characteristic values of the highest possible transmission of forces. The reactive effects of the highest possible transmission of forces have to be traced in all essential machine parts, for which an ultimate state analysis (except for the fatigue strewngth proof) is required, up to the connection to the steel structure of the gate or, if required, up to their bearing points.

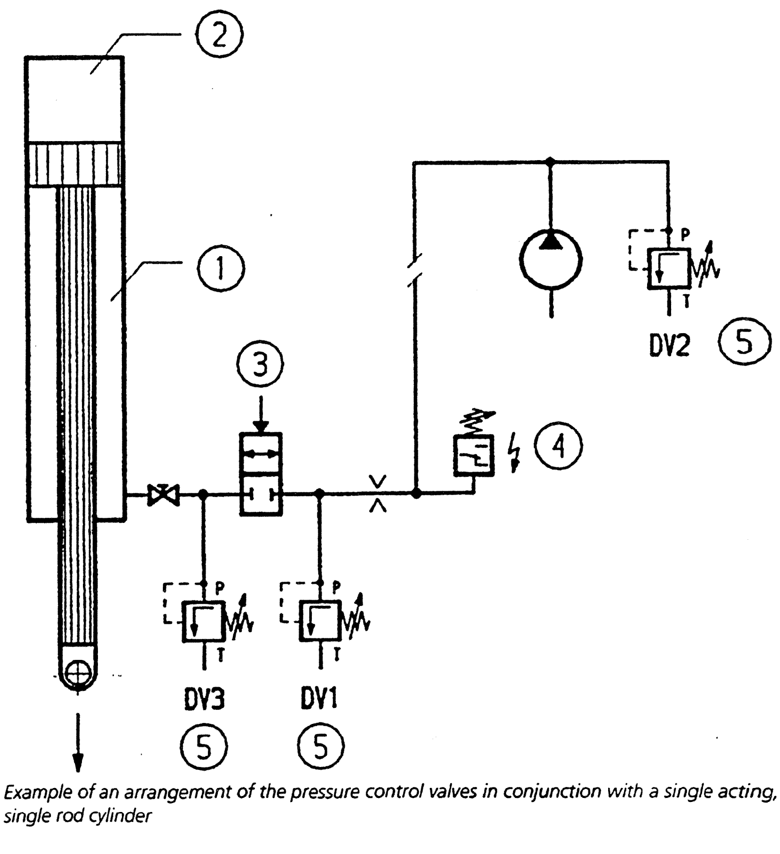
These reactiv effects creates some problems which using mechanical hoists were an acurate overload protection is difficult to achive. With hydraulic hoists this problem can be solved easily by installing maximum pressure relief valves directly on the cylinder. Specially when the power pack is far away from the cylinder the maximum pressure relief valve on the pump has to be set to a higher pressure to obtain the pressure drop in the pipes. In case the gate is blocked this higher pressure can not occur in the cylinder by adjusting the cylinder to exactly the pressure required for the maximum load.

In view of the rating of drives, this results in a striking difference between the "old" and the "new" DIN.

In the exceptional load case it was acceptable (at least not explicitly excluded in the "old" DIN), to run an emergency mode at a maximum pressure of 300 bar over a longer period of time when these conditions occured. According to the new DIN 19704 this is no longer permitted.

As already mentioned, the permissible maximum pressure during **"moving"** amounts to 280 bar which is justified as follows:
All the components of renowned manufacturers are approved for an operating pressure of 280 to 315 bar. The actuators such as solenoids, return springs, etc. are rated for these pressures. Thus, sufficient safety is provided at maximum operating pressure in order to ensure operational safety also under unfavourable conditions, e. g. low temperatures.

From this consideration results the requirement in DIN 19704 - 1 that for all hydraulic components, the continous operating pressure/ nominal pressure must be 25 % higher than the computational operating pressure.



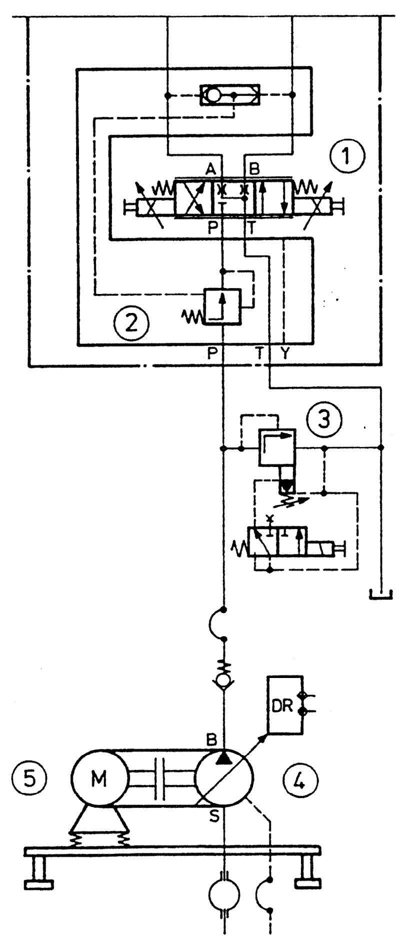
Example of an arrangement of the pressure control valves in conjunction with a single acting, single rod cylinder

Acceleration and deceleration

The following is stipulated here: "The closing-off structure must be accelerated and decelerated within a reasonable time in dependence upon the design type, weight, travel time and for bridges also the own frequency of the bridge leafs". With oil hydraulic drives, acceleration and deceleration are achieved by changing the flow. When accelerating the cylinder or hydraulic motor, the flow continuously increases from 0 or a minimum value up to the required maximum value, when deceleration time must be infinitely variable. It depends on the closing-off structure and its application conditions and usually ranges between 3 and 15 seconds.

The following preferred systems are used:
- Flow control by means of proportional valve
- Flow control by means of variable displacement pumps

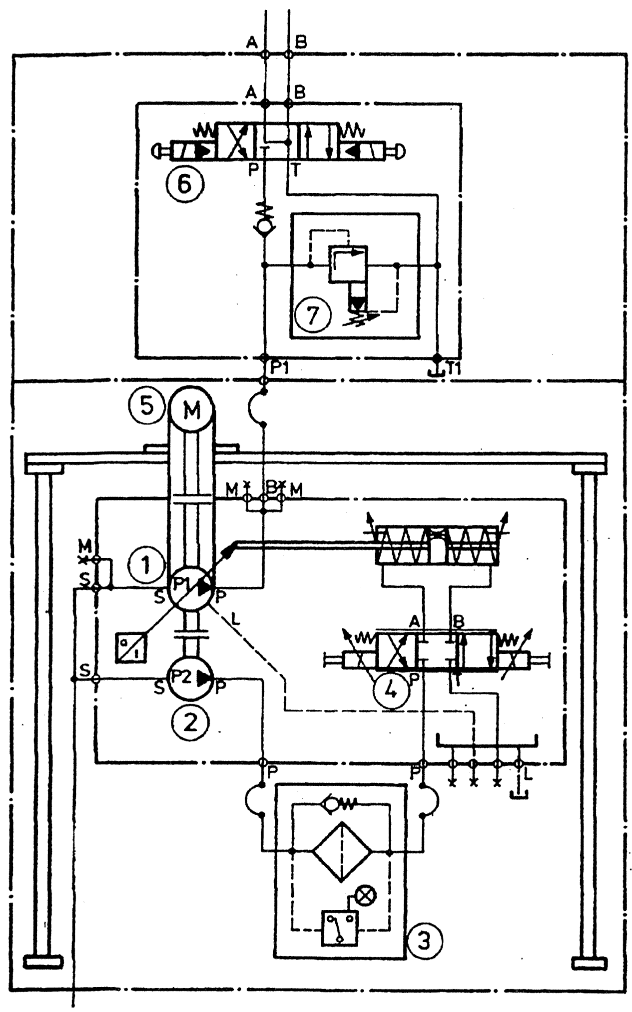
The figure beolow shows a circuit version, using proportional valve technology. The proportional valve is a combination of a directional valve for the control of direction and a flow control valve for controlling the flow volume.



1 Proportional valves
2 Pressure compensator for ensuring a constant Δp across the control spool
3 Pressure relief valve
4 Axial piston pump
5 Electric motor

Proportional valve technology

The figure below shows a system with variable displacement pump.
The pump supplies a variable displacement from 0 to maximum and thus allows the required acceleration or deceleration of the drive. The direction is controlled by means of a directional valve.



Variable displacement pump

1 Axial piston pump with infinitely variable displacement
2 Pump for pilot oil supply
3 Pressure filter
4 Control valve for pump adjustment
5 Electric motor
6 Directional valve for the control of direction
7 Pressure relief valve

Hydraulic fluids

If, in the case of leakage (e. g. in the case of an accident) the hydraulic medium can get into the water, bio-degradable hydraulic fluids have to be used preferably instead of media on the basis of mineral oil.
If synthetic esters or polyglycols are used, special precautions must be taken for planning and for maintenance and operation (e. g. material selection, monitoring).
Triglycerides (vegetable, animal oils) are not suitable for use in hydraulic steel structures due to their ageing behaviour.
The type of hydraulic fluid to be used must be specified by the client. However, the use of fast bio-degradable fluids does not represent a relief from the obligation to prevent the possible leakage of these fluids.

In general, hydraulic fluids must be suitable for a temperature range of -25°C to +60°C.

Filling of the system and subsequent topping up may only be carried out through filtering units with a filter rating according to the filtration requirements to 10.1.4.3.

Hydraulic cylinder - Design and manufacture

Cylinder barrels shall be manufactured from seamless steel tubes, whenever possible without joints, and must be designed for flanges for head and ccap.

The cylinder bore must be manufactured with an arithmetic roughness value $R_a < 0{,}4\ \mu$.
Piston rods of hydraulic cylinders must be manufactured from

a) stainless steel with a weight proportion of chromium of at least 15.5 % and a multi-layer hard chromium plating with an overall thickness of ≥ 50 μ.

or
b) unalloyed steel with oxide ceramic coating.

The arithmetic average roughness value for both constructions should be $R_a < 0.3\ \mu$.

The oxide ceramic coating must be designed to rule out corrosion of the base material.

It should be homogeneous, scratch-resistant, crack-free and non-conductive and have a coating thickness of at least 150 m and a surface hardness of 800 to 1000 HV.

Subsequent sealing of pores is not permitted.

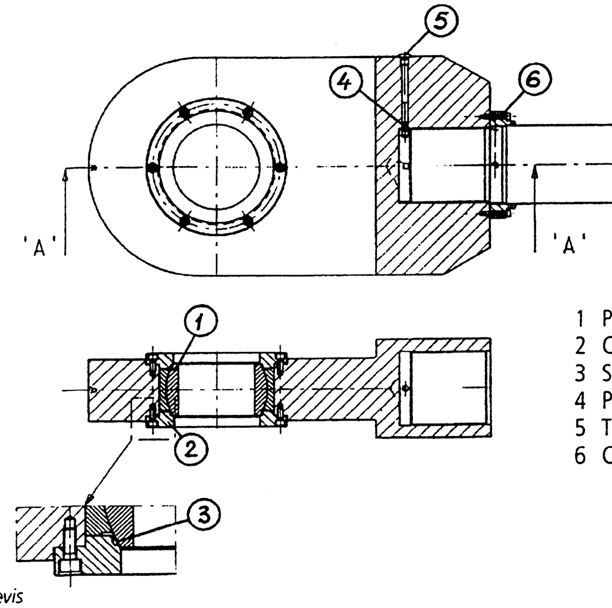
The corrosion resistance of the oxide ceramic coating must meet the requirements of the test according to DIN 50021-ESS over a testing period of 1000 hours.

Piston rods may only be manufactured of several parts in justified, exceptional cases.

In general, the piston rods with piston rod heads, which are fitted with plain bearings, have to be connected to the gate or the supporting structure.

The connection of piston rod/piston rod head should preferably be designed with male threads on the piston rod.

The threads of the piston rod heads must be sealed against the ingress of water. Bores for safety equipment must not be drilled into the thread and must be sealed.



1 Plain bearing
2 Cover
3 Seal for the plain bearing
4 Protection against torsion
5 Threaded plug with seal
6 Cover with seal for sealing the thread

Self-aligning clevis

If the cylinder is mounted by means of clevises, these have to be made of a single part. Welded clevises subjected to tensile stress have to be designed with but welds.

In the case of trunnions or cardanic bearing of the cylinders, all bearings must be self-lubricating. The sliding bearings and bearing pins must be made from stainless steel.

In general, copper alloys shall be used for the guides of pistons and piston rods. Moreover, plastic guides are permitted.

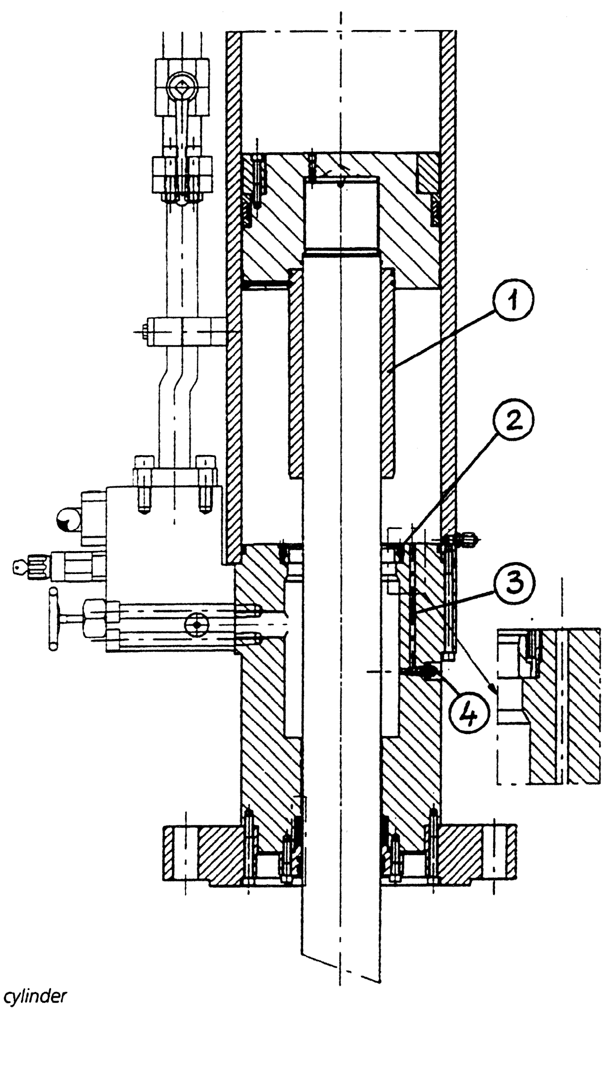
For sealing, only multi-lip seal systems shall be used. Trailing pressure must not be built up.

The seals used between components without counter-movements such as cylinder barrel/cylinder head must be O-ring seals. O-ring seals with diameters ≥ 125 mm must be fitted with additional back-up rings.

The cylinder head must be fitted with dirt wipers at the piston rod passage and, in the case of a possible formation of ice, with additional ice scrapers of a serrated design.

When using cylinders under water, additional seals, which are inserted in a corrosion-resistant housing, shall be provided against the sucking-in of water.

Hydraulic cylinders which are temporarily or permanently pressurized at system pressure must be leakfree isolated in the direction of load by directly flanged-on shut-off or control manifolds. The control manifolds must be equipped with manual shut-off valves between the hydraulic cylinder and the shut-off valve.



1 Tapered sleeve
2 Orifice ring
3 By-pass bore
4 Throttle for adjusting the seating velocity of the closing-off structure

Hydraulic cylinder

Hydraulic cylinders which are submerged temporarily or over a longer period of time, should be monitored for leakage by suitable means. These must be specified by the client.

Both cylinder chambers must be permanently filled with oil. If the gate is lowered without the pumps running, it must be ensured by suitable measures that the pressureless cylinder chamber is filled with oil.

For proper bleeding of the hydraulic cylinder, pressure measurement connections must be provided at suitable locations. If required, a suitable procedure must be specified for the assembly and filling of the cylinder.

Hydraulic components

Pressure is generated by pumps which operate according to the displacement principle with fixed or steplessly variable displacement.

For systems with heavily fluctuating flows, pumps with variable displacement are recommended.

It must be possible to replace motors and pumps without having to remove other components. Motors have to be mounted on anti-vibration mounts.

All the devices required for the control of the hydraulic system such as directional valves, flow control valves, pressure relief valves, etc. have to be clearly arranged on common control plates wherever possible. The actuator ports are directly connected to the manifolds.

For electrically operated valves, DC wet-pin solenoids should be used whereever possible. These valves shall be fitted with an easily accessible manual override with detent.

Pilot operated directional valves have to be indicated by LEDs, except for proportional and servo-valves.

The electrical connnection for any electrical components such as valves, pressure switches and float switches must be made via plug-in connections.

Hydraulic oil filters

Hydraulic stations have to be fitted with at least one return line filter with a maximum filter rating of 20 m with non recycable inserts. Paper filters are not permitted. The filter system must be matched with the components used.

The nominal flow rate of the filter should at least be four times the maximum flow. All filters have to be provided with a visual clogging indicator, with an electrical connection and a by-pass valve having an opening pressure of 3 bar.

Hydraulic stations

The design can be compact, e.g. oil reservoir with mounted-on motor/ pump units and control, or individual assemblies, e.g. oil reservoir, pump station, valve station and, if required, accumulator station.

Oil reservoirs have to be dimensioned sufficiently large to accommodate four times the volume of the maximum flow supplied by the pump(s) in one minute, plus the pendulum volume of all connected cylinders, plus the contents of the piston rod chamber of the largest connected cylinder plus the contents of the associated pipes.

Reservoirs have to be designed with an oblique bottom, drain valve, cleaning openings, permanent oil level indicator and float switch. The latter must be removable without requiring the removal of other components.

Fillet welds must be double-sided whenever possible.

Venting of the reservoir must be realised via a humidity adsorber with transparent container. Air escaping when the oil level increases mut not be directed through the adsorber. Openings in the reservoir must be plugged air-tight.

In general, fittings and valves shall not be arranged within the oil reservoir.

If the drive rooms cannot be deigned to 3.3, the oil reservoir must be erected in a steel sheet tray, which corresponds to the nominal capacity of the reservoir.

Hydraulic variable displacement pumps should be installed in a maintenance-friendly manner next to the reservoir. The suction lines have to be equipped with manually operated shut-off valve with limit switch monitor.

In general, the required total flow is subdivided to at least 2 motor/pump units.

Pipework

When determining the routing of the pipes, good accessibility must be taken into account. The distance of pipes must be so that fittings and flanges can be mounted without difficulties. The pipes should not be laid onto each other.

Moved parts, movable connections and expansion joints have to be fitted with flexible hydraulic hoses. Only hoses to DIN 20066 in conjunction with corrosion-protected fittings are permitted. The installation instructions to DIN 20066-4 have to be observed. The use of rotary joints is permitted.

If the arrangement of pipe or hose lines in flowing water or in its direct vicinity cannot be avoided, protective measures against flotsam have to be provided.

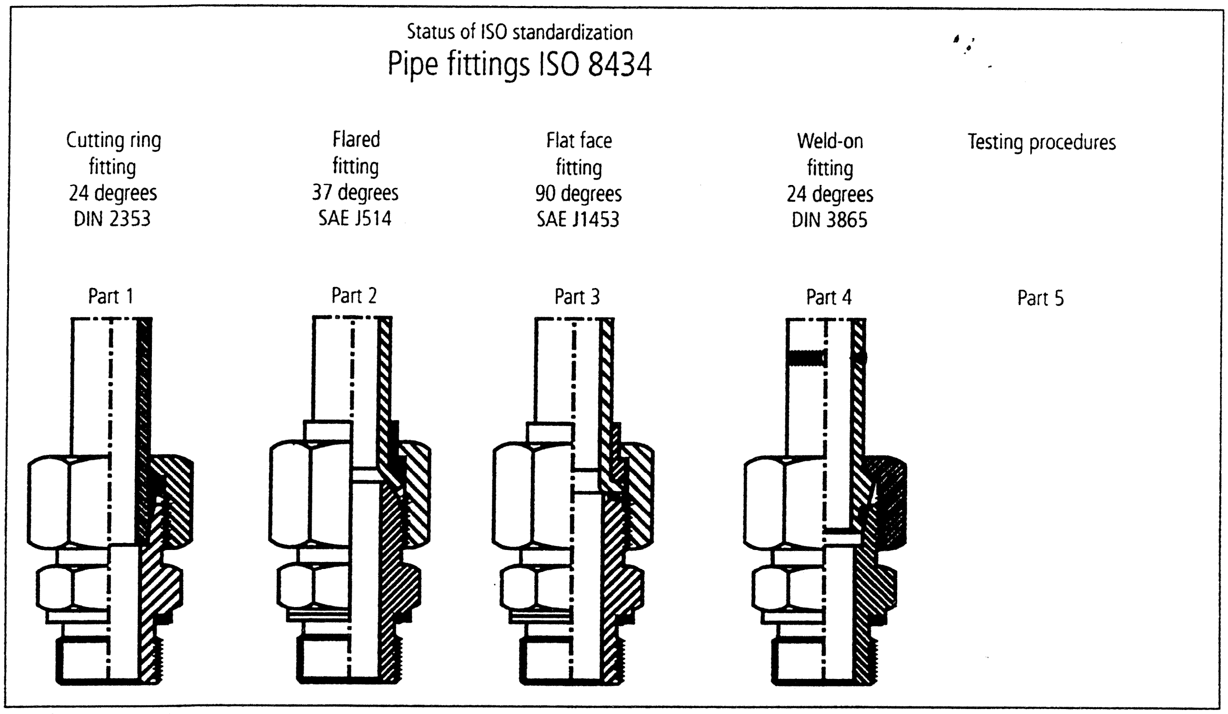
Pipes have to be fitted with manually operated shut-off valves for partial shutdowns, at least at the ports of the hydraulic station and at the ports of hydraulic cylinders and hydraulic motors. Equipment with additional shut-off valves, e.g. on hoses, has to be specified by the client.

Depressurization must be possible - if required, also for sub-sections.

Proper bleeding of the pipe system must be ensured. Pressure measurement connections are reccommended for this.

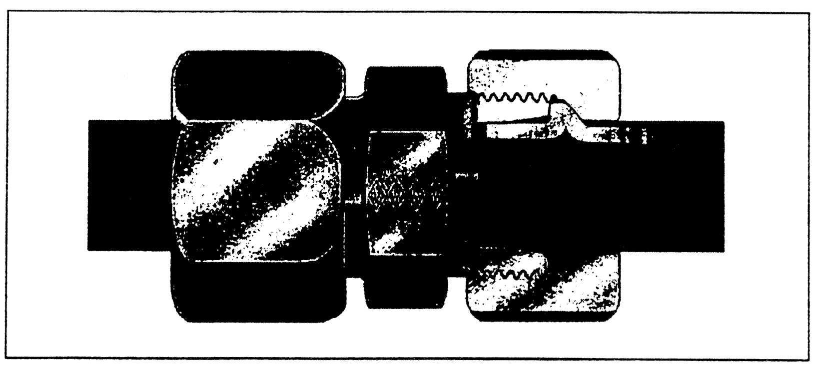
The hydraulic pipe system has to be equipped with monitoring devices, which switch the drives off electrically in the case of a pipe break or hose burst. The use of flow-related, switching pipe burst valves is not permitted.

Possible pipe connecting fittings:



Pipe fittings ISO 8434

New development



Pipe fitting with soft seal

Flow speeds

The following guideline values must be taken for the flow speeds in hydraulic pipework:

Pressure lines	< DN 40	3.0 m/s
(supply and return)	≥ DN 40	5.0 m/s
Pilot oil return and	< DN 40	1.0 m/s
leakage lines	≥ DN 40	1.5 m/s
Pump suction lines		0.6 m/s