Servo Valves, Device Technology

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1 General Information

Rexroth servo valves have been developed as industrial valves and comply with the requirements of industry with respect to reliability, interchangeability and easy servicing. They are of modular design.

This includes:

- the consistent use of standard mounting pattern to DIN 24 340 for all sizes,
- interchangeability of torque motors or pilot stages,
- externally adjustable
- interchangeable pilot stage filter element

The term "servo" is used to describe a wide variety of functions.

In general, this term refers to the function in which a small input signal produces a large output signal (amplifier).

The best known example is probably servo steering in a motor vehicle, where the steering wheel is moved with little effort to produce a large force on the wheels.

The process is similar in servo hydraulics.

A low power control signal, e.g. 0.08 Watts may control by analogue means a large power of more than 100 kW.

The servo valve in the form of an electrically controlled hydraulic amplifier is primarily used in closed loop control circuits, i.e. not only is an electrical input signal converted into a corresponding flow, but also deviations from preset speeds or positions are measured electrically and fed to the servo valve for correction.

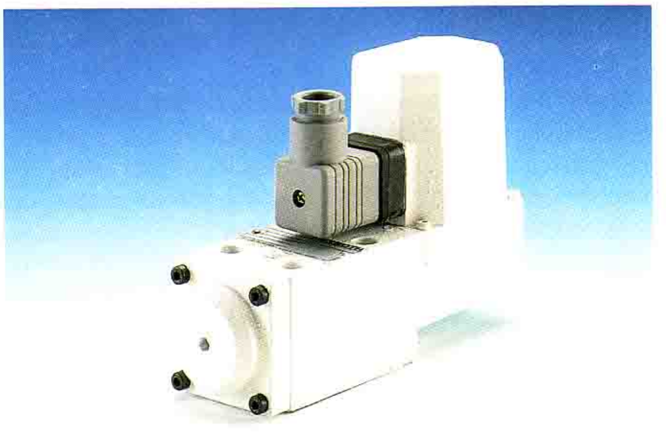


Fig. 154: *Single stage control valve, size 6, with mechanical feedback, type 4 WS1EO6*

Fig. 155: *2-stage directional servo valves, size 10, with mechanical, barometric and electrical feedback*

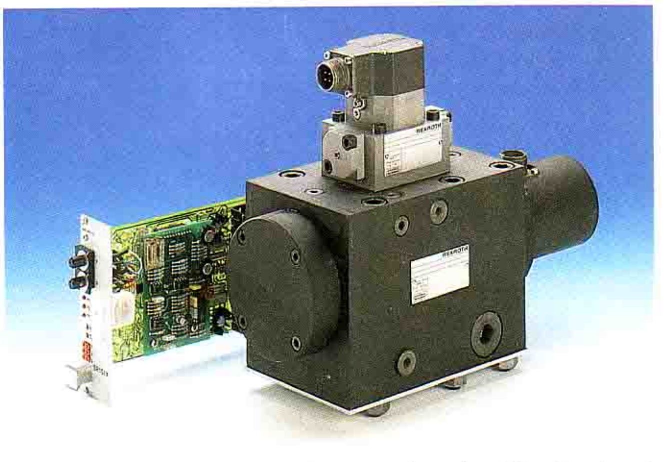


Fig. 156: *3-stage directional servo valve, size 25, with electrical feedback, type 4 WS 3 EE 25*

2 Torque Motor

The torque motor converts a small current into a proportional, mechanical movement. In the case of Rexroth servo valves, the motor is a self-contained unit. It is mounted and tested separately and is interchangeable, hence facilitating servicing and repair.

The "dry torque motor" is hermetically sealed from the hydraulic device and constructed as follows:

- An armature made of soft magnetic material is mounted on a thin flexible tube, which acts as a spring, a seal for the pressure medium, and carries the flapper-jet. The flapper-jet physically belongs to the torque motor, but functionally to the hydraulic amplifier.

- The torque motor is a motor excited by a permanent magnet. Using adjustable "pole screws", the gap between armature and pole screw can be adjusted and hence the motor characteristic optimised.

- The two coils on the armature magnetize the armature. As a result, a torque is exerted on the tube (return spring).

The torque is proportional to the pilot current and equal to zero when the pilot current is zero (I = 0). As a result, the tube (return spring) returns the armature and hence the flapper plate to the centre.

The transfer of torque from armature to flapper-jet in this type of torque motor has clear advantages such as:

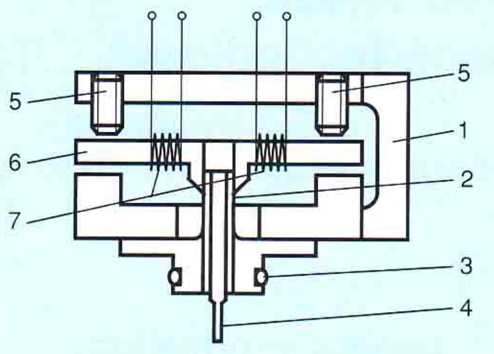
- No friction
- Low hysteresis
- Sealing of pressure medium to torque motor
- No magnetic field in pressure medium

3 1st Stage *(Fig. 159)*

Single stage servo valves are used to pilot control multi-stage servo valves.

They basically consist of:

- the torque motor (1) excited by a permanent magnet
- the hydraulic amplifier (2) designed as a flapper-jet valve



1 Permanent magnet
2 Torque tube (return spring)
3 O-ring seal
4 Flapper plate (ruby coated)
5 Adjustable pole screws
6 Armature
7 Control coils

Fig. 157: *Construction of torque motor*

3.1 Torque Motor

The torque motor is a motor excited by a permanent magnet and hermetically sealed from the hydraulic device.

An armature (3) made of soft magnetic material is secured to a thin, flexible tube (4) which acts as a spring. This tube also carries the flapper plate (5) and seals the torque motor (1) from the hydraulic device. The distances between the armature (3) and the upper pole plate (8) may be adjusted with pole screws (6).

The magnetic flux is equal in the four gaps (9), when the distances are equal and no electrical control signal is applied. If an electrical control signal is applied to the coils (10), the armature (3) is offset. The flapper plate (5) is offset at the same time as the armature (3).

The torque produced in the armature (3) by the pilot current is proportional to the electrical input signal and is equal to zero when the pilot current is zero (I = 0). As a result, the armature and flapper plate are held in the centre by the tube (4).

3.2 Hydraulic Amplifier

The flapper-jet offset is converted into a hydraulic variable by the hydraulic amplifier (2). In this case, the flapper-jet system is used as a hydraulic amplifier *(Fig. 158)*.

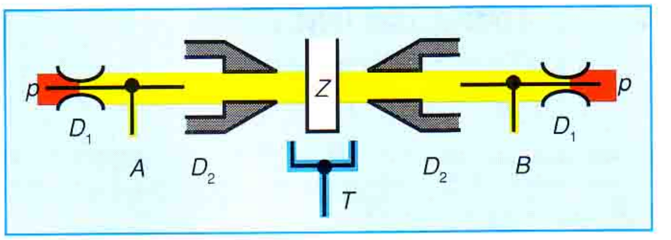
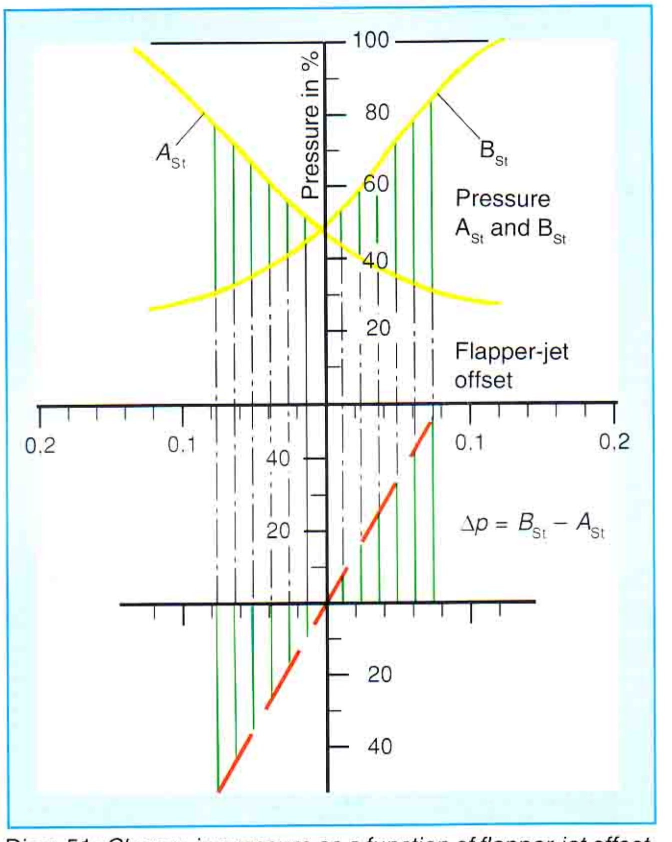


Fig.158: *Principle of flapper-jet system*

The system consists of two fixed orifices (jets) D_1, and 2 control orifices (jets) D_2. The pilot pressure Δp applied at both sides is reduced via the orifices (jets) D_1 and D_2. If the orifice openings are the same size, the same pressure drop occurs across the orifices (e.g. Δp = 100 bar, p_{Ast}=p_{Bst} = 50 bar, pT = 0 bar).

When the flapper plate is offset, the distances to the control orifices change. In the following example the offset is to the left:

As the distance of flapper-jet at left D_2 becomes smaller, it becomes greater at right D_2. The pressure changes at A and B inversely proportional to this. Pressure p_{Ast} increases and pressure p_{Bst} decreases. The pressure difference p_{Ast} - p_{Bs}t is used as the effective signal.



Diag. 51: *Change in pressure as a function of flapper-jet offset.*

Diag. 51 shows the change in pressure dependent on the offset.

The whole is adjusted so, that a linear curve is obtained (pressure difference between ports A_{St} and B_{St}).

The pilot oil is fed from port P via a protective filter (11) to the fixed orifices (12) and on to the control orifices (7).

The pressures p_{Ast} and p_{Bst} are tapped off between the fixed orifices and control orifices.

This pressure difference, which is proportional to the electrical input signal, is then applied to the control spool of a second stage.

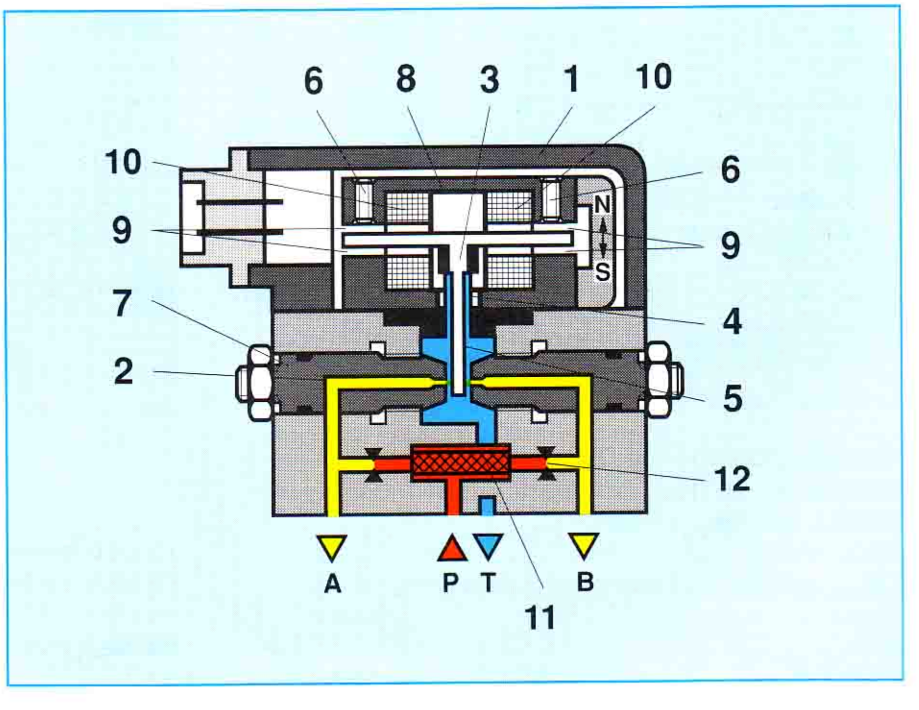


Fig. 159: *Principle of 1st stage*

4 Technical Data and Operating Curves

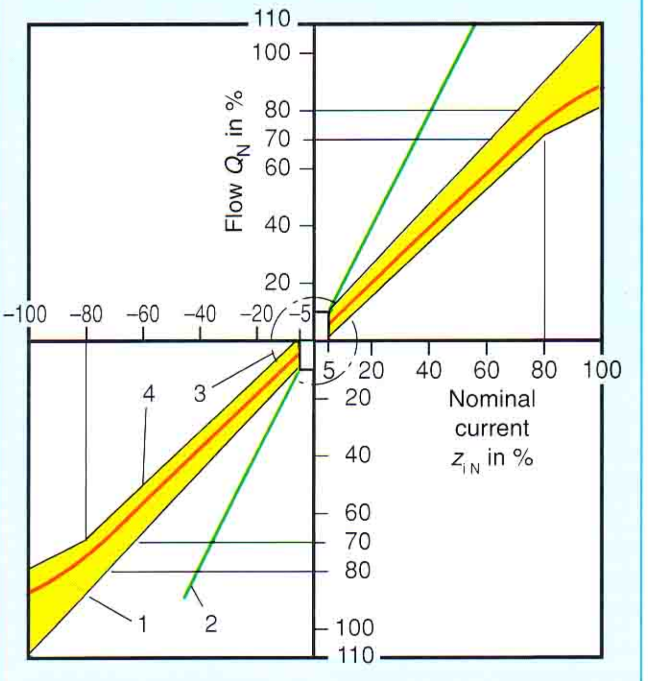
In addition to the servo valve dynamic characteristics, depending on the application, two hydraulic characteristics are of particular importance:

Flow amplification and

spool overlap (defines pressure amplification)

4.1 Flow Amplification *(Diag.52)*

The control bush has rectangular control windows, which are opened by the main spool depending on the input signal. The width of these slots determines flow gain (flow per spool stroke). The flow specified in L/min is that which flows at 70 bar valve pressure drop (i.e. 35 bar from P to A and 35 bar from B to T) and at 100 % input current. With high flow gain, the flow curve is non-linear as a result of housing saturation.



1 Typical flow curve
2 200% flow amplification
3 Zero flow depending on spool overlap
4 Tolerance range

Diag. 52: *Tolerance range of flow/signal function*

4.2 Flow Overlap *(Fig. 160)*

The four control lands of the main spool are matched symmetrically. Thus, a choice can be made between four overlap sizes (positive or negative in % of spool stroke). In the case of positive overlap, the curve is shallower in the centre, the null flow is small and the pressure amplification high. In the case of negative overlap, the curve may be steeper near the centre (flow amplification up to 200 %). The null flow is higher and the pressure amplification lower.

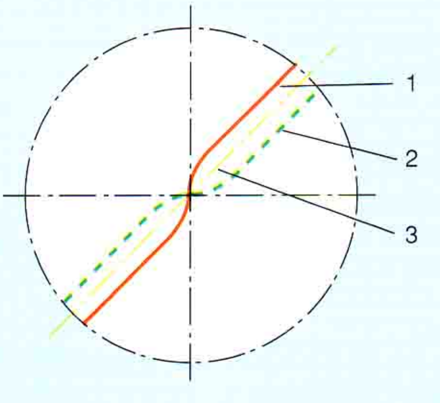
Main applications of overlaps:

Control spool overlap A (0.5 to 1.5 %), positive
Suitable for closed loop velocity control.
Advantage: Lower null flow than in "D".

Control spool overlap B (0.5 to 1.5 %), negative
Suitable for closed loop position and force control.
Advantage: Higher damping, but also greater null flow than in "D".

Control spool overlap C (3 to 5 %), positive
Suitable for open loop control and closed loop velocity control without zero position flow.

Control spool overlap D (0 to 0.5 %), positive
Suitable as universal overlap for closed loop speed, position and force control.
Advantage:
Lower null flow, but also lower damping than in "B".



1 Overlap negative
2 Overlap positive
3 Theoretical curve for zero overlap

Fig. 160: *Principle of spool overlap*

Control spool overlap E (0 to 0.5 %), negative
Suitable for high precision applications. Slightly higher null flow than in "D".
Main application: Closed loop pressure and force control

4.3 Dynamic Characteristics of Directional Servo Valves

The dynamic characteristics of the valve may be deduced from the frequency curve. Control technicians have defined the frequency, at which the amplitude response is -3dB as a reference value. -3 dB means, that the drop in amplitude of the output variable is 30 % of the input variable.

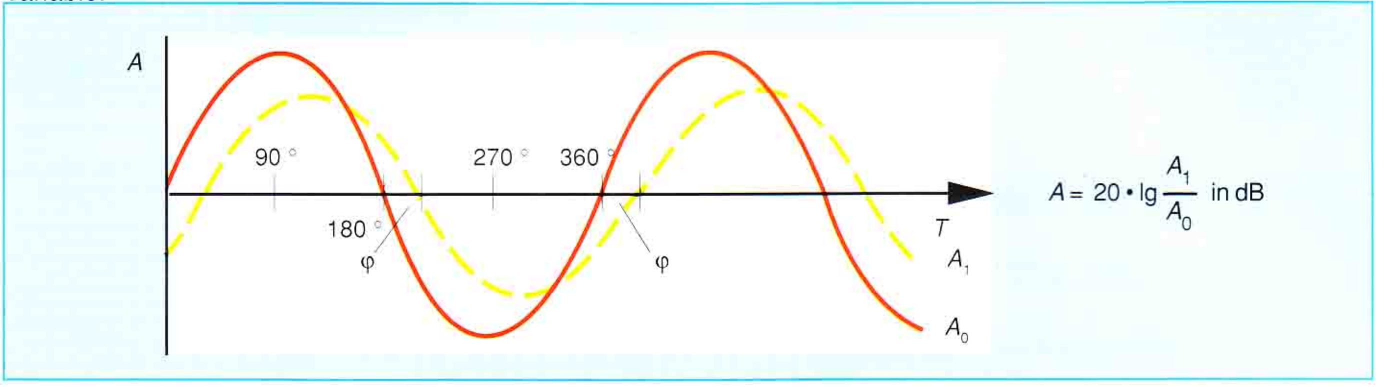


Fig. 53: *Amplitude drop and phase offset*

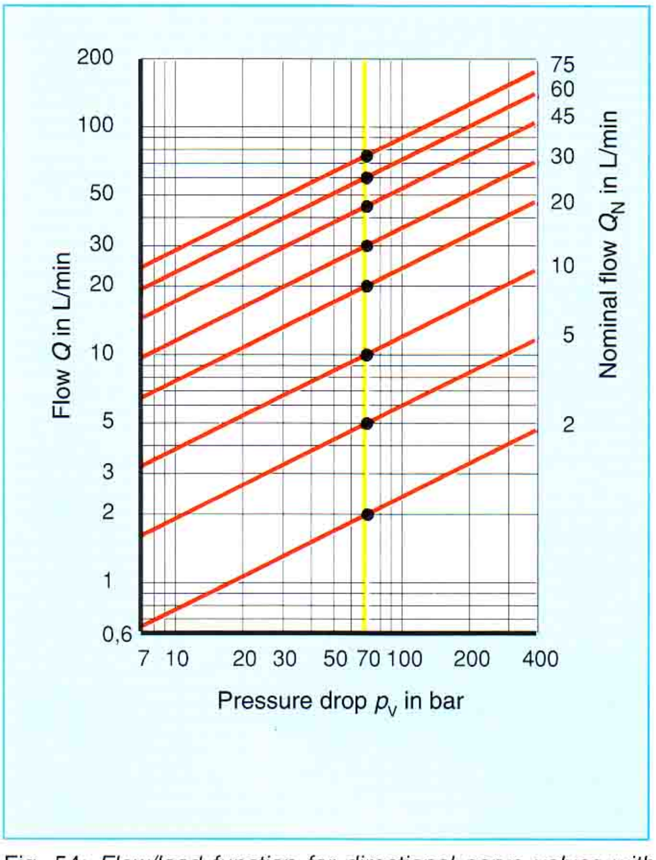


Fig. 54: *Flow/load function for directional servo valves with barometric or electrical feedback (tolerance ±10 %), size 10*

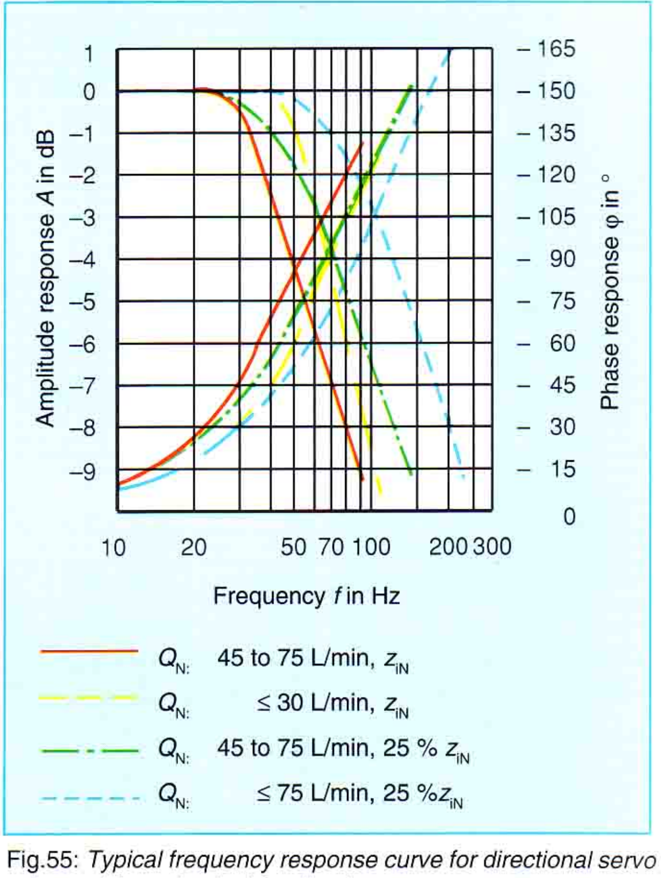


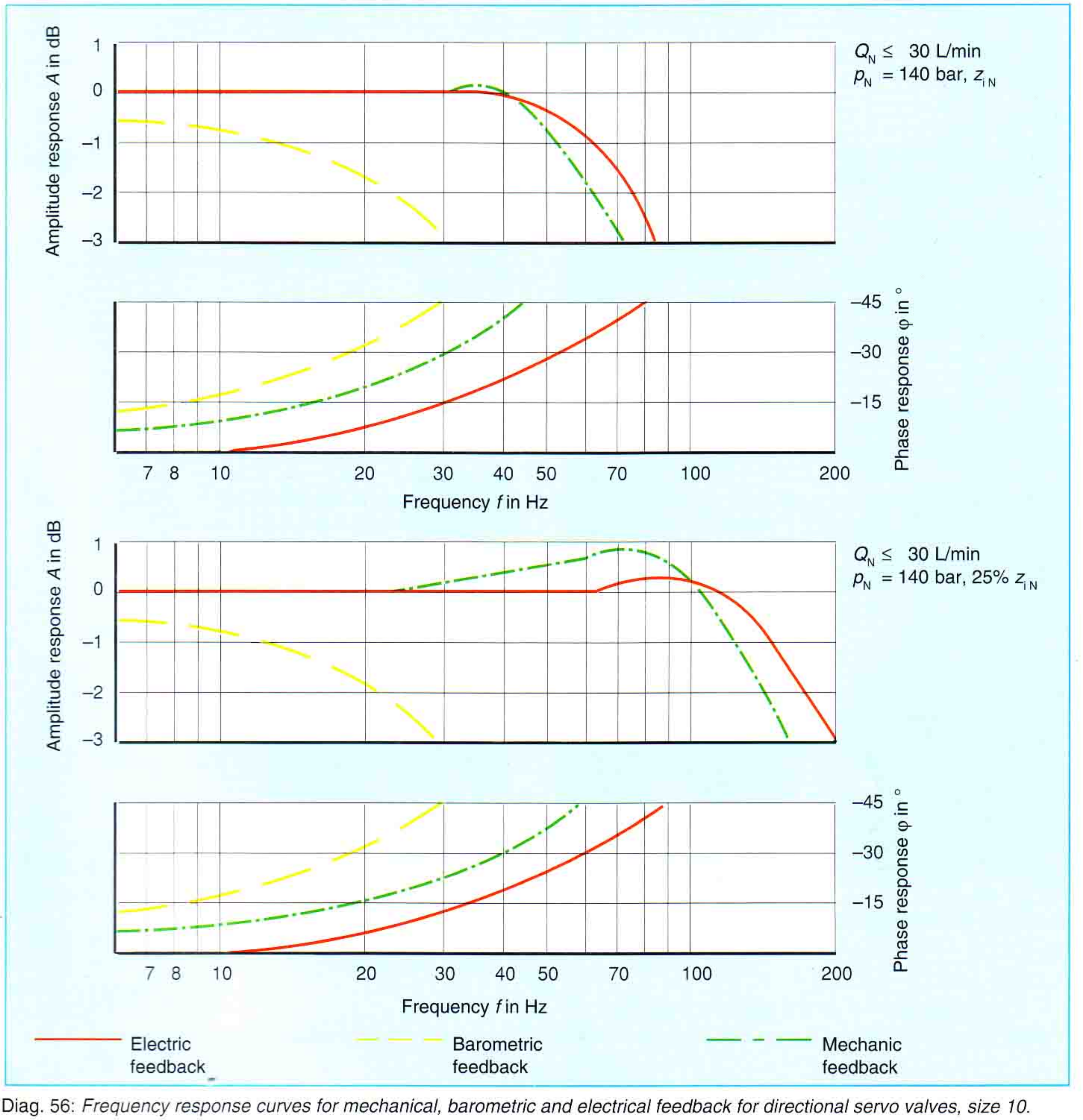
Fig.55: *Typical frequency response curve for directional servo valves with mechanical feedback*

Comparison of the frequency response *(Diag. 56)* of size 10 directional servo valves with either mechanical or barometric feedback, shows that the directional servo valve with mechanical feedback has better dynamic characteristics.

Comparison of hydraulic and dynamic data (table 4) shows the differences between the three feedback systems.

Feedback system		mechanic	electric	barometric
Dither optimized hysteresis	%	≤ 2,0	≤ 0,5	≤ 3,0
Response sensitivity	%	≤ 0,5	≤ 0,2	≤ 1,0
Reversal range	%	≤ 1,0	≤ 0,2	≤ 2,0
Flow symmetry deviation	%	≤ 5	≤ 5	≤ 5

Table 4: *Comparison of hydraulic data*



Diag. 56: *Frequency response curves for mechanical, barometric and electrical feedback for directional servo valves, size 10.*

5 Single Stage Control Valve

Single stage control valves basicaly consist of the torque motor (1) and 4-way horizontal spool stage (3).

The torque motor (1) is an electro-mechanical converter which converts an electrical signal into a linear movement of the pin (4) end. It is hermetically sealed from the hydraulic device. The armature (5), torque tube (6) and pin (4) are rigidly connected. The pin (4) end protruding from the motor is linked to the control spool (2) by means of the tie rod (7). The spring rigidity of the torque tube (6) acts against the force of the torque motor when the pin (4) is deflected. Hence a centring effect occurs.

The movement of the control spool (2) and hence the flow is proportional to the electrical input signal.

The hydraulic null point is adjusted by screw (8) which moves the control sleeve (10) in the housing (9) axially relative to the control spool (2).

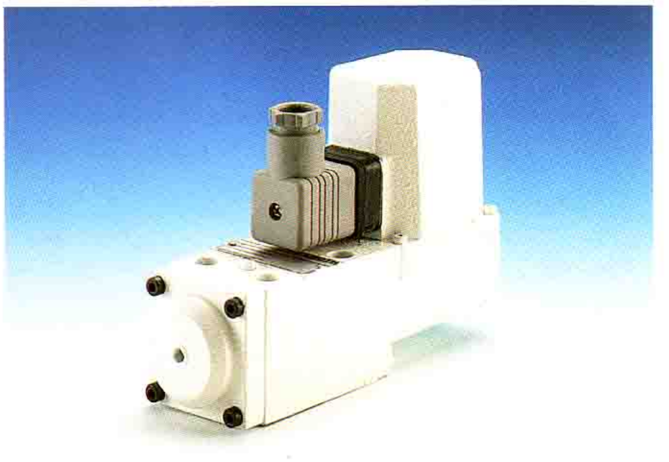
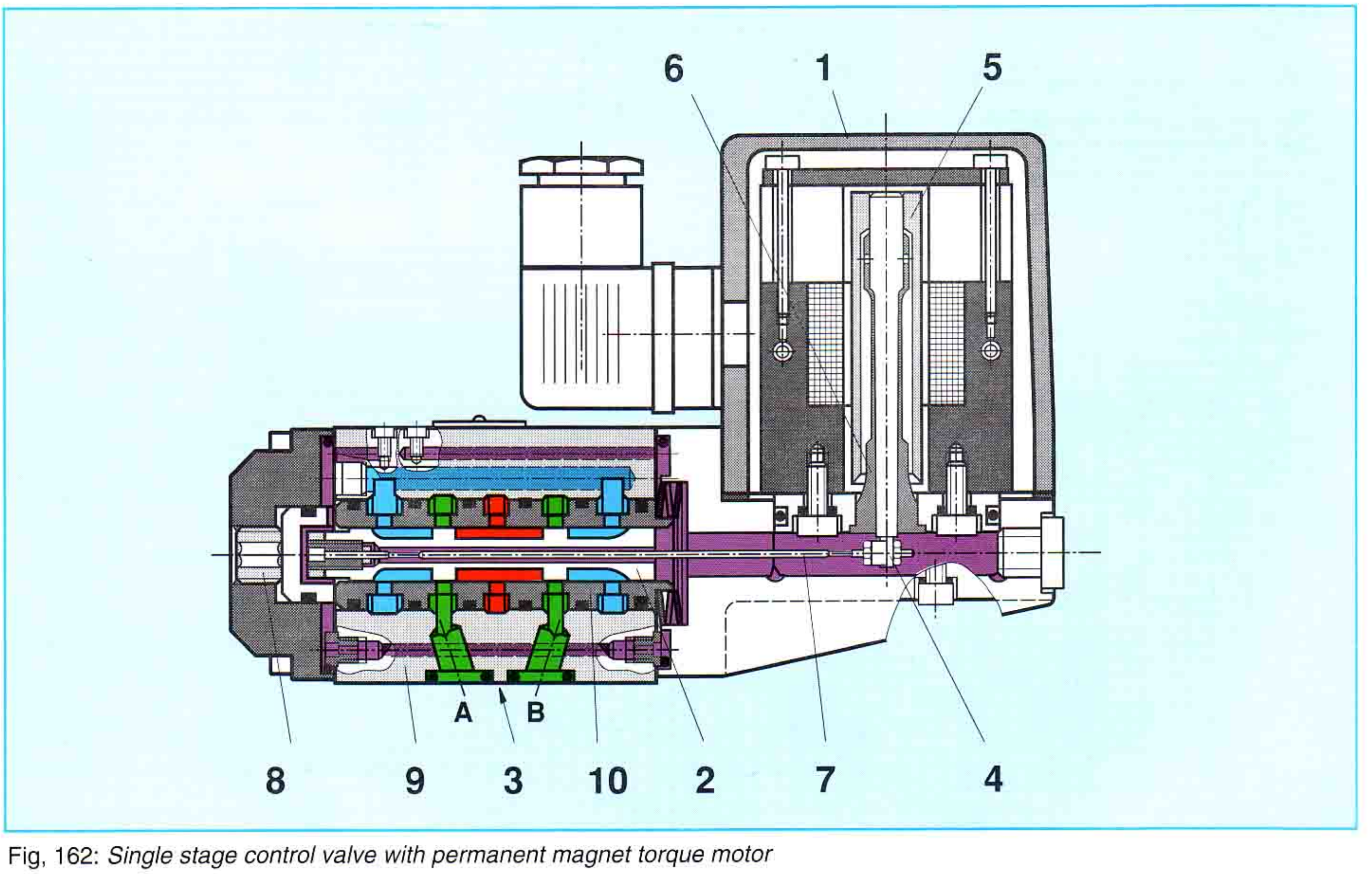


Fig. 161: *Single stage control valve, type 4 WS 1 EO 6*

5.1 Special Valve Features

Connection dimensions for valves in this series are to DIN 24 340.

- The torque motor excited by a permanent magnet is sealed, and centred by a torque tube.
- Control box and spool designed in "servo quality", i.e. linear flow curve and precise control land geometry exist.
- Hydraulic and electrical damping.



Fig, 162: *Single stage control valve with permanent magnet torque motor*

6 Multi-Stage Servo Valves

6.1 2-Stage Valve with Mechanical Feedback, Size 6

2-stage directional servo valves basically consist of:

- the 1st stage
- mechanical feedback (6) as a link between the 1st and 2nd stages, and
- the 2nd stage with interchangeable control sleeve (8) and control spool (7) which is coupled to mechanical feedback (6).

Fig. 163: *2-stage directional servo valve, type 4 WS 2 EM 10*

6.1.1 2nd Stage

The control spool (7) is linked to the torque motor (1) by the mechanical feedback (6).

The torque tube (3) centres the armature (2) and flapper plate (4) when the torque motor (1) is de-energised.

A change in electrical input signal creates unequal torques at the torque motor (1) and feedback spring (6). This causes the flapper plate (4) to be moved from mid position between the control orifices (5). As a result, a pressure difference is produced which acts on the ends of the control spool.

Due to the pressure difference the position of the control spool (7) changes. This change is maintained until the torques are the same again and the pressure difference returns to zero.

The control spool (7) stroke and hence the flow in the directional servo valve, is proportional to the electrical input command signal.

6.1.2 Special Valve Features

- The mounting dimensions of the main stage (2nd stage) of this type of valve correspond to DIN 24 340.
- The dry torque motor avoids having the magnetic gap contaminated by use of pressure fluid.

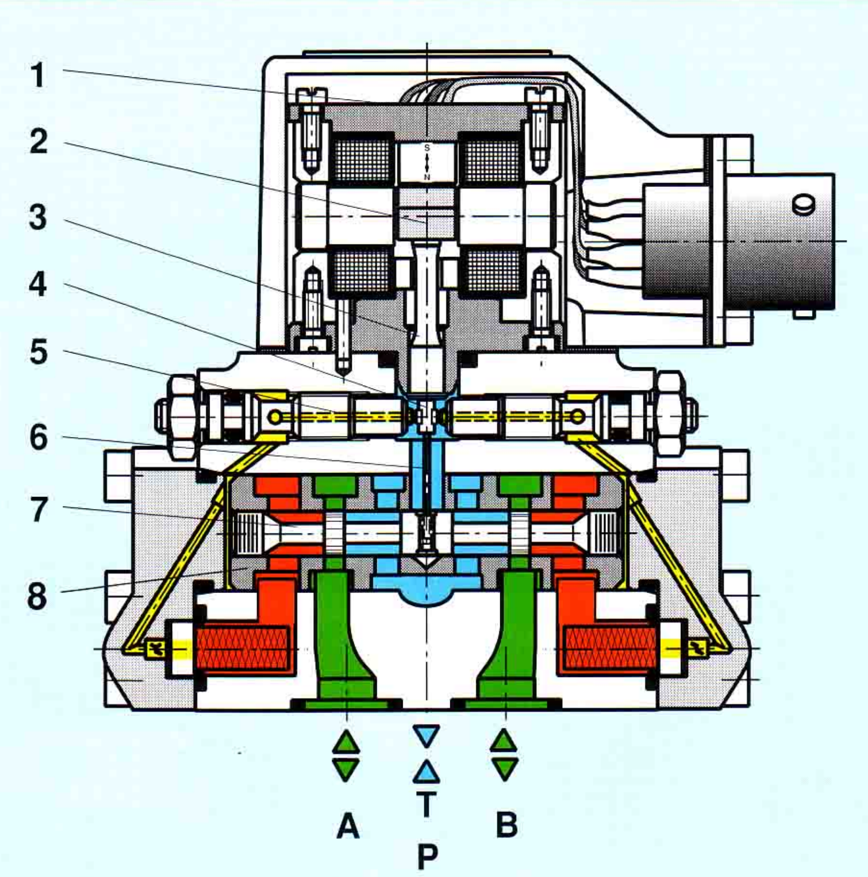


Fig. 164: *2-stage directional servo valve with mechanical feedback, type 4 WS 2 EM 6*

6.2 2-Stage Valve with Mechanical Feedback, Size 10

2-stage directional servo valves basically consist of:

- the 1st stage
- mechanical feedback (3) as a link between 1st and 2nd stages, and
- the 2nd stage with interchangeable control sleeve (4) and control spool (5) which is coupled to mechanical feedback (3).

Fig. 165: *2-stage directional servo valve with mechanical feedback*

6.2.1 2nd Stage

Control spool (5) is linked almost backlash-free to the torque motor (1) of the 1st stage by the mechanical feedback (3).

The type of feedback used in this case is dependent on the torque balance at the torque motor (1) and feedback spring (3).

This means, when a change in electrical input siganl creates unequal torques, flapper plate (6) is first moved from the mid position between the control orifices. As a result, a pressure difference is produced which acts on both ends of the control spool. Due to the pressure difference, the position of the control spool (5) changes. As a result of this change, the feedback spring (3) bends until the flapper plate is pulled back to the centre position to such an extent that the main spool stops moving and the torques are the same again.

The spool stroke and hence flow, which are proportional to the input signal have therefore been re-established.

The two socket screws (8) (located left and right in the valve covers (9)) may be used to move the position of the control sleeve (4) control land with respect to the control spool (5), in order to adjust the hydraulic null point.

6.2.2 Special Valve Features

The connection dimensions of this type of valve correspond to the main stage (2nd stage) to DIN 24 340.

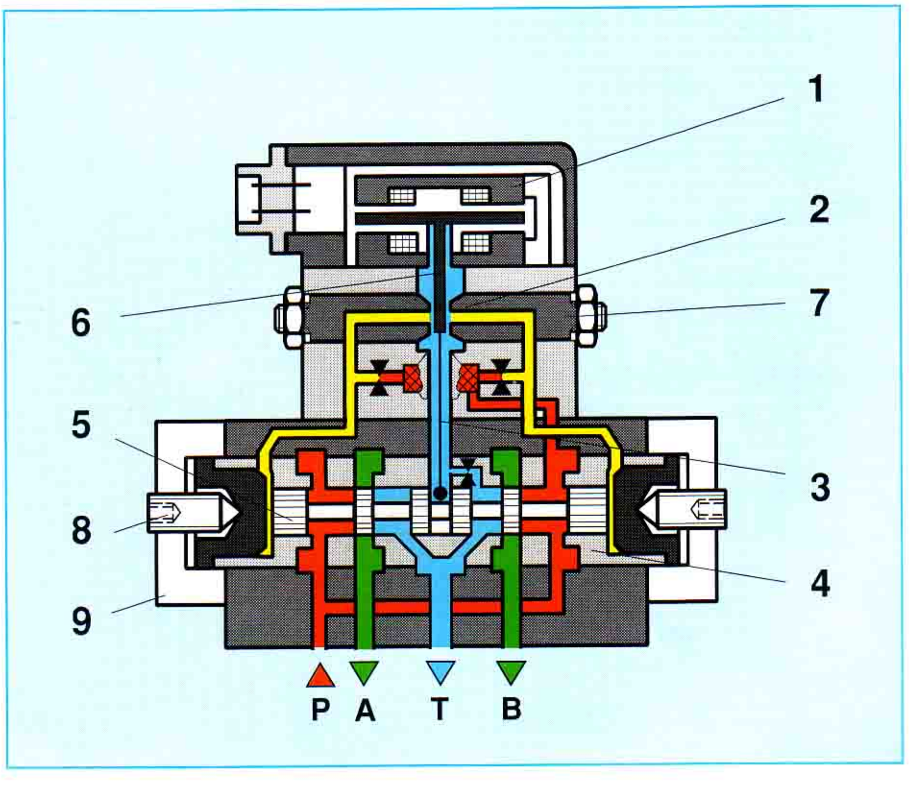


Fig. 166: *2-stage directional servo valve with mechanical feedback*

6.3 2-Stage Valve with Barometric Feedback, Size 10

The 2-stage directional servo valves basically consists of:

- the 1st stage
- the 2nd stage with interchangeable control sleeve (7), control spool (3) and control springs (4).

6.3.1 2nd Stage

The pressure difference between the two control chambers ((8) and (9)) of the control spool (3) is proportional to the electrical input signal of the 1st stage.

With zero power, the control spool (3) is pressure balanced and held in the centre position by control springs (4).

An electrical signal moves the flapper plate, which creates a pressure difference between the two control chambers (8) and (9).

The control spool is shifted and remains shifted until forces are in balance. Forces are balanced when the pressure difference between the two control chambers (8) and (9) of the control spool (3) on the one side, and the spring and flow forces on the opposite side are equal.

Since the control springs (4) also have a linear characteristic, the stroke of the control spool (3) and hence the flow of the directional servo valve are also proportional to the electrical input signal.

Fig. 167: *2-stage directional servo valve with barometric feedback*

The null point adjustment device is easily accessible from both sides.

In the case of servo valves with barometric feedback, amplitude response and phase offset are dependent on system pressure and flow. The devices are specially adapted for certain pressure ranges in order to achieve optimum results. The same applies for certain flow ranges. Hence various frequency curves are obtained.

6.3.2 Special Valve Features

The mounting dimensions of the main stage (2nd stage) of this type of valve correspond to DIN 24 340.

The filter element in the 1st stage can be easily removed and serviced. The enclosed filter chamber prevents dirt particles entering the oil system.

An external pilot oil feed is of advantage in certain valve applications. Since the DIN subplates have no connection for this purpose, a subplate can be mounted between the 1st and 2nd stages.

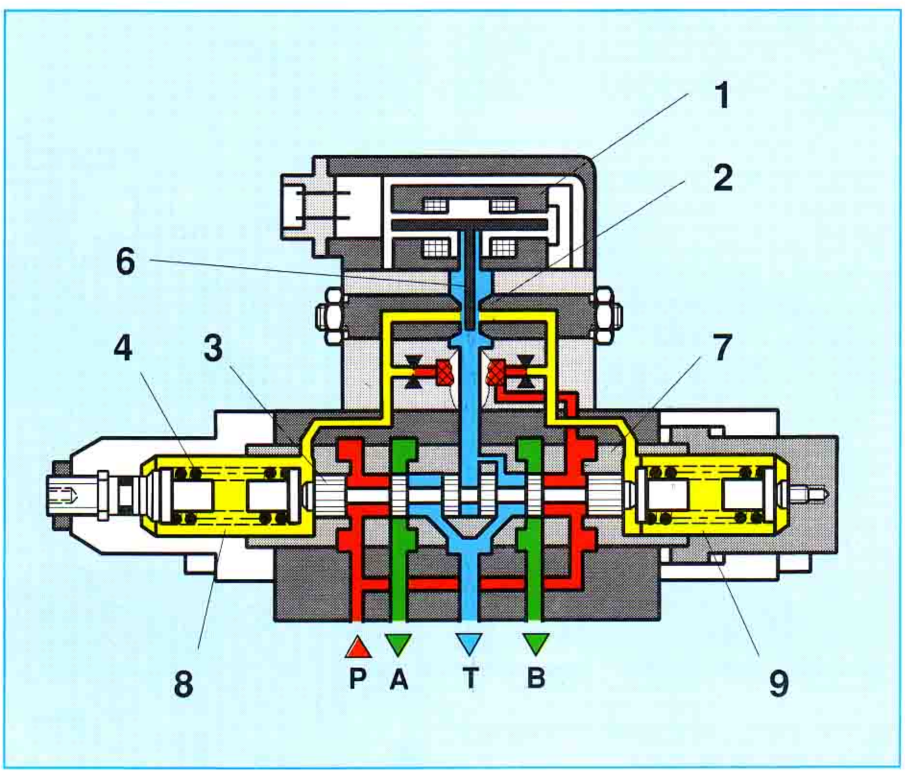


Fig. 168: *2-stage directional servo valve with barometric feedback*

6.4 2-Stage Valve with Electrical Feedback, Size 10

These 2-stage directional servo valves basically consist of:

- the 1st stage
- the 2nd stage with interchangeable control sleeve (3) and
- an inductive positional transducer (4) with its core (5) secured to the control spool (6).

Fig.169: *2-stage directional servo valve with electrical feedback*

6.4.1 2nd Stage

The control spool (6) is coupled to the inductive positional transducer (4) by means of suitable electronics.

A change in the position of the main spool (6), as well as a change in the command signal produce a differential voltage at the output when the core (5)is displaced within the coil of the positional transducer.

The difference between command and feedback signals is measured by suitable electronic components and fed as a closed loop error to the first stage of the valve. This signal moves the flapper plate (7) from the mid-position between the two control orifices (8). As a result, a pressure difference is produced between the two control chambers (9) and (10).

The control spool (6) with the attached core (5) of the inductive positional transducer (4) is shifted until the command signal is the same as the actual signal. When this is the case, the flapper plate returns to the centre position.

In closed loop control, control chambers (9) and (10) are pressure-balanced and the control spool is held in this controlled position.

Due to the position of the control spool (6) with respect to the control sleeve (3) a control opening is produced to control flow, which is proportional to the command signal, in the same way that the spool stroke and flow are proportional to this signal.

The valve frequency response is optimized by means of the electrical gain in the electronic control.

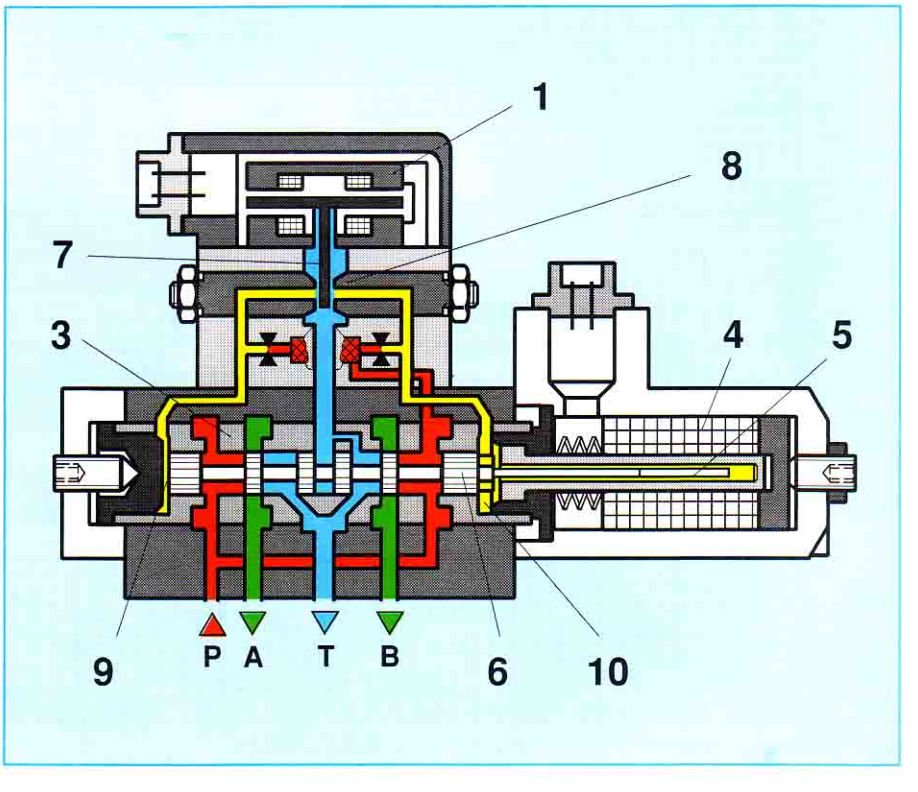


Fig.170: *2-stage directional servo valve with electrical feedback*

6.4.2 Special Valve Features

The connection dimensions of this type of valve correspond to the main stage (2nd stage) to DIN 24 340.

Comparison of hydraulic and dynamic data shows the differences between the three feedback systems.

6.5 3-Stage Valve with Electrical Feedback

These 3-stage directional servo valves basically consist of:

- the 1st stage
- the 2nd stage (3) in the form of a flow amplifier stage for control of the 3rd stage (4)
- the 3rd stage (4) for open loop flow control of the main oil flow and
- an inductive positional transducer (5) whose core (6) is secured to the control spool (7) of the 3rd stage.

6.5.1 3rd Stage

The control spool (7) is coupled to the inductive positional transducer (5) by suitable electronics.

A change in the position of the main spool (7), as well as a change in the command signal produce a differential voltage at the output when the core (6) is displaced within the coil of the positional transducer (5).

The difference between command and feedback signals is measured by suitable electronic components and fed as a closed loop error to the first stage of the valve. This signal moves the flapper plate (8) from the mid-position between the two control orifices (9). As a result, a pressure difference is produced between the two control chambers (10) and (14). The control spool (11) is shifted and a certain oil flow is allowed into control chamber (15) or (16). The control spool (7) with the attached core (6) of the inductive positional transducer (5) is shifted until the command signal is the same as the feedback signal.

In closed loop control, control chambers (15) and (16) are pressure-balanced and the control spool is held in this controlled position.

Due to the position of the control spool (7) with respect to the control sleeve (13) a control opening is produced to control flow, which is proportional to the command signal, in the same way that the spool stroke and flow are proportional to this signal.

The valve frequency response is optimized by means of the electrical gain in the electronic control.

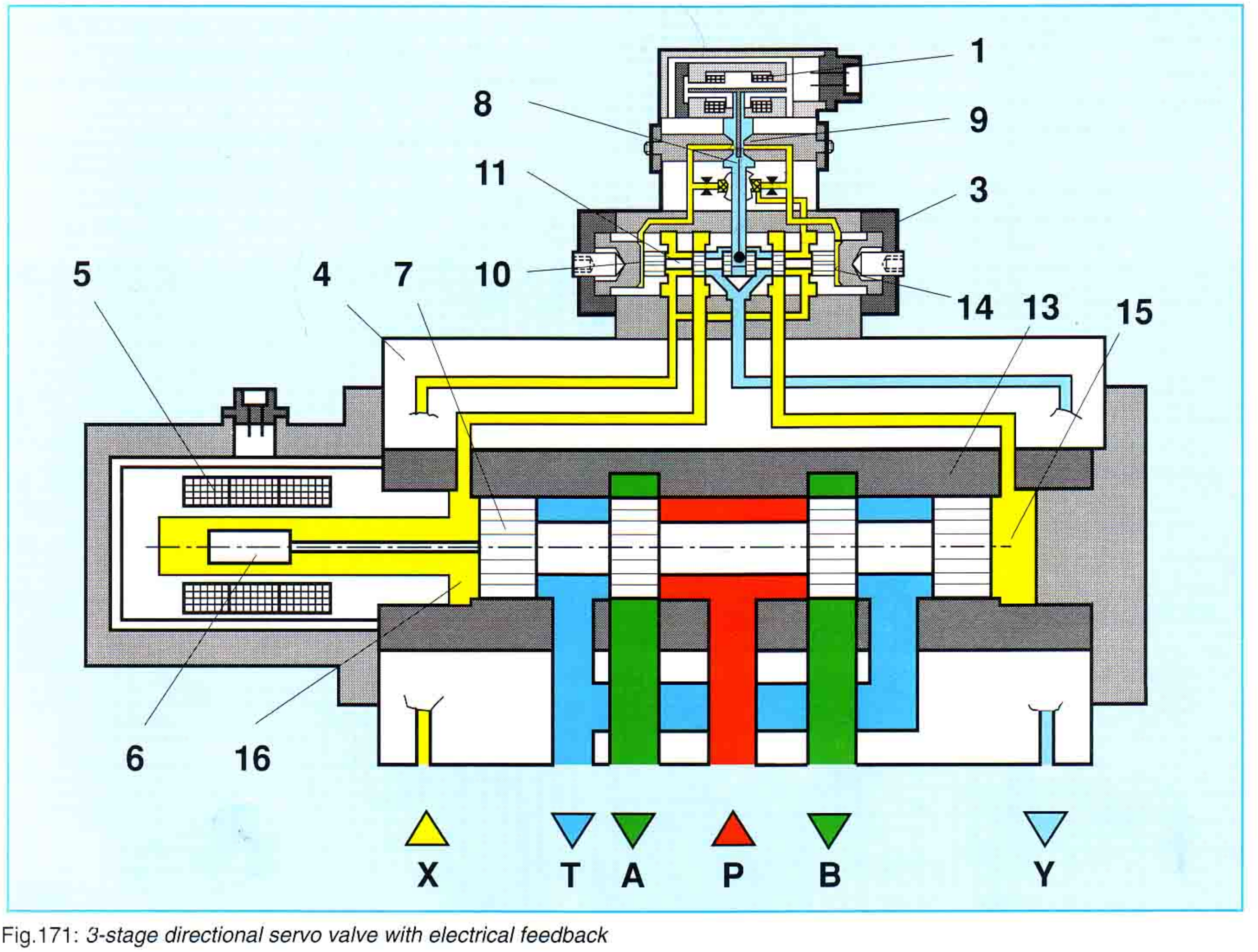


Fig.171: *3-stage directional servo valve with electrical feedback*

7 Assembly, Commissioning and Servicing of Hydraulic Servo Valves

7.1 General

The following notes for the assembly, commissioning and servicing of servo valves are not in detail. In general, data sheets from the manufacturer must be consulted for individual applications. A further aid is the VDI Specifications (Commissioning and Maintenance of Hydraulic Systems, VDI 3027).

7.2 Installation

7.2.1 Assembly Instructions

Before the valve is mounted in the system, the valve type should be compared with the order data.

7.2.1.1 Cleanliness

- When mounting the device, extreme care should be taken to ensure cleanliness of surrounding area and servo valve.
- The tank must be sealed from external contamination.
- Prior to installation, pipes and tank must be cleaned of dirt, scale, sand, metal swarf etc.
- Hot bent or welded pipes must be subsequently pickled, flushed and rinsed with oil. Refer to the detailed information given in paragraph 7.3.6 with respect to system flushing.
- Only use lint-free material or special paper for cleaning purposes.

7.2.1.2 Sealing Material

Sealing material such as hemp, putty or sealing tape must not be used.

7.2.1.3 Hoses

Hoses should be avoided whenever possible.

7.2.1.4 Pipes

Pipes must be seamless precision steel pipes to DIN 2391/C.

7.2.1.5 Connecting Lines

The connecting lines between actuator and valve must be as short as possible. We recommend that the servo valve is mounted directly on the actuator.

The mounting surface must have a surface finish of $R_{max} \leq 4\ \mu m$ and a degree of flatness of ≤ 0.01 mm/100 mm length.

7.2.1.6 Mounting Screws

Mounting screws must be tightened to the torque specified in the data sheets from the manufacturer.

7.2.1.7 Filling and breathing filters

An oil bath air filter is recommended as a filling and breathing filter.
Pore size $\leq 10\ \mu m$.

7.2.1.8 Protective Plate

The protective plate on the servo valve should only be removed immediately prior to installation.

7.2.2 Installation Position

In any position, but preferably horizontal. However, the orientation of the spool is dependent on the type of feedback. If the servo valve is mounted on the actuator, care should be taken to ensure that the valve spool is not parallel to the direction of acceleration of the actuator.

7.2.3 Electrical Connection

Refer to the relevant data sheets from the manufacturer for electrical connection.

Servo valves may be operated in parallel, series or differential circuits.

We recommend a parallel circuit for operational reliability.

Caution:

Due to electrical gain in closed loop control circuits, an electrical signal must not be fed to the valve before operating pressure is applied to the first stage. An exception to this is when 100 % current limitation is provided.

Special protection types require special precautions to be taken.

7.3 Commissioning

7.3.1 Fluids

Mineral oil to DIN 51524, DIN 51525 or VDMA 24318 should preferably be used. A fluid temperature of 50 °C should be maintained when using H-L36 or H-LP36. If possible, the maximum temperatures recommended by the fluid manufacturer should not be exceeded in order to protect the fluid. To ensure constant closed loop control behaviour of the system, it is advisable to maintain the oil temperature constant (±5 °C).
Other fluids on request.

7.3.2 Sealing materials

Is the correct sealing material being used for the O-rings?

For fire resistant fluids type HFD and for temperatures above 90 °C, the valve type must be designated with a "V".

7.3.3 Filtration

- Internally pilot operated servo valves must be protected immediately before the valve in pressure port "P" by a pressure filter without by-pass valve (nominal filter pore size of 10 µm = $\beta_{10} \geq 75$ to cleanliness class 5 to NAS 1638) .
- Externally pilot operated valves must be protected immediately before the valve in the supply line to port "X" by a pressure filter without by-pass valve (nominal filter pore size of 10 µm = $\beta_{10} \geq 75$ to cleanliness class 5 to NAS 1638). In this case, we recommend that the entire hydraulic system is cleaned via another 10 µm filter.
- The permissible differential pressure of these filters must be greater than the operating pressure.
- We recommend filters equipped with contamination indicators.
- Absolute cleanliness must be ensured during filter change. Contamination at the output of the filter is flushed into the system and cause faults.
  Contamination at the inlet reduces the service life of the filter element.

7.3.4 Pilot Pressure

Due to the good control characteristics required, the pilot pressure should be maintained constant (±5 bar).

7.3.5 Adjustment of the Hydraulic Null Point

The hydraulic null point of each servo valve was adjusted on a test bench with the aid of a hydraulic motor. Nevertheless, in order to achieve optimum closed loop control accuracy it may be necessary to readjust the hydraulic null point with respect to the actuator and in accordance with the instructions given in the data sheet from the manufacturer.

7.3.6 Flushing system

All supply and return lines must be flushed prior to commissioning the servo valve. Instead of flushing plates which connect P to T (refer to data sheet for type), the use of directional valves (symbol G or H) is preferred. Using these, operating lines and actuator may also be flushed.

In the case of external pilot oil connection care must be taken to ensure that this connection is also flushed.

The oil in the system should be flushed through the filter at least 150 to 300 times.

Based on this, a reference flushing time can be derived:

$$t = \frac{V}{Q} \cdot X$$

Where: t = Flushing time in hours
V = Tank volume in litres
Q = Pump delivery rate in L/min
X = 2.5 to 5

During the flushing procedure, all filters must be constantly monitored and the filter elements replaced if necessary. After opening connection lines (for any reason whatsoever) about 30 minutes more of flushing is required.

7.4 Maintenance

7.4.1 Refilling of the operating medium

The system must be flushed again when refilling more than 10 % of the tank capacity (see 7.3.6).

7.4.2 Return of Valve for Servicing

When returning a defective valve, it is necessary to protect the base of the valve from the effects of contamination. Careful packing is advisable to ensure no further damage is incurred during transport.

7.4.3 Cleaning and Adjustment Instructions

Past experience has shown that faults in servo valves are mainly due to contamination of the flapper-jet system. Valves may be cleaned in accordance with manufacturer instructions.

7.5 Storage

Servo valves must be stored in a dry, dust-free room with low humidity. Storage rooms must also be free of corrosive materials and vapours. The valves must be checked from time to time to ensure that they are stored correctly. If servo valves are to be stored for longer than 3 months, it is advisable to fill the valves with a preservative oil.