Introduction to Servo Valve Technology

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1 Development of Servo Valves

Servo valves were originally designed to be used in the aviation industry for precise control of a variety of aircraft by means of small electrical input signals. Electrical or electronic control was changed to electro-hydraulic open loop and closed loop control due to high flight speeds and hence high displacement velocities and forces.

The displacement device thus needed to fulfil high requirements with respect to speed, precision and power density.

In the course of time, industry implemented this technology and modified it to suit the accuracy required in industrial applications. It was thus possible to offer the devices at prices acceptable to industry.

1.1 Definition of Servo Hydraulics

"Servo hydraulics" is an established term. Nevertheless, opinions still vary as to its true meaning.

For example, servo hydraulics may be expressed as "closed loop electro-hydraulic control".

This definition includes all closed loop control applications involving hydraulic devices.

Operating in closed loop control means that operation is constantly monitored by means of measurement and deviations from required operation are automatically corrected.

The control parameters are mainly mechanical parameters such as

- displacement or angle of rotation
- velocity or rotary speed
- force or torque

or hydraulic parameters such as

- flow
- pressure.

To be able to control the parameters mentioned, suitable measuring devices are necessary to determine actual parameter measurements.

Servo hydraulics, therefore, does not simply refer to individual hydraulic components, but to the interaction between applied closed loop control, power transmission hydraulics and data processing electronics.

In order to understand and assess closed loop electro-hydraulic control and its power limits, it is necessary to examine:

- Closed loop control
- Electronics
- Hydraulics and
- Measurement technology

1.2 System Servo Hydraulics

Servo hydraulics comes under the broad heading of system technology. This means that all elements within the closed loop control must be considered.

The design of a servo hydraulic system depends on the cooperation everyone working on a project. Good co-operation at an early stage is the best prerequisite for obtaining an optimum solution.

Compromise solutions often result when cooperation does not begin until the essential features of a project have already been irreversibly defined.

2 Difference Between Open Loop and Closed Loop Control

2.1 Open Loop Control

If switch "a" is closed, proportional amplifier "b" actuates proportional directional valve "c" with the command signal . The proportional directional valve opens, thereby enabling flow.

Cylinder piston rod Z then moves.

If it is necessary to stop the cylinder piston of the cylinder at a defined point by opening the switch, then this is only possible under certain conditions.

The reasons for this are:

- The proportional valve switching characteristic varies with oil viscosity.
- The valve pressure drop varies due to losses in the pipes which are dependent on viscosity.
- Varying flow rates result from variations in Δp and produce varying cylinder positional velocities.
- The deceleration distance is dependent on mass moved and positional velocity.

The variables mentioned all effect open loop control.

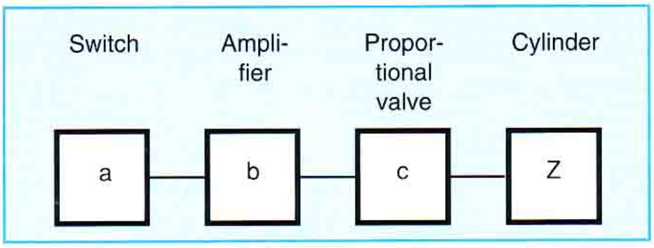


Fig. 148: *Open loop control block diagram*

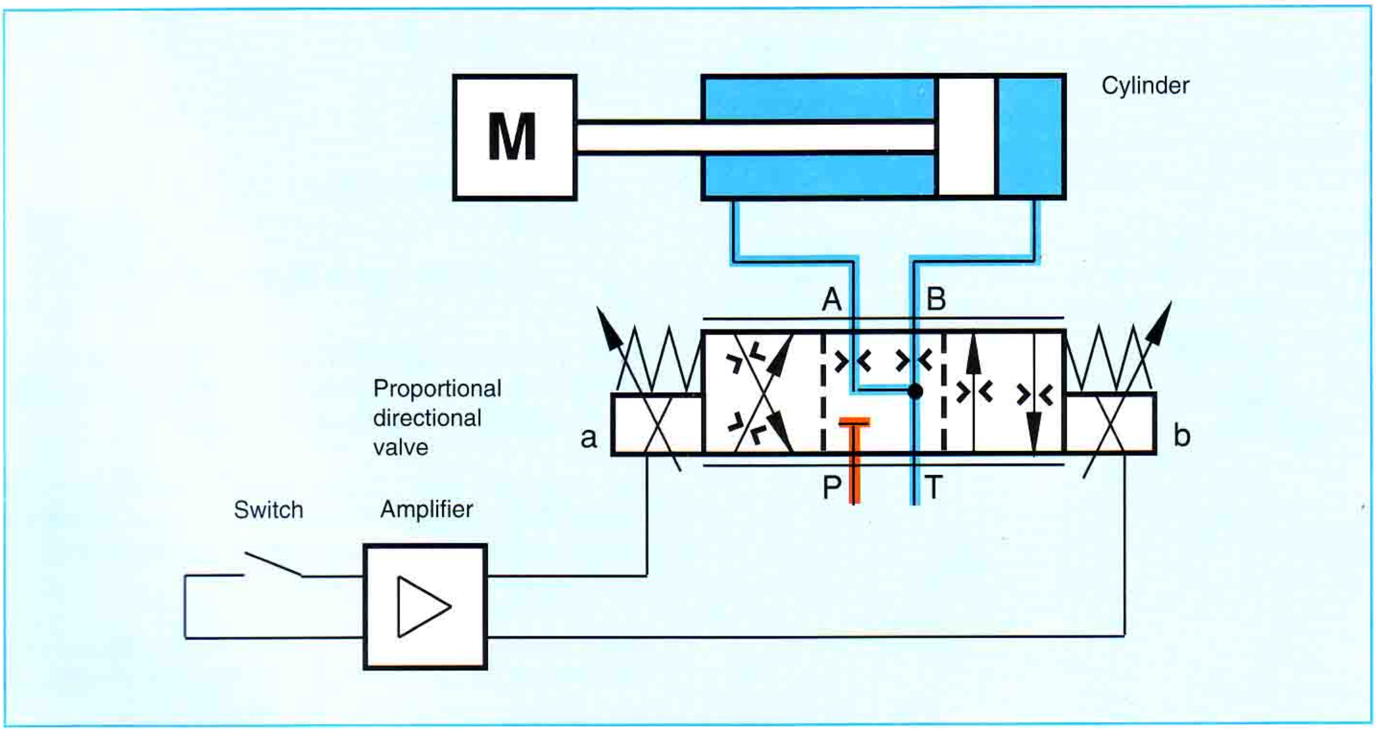


Fig. 149: *Open loop control with proportional directional valve*

2.2 Closed Loop Control

A command voltage is selected via the command voltage potentiometer. This voltage corresponds to the piston position. The actual piston position is measured and fed back as a voltage by the feedback potentiometer. At the amplifier input the difference between these two voltages, i.e. the command/feedback signal difference or closed loop error is created. The error is amplified by the amplifier and is thus able to energize the servo valve coil. As a result, the servo valve opens and the piston moves. As the actual displacement changes, the actual voltage created by the feedback potentiometer also changes. The actual voltage gradually approaches the command voltage, until they are finally both equal when the required position has been reached. During this process, the error becomes smaller and smaller, and despite amplification, less current is available to the servo valve coil. This means the servo valve gradually closes and therefore the piston slows down. When the required displacement has been reached, the error is zero and the servo valve closed.

The variables disrupting open loop control no longer or scarcely effect closed loop control. This is an important feature of closed loop control and therefore also of servo hydraulics.

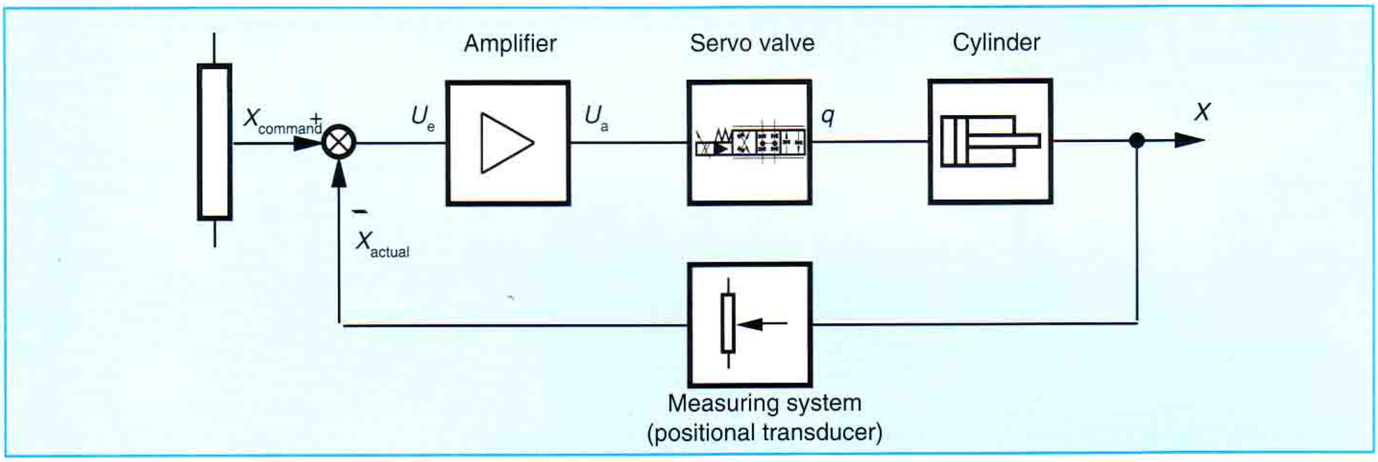


Fig. 150: *Simplified block diagram of a closed loop control circuit*

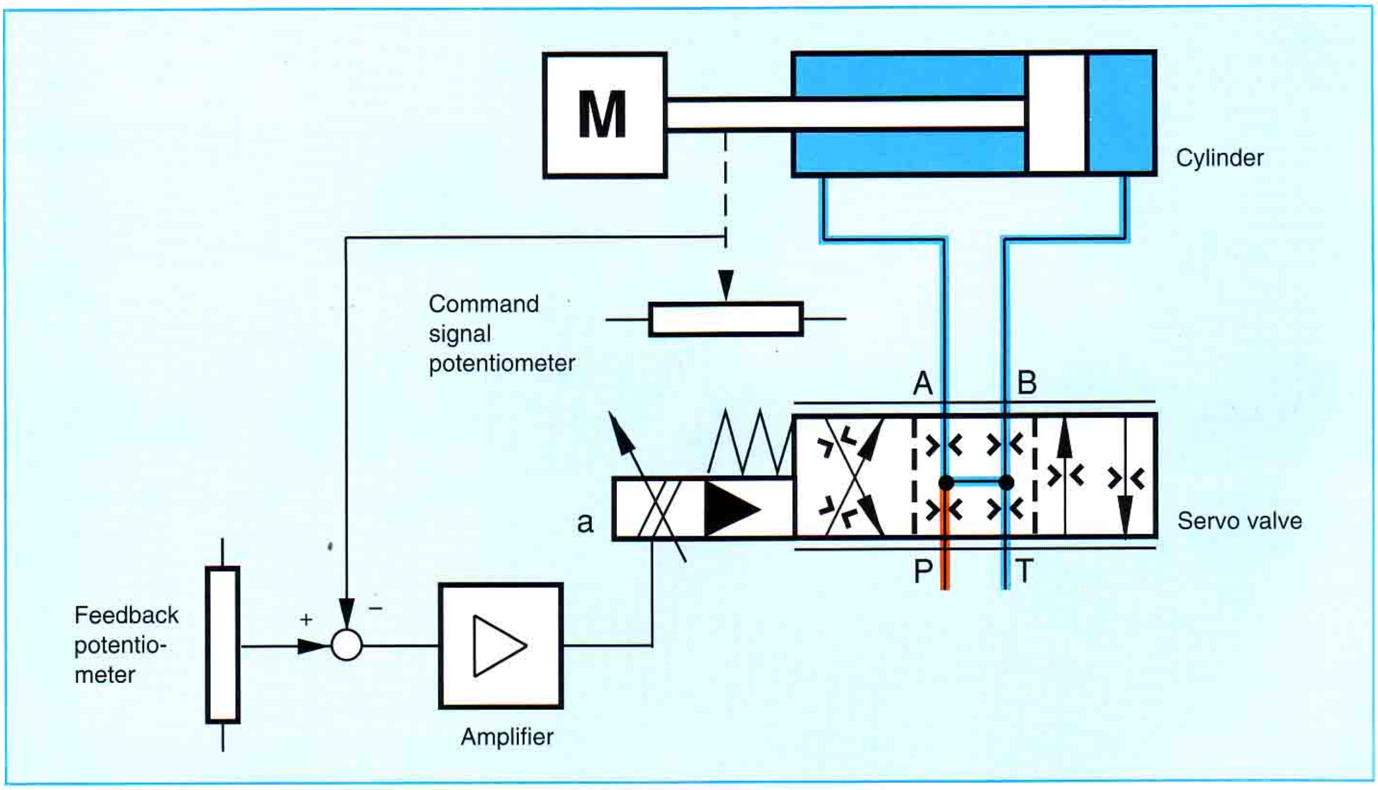


Fig. 151: *Closed loop control circuit with servo valve*

3 Technical Data with respect to Applications

In describing servo valves much terminology is used which must first be explained.

3.1 Static Technical Data

3.1.1 Nominal Flow

The nominal flow of a servo valve is normally quoted at a total pressure drop of 70 bar.

However this does not mean, that operation is limited to a 70 bar pressure drop. Any operating point (flow) may be used.

$$Q = Q_{\text{nominal}} \cdot \sqrt{\frac{\Delta p}{\Delta p_{\text{nominal}}}}$$

Q_{nominal} = Nominal flow at nominal pressure drop $\Delta p_{\text{nominal}}$

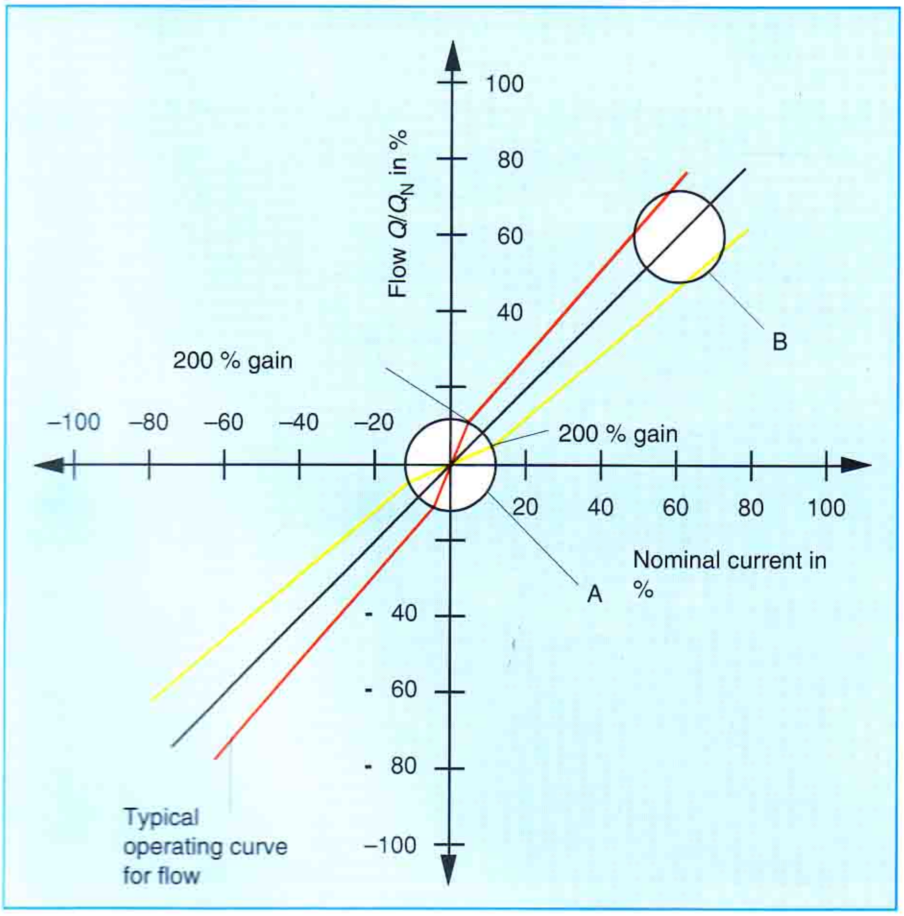
The nominal flow is always with respect to full stroke operation of the servo valve. In the case of partial stroke operation the flow varies in proportion to the stroke.

3.1.2 Operating Curve for Flow

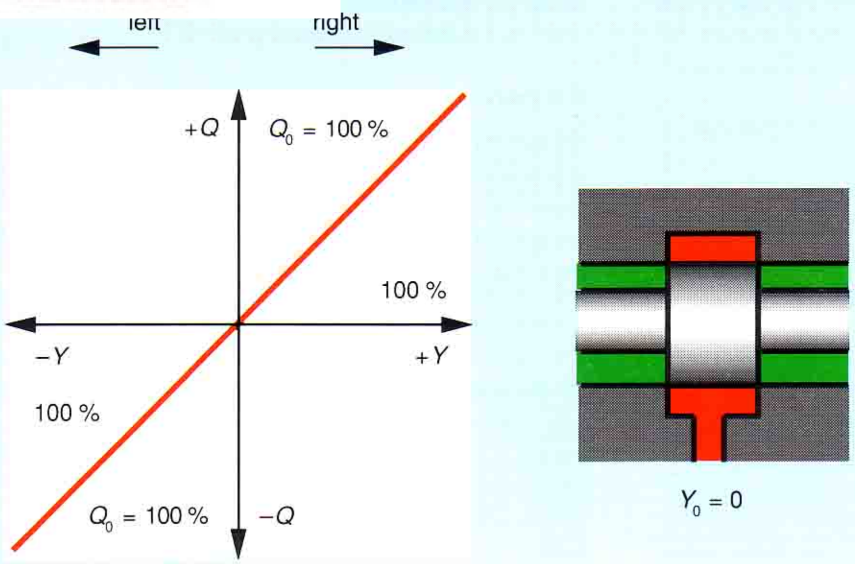
The operating curve for flow shows the relationship between valve flow and electrical input signal.

A, B = Characteristic operating points
A = Null point operation
B = Operating point when open

To understand the importance of operating points in control systems *refer to paragraph 3.1.3.*

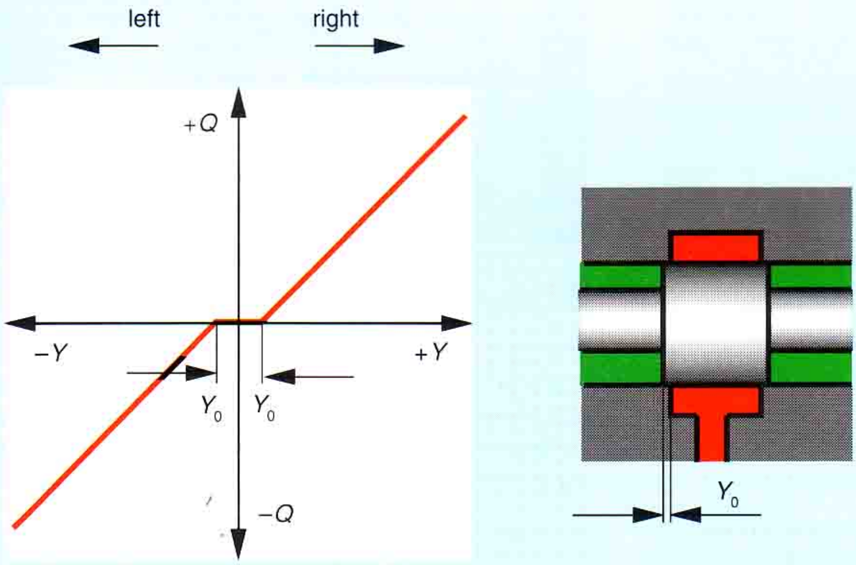


Diag. 41:
Operating curves for flow



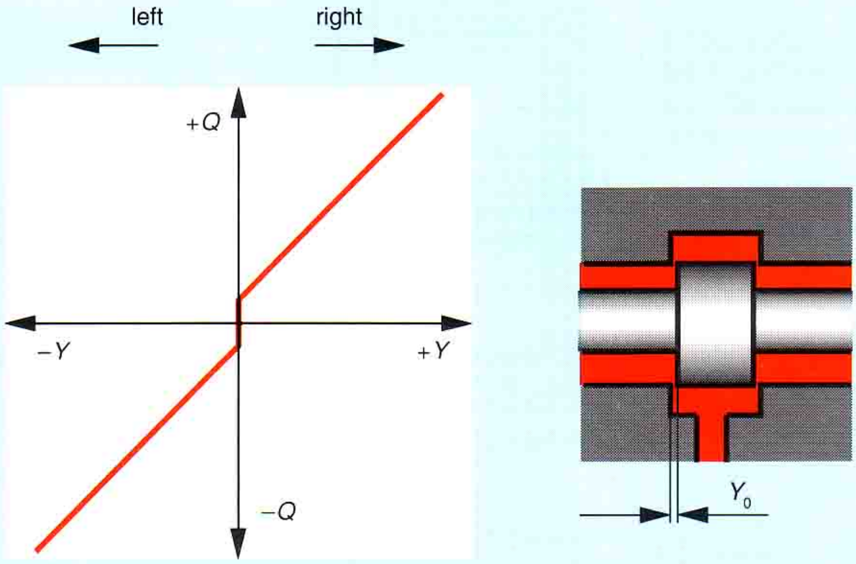
"Zero" overlap

For control spool position $|Y| = 0$ there is no flow.
For $|Y|, > 0$, there is constant flow via a control land.



Positive Overlap

For $|Y| \leq Y_0$, control openings remain closed.
For $|Y| > Y_0$, there is constant flow via a control land.



Negative Overlap

For $Y = Y_0$, there is constant flow via both control lands.
For $|Y| \geq Y_0$, flow is via only one control land.

Fig. 152: *Operating curves for flow for various overlaps at the null point (Point A)*

3.1.3 Assignment of Overlap to Control Function

Position and pressure control

With position and pressure control, the valve operates at operating point "A", i.e. at the null point.

Either a zero or negative overlap must be selected for this application. Positive overlap cannot be used, as signals are not transferred within the overlap area and signals transferred outside the overlap area are distorted. Stable closed loop control is therefore not possible.

Velocity or flow control

In closed loop velocity control, the valve operates at operating point "B". In this case, a positive overlap at the null point is used.

Closing function with positive overlap

A positive overlap will not result in a reliable cut-off. The overlap is normally small so as to ensure that sufficient flow is available for the remaining stroke. If the null point is moved as the result of pressure and temperature fluctuations or a jet being blocked on one side, flow occurs in one direction and the drive moves.

3.1.4 Flow Gain

Gain is normally the relation between input and output signals. Flow gain is therefore defined as

$$V_q = \frac{q}{U_E} \quad \text{in} \quad \frac{\text{L/min}}{\text{Volt}}$$

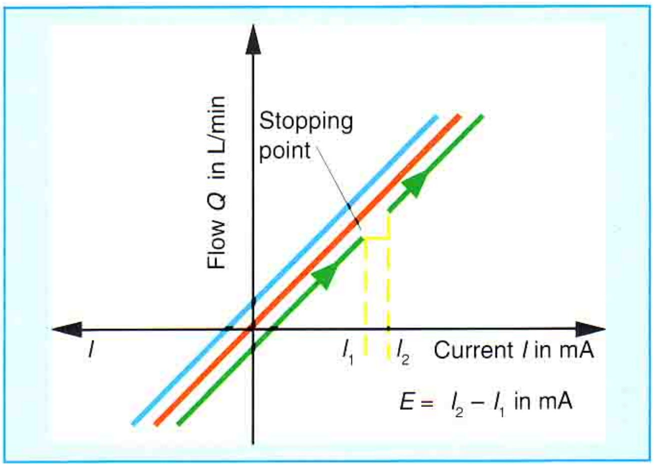
This definition is represented by the average gradient of the operating curve for flow. The gradient of this curve depends on system pressure.

Due to manufacturing tolerances, various gains occur particularly about the null point *(refer to operating curve for flow, Fig. 130)*. As a result, it may be necessary to re-adjust the controller when replacing valves.

3.1.5 Response Sensitivity "E" and Reversal Dead Band "S"

Response Sensitivity *E*

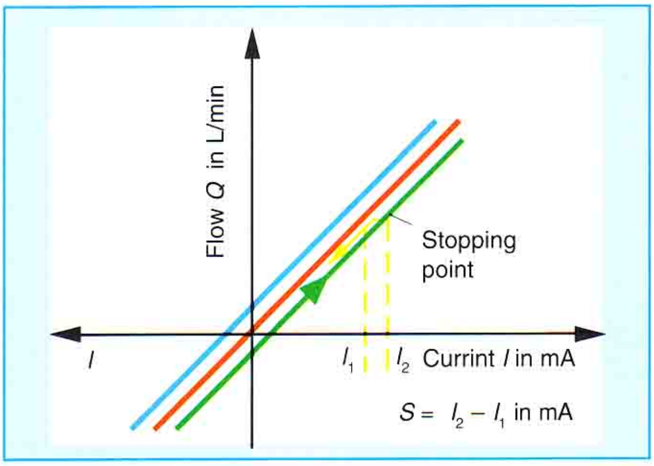
Response sensitivity is the change in electrical input required to generate a measurable change in flow. This must be in the same direction of travel having once stopped in that direction of travel. Sensitivity is specified as a percentage of the rated current.



Diag. 42: *Response sensitivity E*

Reversal Dead Band *S*

The reversal dead band is the change in electrical input required to generate a change in flow. This must be in the opposite direction of travel having once stopped in the other direction of travel. Reversal dead band is specified as a percentage of the rated current.



Diag. 43: *Reversal dead band S*

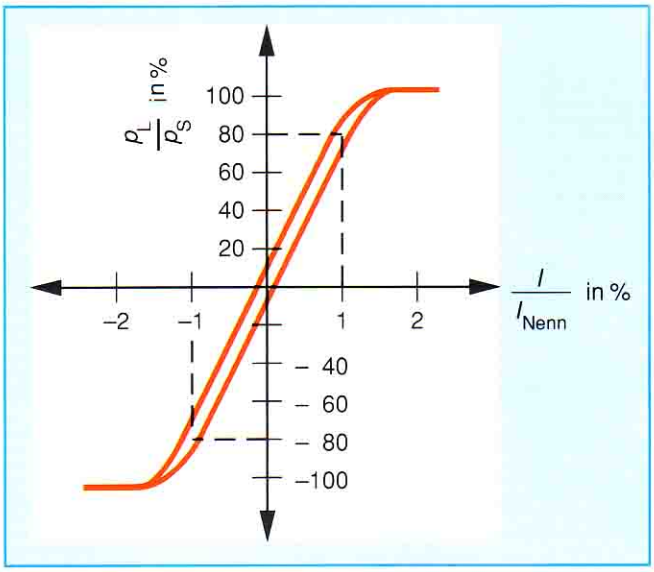
Response sensitivity and reversal dead band represent dead zones which influence the accuracy of closed loop control.

Thus, to be meaningful, any change in input signal applied to a servo valve must be greater than the response sensitivity or reversal dead band (depending on the direction of the correction).

An input signal is produced by a closed loop error, i.e. the difference between command and feedback signals. Neglecting pressure behaviour, this means that the control range in closed loop flow control and the possible position accuracy in closed loop positional control are directly influenced by the servo valve.

3.1.6 Pressure-Signal Characteristic

Force is necessary to correct a drive. For this reason, the behaviour of the output pressure with respect to the input signal is significant. This behaviour is shown in the pressure-signal characteristic.



Diag. 44: *Pressure signal characteristic*

3.1.7 Pressure Gain

The relationship between output pressure and input signal is referred to as pressure gain.

$$V_p = \frac{p_L}{U_E} \text{ in } \frac{\text{bar}}{\text{Volt}}$$

The operating curve for pressure shows how far the servo valve must open in order to have sufficient pressure available for correction.

The opening of the valve is in turn controlled by closed loop control. Hence pressure gain directly effects closed loop control accuracy. Therefore pressure gain should be as large as possible.

In the case of the pressure-signal curve illustrated, 80 % of system pressure is available for correction of the closed loop error at 1 % of the rated current.

3.1.8 Flow-Load Characteristic

A hydraulic servo drive generally consists of a servo valve and a cylinder or motor as the actuator. Movements are effected by throttling the supply oil flow.

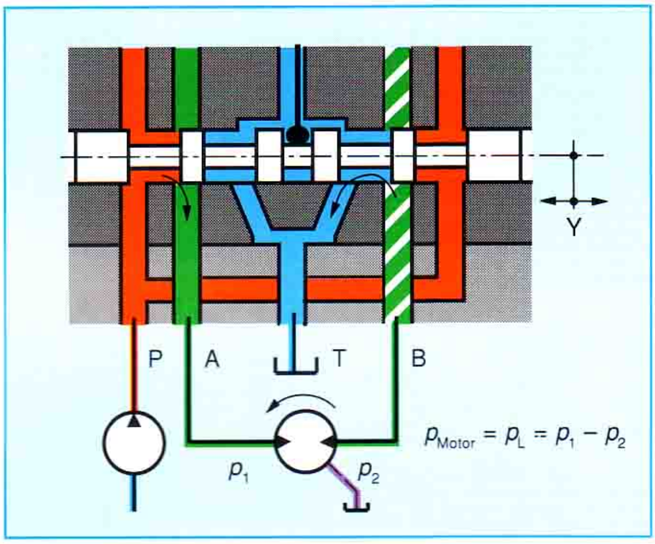


Fig.153: *Four edge throttle control*

Assuming ideal conditions, the oil flow through a throttle is given by

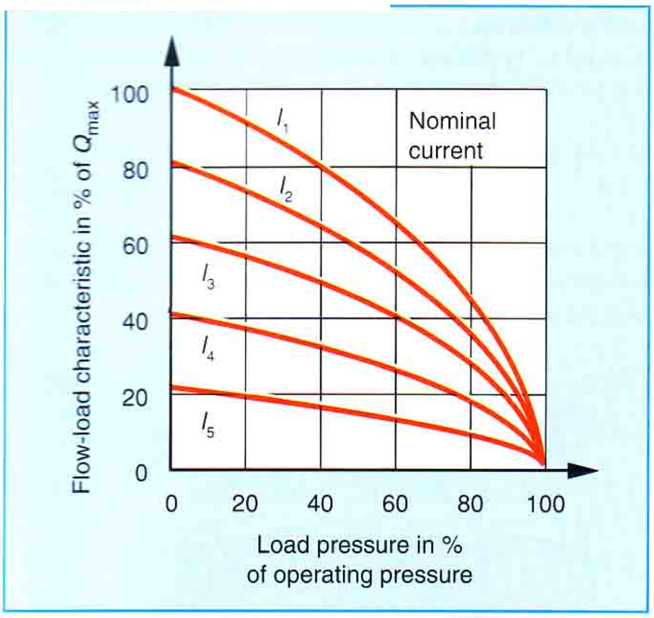
$$Q = Y \cdot K \cdot \sqrt{\Delta p}$$

In this equation, Q = flow, Y = degree of spool movement *(= percentage control, see Diag. 45)*, K = constant, and Δp = pressure drop at the control land. K takes into consideration the geometry of the control opening and the density of oil etc. Depending on the load, the motor connected in the example requires a load pressure p_L. If p_S is the system pressure, then the following pressure drop remains

$$\Delta p = p_S - p_L$$

$$Q = Y \cdot K \cdot \sqrt{p_S - p_L} \; .$$

When the motor is not subject to load, i.e. $p_L = 0$, the entire system pressure is available as Δp. Maximum oil flow is provided. If the motor is blocked, the entire system pressure is applied at the motor and flow is then zero.



Diag. 45: *Flow-load characteristic, $I_1 = I_{max}$*

3.2 Dynamic Technical Data

(Diags. 46 and 47)

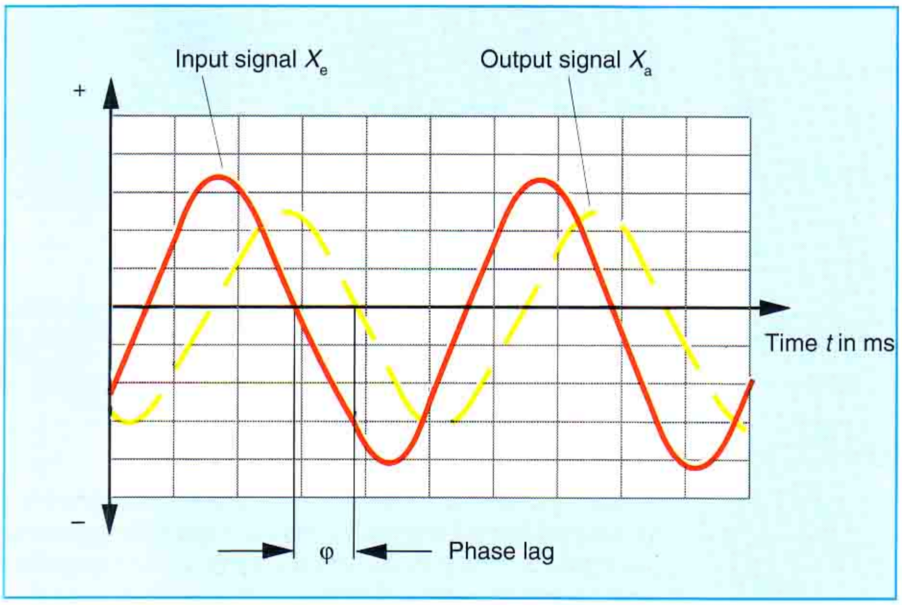
The natural frequency of the drive and resulting total gain determine closed loop control accuracy. The natural frequency of the drive is determined by the dynamics of the servo valve.

An examination of the positioning time of the valve is not sufficient to describe its dynamic characteristics. The most common way of examining the dynamic characteristics is by looking at the frequency response.

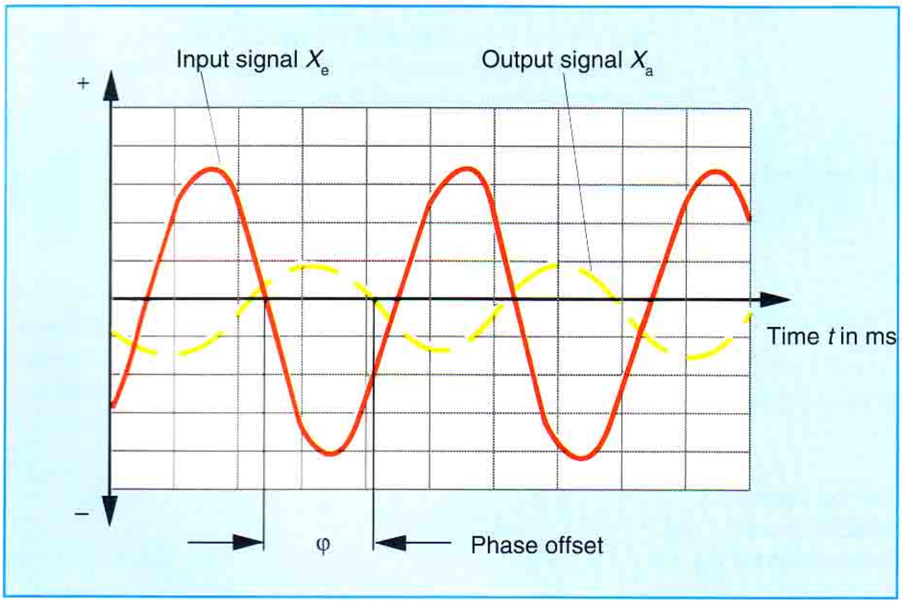
During this process, the servo valve is excited by sine waves and the reaction of the valve to these signals is monitored.

The servo valve response (flow Q) is also sinusoidal. However, its amplitude and phase are offset with respect to the excitation signal.

Initially, the frequency of the applied signal is low and then gradually increased. As a result, as the frequency increases, the output amplitude decreases, and the movement of the valve lags more and more behind the input signal.



Diag. 46:
Frequency response curve

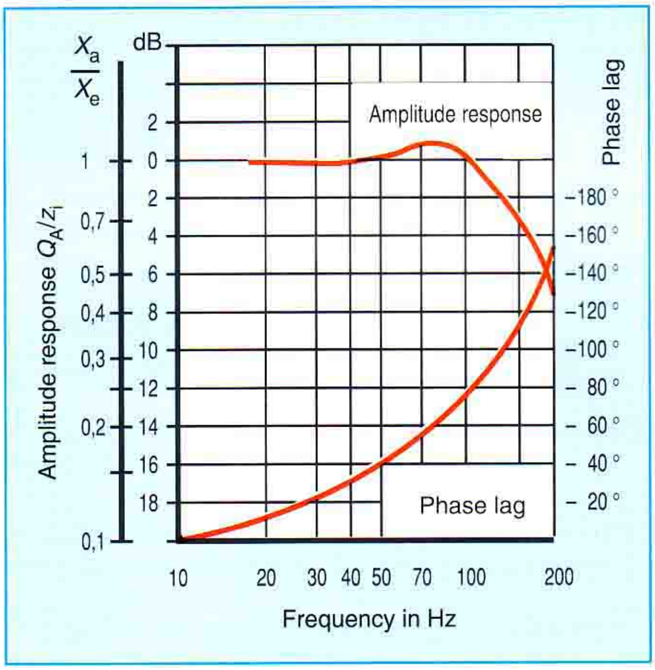


Diag. 47:
Frequency response curve

3.2.1 The Bode Diagram

The relationship between frequency, phase and amplitude is shown in the Bode diagram.

Here, the relationship between output amplitude and input amplitude X_a/X_e is shown with respect to the excitation frequency and hence the "amplitude response" is obtained. Furthermore, the relationship between output signal phase offset and input signal is shown with respect to frequency and hence the "phase response" is obtained. Both characteristics together form the Bode diagram.



Diag. 48: *Bode diagram*

The amplitude response is normally given in dB.

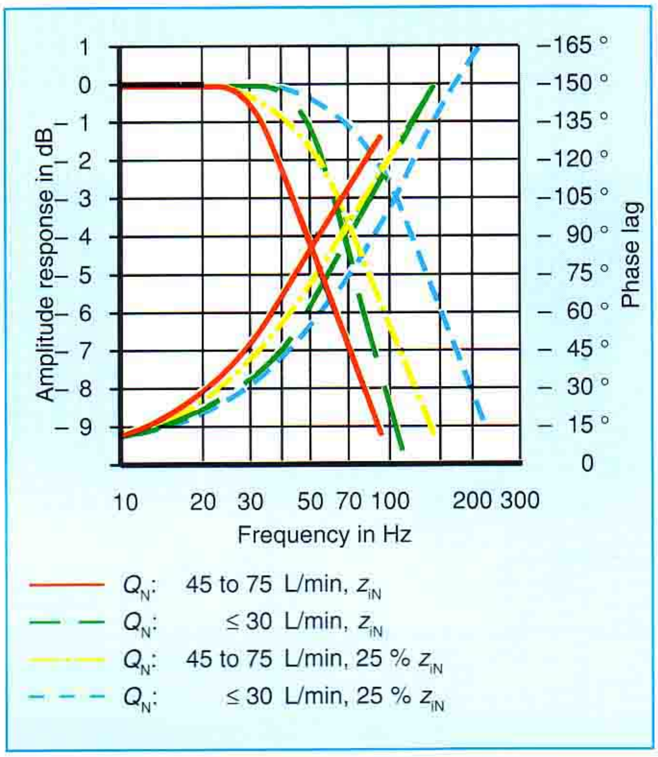
Therefore the amplitude response in dB $= \mathbf{20 \cdot lg} \frac{X_a}{X_e}$

or $\frac{X_a}{X_e} = 10^{\left(\frac{dB}{20}\right)}$

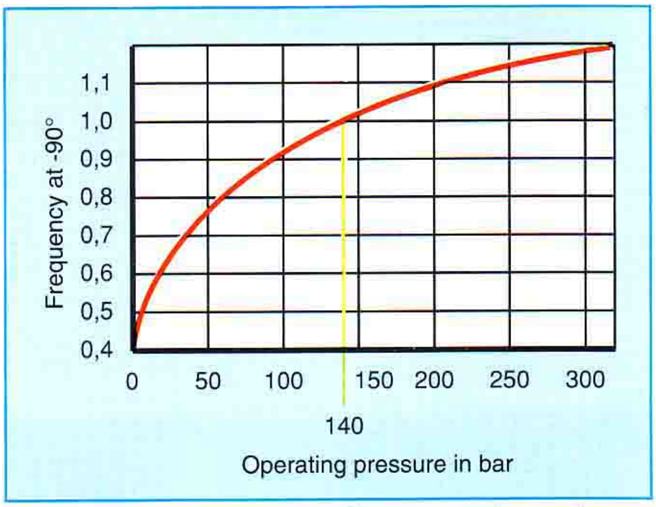
In order to qualitatively describe frequency response for technical data, frequency is defined as -3 dB and at -90°.

f_{-3dB} is defined as the frequency at which the valve output signal Q has dropped by -3 dB with respect to the input signal. This corresponds to $X_a/X_e = 0.707$. This characteristic value describes one point on the amplitude response curve.

$f_{-90°}$ is defined as the frequency at the point on the phase response curve at which the output signal lags behind the input signal by 90°.



Diag. 49: *Frequency response of a size 10 servo valve with mechanical feedback*



Diag. 50: *Relationship between frequency and operating pressure*