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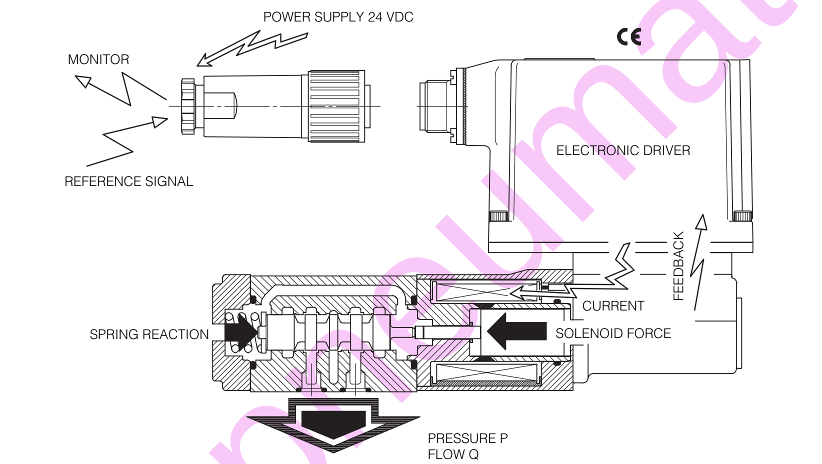
Proportional controls: user's guidelines

1 WHAT IS PROPORTIONAL CONTROL?

Electrohydraulic proportional controls modulate hydraulic parameters according to electronic reference signals.
They are the ideal interface between hydraulic and electronic systems and are used in open or in closed-loop controls, see section 3, to achieve the fast, smooth and accurate motions required by today's modern machines and plants.
The electrohydraulic system is a section of the overall automation architecture. Information, controls, alarms can be transmitted in a "transparent" way from the electrohydraulic system to the centralized control system and viceversa via standard fieldbus, see section 10

2 DESCRIPTION OF FUNCTION

The core of electrohydraulic controls is the proportional valve. The electronic driver regulates a proper electrical current supplied to the valve's solenoid according to the reference signal (normally ±10 V_{DC}). The solenoid converts the electrical current into a mechanical force acting the spool/poppet against a return spring: increasing of the current produces a corresponding increase in output force and consequent compression of return spring thus movement of the spool or poppet. When electrical failure occurs, return springs restore the neutral position according to valve configuration.
In pilot operated executions the proportional pilot regulates flow and pressure acting on the spool/poppet of main operated stage.

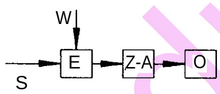


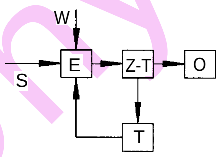
3 CONTROL LOOPS

There are two types of control loops: open-loop and closed-loop

Open loop control, see section 11
Hydraulic control is provided through the modulation of an electric drive signal without the effective result of the regulating loop being verified.

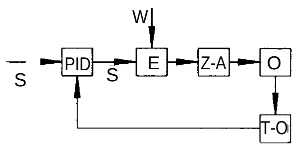
Closed loop control, see section 12, 13
The regulated parameters are continuously verified by feedback transducers thus the closed loop controls are not subject to environmental disturbances.

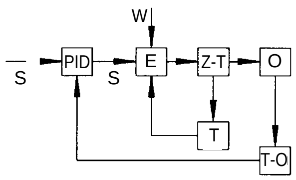




Legend:

W = DC power
S = reference signal
Z-A, -T = valves respectively in -A or -T configuration
E = electronic driver
T = valve transducer
T-O = system transducer
O = actuation system
PID = digital axis controller





Typical block diagrams of proportional systems, i.e. use of -A, -T valves:
Atos code specify: -A = valves without integral transducer; -T = valves with integral transducer; -AE= as A plus integral electronics; -TE = as T plus integral electronics factory preset in control loop, which is the latest and more practical solution.

4 ELECTROHYDRAULICS VERSUS ELECTROMECHANICS

Electrohydraulic axis are easily programmable in a very similar way to electromechanical systems and allow a flexible automation via software by the central controlling unit. In comparison with electromechanical systems, electrohydraulic ones have the following advantages:

- intrinsic overload protection
- self lubrification of the system
- high power density
- automatic force adaption
- simple stepless variation in speed, forces and torques
- fast operating response
- energy storage capability
- long service life and high reliability

Servoactuators with integral transducers and electronics represent the updated electrohydraulic solution, requiring a single piping to the hydraulic source and a simple wiring to the process electronics: they are available in weather-proof configuration for outdoor, mobile and marine applications or in explosion-proof execution for chemical and off-shore installations. They simplify the design with automation flexibility and maximum reliability.

5 **ATOS PROPORTIONAL CONTROL VALVES**

Atos, a leader in pioneering proportional electrohydraulics, offer today one of the most advanced lines.
Atos valves may be of spool type (originated from solenoid valves) or in cartridge execution (from logic elements) and can be grouped as follows:
ZO and **ZOR**, efficient solenoids (30 W) respectively designed for direct-acting valves of ISO/Cetop 03-NG6 and 05-NG10 sizes and assembled in different options as follows:

ZO-A: without integral transducer;
ZO-AE: as ZO-A plus integral electronics;
ZO-T : with integral electronic transducer, featuring high static and dynamic performances;
ZO-TE: as ZO-T plus integral electronics

6 **NEW PROPORTIONAL VALVES VERSUS SERVOVALVES**

New valves of ZO and ZOR lines compare with good servovalves whilst maintaining the typical benefits of proportional hydraulics: less sensitivity, coarser filtration requirements, intrinsic stability, easier servicing and consequently improved reliability.
They can be also utilized in open loop control systems, thanks to their high stability.
Most proportional valves are "fail-safe", reaching automatically the hydraulic safety position in case of lack of signal.

7 **WHY PROPORTIONAL VALVES WITH INTEGRAL ELECTRONICS**

In the new generation of -AE, -TE valves with integral electronics, the electronic signal defines the main spool position and therefore the valve regulation with standard monitor output for possible security controls. They are used more and more in many modern applications also because the integral electronics, factory preset, ensure fine functionality plus valve-to-valve interchangeability and simplify installation wiring and system set-up.
Electronics are housed and resin encapsulated in a metal box to IP65, ensuring antivibration, antishock and weather-proof features; coils are fully plastic encapsulated.

8 **FAIL-SAFE**

Proportional valves may be properly equipped in order to ensure a fail-safe operation, i.e. to ensure that in case of absence of reference signal or, generally, in case of electric system breakdown, the system configuration does not cause damages. Fail-safe can be realized directly by the proportional valve (fail-safe operation intrinsic in valve configuration) or it can be realized by consequential operation of a group of valves.

9 **COMPONENTS FOR PROPORTIONAL CONTROLS**

Proportional valves can be grouped in four different families:
- **pressure control valves: relief valves** and **reducing valves** offer extensive application possibility through their ability to regulate the pressure setting proportionally to the reference signal (up to a pressure limit which is manually adjustable and lockable);
- **4-way directional control valves:** to direct and throttle fluid flow proportionally to the command signal to the valve. These valves can be used in open or closed loop control system to determine the direction, velocity and acceleration/deceleration of actuators and servoactuators. They can also be used to regulate the pressure value in closed loop.
- **throttle cartridge valves:** of different type, pressure relief, pressure reducing, 2 and 3-way directional and flow control .
- **flow control valves:** 2 or 3-way, pressure compensated and therefore mainly used in open loop application;

Control electronics include:
- **drivers for proportional valves without integral transducer:** -AC are for open and closed-loop application.
- **drivers for proportional valves with integral transducer:** -T, -TE(R) and -AE may be used in open or closed-loop application for valve closed-loop control: they compare the valve transducer feed-back signal with the input refence signal (voltage or current) generating the "error signal" and operate the valve regulation proportionally to this "error signal" by modulating the current to the solenoid;
- **accessory cards:** for accessory functions like cycle generation of preset references, generation of presetted references, interfaces, power supplying, display of regulated parameters value etc.;
- **transducers & joysticks:** stroke, speed, pressure transducers for monitoring of regulated parameters, joysticks for remote control;
- **axis electronic controllers:** compare the system transducer feed-back signal with the input signal (voltage or current) generating the "error signal" which is supplied, as reference signal, to the driver of the valve.

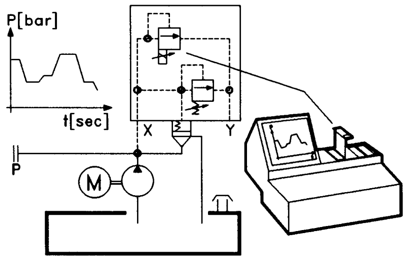
10 **ELECTROHYDRAULIC SYSTEMS INTEGRATED IN FIELD COMMUNICATION NETWORKS**

Modern electrohydraulic systems may be integrated in fields communication network, usually called field bus (i.e. CAN-Bus, PROFIBUS, Devicenet, INTERBUS-S etc.).
The field bus is generally applied to connect sensors, switches, transducers, motors, actuators and other devices.
Up to now the connection and the control of hydraulic valves was mainly realized by serial interfaces or point-to-point connections with expensive wiring and start-up costs.
It is possible to use a fieldbus to control hydraulic proportional valves, by cheap telephonic 2-wire cables to transmit the reference signal from the PLC to the valves and the monitor signal backwards, together with general information from the field.

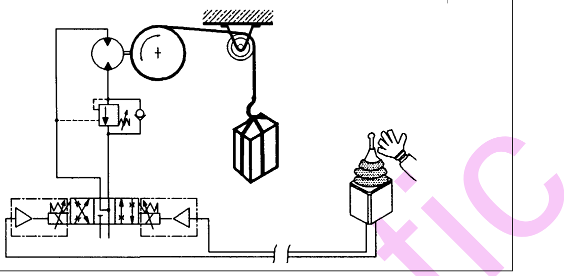
11 OPEN-LOOP CONTROL: TYPICAL SKETCHES

Open-loop control is suitable for providing smooth progression between different levels of hydraulic parameters and where the operator has a continuous control role of visual feed-back, like for instance in "remote control" application.
It is usually applied where high precision is not a requirement: in fact open-loop controls can be subject to various environmental disturbances, such as change in temperature, variations of fluid-viscosity, load inertial effects due to moving masses etc.
Below are represented four typical open-loop applications:

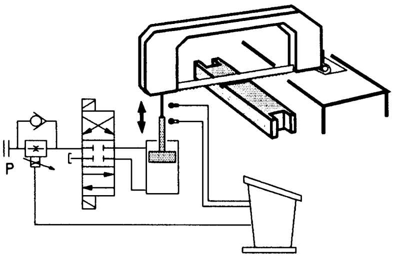
PRESSURE CONTROL



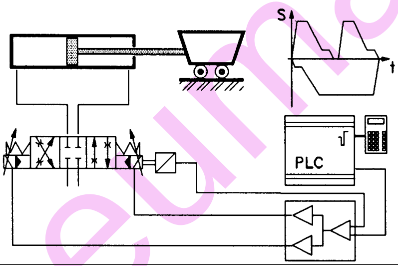
STROKE CONTROL THROUGH JOYSTICK



SAW-BLADE CUTTING SPEED



FAST-SLOW AUTOMATIC TRAVERSE

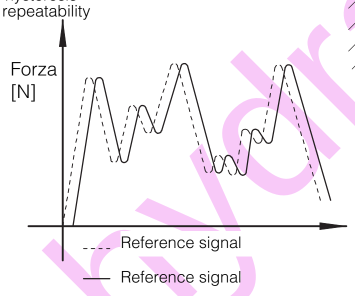


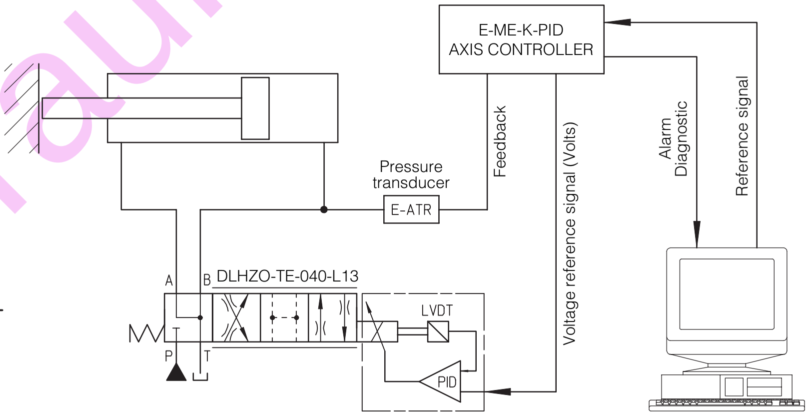
12 CLOSED-LOOP: TYPICAL SKETCHES

In closed-loop control, the regulated parameters are continuously verified by feedback transducers thus the closed loop controls are not subject to environmental disturbances.
Electronic feedback transducers that measure the final results of regulation (position, speed, force, pressure, angle etc.) may be integral in the actuators or externally mounted on the machine. The transducers send electric signals, to the electronic controller. The controller (analogic PID card or digital axis card) receives feed-backs and compares them with refence signals. The discrepancy in these two signals (error) activate the PID control and make changes in the command signal to proportional valve to eliminate the discrepancy.
Closed loop control, provides constant control and uniform results, thereby representing the optimum solution for complete machine control and high performance.

PRESSURE CONTROL

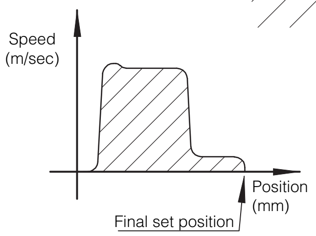
- High dynamics
- Zero minimum pressure
- Zero hysteresis
- Max repeatability

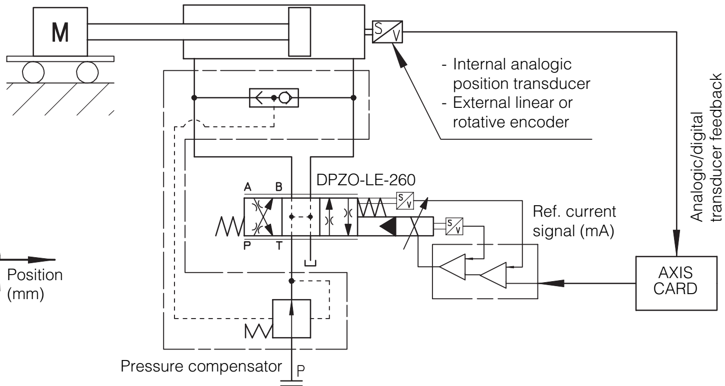




POSITION/SPEED CONTROL

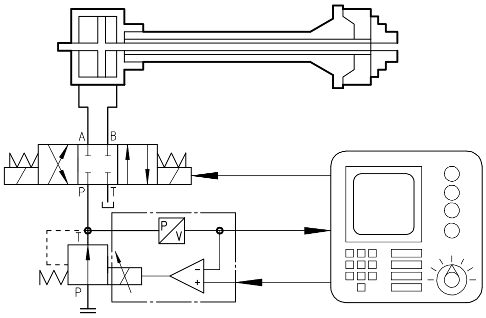
- High precision of final position
- Absolute repeatability of complete cycle





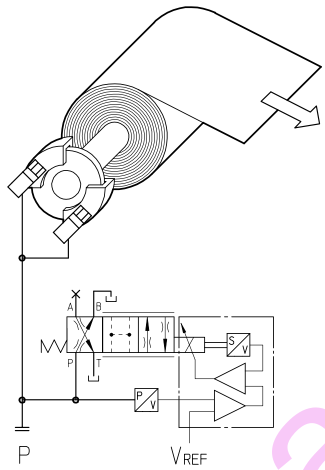
13 CLOSED-LOOP: EXAMPLES OF APPLICATION

Pressure control for mandrel clamping by RZGO-TER



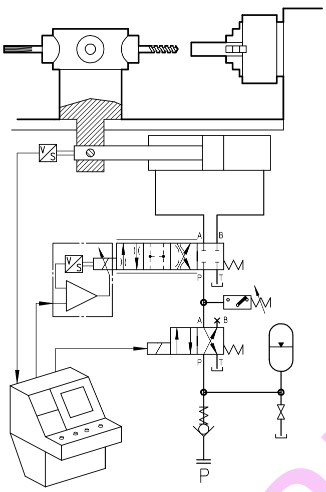
The automatic control of clamping forces is necessarily required on clamping mandrels for deep boring machining, to avoid damages to expensive tools.
The controlling signal is processed by a CNC system and the proportional valve has integral pressure transducer plus closed loop electronics.

Brake control on a spinning - warping machine by DLHZO-TE



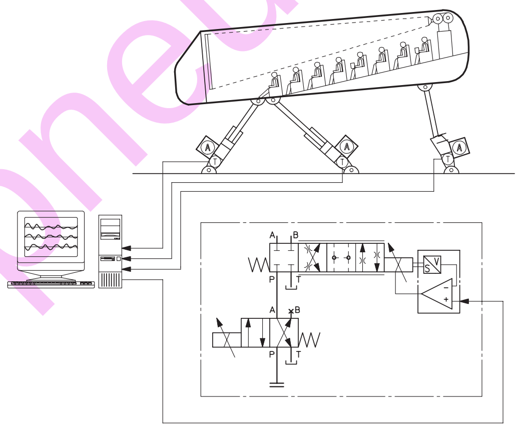
The control of pulling force in a textile warping machine is achieved by a proportional system that regulates the brake action.
The valve has integral electronics able to control braking pressure in closed loop through feedback signal from the pressure transducer; unlike conventional pressure control this system features fine regulation starting from null pressure.

Axis control on transfer units by DLHZO-TE-040



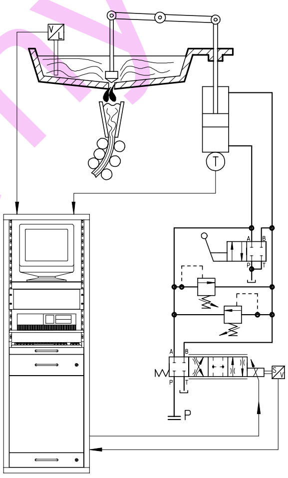
The example shows how the proportional valve, with non-linear characteristics for increased resolution in weak signal range, is governed by proper axes card to obtain accurate speed and position control:
a linear digital transducer applied to the cylinder gives speed and position feedback.
The accumulator system holds a constant hydraulic pressure to assure a suitable Δ pressure across the proportional valve for any operating condition. In emergency the ON-OFF solenoid valve is de-energized (and then energized for restoring operative condition) when proportional valve is in its zero overlap intermediate position.

Simulators for dynamic cinema by DLKZOR-TE



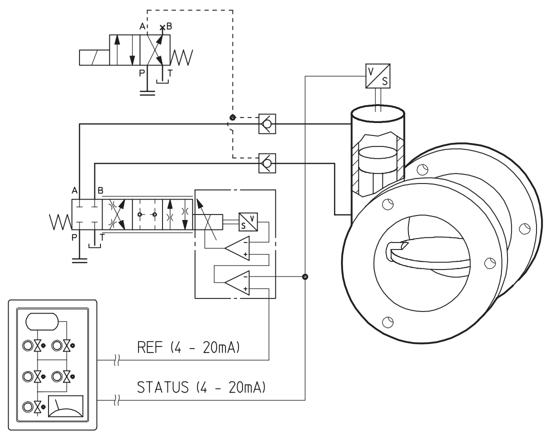
A full variety of simulations may be obtained by devices similar to this example, showing a mobile equipment driven by servocylinders with on board proportional valves and integral electronics.
Movements are coordinated by a computer based electronic system according to screen motions.

Stopper rod control on steel works by DLHZO-TE



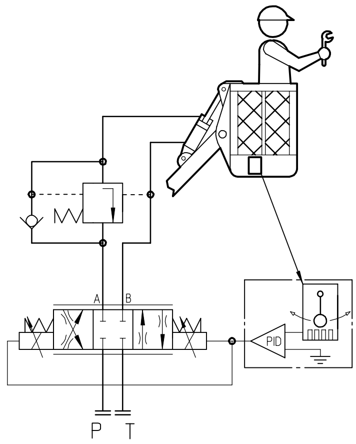
In steel work application, robust electrohydraulic units are specifically designed to assure reliability and performances.
The example shows a specific electrohydraulic system to regulate the level of ible steel, including a proportional valve with integral electronics, a safety manual override equipment, a hydraulic servocylinder with potentiometric transducer and an integral manifold enclosing the control valves: the whole preset and ready to work.

Process valve positioning by DLKZOR-TE



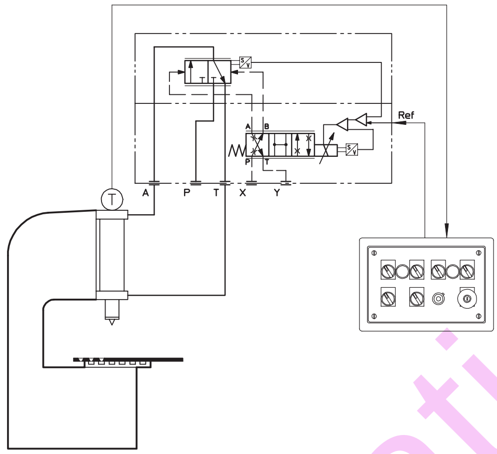
Remote control of process valves is easily achieved by electrohydraulic systems: a set reference signal ranging from 4 to 20 mA defines the opening position and therefore the valve regulations in closed loop, with resident monitor output for possible security controls. The integral electronic driver may be directly controlled through 4-20 mA signal generated by the remote process computer. Safety block is provided by check valves piloted by an on-off solenoid valve.

Automatic levelling on mobile air platform by DHZO-A-073-S



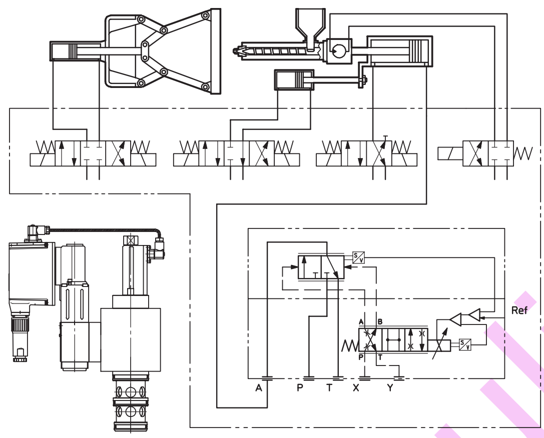
This typical application provides automatic levelling of plat form using a proportional valve controlled by a specific electronics that includes levelling gauge plus electronic driver in closed loop.
The whole electrohydraulic system is a compact module directly applied on board.

Speed control of a punching press by LIQZO-LE (cartridge valve)



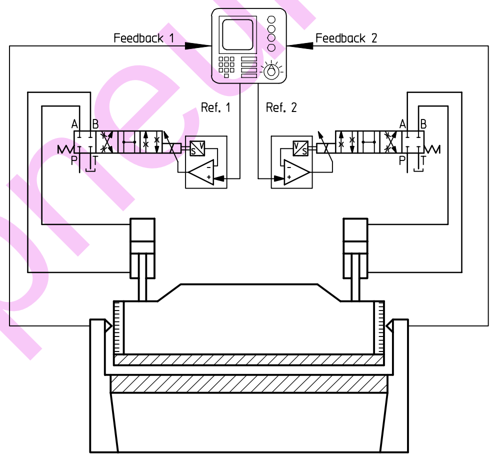
The scheme shows a regenerative circuit using a proportional cartridge valve with integral electronics, set to drive an high frequency punching-press.
High performances are achieved by a closed loop control through a stroke transducer on the punching cylinder.

3-way proportional cartridge for plastic injection presses



In presses for plastic materials a proportional throttle cartridge controls the three main functions, i. e. injection speed, pressure profile and mold filling counterpressure. The electronic control is performed by a proportional valve with integral electronics and with integral postion transducer which closes the loop on the main poppet for precision settings and high dynamics.

Synchronism control system for bending presses



In plate bending machines the two cylinders which actuate the lifting/descent of the beam must move in sincronous and a high position accuracy during the movement is requested. This is succesfully achieved by means of two proportional valves controlled in closed loop by the central unit which uses the signals coming from the position transducers mounted on the beam.

14 TYPICAL TERMS

Repeatability: The maximum difference between subsequent values of a hydraulic parameter obtained at same hydraulic and electrical conditions after variable commands are sent to the valve. Repeatability is measured in percent with reference to the maximum value of the regulated hydraulic parameter and in open loop applications is strictly connected with system accuracy performances.

Leakage: The amount of fluid passing through pressure port and tank port when oil passages are closed, it is directly connected with the quality of the mechanical execution and it can give an idea of the size of minimum controlled flow.

Reference signal: The electric signal which is fed into the electronic regulator to obtain the required driving current to the valve.

Driving current: The current required for driving the valve, expressed in milliampere [mA].

Bias current [mA]: Driving current required for bringing the valve to the null point under any specified set of operating conditions.

Dither: The pulse frequency of driving current.

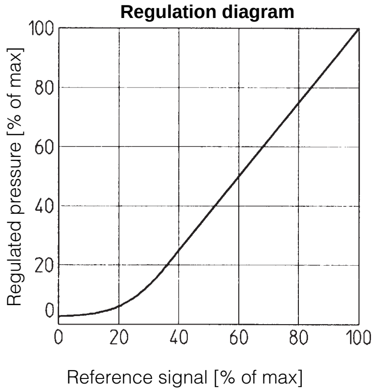
Regulation scale: The relationship between the driving current values and the values of the reference signal is linear and adjustable.

Ramp time: The time required to change the driving current to the valve following a step change in the reference signal.

Electric gain: The factor which multiplies the loop error, to correct the values of the driving current in closed loop controls.

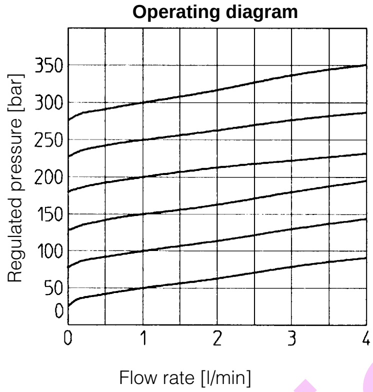
PRESSURE CONTROL VALVES

Regulation diagram



How the valve-regulated pressure varies according to the reference signal

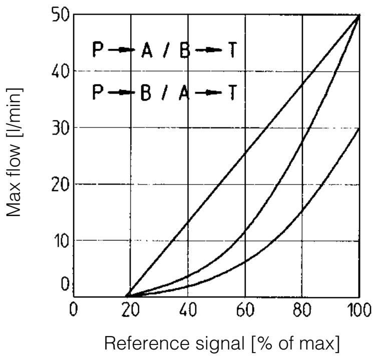
Operating diagram



How the valve-regulated pressure varies according to the flow passing through

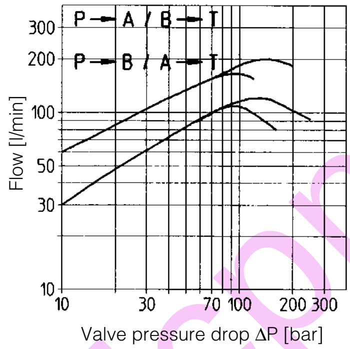
DIRECTIONAL AND FLOW CONTROL VALVES

Regulation diagram at characteristic Δp



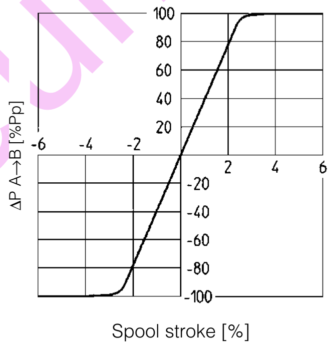
How the valve-regulated flow varies according to the electric reference signal

Regulation diagram at max reference signal



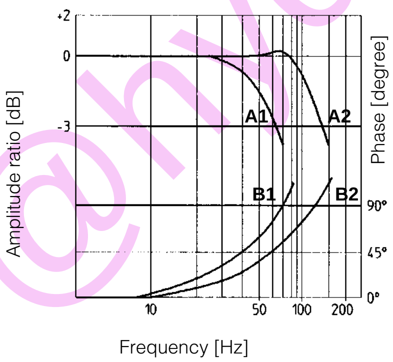
Regulated flow vs. functional Δp at max reference electric signal
How the valve-regulated flow varies according to the valve pressure drop.

Pressure gain diagram



How the outlet pressure on use ports plugged varies according to the spool stroke in valves with zero overlapping in rest position.
On X-axis, spool stroke is expressed in percentage of full stroke.
On Y-axis, the Δp between A and B ports is expressed in percentage of inlet pressure.
Pressure gain is the value of spool stroke [%] at which Δp between A and B ports corresponds to 80% of inlet pressure.

Bode diagram

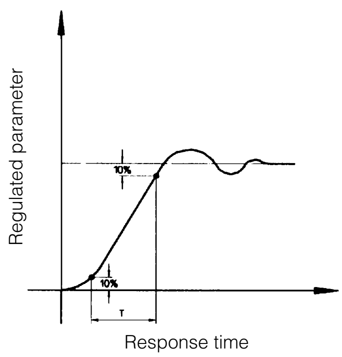


The curve shows for typical regulation ranges (±5% and ± 90%):

A) how the amplitude ratio (between the amplitude of reference signal and the actual amplitude of spool stroke) varies with the frequency of a sinusoidal reference signal;

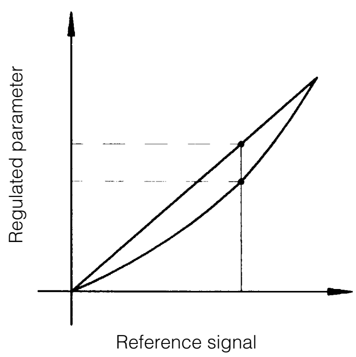
B) how the phase (between a reference sinusoidal signal and the actual spool stroke) varies with the frequency of reference signal

Response time - step input



The time lag required for the valve to reach the requested hydraulic output following a step change in the reference signal (usually 0÷100%).
Response time is measured in millisecond [ms] and is an easy parameter to evaluate the dynamics of the valve.

Hysteresis



The maximum difference between two regulated hydraulic parameter values obtained reaching the same set of the command from 0 to maximum and then from maximum to 0.
Hysteresis is measured in percent of the maximum value of the regulated hydraulic parameter.