Electrohydraulic proportional controls: user's guidelines

1 WHAT IS PROPORTIONAL ELECTROHYDRAULICS?

Electrohydraulic proportional controls modulate hydraulic parameters according to the 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 unit where information, controls, alarms can be transmitted in a "transparent" way to the centralized electronic control unit and viceversa also via standard fieldbus, see tab. F002 for "Digital solutions".

Proportional electrohydraulics is easily programmable like electromechanical systems and allow a flexible automation. In comparison with the electromechanical systems, electrohydraulics provides 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

2 WHAT IS A PROPORTIONAL VALVE?

The core of electrohydraulic controls is the proportional valve that regulates a pressure P or a flow Q according to the reference signal (normally ±10 V_{DC}). Particularly the proportional valve must be operated by an electronic driver which regulates a proper electrical current supplied to the valve's solenoid according to the reference signal. The solenoid converts the electrical current into a mechanical force acting the spool against a return spring: rising of the current produces a corresponding increasing in the output force and consequent compression of the return spring, thus the movement of the spool.

In pilot operated executions the proportional pilot valve regulates flow and pressure acting on the main operated stage.

When electrical failure occurs, return springs restore the neutral position according to valve configuration, 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.

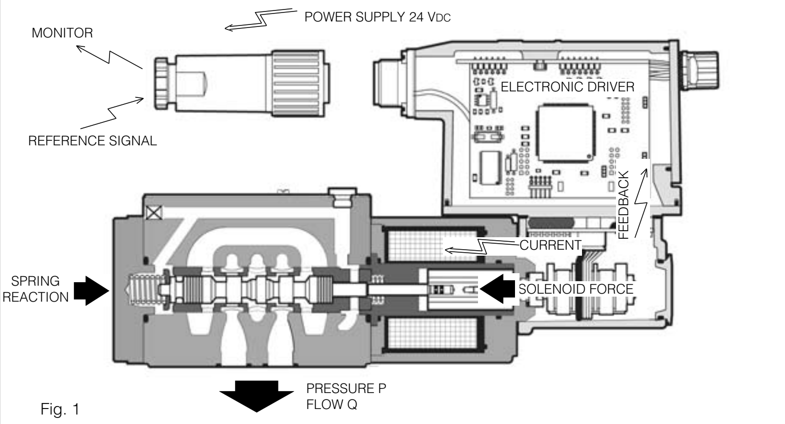


Fig. 1

3 CONTROL LOOPS

The motion control of modern machines is substantially a problem of axis control. Today industrial machines are multi-axis machines, more and more electrohydraulically controlled by proportional devices. The axis motion can be operated in "open loop" or in "closed loop" control, depending to the accuracy level required in the application. In many applications the motion cycles do not require extreme accuracy, so they are performed in open loop, while each time the application requires the positioning of an actuator, a closed loop control must be provided.

OPEN LOOP MOTION CONTROL

Axis control is provided through the supply of an input reference signal to the proportional valve without any feedback of the valve's regulated hydraulic parameter.
The accuracy of the open loop controls is strictly dependent of the good quality of the hydraulic system and particularly of the proportional valve and of the relevant driver.

CLOSED LOOP MOTION CONTROL

Axis control is provided through the supply of an input reference signal to a closed loop controller which receive the feedback signal of the valve's regulated hydraulic parameter by the actuator's transducer and compare the two signals.
The resulting error is then processed by the controller to the proportional valve, in order to align its regulation to the PID control loop requirements.
The accuracy of the closed loop controls is much better respect to the open loop ones and it is less influenced by the external environmental disturbances, thanks to the presence of the feedback.
Anyway the best is the overall quality of the hydraulic system, the best is the accuracy of the axis control.

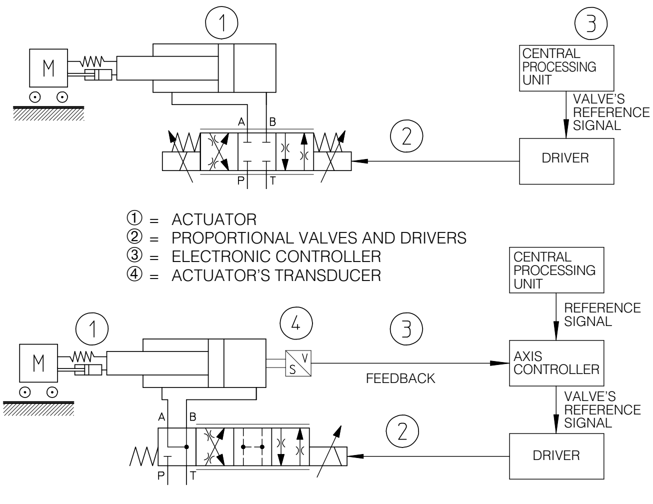


Fig 2: Electrohydraulic axes: a basic block diagrams

Atos proportional valves can work in open loop (valves without transducer) or in closed loop (valves with LVDT position transducer), see fig. 1.
The proportional valves without transducer are fed through electronic drivers supplying a modulated current to the solenoid proportionally to the reference signal. To assure the best operation the driver should be supplied by the manufacturer of the valve.
The proportional valves with LVDT position or pressure transducer are fed through electronic drivers supplying a modulated current in order to control the regulated parameter (spool position or pressure) proportionally to the reference signal.
Proportional valves with transducer are the best choice for closed loop electrohydraulic motion controls as they enhance the system performances.

4 PROPORTIONAL VALVES AND DRIVERS

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 in three different functional families:

- **pressure control valves: relief valves** and **reducing valves** regulate the hydraulic system pressure proportionally to the reference signal;
- **4-way directional control valves:** direct and modulate the flow to an actuator proportionally to the command signal to the valve. These valves can be used in open or closed loop control system to determine the direction, speed and acceleration of actuators;
- **flow control valves:** 2 or 3-way, pressure compensated, to modulate the flow in the system, indipendentely to the user loads.

Atos proportional valves are equipped with **ZO** and **ZOR**, efficient solenoids (30 W and 40 W) respectively designed for direct-acting valves of ISO 4401 size 06 and 10 and they are assembled in different options as follows:

ZO(R)-A: without integral transducer, open loop;
ZO(R)-AE: as ZO-A plus integral electronic driver;
ZO(R)-T, -L: with integral LVDT single/double position transducer, closed loop, featuring high static and dynamic performances;
ZO(R)-TE, -LE: as ZO-T, -L plus integral electronic driver

In the new generation of -AE, -TE, -LE valves, the electronic driver is integral to the proportional valves and it is factory preset to ensure fine functionality plus valve-to-valve interchangeability and to simplify installation wiring and system set-up. Thanks to these enhanced features they are used more and more in the modern applications and systems. Electronics are housed and resin encapsulated in a metal box to IP67, ensuring antivibration, antishock and weather-proof features; coils are fully plastic encapsulated.

Electronic drivers include:

- **separated drivers for proportional valves without transducer:** E-MI-AC, E-BM-AC, E-ME-AC (see tab. G010, G025, G035)
- **integral drivers for proportional valves without transducer:** E-RI-AE (see tab. G110)
- **separated drivers for proportional valves with LVDT transducer:** : E-ME-T, E-ME-L (see tab. G140, G150)
- **integral drivers for proportional valves with LVDT transducer:** E-RI-TE (see tab. G200)
- **integral drivers for proportional valves with pressure transducer:** E-RI-TERS (see tab. G205)

The reference signal to the electric drivers is normally voltage type (Volt); alternatively it may be current (Ampere), the latter used when great lengths apply to reference and feedback connections, causing interferences and electrical noise.
In any case pay attention to shield the electrical cables with shield or cablebraid type connected to the ground - see table F003, section 5.
For detailed information on drivers, see technical tables on section G.

5 ELECTRONIC CONTROL SYSTEM

The electronic control system includes a control unit and one or more axes cards. The overall performances of the electro-hydraulic axis controls are strictly dependent to the correct choice of the proportional valve and of the electronic control system which must be selected by an electrohydraulic specialist.

A large number of electronic System integrators can provide to the customers the best standard hardware and customized software.

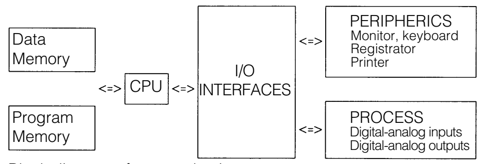


Fig. 3: Block diagram of a control unit

The machine control unit includes a data processing unit (PLC, PIC, CNC) to elaborate the Input/Output signals (Fig. 3).
This data processing unit is equipped with a terminal board to input the programming data and it is fitted with dedicated peripheral units, i.e. axis cards and other electronic controllers for coordination of various axes.
The electrohydraulic control system can be optimized on both hydraulics and electronics side. Atos Technology Department ais available to cooperate with the customer's system integrator for a detailed application analysis.

The axes card is the interface between the control processing unit (which processes the overall machine cycle and program) and the electrohydraulic systems.
Digital axes cards are directly interfaceable with encoders linear and rotative and magnetosonic transducers and easily with inductive ones, by means of proper auxiliary cards. To interface an analog transducer with an axes card, an A/D converter must be provided. A resolution of 12 bit or better, is recommended for good performances.
Essentially, an axes card compares reference and feed-back signals obtaining the relevant error and the performs the computing controller of the output reference signal to the proportional valve. The most common controller is the PID type where adjustable parameters are:
P: proportional to the error; **I**: proportional to the steady state error; **D**: proportional to the rate of change of the error.
Several manufacturers offer advanced axes controllers and regulation cards: SIEMENS, OMRON, ALLEN BRADLEY, TELEMECANIQUE, etc.
Atos Technology Department is available to cooperate with customers and system integrators a the detailed application analysis and for the best choice of the electrohydraulic system characteristics.

6 ACTUATORS AND TRANSDUCERS

Electrohydraulic motion is resolved by linear or rotative actuators. The former can be monitored by analog or digital position transducers that can be directly mounted on the actuator (built-in transducer). Usually the servocylinders are equipped with integral proportional valves to increase the stiffness of the system.
Atos servocylinders are in low friction execution with high static and dynamic characteristics to improve the control performances, see tab. B310.

7 CLOSED LOOP CONTROLS SELECTION GUIDELINES

Single solenoid valves are the best choice for running a closed loop system, by making the control easier and cost effective.
While selecting the proper proportional valve, consider:
- select spool with zero overlapping (i.e. valve type DLHZO, table F180);
- choose a valve with a frequency response characteristic of at least 30 Hz at 90° phase shift (Bode diagram);
- choose the proper fail-safe configuration (Fig. 4) to prevent from damages in case of electric breakdown;
- use a linear spool for position controls (/L* version in the code);
- repeatibility and hysteresis ≥0.2%.

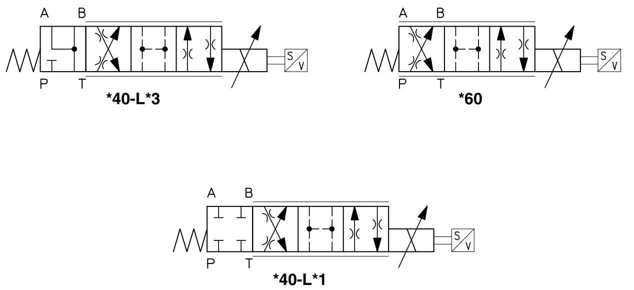


Fig. 4: Fail-safe configurations.

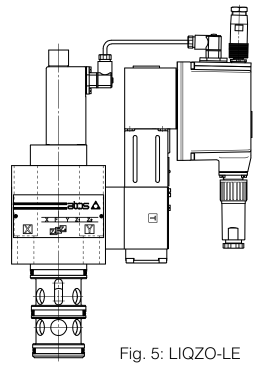


Fig. 5: LIQZO-LE

- select spools with max flow rate 10÷25% more than max regulated flow (better control of minimum flow rate and of hydraulic gains).
- if high speeds and accurate positioning requirements are combined, use the “breaked” regulation of series “T” valves and relative drivers (see table F180).

For high flow rate, proportional cartridge valves, 2 way and 3 way are available too, see Fig. 5 (see also tab. F300 to F340). They are standard elements for manifold mounting resulting in compact and cost effective solutions.
Atos proportional valves and relative drivers are marked “CE” according to the EMC (72/23/CEE) and to the Low Voltage Directives, see tab. P004.
For complete information about proportional valves and controls see specific technical tables.

8 CLOSED LOOP SYSTEM ANALYSIS

This section is designed to provide a basic and practical approach to performance estimation of closed-loop systems.
The basic concepts described in the following are nowdays integrated with the tools of advanced simulation programmes. With them it’s possible to build up complex circuits connecting the different functional blocks to represent the loop, after determining every element’s output characteristics. Furthermore, it’s possible to simulate the behaviour of complex systems and to analize their dynamic response: in particular it’s easy to develop parametric studies (varing stiffness, mass, type and size of proportional valves).

The electrohydraulic applications may be essentially classified into:
- dynamic applications: movement of loads at high speed/frequency;
- force applications: to transmit high forces at low speed.

The problems arising in dynamic applications are of difficult evaluation but of great importance. Most malfunctioning derive from neglecting a frequency approach to the system.
Two aspects are to be considered:
- hydraulic stiffness of the system;
- inertia of the loads.

In many applications, hydraulic fluid is considered to be incompressible. This is not correct in absolute, since when pressurized, a fluid will compress in the same way as a very riged spring (Fig. 6).

In fast-acting servo systems with high dynamic loads even piping may be seen as elastic, above all for high values of pressure. Attention should be paid to the presence of accumulators: as they make the system more critical from the dynamic point of view.

A closed loop control system analysis can be simplified by regarding components (or set of components) as blocks (Fig. 7). The relationship between the input and output of a single block is the **transfer function** (G).
The system loop gain ***Kv*** (fig. 8) can be got multiplying the gains of the single blocks of the loop (amplifier ***GD’***, proportional valve ***Gv’***, cylinder ***Gc’***, feedback). The higher the system open loop gain, the better overall performances.

However, an excessive gain may cause the system to get unstable (Fig. 9).
In this situation the overshoots and undershoots diverge. The maximun value of the gain, that can be used to assure system stability is determined by:
- the load mass (M); the bigger the mass, the greater the inertia forces, the greater the tendency to oscillate.

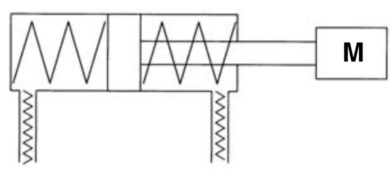


Fig. 6: Actuator as a spring/mass system

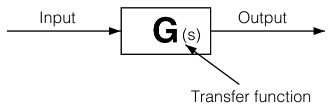
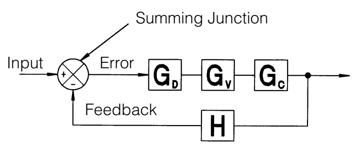


Fig. 7: System transfer function



Open loop: $K_V = G_D \times G_V \times G_C$

Closed loop: $\frac{K_V (s)}{1 + K_V (s) \times H (s)}$

Fig. 8: System loop gain

- the stiffness of the actuator (***C_H***); low stiffness means high tendency to oscillate, so the stiffness should be as high as possible;
- the damping coefficient (ξ) of the system (tipically $\xi = 0.05 \div 0.3$). This parameter is mainly influenced by the characteristic of the valve (non linear characteristics, etc.) and by the system friction.
  To ensure the system stability: $K_V \geq 2\xi\omega_S$

  where ω_S, the natural frequency of the complete closed loop system, is the minimun among:
  - ω_V: natural frequency of the valve (assumed to be the frequency at 90° phase shift; see tables F165, F172, F180);
  - $\omega_O = \sqrt{C_H/M}$: natural frequency of the mechanical system (generally 10 ÷ 100 Hz);
  - $\omega_{\alpha\tau}$: natural frequency of amplifier and feedback transducer (usually ignored, because at least ten times higher than ω_V, ω_O).

  In industrial electrohydraulic applications the critical frequency is always ω_O.

For linear actuators ω_o is calculated with the following formula:

$$\omega_O = \sqrt{\frac{40\,EA_1}{cM} \cdot \frac{1+\sqrt{\alpha}}{2}} \left[\frac{rad}{sec}\right]$$

E = 1.4 10^7 Kg/cm.sec^2 (oil elastic modulus)
c = stroke (mm)
M = mass (kg)
A1 = piston area (cm^2)
A2 = anulus area (cm^2)
α = A2/A1 = anular/piston cross section ratio

The natural frequency ω_O for a cylinder-mass system is directly related to the minimum acceleration/deceleration time permissible to maintain the functional stability (Route-Hurwitz criterium).

$t_{min} = 35/\omega_O$ (s)

Experience has shown that if the t_{min} to assure stability in a system is lower than approximately 0.1 seconds, the system should be re-examined (see fig. 11).
Once fixed the total cycle time and stroke, it is possible to obtain the maximum speed:

$V_{max} = S_{tot} / (t_{tot} - t_{min})$ S_{tot} = total stroke (mm) t_{tot} = total cycle time (s)

and consequently the maximum acceleration

$a_{max} = V_{max} / t_{min}$

Overall stiffness is important even to determine the performance in terms of how accurately the electrohydraulic axis achieves and maintains a demand position, being more reactive to possible external disturbances: reactive loads on actuators (tool forces, shock loads), load weight (vertically mounted cylinders), friction on slides, gap at joint.
Further parameters to strictly monitor are: valve null shift due to temperature or pressure variations, accuracy or resolution of feedback transducer.

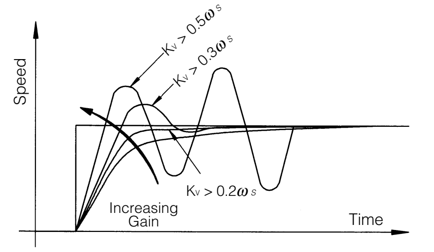


Fig. 9: Answer to a step signal increasing gain

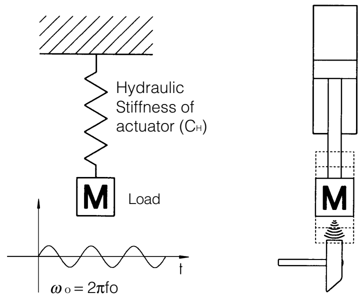


Fig. 10: The mass/spring mechanism.

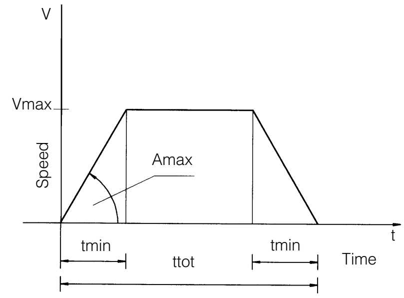


Fig. 11: Positioning cycle

9 CLOSED LOOP SYSTEM ANALYSIS: AN EXAMPLE

The following example shows the great influence of the dynamic characteristics in a closed-loop system.
Consider the simple sketch in Fig. 12. The cylinder is connected to a proportional valve; the machine cycle requires that the cylinder must complete its forward stroke in a time of 2 sec.
Using the relations of section [8], we get:

ω_O = 69.12 rad/sec

t_{min} = 0.51 sec

V_{max} = 0.67 m/sec

a_{max} = 1.31 m/sec^2

$Q_{max} = V_{max} \times A1 = 0.67 \times 19.6 \times 60/10 = 78.9$ l/min

$F_{inertia} = M\,xa = 2620N$

$P_{min} = (F_{inertia} + F_{load})/A1 = (2620 + 19620)/19.6 \left[\frac{N}{cm.^2}\right] = 1.135 \left[\frac{N}{cm.^2}\right] = 113.5$ bar

$P_{required} = P_{min} + \Delta p_{nom.valve} + \Delta p_{circuit\text{-}drops} = 113.5 + 70 + 16 = 199.5$ bar

$P_{required}$ is the value of pressure supplied by the hydraulic power unit.

Select a proportional valve with a $\Delta p_{nom.valve}$ in the range shown in the technical tables. In the previous example you may choose a DLKZO-TE-040-L71 valve (Q = 100l/min, $\Delta p_{nom.valve}$ = 70 bar).
The above calculations determine the needed pressure to perform the cycle with the required dynamics.

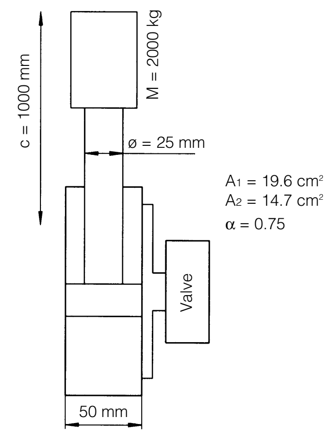


Fig. 12: The system analysed on the example.

10 TYPICAL ELECTROHYDRAULIC TERMS

Repeatability: The maximum difference between subsequent values of a hydraulic parameter obtained at same hydraulic and electrical conditions and the same reference signal, 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 P to tank port T when valve's oil passages are closed, it is directly connected with the quality of the valve's mechanical execution and it gives an idea of the size of the valve's 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 solenoid valves, expressed in milliampere [mA].

Bias current: Static offset added to the reference signal required for bringing the valve to its null point.

Dither: The pulse frequency of the valve regulation used to minimize the hysteresis.

Regulation scale: Setting of the valve regulation with the max reference signal.

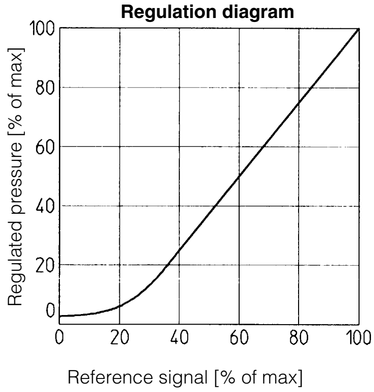
Ramp time: Time (in sec.) required to operate the valve from zero to the max regulation.

Electric gain (Gd): Transfer function between error signal and reference signal.

11 TYPICAL DIAGRAMS OF PROPORTIONAL CONTROLS

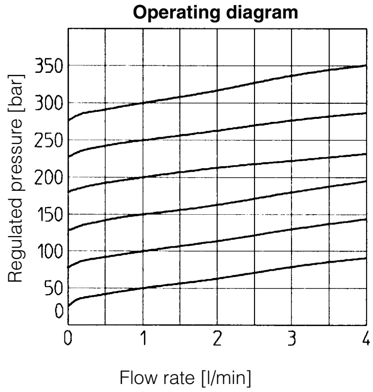
PRESSURE CONTROL VALVES

Regulation diagram



Valve's-regulated pressure variation according to the reference signal

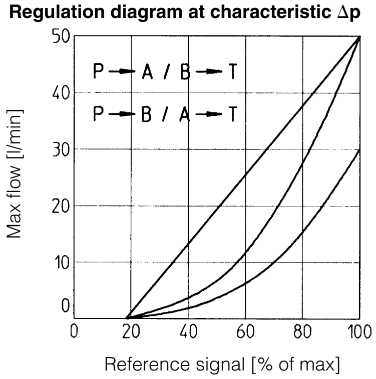
Operating diagram



Valve's-regulated pressure variation according to the flow passing through the valve

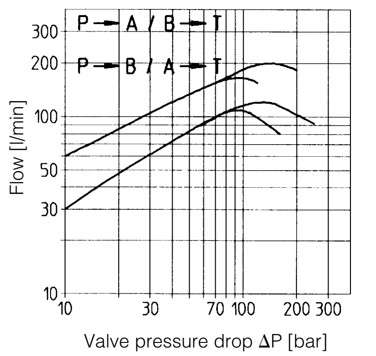
DIRECTIONAL AND FLOW CONTROL VALVES

Regulation diagram at characteristic Δp



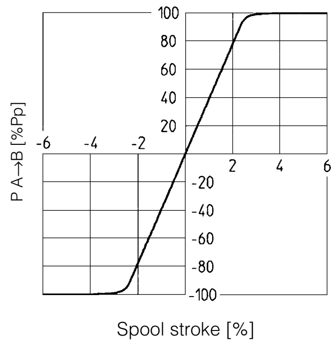
Valve's-regulated flow variation according to the electric reference signal

Regulation diagram at max reference signal



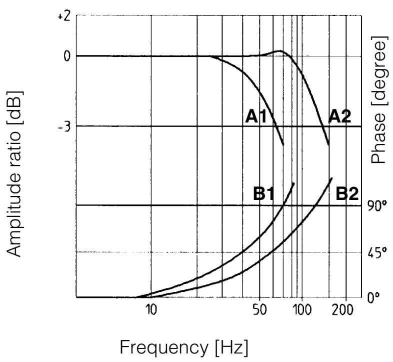
Regulated flow vs. functional Δp at max reference electric signal
Valve's-regulated flow variation according to the valve pressure drop.

Pressure gain diagram



Outlet pressure on use ports plugged variation according to the spool stroke only for 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

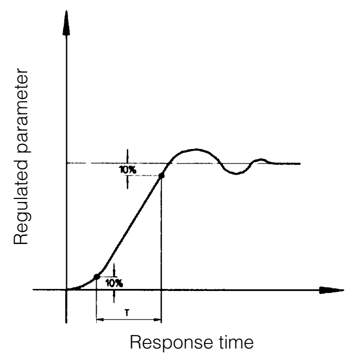


The curve shows for typical regulation ranges (±5% and ± 90%):

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;

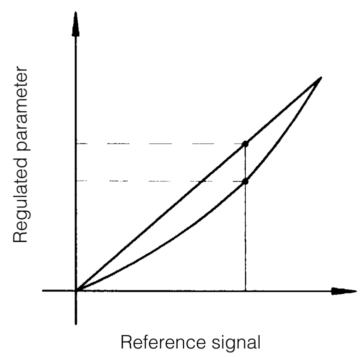
B) how the phase (between a reference sinusoidal signal and the actual spool stroke) varies with the frequency of reference signal

Response time - step input



The time lag required for the valve to reach the requested hydraulic ragulation following a step change in the reference signal (usually 0÷100%).
Response time is measured in millisecond [ms] from 10 to 90 % of the step valve and it 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.

Digital electrohydraulics

1 DIGITAL TECHNOLOGY FOR PROPORTIONAL VALVES

Modern world is driven by digital electronics: computers, automation systems, cars and missiles, telecomunications and advanced network are all based on digital technology… …thanks to its typical benefits in comparison with analog: fast and powerful data processing, easy programmability, high immunity to electromagnetic noise, process parameters and data storage.

In electrohydraulics, digital electronics gives important advantages:
- better performances of electrohydraulic components: hysteresis, response time, linearity;
- numerical software setting of hydraulic parameters (scale, bias, ramp, compensation of non-linearities) for full repeteability and easy data storage
- diagnostic (fault, monitor) and computer assisted maintenance of machines and systems;
- direct interfacing to field-bus networks.

Atos, leader in pioneering proportional electrohydraulics, is active from years on digital electrohydraulics including: simulation models of valves and systems, research and testing of new DSP microcontrolles, R&D of new solutions.

New digital electrohydraulics with on board electronics enable new funcionalities within the conventional control architectures and represent the foundamental premise to realize new compact machines with high technological contents.
The digital electronics integrate several logic and control functions (distributed intelligence) and make it feasible and inexpensive the introduction in the hydraulic system of the most modern fieldbus communication networks.

Atos digital driver's range replicate the analogue one:
- **E-RI-AES** for valves without transducer
- **E-RI-TES/LES** for valves with single/double LVDT transducer
- **E-RI-TERS** for valves with pressure transducer

2 COMMUNICATION INTERFACES

The communication interface is the channel trough which the valve receives commands and/or setting parameters and it returns information to the fieldbus controller.
Atos digital proportional valves are available with 3 optional communication interfaces:
- basic **-PS**: standard RS232 interface, to be coupled to an user-friendly PC software (E-SW-PS) optimized with grafic interface, for the management of all the functional parameters, see tab. G500.
  The main feature of this basic version is the full interchangeability with the corresponding analog executions, in fact the reference and the monitor signals are analog, whereas the serial interface allows to manage the diagnostics and to set the best configuration of the valve for the application's requirements.
  This approach enables a gradual introduction of the advantages of digital technology, without perturbing the whole application/machine's structure.
- option **-BC:** CANBus (CanOpen DS408 v1.5 protocol)
- option **-BP:** Profibus-DP (Fluid Power Technology protocol).

The valves with option -BC and -BP can be connected to the fieldbus network and thus digitally operated by the machine control unit.
The functional parameters can be set via fieldbus using the standard communication protocol implemented by Atos, or alternatively using the PC graphic software E-SW-PS with the relevant USB interface supplied with the software KIT (see fig. 2 and tab. G500). For start-up or maintenance operations, the valves with -BC or -BP interfaces can be operated with analogue signals via the 7 (or 12) pins power supply connector.

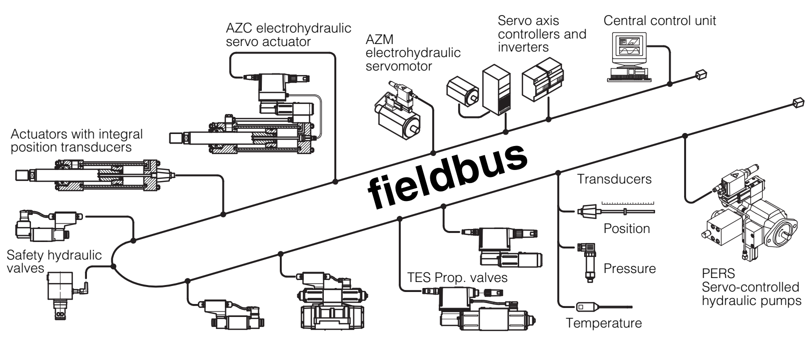
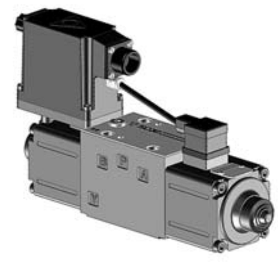
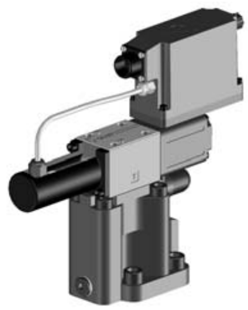
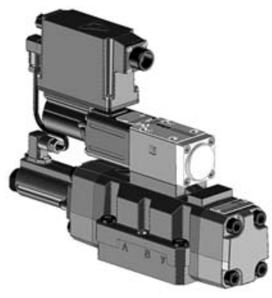


fig. 1


DKZOR-AES


AGMZO-TERS


DPZO-TES


LIQZO-LES


fig. 2 software setting of digital proportionals

3 DIGITAL SETTINGS AND DIAGNOSTICS

A large number of the functional parameters of the valve can be numerically set trough the communication interface, as:

- the bias and scale (fig. 4)
- the ramps, corresponding to the transition time from 0% to 100% of the valve's regulation (fig. 5)
- the linearization of the regulation curve, allows to modify the hydraulic regulation of any valve, as linearizing the characteristic of pressure control valve or change from linear to progressive the characteristic of a directional control valve (fig. 6).

Many other regulations are available like: customized configuration of the reference signal (standard ± 10 V), internal static self generation of the reference signal, dither signal, PID parameters for dynamic behaviour, alarm setting of the high/low limits of the electronics temperature, etc.

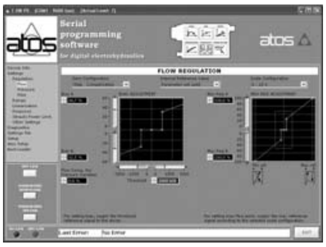


fig. 3 Software graphic interface

SCALE AND BIAS

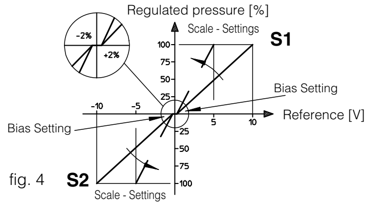


fig. 4

UP AND DOWN RAMPS

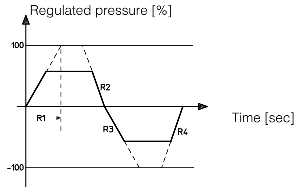


fig. 5

LINEARIZATION

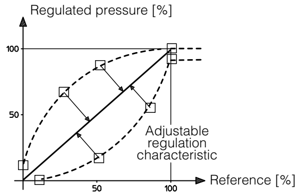


fig. 6

Detailed diagnostics information can be checked through the communication interface. They allow a complete analysis of the component state and of its eventual malfunctionings, as for example:

- real time monitoring of the reference signal, of the feedback signals and of the electronics temperature
- alarm in case one of the above parameters overcome the set limits
- alarm in case of interruption of the feedback cable

4 COMBINED P/Q CONTROLS FOR DIRECTIONAL VALVES AND PUMPS

The high computing capability of Atos digital electrohydraulic and its great flexibility allow to realize new functionalities:

- new drivers E-RI-TES with /SP and /ZP options perform the combined pressure and flow control on directional control valves. A remote pressure transducer must be installed on the system where is required the max pressure control and its feedback has to be interfaced to the valve. If the real value of the pressure in the system (measured by the pressure transducer) remains below the relevant reference signal, provided by the machine controller, then the digital driver regulates in closed loop the valve's spool position, according to the flow reference signal. When the real pressure become close to the relevant reference signal, the driver automatically performs the closed loop control of the pressure. This option allows to realize accurate dynamic pressure profiles. A multiple set of PID parameters can be real time selected during the axis motion via on-off signal to the 12 poles connector (option /SP) or through the - BC or -BP interfaces (option /ZP), to optimize the control performances in the different phases of the machine cycle.
- new drivers E-RI-PES for variable displacement axial piston pumps (see fig. 7), integrate the digital combined pressure and flow control (see above) with an electronic max power limitation. A multiple set of PID parameters can be real time selected during the axis motion via the 12 pin connector (option /S) or through the -BC or -BP interfaces (option /Z), to optimize the P/Q control performances.

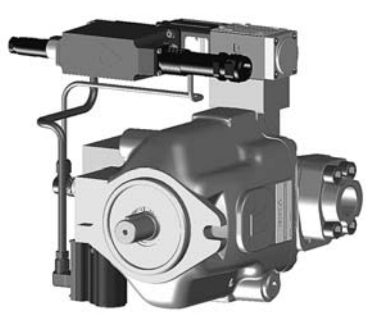


fig. 7

5 DIGITAL SOLUTIONS FOR BASIC SERVOSYSTEMS

The concept of distributed intelligence is applied in its easiest form to the drivers type E-RI-AEG, see fig. 8 and tab. G120.
This controller self-manages open loop "fast-slow" positioning cycles, interfacing up to five inductive proximity sensors.
For any of the cycle phases it is possible to set speed and ramps.
This solution has been developped for applications with repetitive cycles. The complete cycle is managed by the valve itself without auxiliary axis controller.

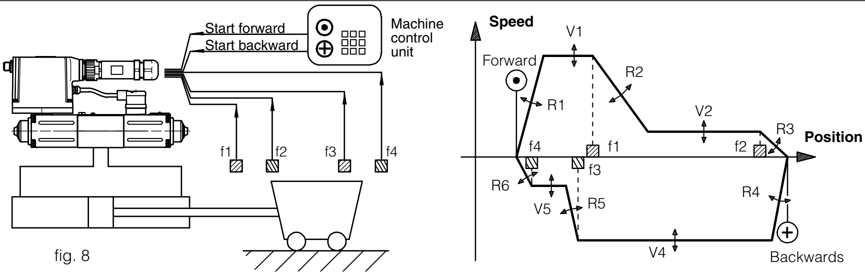


fig. 8

6 DIGITAL SERVOACTUATORS

Servoactuators integrate several control functions within the driver itself, thus realizing truly compact electrohydraulic motion units.

E-RI-TEZ drivers for servoactuators, see fig. 9, besides driving the valve on which they are integrated, also perform a position, speed and/or force control on the actuator itself.

For the end user, the main advantages of this kind of servosystems are:

- the self management of the motion control, with no need of using external axis cards
- the reduced number of wirings, thanks to the direct connection of the electronics to the peripherial sensors.

The distributed intelligence permits to locally manage the "fast" signals required by high performances closed loop controls, avoiding to unnecessarily overload the fieldbus communication line.

Application of such servoactuator solutions takes place for example:

- for closed loop speed/position and pressure control of the injection phase in plastic presses
- for speed and force control of the moulds closing in plastic presses
- for parison control is blow moulding machines
- for master/slave syncronism in wood machines and bending presses.

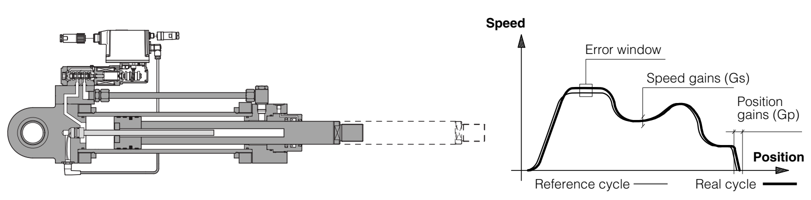


fig. 9

Electrohydraulic controls: commissioning and trouble shooting

The following notes give some general suggestions and cautions on the procedures to ensure the good operation of an electrohydraulic system, with particular reference to the closed-loop circuits, typical of modern electrohydraulic axes and of high-performances proportional components with integral analog and digital electronics. For more detailed information about specific components see the relevant technical tables. For proper operation of electrohydraulic components, following prescription must be respected.

1 HYDRAULIC SECTION

1.1 Power packs tank and tubes cleaning

Power unit tank has to be accurately cleaned, removing all the contaminants and any extraneous object; piping has to be cold bended, burred and pickled. When completely assembled an accurate washing of the piping (flushing) is requested to eliminate the contaminants; during this operation the proportional valves have to be removed and replaced with by-pass connections, or on-off valves.

1.2 Hydraulic connections

The flexible hoses have to be armoured type on pressure line between powerpack and proportional valve and on return line from proportional valve. If their potential breackage may cause damages to any machine or system or can cause injure to the operator, a proper retention (as the chain locking at both the pipe-ends) or alternately a protecting carter must be provided.
The proportional valve must be installed as close as possible to the actuator, to assure the maximum stiffness of the circuit and so the best dynamic performances.

1.3 Hydraulic fluid

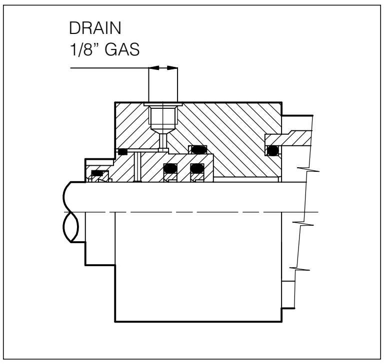
Use only good quality fluids according to DIN 51524..535, with high viscosity index. The recommended viscosity is 15÷100 mm^2/sec at 40°C. When fluid temperature exceeds 60°C select viton seals for components; in any case the fluid temperature must not exceed 80°C.

1.4 Fluid filtration

The fluids filtration prevent the wearing of the hydraulic components caused by the contaminans present in the fluid.
Fluid contamination class must be in accordance to ISO 18/15 code by mounting in line pressure filter at 10µm value and β_{10}=75.
In line filters must be mounted, if possible, immediately before proportional valve; the filtering element is high cracking pressure type with clogging electrical indicator, without by-pass valve.
The flushing (at least 15 min. long) has to be performed at the system commissioning to remove the contaminants from the whole circuit.
After this operation filtering elements and flushing accessories cannot be used again, if clogged.
Following additional warnings to be considered:
- make sure that the filters are of correct size to ensure efficiency;
- the main source of contamination of an hydraulic system is the air exchanged with the environment: proper air filters on the power unit tank to be always provided;
- filter the fluid when filling the tank (new fluid is contaminated) with filtration Group GL-15 (table L150) or similar.

1.5 Hydraulic drains and return lines

The function of drains is essential in all systems, because they define the minimum pressure level.
They must be connected to the tank without counter-pressures.
Drain connections is provided on tie rod side of the servocylinder, see figure.



Return line from proportional valve to tank has to be sized in order to avoid variable counter pressure < 1 bar; for this reason it is recommended to use multiple separated return lines directly connected to tank.

1.6 Fluid conditioning

A high-performance system must be thermally conditioned to ensure a limited fluid temperature range (generically between 40 and 50°C) so that the fluid viscosity remains constant during operation.
The operating cycle should start after the prescribed temperature has been reached.

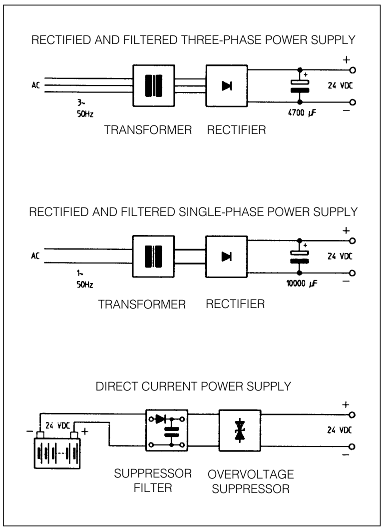
1.7 Air bleeds

Air in the hydraulic circuits affects hydraulic stiffness and it is a cause of malfunctioning.
Air bleeds are provided in the proportional valves and servocylinders; air dump valves must be inserted at possible air accumulation points of the hydraulic system.
Following additional warnings to be considered:
on starting the system all the bleeds must be released to allow removal of air. In particular for servocylinders be careful to bleed the transducer chamber, which is done by releasing the dump valve at the rod end;
- for the piping untight the connections;
- the system must be bled on first start-up or after maintenance;
- use a precharged check valve (e.g. to 4 bars) on the oil general return line to tank to avoid emptying of the pipes following a long out of service.

2 ELECTRONIC SECTION

2.1 Power supply

The voltage values to be within the following range (depending on the type of supply devices):
nominal voltage: V = 24 V_{DC};
filtered and rectified voltage: Vrms=21÷33 V (ripple max = 2Vpp);
The supply device must be sized in order to generate the correct voltage when all utilities require max current at same time; in general 50W max intake electrical power can be considered for each supplied valve.
Following additional notes to be considered, see figure below:
- power supply from a battery: overvoltages (typically greater than 34 Volts) damage the electronic circuits; it is recommended the use of suitable filters and voltage suppressors;
- rectified AC power supply: the average value to be within the limit Vrms = 21÷28 Volts, with a supply capacitor equal to 10000 µF for each 3A of current expected when single-phase power supply; 4700 µF when three-phase power supply.



2.2 Electrical wiring

The power cables (coils, electronic adjusters or other loads) to be separated from the control cables (references and feed-backs, signal grounds) to avoid interferences.

The electrical cables of the electronic signals must be shielded as indicated in section 5 with shield or cablebraid connected to the ground (according to CEI 11-17).

Recommended cable cross section;

- Supply and earth: 0,75 mm^2;
- Coils: 1mm^2 (Lmax = 20 m); 1,5 mm^2 (for longer distance) of shielded type;
- Voltage reference and LVDT feedback: 0,25mm^2 (Lmax = 20m) of shielded type;

Note: current reference signals options must be provided when greater lengths apply to reference and feedback connections; suitable electronic units and transducers or voltage to current converters are available.

- Service signal: 0,25mm^2 (Lmax = 20 m) of shielded type;
- Electronic transducers: 0,25mm^2 (Lmax = 20 m) of shielded type;

2.3 Suppression of interferences by electrical noise

When starting the system, it is always advisable to check that feedbacks, references and signal grounds are free from interferences and electrical noise which can affect the characteristics of the signals and generate instability in the whole system.

Electrical noises are high non-stationary oscillations both on amplitude and frequency around the signal average value; they can be suppressed by shielding and grounding the signal cables, see section 5.

Most of electrical noises are due to external magnetic fields generated by transformers, electric motors, switchboards, etc.

2.4 Integral drivers service signals and options

- **Monitor signal (standard)**
  The output signal (0÷5V, ±10V) is available to monitor the current to the solenoid (AE, AES) or the spool position of the valve (TE, LE, TES, TERS). Both signals can be connected to main control unit for sequence operations and diagnostics.
  Note: electrical monitor signals taken via valve electronics must not be used to switch off the machine safety functions. This is in accordance with the European regulations standard (Safety requirements fluid Technology systems and components);
- **Current reference signal (option /I)**
  It provides the 4÷20 mA current reference signal and the current feedback signals instead of the standard 0÷10V (± 10V). It is normally used in case of long distance between the machine control unit and the valve or where the reference signal can be affected by electrical noise. In case of breakage of the reference signal cable, the valve functioning is disabled.
- **Fault signal (option /F)**
  Safety option providing an output signal which switches to zero in case of interruption of the transducer feedback cable. In this condition the valve functioning is disabled.
- **Enabling contact (option /Q)**
  Safety option providing the possibility to enable or disable the valve functioning without cutting the power supply.
- **Fail safe conditions**
  In case of no feedback signal due to shortcircuit or break in the transducer cabling, an automatic inhibition of the control card operates and zero current is fed to valves. At the same time a LED (inside the housing for the integral electronics) is signalling the emergency condition.
- **Logic state signals for E-RI-TE and E-RI-LE (option /S)**
  This function gives three output signal in order to control in real time the valve's spool position to allow the diagnostic controls. The signal "**Zero position**" is "on" (22V 20 mA) when the spool is in the central position, while the other two signals ("**Position S1**" and "**Position S2**") are "on" when the spool is moving according to the excitation of the S1 or S2 solenoid, respectively. This safety signals can be used to switch-off the machine safety functions.
- **Enable fault and monitor for E-RI-TE and E-RI-LE (option /Z)**
  Option providing the same characteristics of **/F** and **/Q** plus the monitor signal 0 ÷ 10 V (or ± 10 V) of the spool position.
- **Double power supply enable and fault for E-RI-TES, E-RI-TERS, E-RI-LES (option /Z)**
  Safety option, specifically introduced for -BC and -BP fieldbus interfaces, provides two separated power supplies for the digital electronic circuits and for the solenoid power supply stage. The Enable and Fault signals are also available. The option **/Z** allows to interrupt the valve functioning by cutting the solenoid power supply (e.g. for emergency, as provided by the European Norms EN954-1 for components with safety class 2), but keeping energized the digital electronic circuits, thus avoiding fault conditions of the machine fieldbus controller.
- **P/Q control for E-RI-TES-PS and E-RI-LES-PS (option /SP)**
  Option providing in addition to the standard valve functions, a closed loop control of the max pressure regulated by the proportional valve in the system, thus realizing a P/Q regulation. A remote pressure transducer must be installed on the system and its feedback has to be interfaced to the valve. If the real value of the pressure in the system remains below the relevant reference signal, the driver regulates in closed loop the valve's spool position, according to the flow reference signal. When the real pressure become close to the relevant reference signal, the driver automatically performs the closed loop control of the pressure. This option permits to realize accurate dynamic pressure profiles. Up to 4 set of PID pressure parameters can be real time selected during the axis motion via on-off signals to the main 12 poles connector to optimize the control performances in the different phases of the machine cycle.
- **P/Q control for E-RI-TES-BC (-BP) and E-RI-LES-BC (-BP) (option /ZP)**
  Integral digital P/Q controller providing the same characteristics of option **/SP** plus additional double power supply, enable and fault. In this option the multiple set of PID pressure parameters can be real time selected during the axis motion through the -BC or -BP interfaces.
- **Current feedback signal for E-RI-PES (option /C)**
  The pump electronics is set to receive 4÷20 mA feedback signal from the remote pressure transducer, instead of the standard 0÷10 V.
- **P/Q control for E-RI-PES-PS (option /S)**
  Option providing up to 4 set of PID pressure parameters can be real time selected during the axis motion via on-off signals to the 12 poles connector to optimize the control performances in the different phases of the machine cycle.
- **P/Q control for E-RI-PES-BC (-BP) (option /Z)**
  Integral digital P/Q controller providing the same characteristics of option **/SP** plus additional double power supply, enable and fault. In this option the multiple set of PID pressure parameters can be real time selected during the axis motion through the -BC or -BP interfaces.

2.5 Electronic calibrations

The valves with integral electronics normally don't need any calbration by final customer because these operations have been already performed before delivery of component (the valves with integral electronics are used more and more for their easier servicing and improved reliability).

However Bias adjustment is allowed, to permit the regulation between the input reference electrical zero and the spool center position (actuator in a steady position); a new calibration can be executed with particular hydraulic conditions (i.e. cylinder with high differential ratio value and/or high Δp pressure operations). When electronic regulators in Eurocard or other format are installed in the control unit, the setting procedures are shown on related technical tables; consult them carefully before proceeding with the start-up. Personalised calibrations in case of particular requirements can be carried out with the collaboration of Atos technical dept.

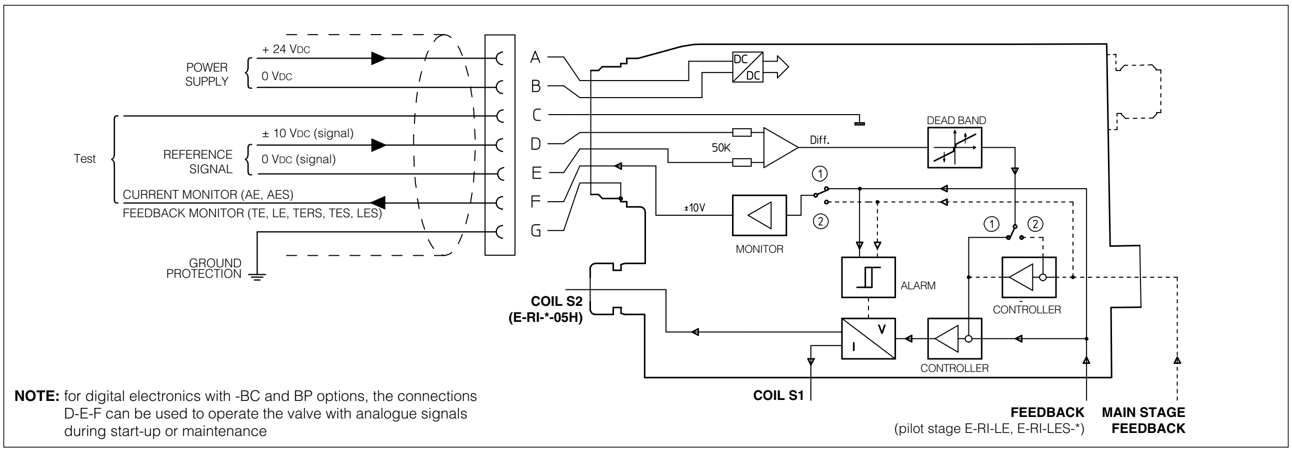
2.6 Temperatures and environments

Always chek that the operating environment is compatible with the data given in the product tables. If necessary provide conditioning of the electronic cabinet.

In particular the integral electronics cannot be used when ambient temperature is higher than +60°C or lower than -20°C (-20°C to +50°C for digital -TERS execution).

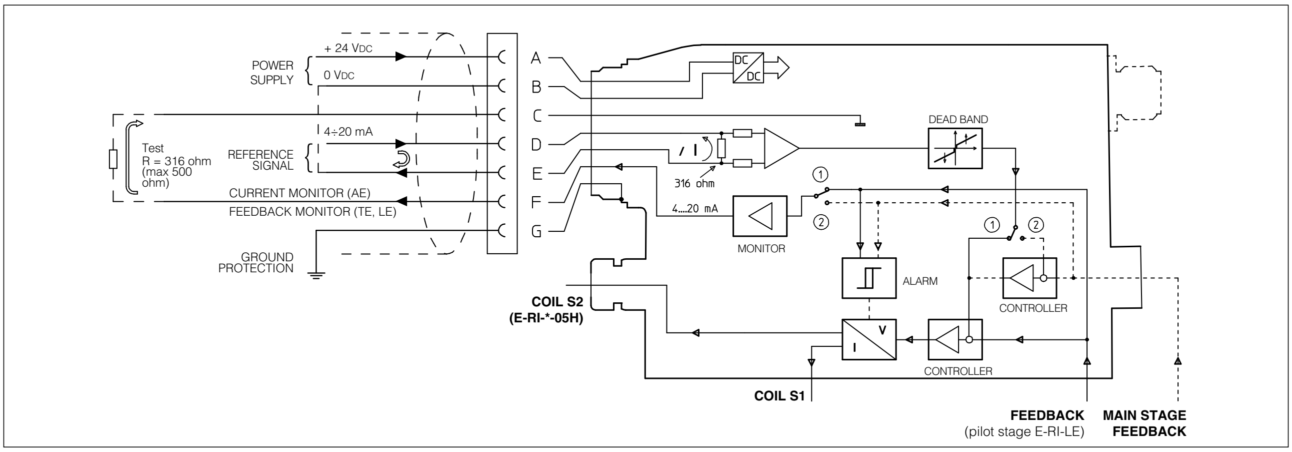
3 ELECTRONICS WIRING

3.1 E-RI-AE (-AES), E-RI-TE (-TES), E-RI-LE (-LES), E-RI-TERS Standard versions

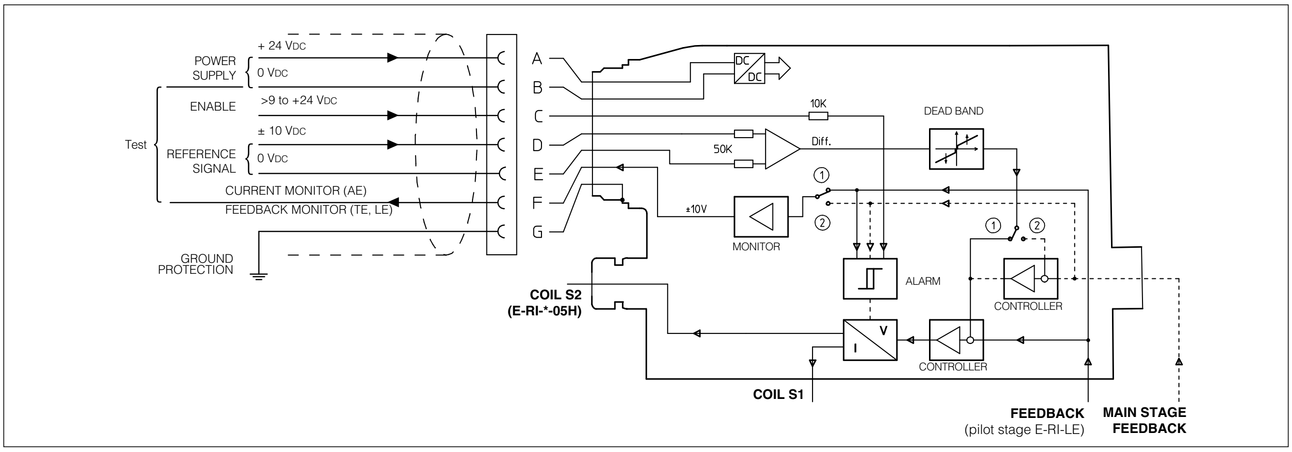


NOTE: for digital electronics with -BC and BP options, the connections D-E-F can be used to operate the valve with analogue signals during start-up or maintenance

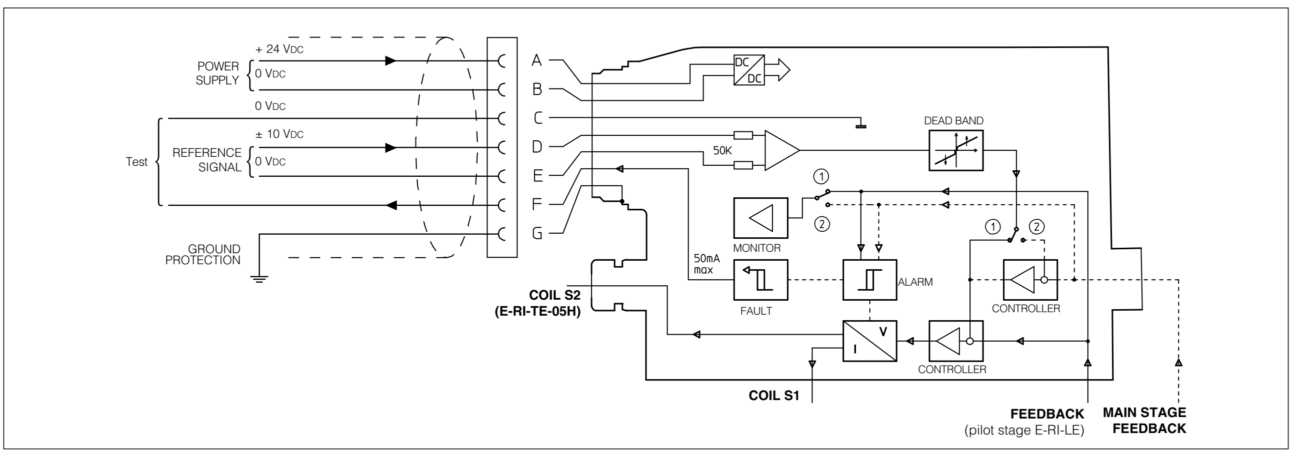
3.2 E-RI-AE, E-RI-TE, E-RI-LE, E-RI-TERS Option /I



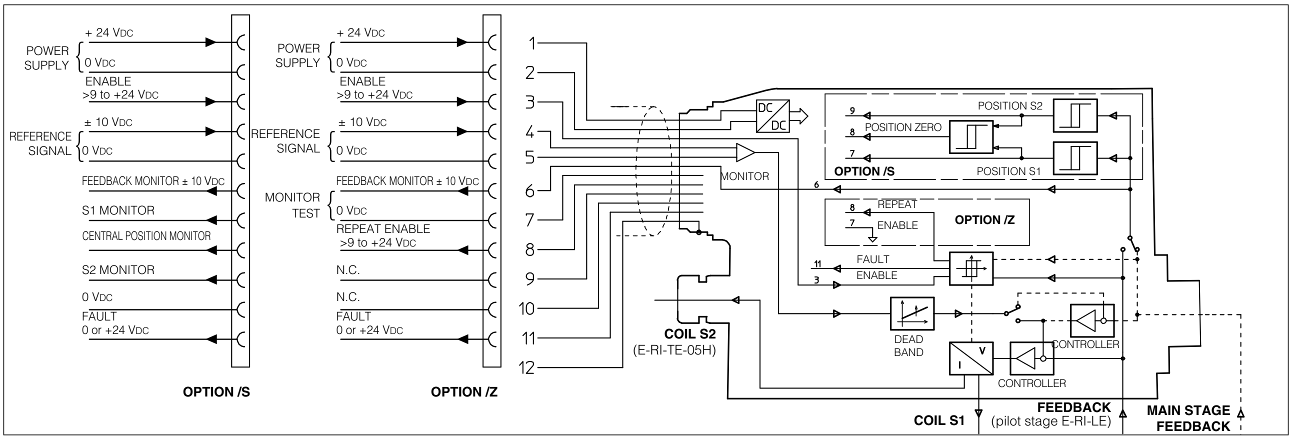
3.3 E-RI-AE, E-RI-TE, E-RI-LE Option /Q



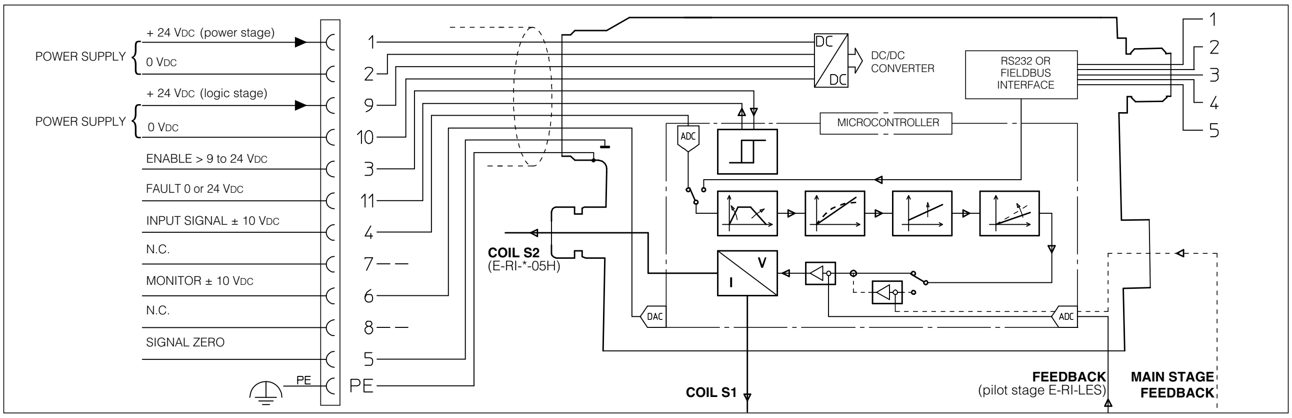
3.4 E-RI-TE, E-RI-LE Option /F



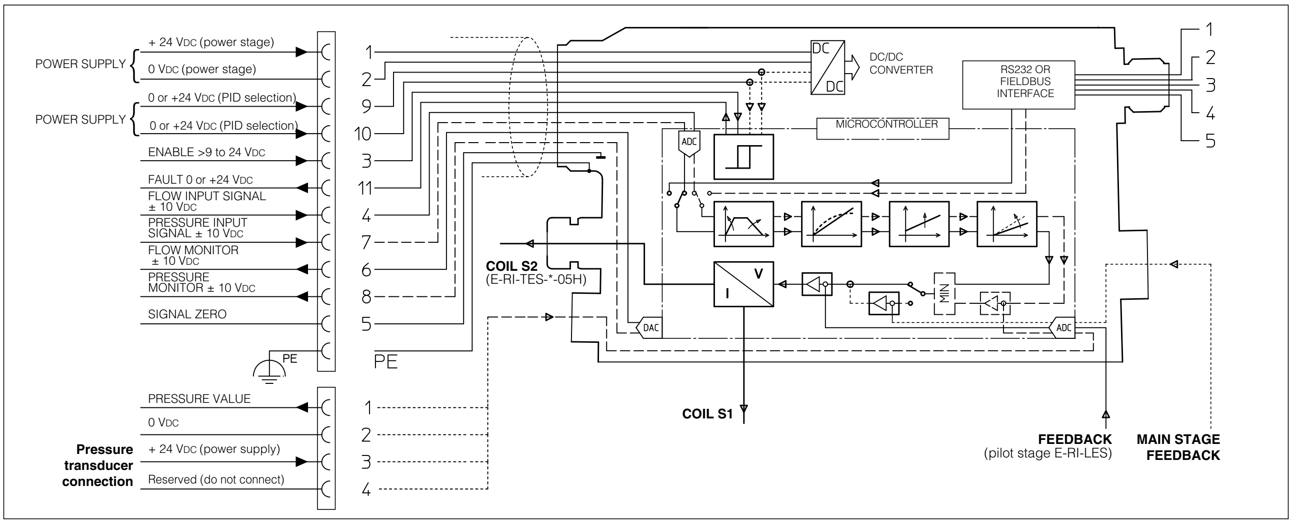
3.5 E-RI-TE, E-RI-LE Option /S and /Z (12 pin connector)



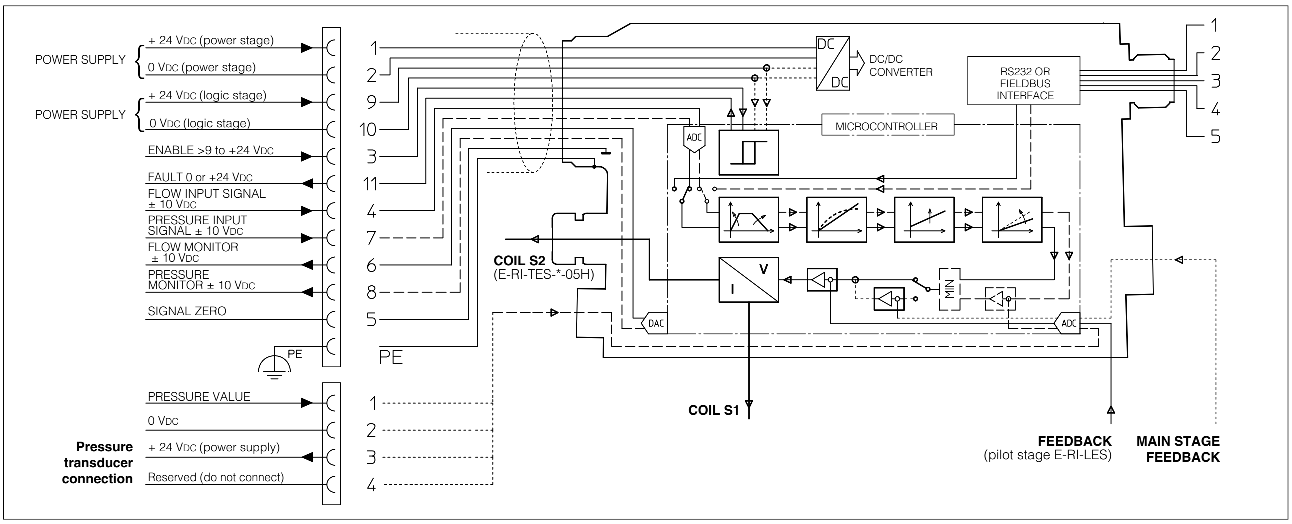
3.6 E-RI-AES, E-RI-TES, E-RI-LES Option /Z (12 pin connector)



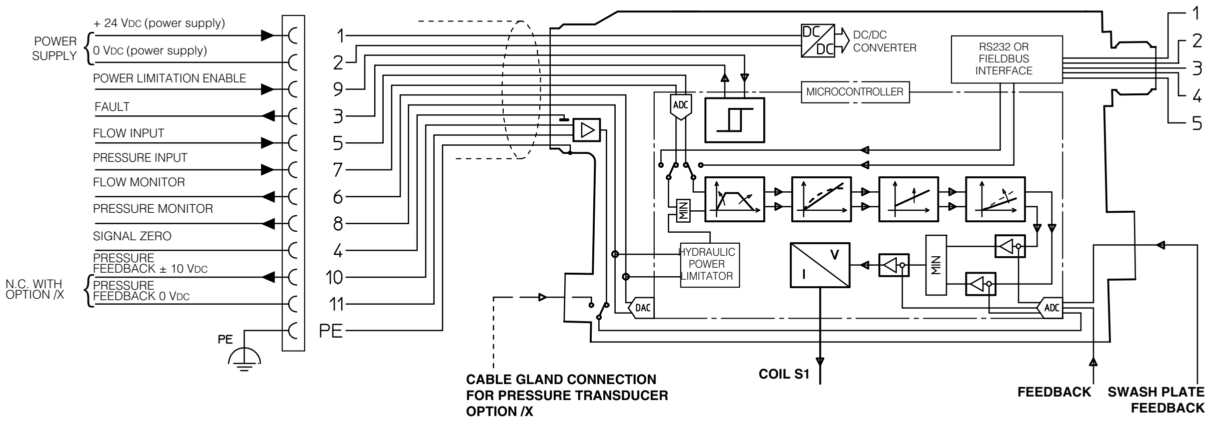
3.7 E-RI-TES, E-RI-LES Option /SP (12 pin connector)



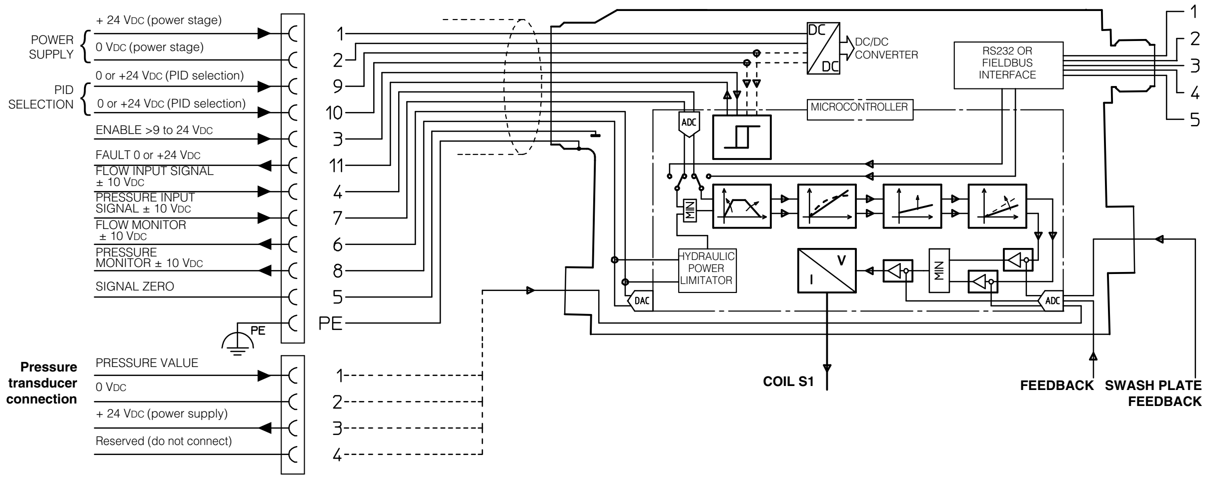
3.8 E-RI-TES, E-RI-LES Option /ZP (12 pin connector)



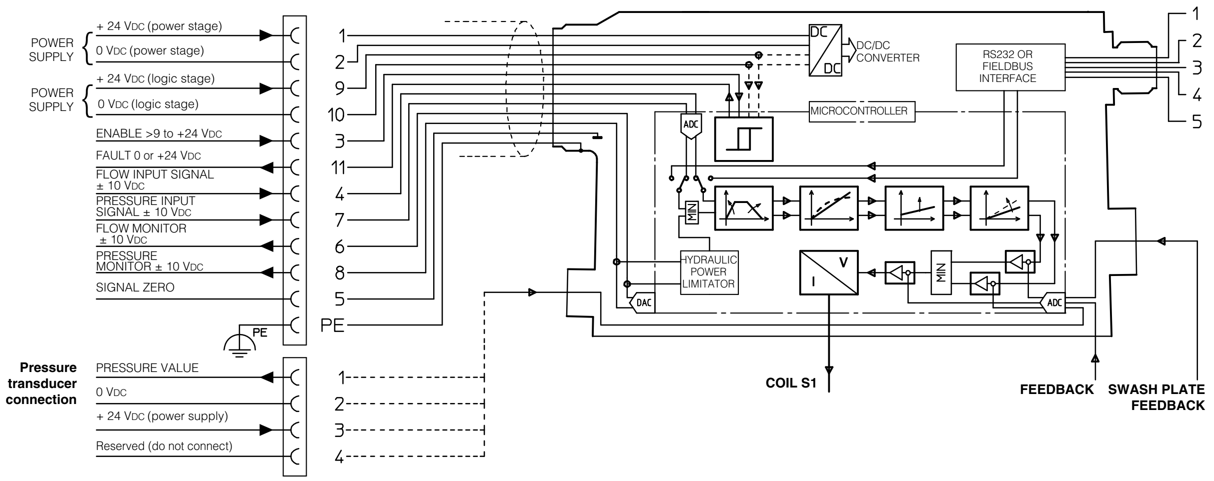
3.9 E-RI-PES Standard and option /X



3.10 E-RI-PES Option /S



3.11 E-RI-PES Option /Z



4 COMMAND SIGNAL WIRING

The connection of the command signal to the electronics is depending to the type of signal generated from the PLC or CNC.
The following figures show the typical connections in case of common zero or differential command situations.

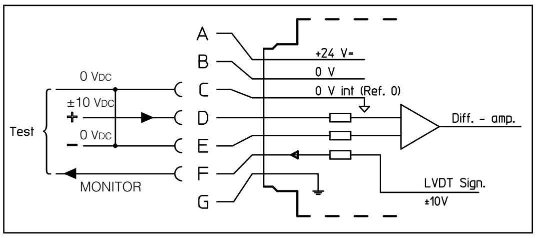


Fig. A Power supply and signal common zero

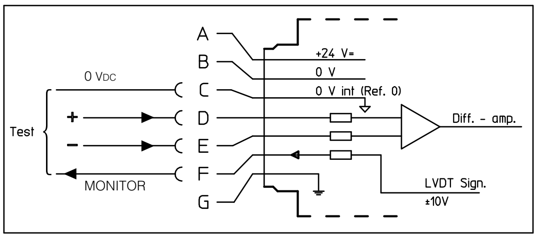


Fig. B Differential signals not connected with zero (floating)

COMMAND SIGNAL FOR OPTION /I

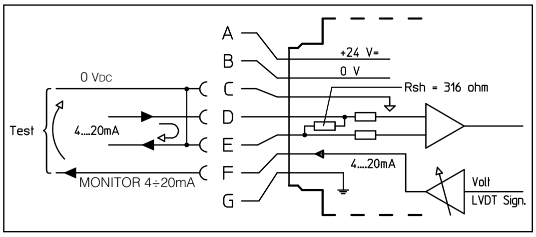


Fig. C Common zero

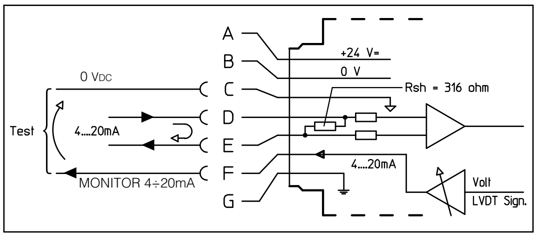


Fig. D Differential input signals

5 SHIELD CONNECTIONS

The correct shielding of signal cables has to be provided to protect the electronics from electrical noise disturbances, which could affect the valve functioning.
Examples of correct shielding criteria are shown in the following fig. E and F.
The shield connections of fig. G and H must be avoided because they could generate ground loops which enhance the noise effect.

CORRECT SHIELD CONNECTIONS

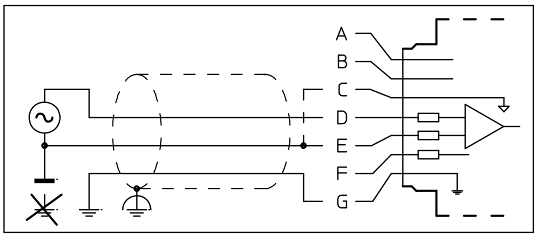


Fig. E Shield connected to the protected earth

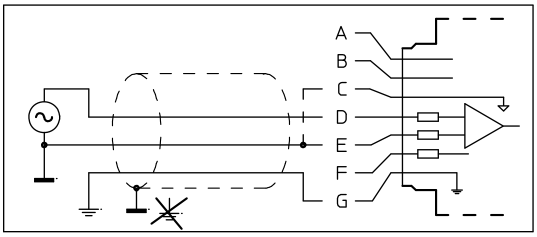


Fig. F Shield connected to the same power supply GND

WRONG SHIELD CONNECTIONS

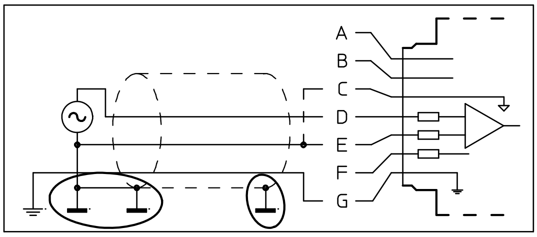


Fig. G Never connect the shield on both sides

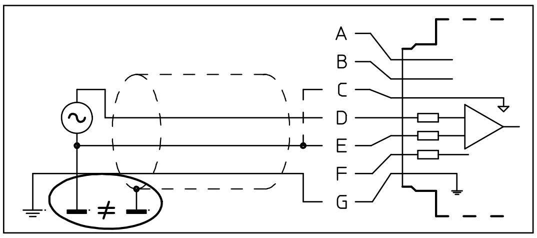


Fig. H Never connect the shield to grounding facilities having different potential

Symbols: ⏚ Standard earth ⊥ Supply GND ⏚ Protected earth

6 TROUBLE SHOOTING TABLES

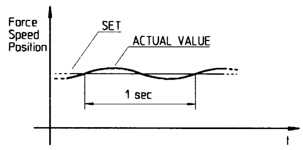
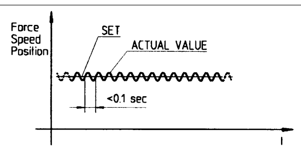
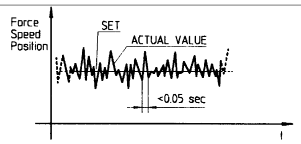
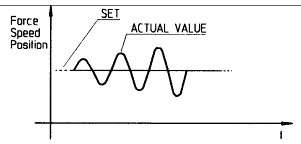
To evaluate the fault and to find the defective component within an electrohydraulic system it is necessary a good cooperation between electronic and hydraulic engineers.
Besides a good knowledge of the technical tables for each component, for performing analysis of the system it is necessary to evaluate the hydraulic scheme and the electric wiring diagram related to operation cycle.
There is no general recipe for succes in fault finding due to quite diverse nature of the electrohydraulic systems; however the following table provides a useful start point.

Notes:
- Most problems are solved by the replacement of defective components on site. The defective components can be repaired by the manufacturer.
- Following tables don't consider a system design fault

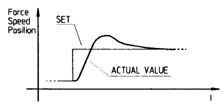
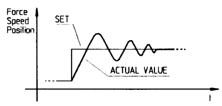
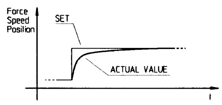
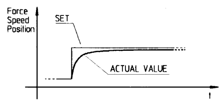
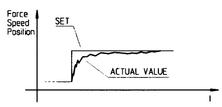
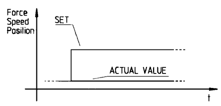
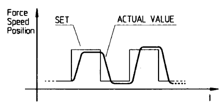
6.1 Open loop applications

PROBLEMS	CAUSES OF THE FAULTS	
	Mechanical/Hydraulic	**Electrical /Electronic**
Unstable axes movement Pressure and/or flow fluctuations	Defective pump Air in the circuit Fluid contaminated Insufficient piloting pressure of double stage valves Stick-slip effect due to excessive friction of cylinder seals Speed below minimum for hydraulic motors	Insufficient powered electrical supply Noisy signals-bad grounding or shielding Electrical or electromagnetic disturbances
Actuator overrun	Hoses too elastic Remote controlled check valve not closing immediately Insufficient bleeding Internal leakages	Bias current set too high Ramp time too long Limit switch overrun Electrical switching time too slow
Standstill or not controllable axes	Defective pump Proportional control valve blocked (dirt) Hand valves and settings not in correct position	Cabling error Open circuit in electrical control leads Signalling devices incorrectly set or defectives Lack of electrical power and/or reference signal Transducers mechanically uncalibrated
Actuator running too slow	Internal pump leaks due to wear Flow control valve set too low	Reference signal not correct Scale adjustment not correct
Insufficient output forces and torques	Excessive resistance in the return and delivery lines Operating pressure setting of control valves too low Excessive pressure drop across control valves Internal leaks of pump and valves due to wear	Reference signal not correct Scale adjustment not correct
Line hammer during control operation	Switching time of proportional control valves too rapid Throttles or orifices damaged No throttling before accumulator system Excessive masses and forces applied to drive	Ramp time too short or absent
Excessive operating temperature	Insufficient lines cross section Excessive continuous delivery Pressure setting too high Cooling system not operative Zero pressure circulation inoperative during working intervals	
Excessive noise	Filters blocked Foaming of the fluid Pump or motor mounting loose Excessive resistance in the suction line Proportional control valves buzz Air in the valve solenoid	Dither adjustment not correct

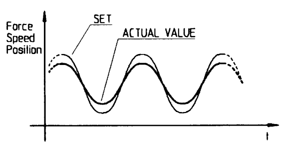
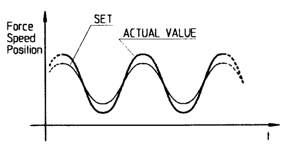
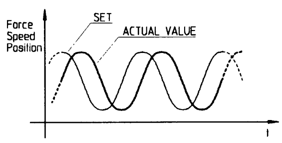
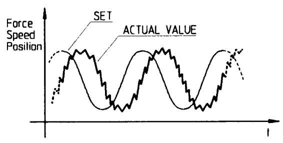
6.2 Closed loop applications - static conditions

PROBLEMS		CAUSES OF THE FAULTS	
		Mechanical/Hydraulic	**Electrical /Electronic**
Low frequency oscillations		Insufficient hydraulic power supply Insufficient piloting pressure Proportional valve defective due to wear or dirt	Axes card proportional and integral Gains set too low Axes card Sampling time too long
High frequency vibration		Foaming of the fluid Prop. valve defective due to wear or dirt Too high Δ pressure across valve Air in the solenoid of the proportional valve	Axes card proportional Gain set too high Electrical noises
Short time peak (random) in one direction or both		Mechanical couplings not rigid Air in the solenoid of the proportional valve Proportional valve defective due to wear or dirt	Driver's bias current not correct Electromagnetic disturbances
Self amplificating oscillations		Hydraulic hoses too elastic Mechanical couplings not rigid Too high Δ pressure across prop. valve Too high hydraulic proportional valve gain	Axes card proportional and integral Gains too high

6.3 Closed loop applications - dynamic conditions: step response

PROBLEMS		CAUSES OF THE FAULTS	
		Mechanical/Hydraulic	**Electrical /Electronic**
Overshoot in one direction		Too high Δ pressure across valve	Axes card Derivative Gain set too low
Overshot in both directions		Mechanical couplings not rigid Hoses too elastic Proportional control valve mounted too far from the actuators	Axes card Proportional Gain set too high Axes card Integral Gain set too low
Slow approach to set		Pressure Gain of the proportional control valve too low	Axes card Proportional Gain set too low Driver’s Bias current not correct
Drive unable to reach the set		Insufficient hydraulic pressure or flow	Axes card Integral Gain set too high Proportional and Derivate Gains set too low Driver’s Scale and Bias not correct
Unstable control		Actuator’s feedback transducer connection intermittent Hoses too elastic Air in the solenoid of the proportional valve to high friction	Proportional Gain set too high Integral Gain set too low Electrical noises
Inhibited control		Actuator’s feedback transducer mechanically uncalibrated Lack of hydraulic power	Lack of electrical power Lack of reference or feedback signal Cabling error
Bad repeatability and high hysteresys		Actuator’s feedback transducer connection intermittent	Axes card Proportional Gain set too high Integral Gain set too low

6.4 Closed loop applications - dynamic conditions: frequency response

PROBLEMS		CAUSES OF THE FAULTS	
		Mechanical/Hydraulic	**Electrical /Electronic**
Amplitude damping		Insufficient pressure and flow	Axes card Proportional Gain too low Driver’s scale adjustments set too low
Wave amplifier		Hoses too elastic Proportional control valve too far from drive	Driver’s scale adjustment not correct
Time delay		Insufficient pressure and flow	Ramp time inserted Axes card derivative gain set too low
Vibrating control		Air in the solenoid of proportional valve	Axes card proportional and Derivative Gains too high Electrical noises Derivative Gain set too high