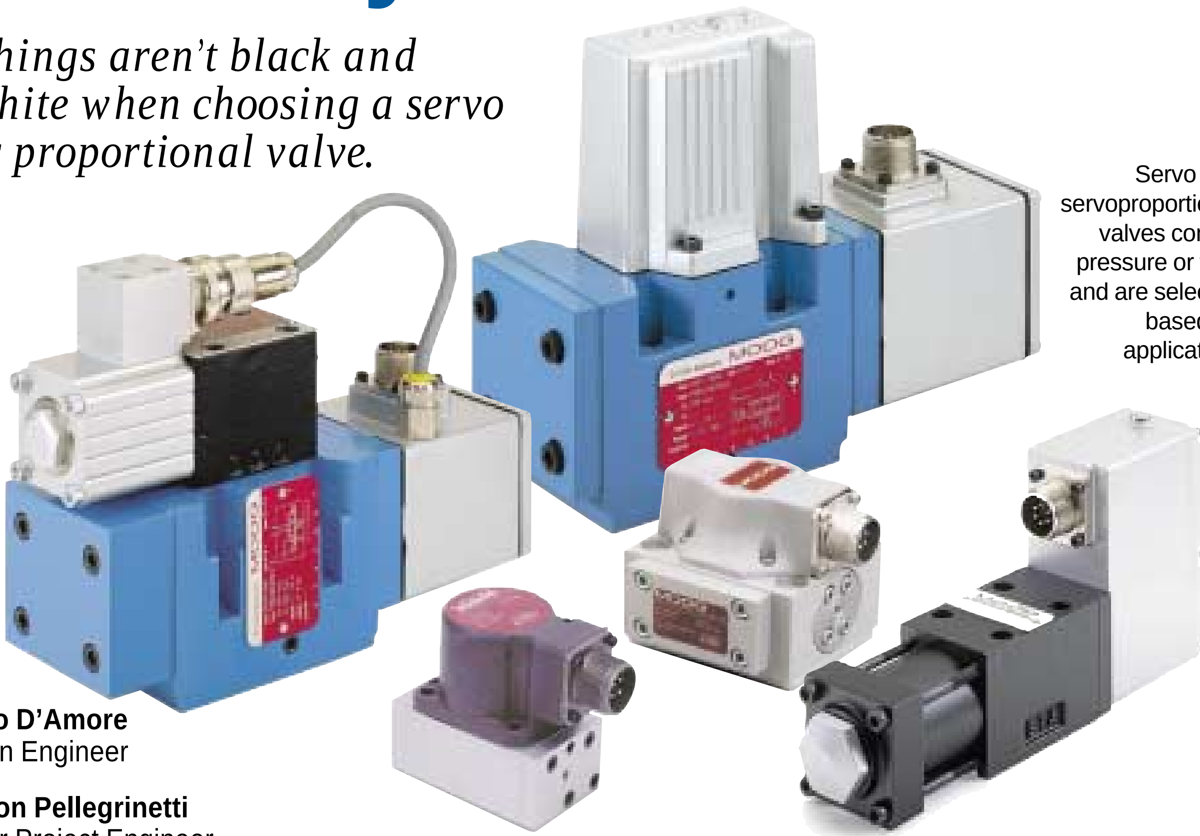
As seen in MACHINE DESIGN April 5, 2001

Fluid power

Edited by Victoria Reitz

Dissecting high-performance electrohydraulic valves

Things aren't black and white when choosing a servo or proportional valve.



Servo and servoproportional valves control pressure or flow and are selected based on application.

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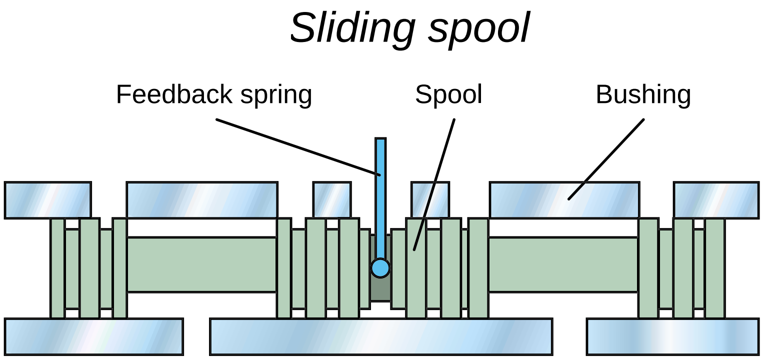
High-performance valves are usually classified as either servo or proportional, a distinction that gives an indication of expected performance. Unfortunately, this classification tends to generalize and blur the true differences between various valve styles. Selection depends on the application and each valve has merit when it comes to controlling pressure (load control) or flow (piston or motor velocity control).

Traditionally, the term servovalve describes valves that use closed-loop control. They monitor and feed back the main-stage spool position to the pilot stage or driver either mechanically or electronically. Proportional valves, on the other hand, displace the main-stage spool proportionally to command but they usually do not have any means of automatic error correction (feedback) within the valve. Typically, proportional valves displace the spool by driving it against a set of balanced springs, which makes the position proportional to the driving current. These springs also center the main-stage spool. Accuracy and repeatability of the main-stage spool position is a function of the springs' symmetry and ability of the design to minimize nonlinear effects of spring hysteresis, friction, and machining-tolerance variations.

Hydraulic system design

To choose the proper hydraulic valve for a specific application, designers must con-



Proportional and servovalves control flow or pressure via a sliding spool element.

sider specific application and system configurations. Supply pressure, fluid type, system force requirements, valve dynamic response, and load resonant frequency are examples of the various factors affecting system operation.

Hydraulically piloted valves are sensitive to supply pressure disturbances, whereas direct-drive valves are unaffected by supply pressure variation. Fluid type is important when considering seal compatibility and viscosity effects on performance over the system's operating temperature range. Moog valves, for instance, operate most effectively with a fluid viscosity between 60 to 450 SUS at 100°F.

Total force requirements must include all static and dynamic forces acting on the system. Load forces can aid or resist, depending on load orientation and direction. Forces required to overcome inertia can be large in high-speed applications and are critical to valve sizing.

The load resonance frequency is a function of the overall travel stiffness, which is the combination of the hydraulic and structural stiffness. For optimum dynamic performance, a valve's 90° phase point should exceed the load resonant frequency by a factor of three or more.

The valve's dynamic response is defined as the frequency where phase lag between input current and output flow is 90°. This 90° phase lag point varies with input signal amplitude, supply pressure, and fluid temperature so comparisons must use consistent conditions.

Servovalves

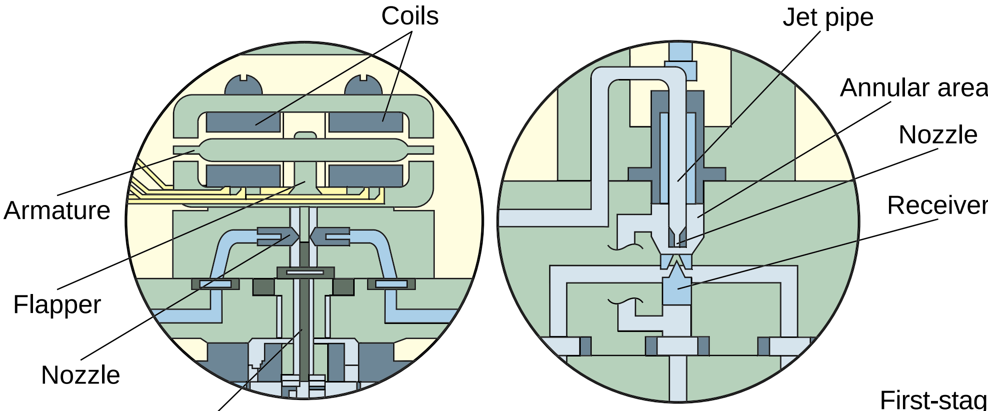
The term servovalve traditionally leads engineers to think of mechanical feedback valves, where a spring element (feedback wire) connects a torque motor to the main-stage spool. Spool displacement causes the wire to impart a torque onto the pilot-stage motor. The spool will hold position when torque from the feedback wire's deflection equals the torque from an electromagnetic field induced by the current through the motor coil. These two-stage valves contain a pilot stage or torque motor, and a main or second stage. Sometimes the main stage is referred to as the power stage. These valves can be separated primarily into two types, nozzle flapper and jet pipe.

The electromagnetic circuit of a nozzle flapper or jet-pipe torque motor is essentially the same. The differences between the two lies in the hydraulic bridge design. A hydraulic bridge controls the pilot flow which, in turn, controls the main-stage spool movement. In a nozzle flapper, the torque produced on the armature by the magnetic field moves the flapper toward either nozzle depending on command-signal polarity. Flapper displacement induces a pressure imbalance on the spool ends which moves the spool. In a jet pipe, the armature movement deflects the jet pipe and asymmetrically imparts fluid between the spool ends through the jet receiver. This pressure imbalance remains until the feedback wire returns the jet pipe or flapper to neutral.

Historically, jet pipe and nozzle-flapper servovalves have competed for similar applications that require high dynamics. Typically, better first-stage dynamics gives the nozzle flapper better overall response, whereas improved pressure recovery of the jet/receiver bridge design gives the jet-pipe motors higher spool driving forces (chip-shearing capability). Both valves require low command currents and therefore offer a large mechanical advantage. Motor current for these style valves is typically less than 50.0 mA. Note that these servovalves are also proportional valves, because spool displacement and flow are directly proportional to the input command.

Direct-drive valves

Direct-drive valves, unlike hydraulically piloted two-stage valves, displace the spool by physically linking it to the motor armature. These valves usually come in two basic varieties, those driven by linear force motors (LFM) and those actuated by proportional solenoids. Within these two general classifications, the valves can be separated into proportional and servoproportional. The distinction is based on the use of a position transducer to provide spool position feedback. Servoproportional valves must incorporate closed-loop spool position feedback to



Nozzle flapper and jet-pipe valves

First-stage configurations for nozzle flapper and jet-pipe valves.

TERMINOLOGY

The terminology used to describe hydraulic valves is defined according to the recommendations of the SAE Aerospace Recommended Practice (ARP490). A review of some frequently used terms is contained below.

Control flow: The flow through the valve control ports to the load.

Flow gain: The normal relationship of control flow to input current.

Frequency response: The relationship of no-load control flow to input current when the current varies sinusoidally at constant amplitude over a range of frequencies. Frequency response is expressed by the amplitude ratio in decibels and phase angle in degrees over a specific frequency range. Often, the recommended peak-to-peak signal amplitude is 80% of the valve rated current.

Hysteresis: The difference in valve input currents required to produce the same valve output as the valve slowly cycles between plus and minus rated current.

Internal leakage: The total internal valve flow from pressure to return with zero control flow (usually measured with control ports blocked). Leakage flow varies with input current, but is generally maximum at the zero level of null (called null leakage).

Lap: In a sliding-pool valve, the relative axial position relationship between the fixed and movable flow metering edges within the null region. Lap is measured as the total separation at zero flow of straight-line extensions of nearly straight portions of the flow curve.

Linearity: The maximum deviation from control flow from the best straight line of flow gain, expressed as a percent of rated current.

Load-pressure drop: The differential pressure between the control ports, that is, across the load actuator.

No load flow: The control flow with zero load-pressure drop.

Null: The condition where the valve supplies zero control flow at zero load-pressure drop.

Null bias: The input current required to bring the valve to null, excluding the effects of valve hysteresis, expressed as percent of rated current.

Null shift: The change in null bias resulting from changes in operating conditions or environment, expressed as percent of rated current.

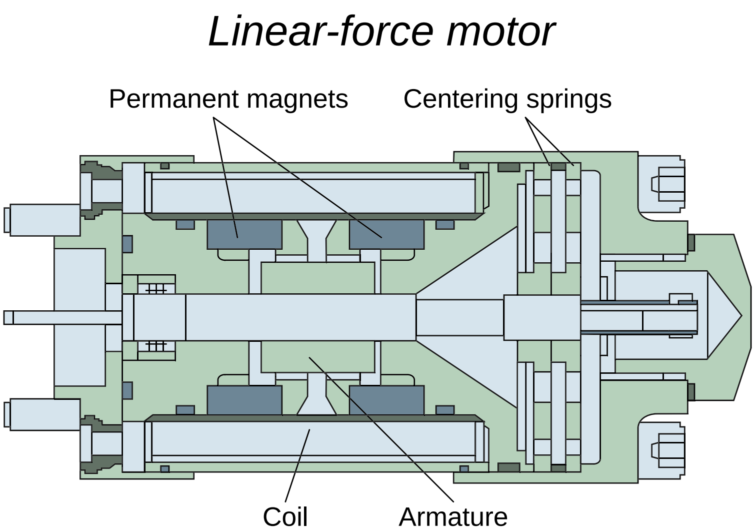
Pressure gain: The change of load-pressure drop with change of input current at zero control flow (control ports blocked), expressed throughout the range of load pressure between 40% supply pressure.

Rated flow: Servovalves are typically rated at 1,000-psi drop, while proportional valves are rated at 150-psi drop.

Symmetry: The degree of equality between the flow gain of one polarity and that of reversed polarity. Measured as the difference in flow gain for each polarity, it is expressed as the greater percentage.

Threshold: The increment of input current required to produce a change in valve output. Valve threshold is usually measured as the current increment required to change from an increasing output to a decreasing output, expressed as a percent of rated current.

Valve-pressure drop: The sum of the differential pressure across the control orifices of the valve spool. Valve-pressure drop equals the supply pressure, minus return pressure and load-pressure drop.



The linear force motor shows permanent magnets, centering springs, coil, and armature.

increase repeatability and accuracy necessary for high-control applications. Typically, servoproportional, direct-drive valves have an overall lower dynamic response than hydraulically piloted two-stage valves with the same flow characteristics. This is usually due to the large armature mass of the LFM or solenoid and the large time constant associated with the coil, which is a function of the induction and resistance of the coil.

Unlike hydraulically piloted servos, direct-drive valve performance does not vary with changes in supply pressure. This makes them ideal for applications where pilot flow for first-stage operation is not available. Direct-drive valves also tend to be viscosity insensitive devices whereas nozzle flapper and jet-pipe valves work best with oil viscosity below 6,000 SUS. However, most direct-drive valves cannot generate the high spool driving forces of their hydraulically piloted counterparts.

Like the torque motor used in the nozzle flapper/jet pipe servos, the LFM allows for bidirectional movement by adding permanent magnets to the design and therefore making the armature motion sensitive to command polarity. In the outstroke, the LFM must overcome spring force plus external flow and friction forces. During the backstroke to center position, however, the spring provides additional spool-driving force which makes the valve less contamination sensitive. Magnetic-field forces are balanced by a bidirectional spring that lets the spool remain centered without expending any power.

Unlike the LFM, the proportional solenoid is a unidirectional device. Two solenoids oppose each other to achieve a centered, no power, failsafe position. When a single solenoid is used, holding the spool at midstroke requires a continuous current to balance the load generated by the return spring. This makes the design less energy efficient than its LFM or a dual-solenoids counterpart. During a power loss, the LFM and dual proportional solenoid designs fail to a neutral position and block flow to the load, that is the piston. When a single solenoid design loses power, the spool must move through an open position that tends to cause uncontrolled load movements.

Multistage valves

All of the aforementioned designs can be used to create a multistage hydraulic valve. The approach for each design is specific to the application requirements. Usually, most designs do not exceed three stages. Mounting a nozzle flapper, jet pipe, or direct-drive valve onto a larger main stage satisfies most requirements for dynamics and flow. Sometimes, the jet-pipe valve is used in a multistage configuration where the mechanical feedback of a traditional jet pipe is replaced with electronic feedback. This servojet style has pilot characteristics of a typical jet pipe. Depending on the required control, many multistage valves close a position loop about the main stage using a linear variable differential transducer. This device monitors the spool position. In case of hydraulic power loss, springs on opposite sides of the main stage spool return it to a neutral position. ■

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