



AEROSPACE RECOMMENDED PRACTICE

ARP4493™**REV. B**Issued 2000-07
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Superseding ARP4493A

(R) Recommended Design and Test Requirements for Direct Drive Servovalves

RATIONALE

This document has been updated to align with the recommended design and test requirements of ARP490.

FOREWORD

The recommendations in this SAE Recommended Practice (ARP) are primarily confined to the input and output characteristics of direct drive servovalves (DDVs). The only exception to this approach involves the definition and specification of chip shear force, which is not typically measurable by nondestructive external testing. The information presented should be useful in standardizing the terminology, the specification of physical and performance parameters, and the test procedures used in conjunction with these components.

There are two basic types of DDVs, namely open-loop and closed-loop. In the case of an open-loop DDV, the significant input is the motor current, as is the case with electrohydraulic servovalves covered in ARP490. A closed-loop DDV includes a means of position feedback and relies on an electronic controller to control its performance characteristics. Because of the importance of the closed-loop category of DDVs, many specifications will be written for the closed-loop performance. To generalize this document, the system input signal has been referred to as the "command" and applies equally well to open-loop valves, in which the command will usually be expressed in amps, and to closed-loop valves, which usually receive commands as an input voltage to the valve controller. Many provisions of this document apply equally to larger tandem main control valve (MCV) type DDVs and standard-size single hydraulic system valves.

The specifications contained herein should be used to describe direct drive flow control servovalves. Additional specifications may be necessary to define special requirements for specific control systems. Also, specialized test procedures may be necessary to measure DDV performance in these unusual specification areas. These considerations are beyond the scope of this ARP.

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1. SCOPE

This ARP provides definitions and background information regarding the physical performance and testing of DDVs. This ARP also provides extensive guidance for the preparation of procurement specifications and functional testing.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (U.S. and Canada only) or +1 724-776-4970 (Outside U.S. and Canada), www.sae.org.

ARP490	Electrohydraulic Servovalves
ARP1383	Aerospace - Impulse Testing of Hydraulic Components
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
AS4059	Contamination Classification for Hydraulic Fluids
AS4536	Safety Cable Kit Procurement Specification and Requirement for Use
AS4941	Aerospace - General Requirements for Commercial Aircraft Hydraulic Components
AS5440	Hydraulic Systems, Military Aircraft, Design and Installation, Requirements For
SAE J2470	Hydraulic Fluid Power - Valves - Method for Assessing the Lock Sensitivity to Contaminants

2.1.2 AIA Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NASM33540	Safety Wiring and Cotter Pinning, General Practice for
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2.1.3 RTCA Publications

Available from RTCA, Inc., 1150 18th Street NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
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2.1.4 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests

2.2 Recommended Terminology

The following definitions describe recommended terminology for DDVs. Additional terminology may be used per ARP4386.

2.2.1 General

DIRECT DRIVE FLOW-CONTROL SERVOVALVE: This is an electrically commanded single-stage flow control valve that produces continuously increasing flow in approximate proportion with the input voltage and drive current.

NOTE: The term “direct drive” implies that electrical energy is converted to metering spool motion by mechanical means.

FORCE MOTOR: This is the electromechanical device that is used to directly drive the hydraulic flow control element.

NUMBER OF COILS: This is the number of independent and isolated motor windings that may be used to drive the valve.

NOTE: The effect of all coils is nominally identical.

OUTPUT STAGE: This is the final stage of hydraulic distribution used in a DDV.

PORT: This is the fluid connection to the DDV (e.g., supply port, return port, control port).

THREE-WAY VALVE: This is a multi-orifice flow-control component with a supply port, return port, and one control port arranged so that valve action in one direction opens the supply port to the control port and reversed valve action opens the control port to the return port.

FOUR-WAY VALVE: This is a multi-orifice flow-control component with a supply port, return port, and two control ports arranged so that valve action in one direction opens the supply port to the control port #1 and opens the control port #2 to the return port.

NOTE: Reversed valve action opens the supply port to the control port #2 and opens the control port #1 to the return port.

TANDEM DDV: This is a DDV that simultaneously controls the flow of two independent hydraulic systems.

CHIP SHEAR FORCE: This is the valve force available at the metering element to shear a lodged chip or foreign particle.

NOTE: This is typically defined at the maximum valve stroke, the closing direction, and includes forces produced by the motor and by mechanical springs but does not include flow forces.

NATURAL FREQUENCY: This is a frequency at which, in the absence of damping, a limited input tends to produce an unlimited output.

NOTE: It is a function of the valve mass elements and spring rates (which includes flow forces, where applicable).

OPEN-LOOP DDV: This is a DDV that has no electrical position feedback means for correcting errors between the commanded position and the actual position.

NOTE: These devices usually feature centering or biasing springs on the hydraulic output stage and/or force motor.

ELECTRICAL FEEDBACK DDV: This is a DDV that uses electrical position feedback and an electronic amplifier to minimize the error between the commanded position and the actual control element position.

RIP STOP CONSTRUCTION: This is a mechanical means of construction that prevents a structural failure of one hydraulic system from propagating into another.

POSITION FEEDBACK: This is an electrical or mechanical means for closing a position loop within the DDV.

NOTE: Closed loop systems typically enjoy improved-performance characteristics and reduced sensitivity to construction variations at the cost of added complexity. Devices for electrical position feedback include LVDTs, RVDTs, ratiometric potentiometers, and Hall-effect sensors. Mechanical feedback can be accomplished using springs, linkages, or gears.

2.2.2 Electrical Characteristics

INPUT CURRENT: This is the DC or effective pulse width modulated current supplied to the motor coils expressed in amps per channel or amps total.

RATED CURRENT: This is the input current of either polarity, supplied to the motor coils, which is required to produce rated no-load flow under specified conditions of fluid temperature, number of operating channels, and differential pressure, expressed in amps per coil or amps total.

MAXIMUM CURRENT: This is the maximum input current expressed in amps per coil or amps total that may be applied to the DDV motor coils as limited by the control amplifier.

CHIP SHEAR CURRENT: This is the input current expressed as amps per coil or amps total required to produce the specified chip shear force at the valve metering element.

NOTE: Typically, the chip shear current and the maximum current are the same. However, high amplitude and high frequency dynamic response requirements may require the maximum current be higher than the chip shear current.

SUPPLY VOLTAGE: This is the maximum voltage that may be used in meeting the specified performance requirements.

RATED VOLTAGE: This is the input voltage of either polarity that is required to produce the rated current.

NOTE: This parameter is specified at 68 °F (20°C) and is expressed in VDC unless otherwise noted.

CHIP SHEAR POWER: This is the electrical power required to produce chip shear force specified at 68 °F (20°C) and expressed in watts unless otherwise noted.

CONTINUOUS POWER: The electrical power level which may be sustained for a specified time with the DDV at specified fluid and ambient temperatures, without exceeding material limitations that may damage the assembly or degrade performance beyond acceptable limits.

NOTE: Normally, this is specified at the maximum current level.

MAXIMUM POWER: This is the power level that corresponds with the maximum current level for the specified conditions of fluid temperature and ambient temperature.

NOTE: Maximum power is expressed in watts.

COIL RESISTANCE: This is the DC resistance of each motor coil expressed in ohms and measured at a nominal temperature of 68 °F (20°C) unless otherwise noted.

COIL INDUCTANCE: This is the coil self-inductance as measured at the winding leads with the motor at null.

NOTE: The inductance is expressed in millihenries (mH) and measured at 1000 Hz. Since a moving motor will generate a back-EMF that will effectively increase inductance, the user should specify whether a specified inductance assumes a locked motor or one that is free.

TRANSFORMER COUPLING: This is the mutual inductance between individual coils of the motor driven by separate control amplifier channels.

NOTE: The measurement may be expressed in V/V with the test coil left open circuit or in amps/amp with the test coil shorted and in a specified frequency range.

POLARITY: This is the relationship between the direction of control flow and the direction of input current or voltage.

DITHER: This is a low amplitude, relatively high frequency (when compared to the DDV natural frequency) periodic electrical signal, sometimes superimposed on the DDV input to reduce the threshold.

NOTE: Dither is expressed by the dither frequency (hertz) and the peak-to-peak dither current amplitude.

2.2.3 Static Performance Characteristics

CONTROL FLOW: This is the flow through the valve control ports, expressed in cubic inches per second (cis) or gallons per minute (gpm).

NOTE 1: Control flow is referred to as no-load flow when there is zero load-pressure drop.

NOTE 2: Control flow is referred to as loaded flow when there is a load pressure drop.

NOTE 3: Conventional test equipment normally measures no-load flow.

RATED FLOW: This is the specified control flow corresponding to the rated command at the specified temperature and pressure conditions and specified load pressure drop.

NOTE: Rated flow is normally specified as the no-load flow.

FLOW CURVE: This is the graphical representation of control flow versus input current or command.

NOTE: This is usually a continuous plot of a complete full-flow valve cycle (see Figure 1).

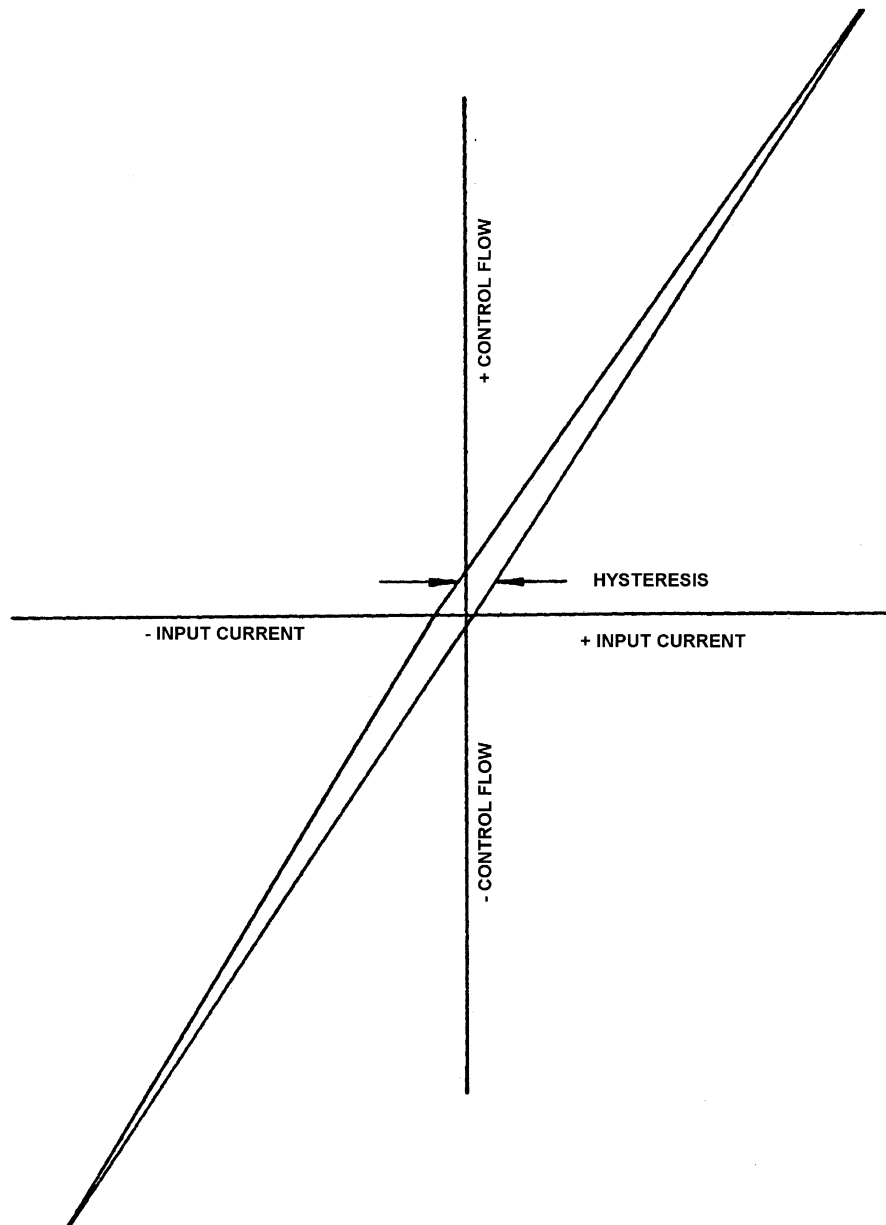


Figure 1 - Flow curve

NORMAL FLOW CURVE: This is the locus of the midpoints of the complete cycle flow curve, which is the zero hysteresis flow curve.

NOTE: Usually, valve hysteresis is sufficiently low, such that one side of the flow curve can be used for the normal flow curve (see Figure 2).

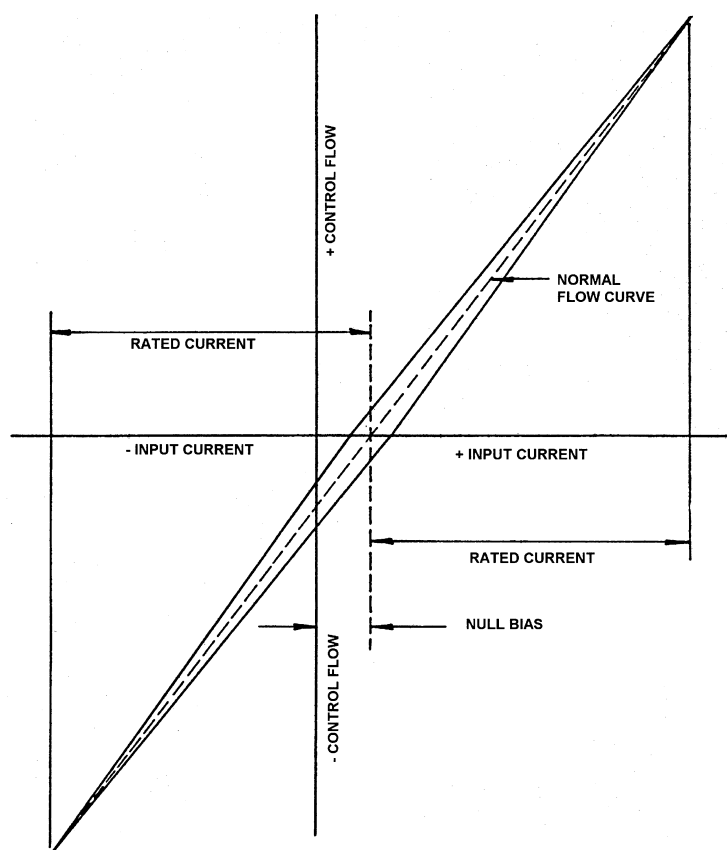


Figure 2 - Normal flow curve

FLOW GAIN: This is the slope of the control flow versus input command curve in any specific operating region, expressed in cis/A, gpm/A, cis/V, gpm/V, cc/min/A, L/min/A, L/min/V, etc.

NOTE 1: Three operating regions are usually significant with flow control valves. These are the null region, the region of normal flow control, and the region where flow saturation effects may occur.

NOTE 2: Where this term is used without qualification, it is assumed to be defined by the region of normal flow gain (see Figure 3).

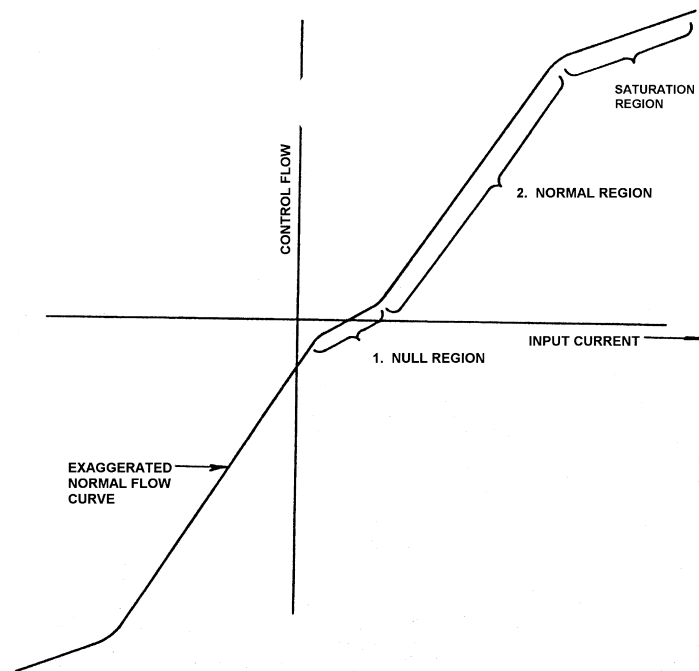


Figure 3 - Operating regions

NORMAL FLOW GAIN: This is the slope of a straight line drawn from the zero-flow point of the normal flow curve, throughout the range of rated current of one polarity, and drawn to minimize deviations of the normal flow curve from the straight line.

NOTE: Flow gain may vary with the polarity of the input, with the magnitude of load differential pressure and with changes in operating conditions (see Figure 4).

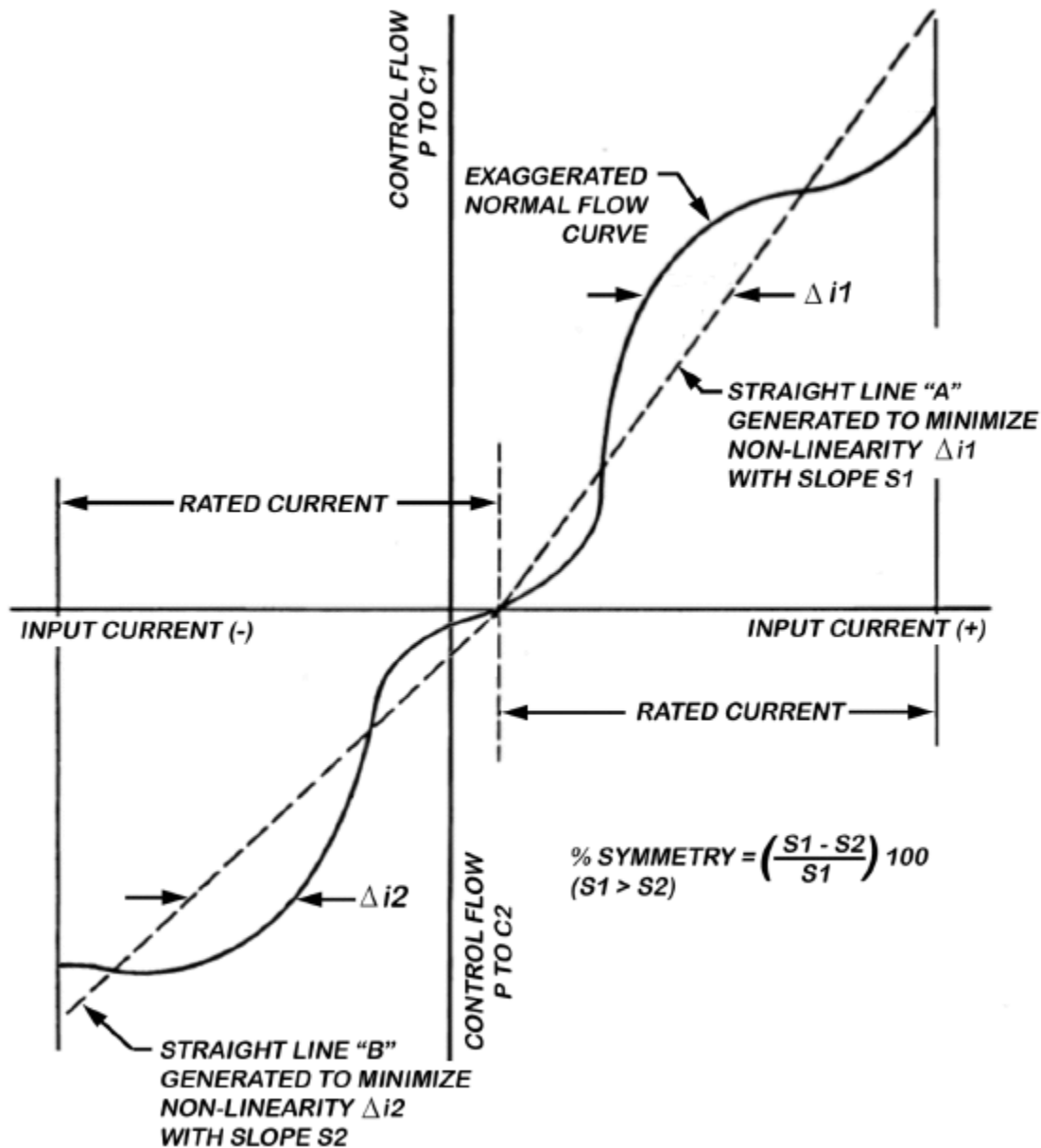


Figure 4 - Linearity/symmetry

RATED FLOW GAIN: This is the ratio of rated flow to rated current or command, expressed in cis/A, gpm/A, cis/V, gpm/V, cc/min/A, L/min/A, L/min/V, etc.

FLOW LIMIT: This is the condition wherein control flow no longer increases with increasing input current.

NOTE: Flow limitation may be deliberately introduced within the DDV.

SYMMETRY: This is the degree of equality between the normal flow gain of each polarity, expressed as a percentage of the greater (see Figure 4).

LINEARITY: This is the degree to which the normal flow curve conforms to the normal flow gain line with other operational variables held constant.

NOTE: Linearity is measured as the maximum deviation of the normal flow curve from the normal flow gain line, expressed as a percentage of the rated command (see Figure 4).

HYSTERESIS: This is the difference in the valve input command required to produce the same valve output during a single cycle of valve stroke when cycled at a rate below that at which dynamic effects are important.

NOTE: Hysteresis is normally specified as the maximum difference occurring in the flow or pressure gain curve throughout the plus or minus rated command and is expressed as a percentage of the rated command (see Figure 1 or 5).

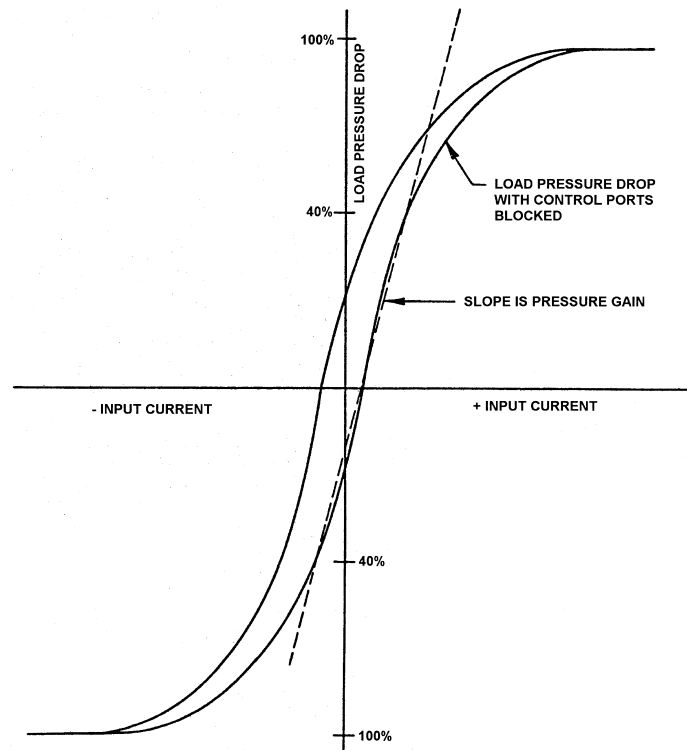


Figure 5 - Pressure gain

THRESHOLD: This is the increment of input command required to produce a change in valve output, expressed as a percentage of the rated command increment required to revert from a condition of increasing output to a condition of decreasing output, when valve command is changed at a rate below that at which dynamic effects are important.

INTERNAL LEAKAGE: This is the total internal valve flow from pressure to return with zero control flow.

NOTE 1: It is usually measured with control ports blocked),

NOTE 2: It is expressed in cis, gpm, cc/min, or L/min.

NOTE 3: Leakage flow will vary with valve position, generally being a maximum at the valve null (null leakage).

LOAD PRESSURE DROP: This is the differential pressure between the control ports, expressed in psi or kPa.

NOTE: In conventional DDVs, load pressure drop (P_L) may be expressed as an equation, wherein it is equated to the supply pressure (P_s), less return pressure (P_r), and less the valve pressure drop: (P_o). ($P_s - P_r - P_o = P_L$).

VALVE PRESSURE DROP: This is the sum of the differential pressures across the control orifices of the output stage, expressed in psi or kPa.

NOTE: Valve pressure drop will equal the supply pressure minus the return pressure minus the load pressure drop.

PRESSURE GAIN: This is the rate of change of load pressure drop with input command at zero control flow (control ports blocked), expressed in psid/A, psid/V, kPa/A, or kPa/V, etc.

NOTE: Pressure gain is usually specified as the average slope of the curve of load pressure drop versus command between $\pm 40\%$ of maximum load-pressure drop (see Figure 5).

NULL REGION: This is the region about null wherein the effects of the lap (i.e., initial metering, geometry) in the output stage are dominant.

VALVE HYDRAULIC NULL: This is the valve position where, if each valve hydraulic channel were connected to its own equal area cylinder in a tandem actuator, with a specified set of supply and return pressures, the actuator would not move.

NOTE: Except for a simplex valve, this valve position will generally not coincide with the null positions of the individual elements.

NULL PRESSURE: This is the pressure existing at both control ports at null, expressed in psi or kPa, and measured with control ports blocked.

NULL BIAS: This is the input command required to bring the valve to null, excluding the effects of valve hysteresis, expressed as a percentage of the rated current or voltage.

NULL SHIFT: This is a change in null bias, expressed as a percentage of the rated command.

NOTE 1: For open-loop DDVs, a null shift may occur with changes in supply pressure, temperature, and other operating conditions.

NOTE 2: Null shift is predominately dependent on feedback position transducer characteristics for closed-loop valves.

LAP: In a spool valve, this is the relative axial position relationship between the fixed and movable flow-metering edges with the spool at null.

NOTE: For a DDV, lap is measured as the separation of the zero flow intersections of the straight-line extensions of nearly straight positions of the normal flow curve, drawn separately for each polarity, expressed as a percentage of the rated command.

ZERO LAP: This is the lap condition where there is no separation of the straight-line extensions of the normal flow curve (see Figure 6A).

NOTE: This is also known as the critical lap.

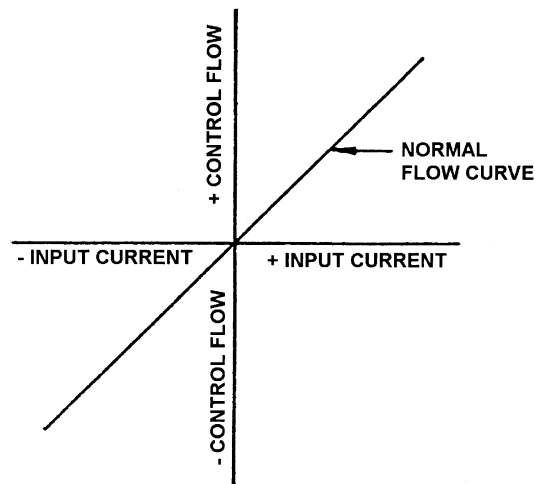


Figure 6A - View A, zero lap

OVERLAP: This is the lap condition that results in a decreased slope of the normal flow curve in the null region (see Figure 6B).

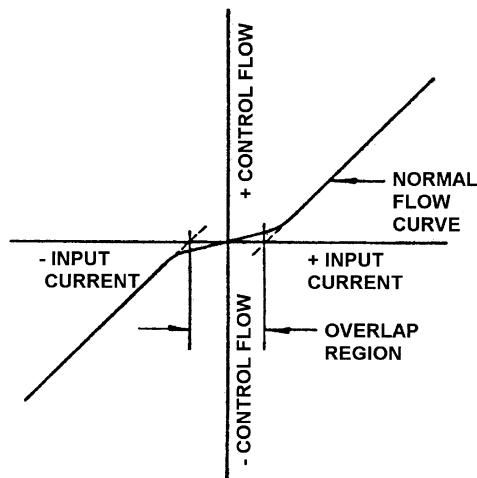


Figure 6B - View B, overlap

UNDERLAP: This is the lap condition that results in an increased slope of the normal flow curve in the null region (see Figure 6C).

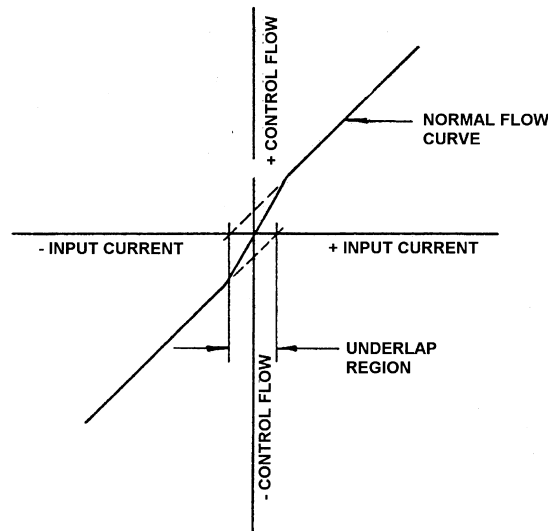


Figure 6C - View C, underlap

INTERSYSTEM LEAKAGE: This applies to tandem valves wherein fluid from one hydraulic system may be internally transferred to the other system.

NOTE 1: This is measured with one system at the specified operating pressures while the system under test is vented to the atmosphere.

NOTE 2: The leakage is usually expressed in cis, gpm, or cc/min, and this measurement is normally made with the valve held at null.

NULL COINCIDENCE: On valves that incorporate a means to measure output element position, this is the difference between the zero position measurement and the hydraulic null of the valve on each side of a tandem valve, expressed in displacement units.

PRESSURE MISMATCH: This is the differential pressure (in psi or kPa) between the output pressures of the elements of a tandem valve when the valve assembly is at hydraulic null as defined above.

FLOW MISMATCH: This is the difference in flow between any two valve elements, expressed as a percentage of the smaller flow, with the valve at a fixed position and with the same supply and return pressures applied to each system.

2.2.4 Dynamic Performance Characteristics

FREQUENCY RESPONSE: This is the complex ratio of control flow to input command as the command is varied sinusoidally over a range of frequencies.

NOTE 1: Frequency response is normally measured with constant input-command amplitude and zero load pressure drop, expressed as amplitude ratio, and phase angle.

NOTE 2: Valve frequency response may vary with the input-command amplitude, temperature, and other operating conditions.

NOTE 3: DDVs also may measure frequency response by using the output spool position if a transducer is employed.

NORMALIZED AMPLITUDE RATIO: The ratio of the control-flow amplitude to the input-command amplitude at a particular frequency divided by the same ratio at the same input-command amplitude at a specified low frequency (usually 1 Hz).

NOTE: Amplitude ratio may be expressed in decibels where $\text{dB} = 20 \log_{10} \text{AR}$.

PHASE LAG: This is the instantaneous time separation between the input command and the corresponding control-flow variation, measured at a specified frequency and expressed in degrees (time separation in seconds x frequency in Hz x 360 degrees per cycle).

2.3 Abbreviations

AC	alternating current
A	amperes
AR	amplitude ratio
°C	degrees Celsius
cc	cubic centimeters
cis	cubic inches per second
dB	decibels
DC	direct current
DDV	direct drive servovalve
emf	electromotive force
°F	degrees Fahrenheit
g	standard acceleration of gravity
gpm	gallons per minute
hp	horsepower
Hz	Hertz
in	inch(es)
kg	kilogram
k-	kilo (prefix)
lb	pounds
mH	millihenries
mW	milliwatts
P _L	load pressure
pm	pulse modulated

P_o	orifice pressure
P_r	return pressure
P_s	supply pressure
psi	pounds per square inch
pwm	pulse width modulation
μ -	micro (prefix)
μm	micrometer (micron)
V	volts
V_{rms}	volts, root mean squared
W	watts

3. PROCUREMENT SPECIFICATION

3.1 Introduction

This section is intended to be a guide for the preparation of specifications covering DDVs. Certain background information is given to explain various considerations appropriate to such specifications. This background material is presented in 3.2.

Appendix A contains a sample specification for a standard DDV.

The format of the proposed specification is:

1. SCOPE
2. APPLICABLE DOCUMENTS
3. REQUIREMENTS
 - 3.1 Design Requirements
 - 3.1.1 Mechanical
 - 3.1.2 Electrical
 - 3.1.3 Hydraulic
 - 3.2 Performance Requirements
 - 3.2.1 Rated Test Conditions
 - 3.2.2 Static
 - 3.2.3 Null
 - 3.2.4 Dynamic

- 3.3 Environmental Requirements
- 4. QUALITY ASSURANCE PROVISIONS
- 5. PREPARATION FOR DELIVERY
- 6. NOTES

The recommended specification limits included in 3.2 and Appendix A are typical of most systems and can be met with reliable DDV designs with a proven producibility. It is important to understand and appreciate that compromises can be made in the specification of a flow-control DDV. Specific performance parameters can often be improved by relaxing other performance requirements. For example, valve internal leakage can be reduced by allowing overlap, but this will cause reduced valve flow gain in the null region and resultant degraded small-signal response performance in the actuator or require some electronic compensation techniques.

Reduction of the tolerances recommended in 3.2 and Appendix A will generally affect the producibility of the DDV. Moreover, particularly close parameter control often can require a design that reduces the basic component reliability and increases its life cycle cost. Therefore, improvements over the recommended specifications should be carefully related to system performance requirements before closer parameter control is arbitrarily imposed.

3.2 Specification Considerations

3.2.1 Scope

The introductory paragraph of the DDV specification should identify specifically the type of component. It is particularly important to indicate if the valve is to be operated in the open-loop or electrical feedback mode with external electronic or electrical feedback with integral electronics. It is often helpful if a brief description of the application can be included in the introductory paragraph, together with any additional information, which describes broadly the DDV requirements. Any unusual design or performance requirements could be cited to indicate the general nature of the hardware to be procured by the specification (e.g., high temperature, high response, three-way, etc.).

3.2.2 Applicable Documents

Documents listed in this section should include those specifications and/or drawings specifically referenced in the text of the specification. All referenced specifications should apply only to the extent specified in the text of the DDV specification. Military specifications, standards, publications, etc., should be listed by number and complete title, preceded by a statement as follows: "The following documents of the issue in effect on the date of invitation for bids form part of this specification to the extent specified herein." Contractors' specifications and/or drawings should be listed under the contractor's name and should always be identified by the specific date of issue that is applicable.

The priority of any specified documents should be clearly indicated to avoid misunderstanding. Some parts of applicable government documents may be incompatible with the particular application. In such cases, it should be noted whether these should be disregarded or that approval to deviate from the requirements indicated should be obtained.

3.2.3 Requirements

3.2.3.1 Design Requirements

3.2.3.1.1 Mechanical

3.2.3.1.1.1 Design Configurations

There are many possible design configurations for direct drive valves. Most designs have some distinct advantage for a given application. It is recommended that specific configurations should not be specified unless requirements clearly indicate otherwise. The motor-to-metering element arrangements include, but are not limited to, linear motor to linear spool or plate, rotary motor to linear spool or plate, and rotary motor to rotary metering element.