SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4493 REV. A

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Superseding ARP4493

(R) Aerospace - Direct Drive Servovalves

RATIONALE

Revision A to ARP4493 is being made for the following reasons:

a. The technical information and the references called out in the document have been updated.

b. Editorial changes have been made, where appropriate, to improve the readability of the document.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) is intended as a guide to aid in the specification and testing of Direct Drive Servovalves, but does not include the associated electronic controller.

The recommendations contained in this ARP are primarily confined to the input and output characteristics of Direct Drive Servovalves (DDV). 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.

Direct drive servovalves are of two basic types: open loop and closed loop. In the case of open loop direct drive servovalves, the significant input is the motor current as is the case with electrohydraulic servovalves covered in ARP490. A closed loop direct drive servovalve 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 as well as 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 recommended practice.

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 conflict between the text of this document and 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 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP490 Electrohydraulic Servovalves

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

ARP1281 Actuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification For

ARP1383 Impulse Testing of Aerospace Hydraulic Actuators, Valves, Pressure Containers, and Similar Fluid System Components

AS4059 Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids

ARP4386 Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies

AS4536 Safety Cable Kit Procurement Specification and Requirements 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 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, https://assist.daps.dla.mil/quicksearch/.

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

2.1.3 NAS Standards

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

2.1.4 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

2.2 Recommended Abbreviations

ac - alternating current

amp - amperes

AR - amplitude ratio

°C - degrees Celsius

cc - cubic centimeters

cis - cubic inches/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

Po - orifice pressure

Pr - return pressure

Ps - supply pressure

psi - pounds per square inch

pwm - pulse width modulation

μ- - micro (prefix)

μm - micrometer (micron)

v - volts

vrms - volts, root mean squared

W - watts

3. RECOMMENDED TERMINOLOGY

The following definitions describe recommended terminology for Direct Drive Servovalves. Additional terminology may be used in accordance with ARP4386.

3.1 Servovalve, Direct Drive Flow-Control

An electrically commanded single stage flow control valve that produces continuously increasing flow in approximate proportion with the input voltage and drive current. The term "Direct Drive" implies that electrical energy is converted to metering spool motion by mechanical means.

3.1.1 Force Motor

The electromechanical device that is used to directly drive the hydraulic flow control element.

3.1.2 Number of Coils

The number of independent and isolated motor windings that may be used to drive the valve. The effect of all coils is nominally identical.

3.1.3 Output Stage

The final stage of hydraulic distribution used in a DDV.

3.1.4 Port

Fluid connection to the DDV (e.g., supply port, return port, control port).

3.1.5 Two-Way Valve

An orifice flow-control component with a supply port and one control port arranged so that action is in one direction only, from supply port to control port.

3.1.6 Three-Way Valve

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 supply port to control port and reversed valve action opens the control port to return port.

3.1.7 Four-Way Valve

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

3.1.8 Simplex DDV

A DDV that controls hydraulic flow from a single supply of fluid.

3.1.9 Tandem DDV

A DDV that simultaneously controls the flow of two independent hydraulic systems.

3.1.10 Chip Shear Force

The valve force available at the metering element to shear a lodged chip or foreign particle. 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.

3.1.11 Natural Frequency

A frequency at which, in the absence of damping, a limited input tends to produce an unlimited output. It is a function of the valve mass elements and spring rates (which includes flow forces where applicable).

3.1.12 Open Loop DDV

A DDV that has no electrical position feedback means for correcting error between the commanded position and the actual position. These devices usually feature centering or biasing springs on the hydraulic output stage, and/or force motor.

3.1.13 Electrical Feedback DDV

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.

3.1.14 Rip Stop Construction

A mechanical means of construction that isolates a structural failure of one hydraulic system from propagating into another.

3.1.15 Position Feedback

Electrical or mechanical means for closing a position loop within the DDV. 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 potentiometer, and Hall-effect sensors. Mechanical feedback can be accomplished by the use of springs, linkages, or gears.

3.2 Electrical Characteristics

3.2.1 Input Current

The dc or effective pulse modulated current supplied to the motor coils expressed in amps per channel or amps total.

3.2.2 Rated Current

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.

3.2.3 Maximum Current

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.

3.2.4 Chip Shear Current

The input current expressed as amps per coil or amps total required to produce the specified chip shear force at the valve metering element. Typically the chip shear current and the maximum current are the same.

3.2.5 Supply Voltage

The maximum voltage that may be used in meeting the specified performance requirements.

3.2.6 Rated Voltage

The input voltage of either polarity that is required to produce rated current. The parameter is specified at 68 °F and is expressed in volts dc unless otherwise noted.

3.2.7 Rated Power

The electrical power, expressed in watts, required to produce rated current. The power is specified at 68 °F unless otherwise noted.

3.2.8 Chip Shear Power

The electrical power required to produce chip shear force specified at 68 °F and expressed in watts unless otherwise noted.

3.2.9 Continuous Power

The electrical power level which may be sustained for a specified period of 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. Normally this is specified at the maximum current level.

3.2.10 Maximum Power

The maximum power level which corresponds with the maximum current level for the specified conditions of fluid temperature and ambient temperature. Maximum power is expressed in watts.

3.2.11 Coil Resistance

The dc resistance of each motor coil expressed in ohms and measured at a nominal temperature of 68 °F unless otherwise noted.

3.2.12 Coil Inductance

The coil self-inductance as measured at the winding leads with the motor at null. The inductance is expressed in mH (millihenries) 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 to rotate.

3.2.13 Transformer Coupling

The mutual inductance between individual coils of the motor driven by separate control amplifier channels. 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.

3.2.14 Polarity

The relationship between the direction of control flow and the direction of input current or voltage.

3.2.15 Dither

A low amplitude, relatively high frequency (when compared to the DDV natural frequency) periodic electrical signal, sometimes superimposed on the DDV input to reduce threshold. Dither is expressed by the dither frequency (Hz) and the peak-to-peak dither current amplitude.

3.3 Static Performance Characteristics

3.3.1 Control Flow

The flow through the valve control ports, expressed in cis or gpm. Control flow is referred to as No-Load Flow when there is zero load-pressure drop. Control flow is referred to as Loaded Flow when there is load-pressure drop (see 3.3.12). Conventional test equipment normally measures no-load flow.

3.3.2 Rated Flow

The specified control flow corresponding to rated command at specified temperature and pressure conditions, and specified load pressure drop. Rated flow is normally specified as the no-load flow.

3.3.3 Flow Curve

3.3.3.1 General

The graphical representation of control flow versus input current or command. This is usually a continuous plot of a complete full flow valve cycle (see Figure 1).

3.3.3.2 Normal Flow Curve

The locus of the midpoints of the complete cycle flow curve, which is zero hysteresis flow curve. 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).

3.3.4 Flow Gain

The slope of the control flow versus input command curve in any specific operating region, expressed in cis/amp, gpm/amp, cis/v, gpm/v, etc. Three operating regions are usually significant with flow control servovalves: (1) the null region, (2) the region of normal flow control, and (3) the region where flow saturation effects may occur. Where this term is used without qualification, it is assumed to be defined by the region of normal flow gain (see Figure 3).

3.3.4.1 Normal Flow Gain

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. 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).

3.3.4.2 Rated Flow Gain

The ratio of rated flow to rated current or command, expressed in cis/amp, gpm/amp, cis/v, gpm/v, etc.

3.3.5 Flow Saturation Region

The region where flow gain decreases with increasing command.

3.3.6 Flow Limit

The condition wherein control flow no longer increases with increasing input current. Flow limitation may be deliberately introduced within the DDV.

3.3.7 Symmetry

The degree of equality between the normal flow gain of each polarity, expressed as percent of the greater (see Figure 4).

3.3.8 Linearity

The degree to which the normal flow curve conforms to the normal flow gain line with other operational variables held constant. Linearity is measured as the maximum deviation of the normal flow curve from the normal flow gain line, expressed as percent of rated command (see Figure 4).

3.3.9 Hysteresis

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. Hysteresis is normally specified as the maximum difference occurring in the flow or pressure gain curve throughout plus or minus rated command, and is expressed as percent of rated command (see Figures 1 or 5).

3.3.10 Threshold

The increment of input command required to produce a change in valve output, expressed as percent of 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.

3.3.11 Internal Leakage

The total internal valve flow from pressure to return with zero control flow (usually measured with control ports blocked), expressed in cis or gpm. Leakage flow will vary with valve position, generally being a maximum at the valve null (null leakage).

3.3.12 Load Pressure Drop

The differential pressure between the control ports, expressed in psi. In conventional DDVs, load pressure drop may be expressed as an equation, wherein it is equated to the supply pressure, less return pressure, and less the pressure drop across the active control orifices. ($P_s - P_r - P_o = P_L$).

3.3.13 Valve Pressure Drop

The sum of the differential pressures across the control orifices of the output stage, expressed in psi. Valve-pressure drop will equal the supply pressure minus the return pressure minus the load pressure drop.

3.3.14 Pressure Gain

The rate of change of load pressure drop with input command at zero control flow (control ports blocked), expressed in psid/amp, psid/volt, etc. Pressure gain is usually specified as average slope of the curve of load pressure drop versus command between ±40% of maximum load pressure drop (see Figure 5).

3.3.15 Null Region

The region about null wherein effects of lap (i.e., initial metering, geometry) in the output stage are dominant.

3.3.15.1 Null

3.3.15.1.1 Element Null

Each hydraulic channel has its own, individual, null. It is the valve position where, with a specified set of supply and return pressures, that hydraulic channel supplies zero control flow at zero load pressure drop.

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

3.3.15.2 Null Pressure

The pressure existing at both control ports at null, expressed in psi, and measured with control ports blocked.

3.3.15.3 Null Bias

The input command required to bring the valve to null, excluding the effects of valve hysteresis, expressed as percent of rated current or voltage.

3.3.15.4 Null Shift

A change in null bias, expressed in percent of rated command. For open-loop DDVs null shift may occur with changes in supply pressure, temperature, and other operating conditions. Null shift is predominately dependent on feedback transducer characteristics for closed-loop valves.

3.3.16 Lap

In a spool valve, the relative axial position relationship between the fixed and movable flow-metering edges with the spool at null. For a DDV, lap is measured as the separation in the minimum flow region of the straight line extensions of nearly straight positions of the normal flow curve, drawn separately for each polarity, expressed as percent of rated command.

3.3.16.1 Zero Lap

The lap condition where there is no separation of the straight line extensions of the normal flow curve (see Figure 6, View A). Also known as critical lap.

3.3.16.2 Overlap

The lap condition that results in a decreased slope of the normal flow curve in the null region (see Figure 6, View B).

3.3.16.3 Underlap

The lap condition that results in an increased slope of the normal flow curve in the null region (see Figure 6, View C).

3.3.17 Intersystem Leakage

Applies to tandem valves wherein fluid from one hydraulic system may be internally transferred to the other system. This is measured with one system at the specified operating pressures while the system under test is vented to atmosphere. The leakage is usually expressed in cis, gpm, or cc/min, and this measurement is normally made with the valve held at null.

3.3.18 Null Coincidence

On valves that incorporate a means to measure output element position, the difference between the zero position of such a measurement and hydraulic null of the valve or each side of a tandem valve, expressed in displacement units.

3.3.19 Pressure Mismatch

The differential pressure (in psi) between the output pressures of the elements of a tandem valve when the valve assembly is at hydraulic null as defined in 3.3.15.1.2.

3.3.20 Flow Mismatch

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.

3.3.21 Position Measurement Error

On valves that incorporate means to measure output element position, the difference between the measured position and the actual position expressed as a percentage of the rated stroke of the output element.

3.4 Dynamic Performance Characteristics

3.4.1 Frequency Response

The complex ratio of flow-control flow to input command as the command is varied sinusoidally over a range of frequencies. Frequency response is normally measured with constant input-command amplitude and zero load pressure drop, expressed as amplitude ratio, and phase angle. Valve frequency response may vary with the input-command amplitude, temperature, and other operating conditions. DDVs also may measure frequency response by using output spool position if a transducer is employed.

3.4.2 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 5 or 10 Hz). Amplitude ratio may be expressed in decibels where $dB = 20 \log_{10} AR$.

3.4.3 Phase Lag

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).

3.4.4 Rise Time

The time required to achieve 90% of commanded spool position or flow following the initiation of a specified step command amplitude under no-load conditions.

3.4.5 Overshoot

The valve is said to have overshoot when the valve control spool momentarily travels beyond the commanded steady state position following a step command. Overshoot is expressed as the percentage of over travel with respect to the commanded position and is measured with step input commands of specified amplitude.

4. PROCUREMENT SPECIFICATION

4.1 Introduction

This section is intended to be a guide for the preparation of specifications covering direct drive servovalves. Certain background information is given to explain various considerations appropriate to such specifications. This background material is presented in 4.2. 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 4.2 and Appendix A are typical of most systems and can be met with reliable direct drive servovalve designs of 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 4.2 and Appendix A will generally affect 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.

4.2 Specification Considerations

4.2.1 Scope

The introductory paragraph of the direct drive servovalve 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.).

4.2.2 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 shall be applicable only to the extent specified in the text of the DDV specification. Military specifications, standards, publications, etc., shall 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 shall be listed under the contractors' name and shall always be identified by the specific date of issue that is applicable.

The priority of any specified documents shall 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 shall be disregarded or that approval to deviate from the requirements indicated shall be obtained.

4.2.3 Requirements

4.2.3.1 Design Requirements

4.2.3.1.1 Mechanical

4.2.3.1.1.1 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, rotary motor to rotary metering element

A single valve may control one, two or more hydraulic systems and the hydraulic control element may be two-way, three-way or four-way configuration. The drive element and position indicator, if present, may contain one or several electrical channels.

System design should take into consideration the interrelations between the DDV and other hydraulic and electric components, as they may affect overall performance.

The direct drive valve may be used either as a stand-alone device or as the first stage in a multistage servovalve.

The specification should also note if control electronics are to be provided with the DDV. Specification of the electronic equipment requirements should follow the guidelines presented in other generally accepted standards. Since the performance of the closed loop DDVs is entirely influenced by control loop architecture and design, sufficient detail should be provided concerning allowable loop gains, stability margins, feedbacks (i.e., position, rate, and acceleration etc.). In the alternate case where the prime contractor or third party subcontractor is providing control electronics, sufficient detail of a controller itself must be provided to the DDV supplier for development, integration and acceptance testing. Fault tolerance and redundancy management issues must also be covered but, with the exception of number of coils and electronic feedback devices, is beyond the scope of this document. Electronic controllers can also offer the possibilities for nonlinear gains and flow shaping, but both will require added levels of specification not presented in this document.

4.2.3.1.1.2 Physical Description

The installation requirements for the direct drive servovalve shall be specified. Those are normally referenced in a specification control drawing and include:

Envelope Drawing	Coil Connections
Mounting Details and Porting	Valve Polarity
Mating Electrical Connector	Dry Weight

If appropriate for the installation, the direct drive servovalve port connections shall be legibly marked. Suitable locations pins may be provided to prevent incorrect connection of DDV and manifold. The following identification of DDV ports is recommended:

Supply	P
Return	R
Control Port 1	C1
Control Port 2	C2

The envelope given normally represents the installation space for the direct drive servovalve. It should indicate maximum dimensions and specify the location and dimensions of electrical connectors or other critical areas if applicable.

4.2.3.1.1.3 Identification

An area on each DDV should be available for the engravement or secure attachment of identifying information. Identification as a minimum should include:

Manufacturer Model Number (Supplier's Model or Part Number) and Serial Number
Manufacturers' Name and Date of Assembly, Bar Code (if required)

The following additional information also may be included:

Part Number (Customer)
Rated Pressure
Rated Current
Fluid

4.2.3.1.1.4 Materials

Material used should conform to all applicable specifications and specified environments.

Fluid or environmental conditions, etc., often require special precautions to be taken regarding the selection of compatible materials to minimize the effects of chemical or electrical reaction, fungus growth, etc. Where applicable, these conditions should be specified.

4.2.3.1.1.5 Standard Parts

Standard parts such as MS, AN or SAE AS should be used wherever they are suitable for the purpose.

4.2.3.1.1.6 Locking Devices

All threaded parts should be securely locked or safetied by safety wiring, safety cable, self-locking nuts, or other approved methods. Safety-wire should be applied in accordance with standard NASM33540. Safety-cable should be applied in accordance with standard AS4536. Snap rings should not be used as retainers unless they are positively retained in their installed position.

4.2.3.1.1.7 Structural Strength

All parts of the DDV should have sufficient strength to withstand all loads or combinations of loads resulting from hydraulic pressure, temperature, vibration, shock, actuation, and torque loads imposed during installation and operation under rated conditions.

4.2.3.1.1.8 Seals

Seals, gaskets, and packings should be of such composition and installation as to satisfy the requirements of AS5440 for military applications or AS4941 for commercial applications. If a specific seal compound is desired for certain fluid or environmental conditions, the specification for the compound should be included.

4.2.3.1.1.9 Chip Shear Force

Chip shear force is of particular significance to Direct Drive Valves since there is typically no hydraulic power available to assist the first stage spool motion. The force motor and its associated linkage must be capable of directly imparting the specified shear force to the control element. Although no standard has yet been defined, typical specifications for flight critical applications require a minimum force that considers normal flow forces, hydromechanical spool friction, plus somewhat abnormal but reasonable induced spool friction which could occur from fluid contamination, silting, possibly an initial onset of fretting corrosion, or other reasonably realistic condition. Quite often, chip shear force also is defined as the force needed to shear a chip of specified hardness which fills some percentage of a full open metering slot, whichever is larger. Care must be taken to assure that the specified chip shear force provides ample margin for DDV performance and operation; however, over specification will have an adverse impact on the DDV design and on system performance.

4.2.3.1.1.10 Rip Stop Construction

In tandem hydraulic servoactuators, rip stop construction often is imposed upon the manifold and main ram design. Rip stop construction is intended to stop the propagation of a structural failure in one system from taking out the hydraulic supply of the second system in tandem designs. Imposing this requirement on the DDV will typically add to weight, volume, and cost.

4.2.3.1.1.11 Natural Frequency

If the direct drive valve is to be operated in the mechanical feedback mode (i.e., no position or rate feedback), the natural frequency of the valve is essentially the bandwidth of the valve. In such cases it is appropriate to specify a minimum natural frequency to meet the system requirements. If a valve is operated in an electrical feedback mode, the controller can enhance the valve stiffness, thus increasing the system's natural frequency. In this case, it is more appropriate to specify the system amplitude ratio and phase characteristics.

4.2.3.1.2 Electrical

4.2.3.1.2.1 Coil Connections

The external wiring configuration for single and redundant motor coils should be specified, together with the connector pin identification or pigtail color coding, as applicable.

4.2.3.1.2.2 Rated Command

Stating a rated current is particularly applicable to mechanical feedback DDVs. In the closed loop case, specifying a rated voltage (e.g., 5 Vdc) is more appropriate. The rated current of closed loop DDV is an independent function of flow forces and load pressures. Rated command should be specified under a specific set of test conditions including supply pressure, fluid, temperature, and control port loading.

4.2.3.1.2.3 Maximum Current

The maximum input current expressed in amps per coil or amps total should be specified and is applicable to both mechanical and electrical feedback devices. This requirement is generally set by amplifier or power supply limits. Low maximum currents tend to increase the size of the motor.

4.2.3.1.2.4 Chip Shear Current

The maximum allowable chip shear current is usually limited by available power or drive amplifier limitations. Imposing low chip shear currents will tend to increase the required motor size. The design will require close attention to thermal issues and time at chip shear current levels.

4.2.3.1.2.5 Supply Voltage

The supply voltage is generally that which is available in the system. Very low supply voltages will tend to drive current requirements higher and may negatively impact dynamic performance.

4.2.3.1.2.6 Chip Shear Power

Not normally specified since it may be easily calculated from the chip shear current and the motor resistance.

4.2.3.1.2.7 Continuous Power

Not normally specified since it may be easily calculated from the continuous current and the motor resistance. For reliability reasons, the ability of the motor to withstand an application of a current input indefinitely in a specified environment may be required.

4.2.3.1.2.8 Maximum Power

The maximum power is not normally specified because it may be easily calculated from the maximum current and the motor resistance.

4.2.3.1.2.9 Insulation Resistance and Dielectric Strength

Minimum insulation resistance of valve coils and leadout wires to the valve body should be specified under the full environment. For test purposes, it is recommended that this value be 100 MΩ under room temperature and humidity conditions following a 60-s application of a dc differential equal to 500 V. Dielectric strength between mutually insulated circuits and between insulated circuits and ground should be specified. It is recommended that this value be 1050 Vac, 60 Hz for 1 min at sea level. Repeated applications of high voltage to the DDV may eventually break down the coil insulation, so subsequent testing is usually done at 50% of initial level.

4.2.3.1.2.10 Coil Resistance

The dc resistance of the valve coil or coils should be specified. A ±10% tolerance for individual coil resistance is recommended and the temperature (usually 68 °F (20 °C)) at which resistance is measured should be stated. If more than one coil is required, it may be necessary to specify the resistance match of the coils (usually within 10% of the nominal specified resistance).

4.2.3.1.2.11 Coil Inductance

The coil inductance and the mutual inductance between any two coils and between any coil and the armature at null or full stroke may be specified. This is expressed in millihenries and is usually measured at 1000 Hz. If specified, a ±25% tolerance is recommended.

4.2.3.1.2.12 Transformer Coupling

Transformer coupling limitations may be specified. This is usually expressed in terms of coupling in a specified frequency range.

4.2.3.1.2.13 Dither

Dither can be useful for reducing the hysteresis and threshold in mechanical feedback direct drive valves but should be avoided due to concern for valve wear. Dither offers little advantage in electrical feedback valves.

4.2.3.1.2.14 Electrical Feedback Device Specification

An electrical feedback device specification must be included for electrical feedback applications and for valves that require monitoring for redundancy management applications.

4.2.3.1.3 Hydraulic

4.2.3.1.3.1 Operating Pressures

The system supply pressure should be specified together with the nominal return pressure.

4.2.3.1.3.2 Proof Pressure

The DDV should withstand, without evidence of external leakage (other than slight wetting insufficient to form a drop) or permanent performance degradation, the following proof pressures: 1.5 times the nominal supply pressure applied simultaneously to all supply and control ports for 2 min, and normal supply pressure applied to the return port(s). Normally, proof pressure tests are applied at room temperature for production acceptance test and at maximum temperature during a qualification test. Proof pressure should be applied at a maximum rise rate of 25 000 psi/min (172 500 kPa/min).

4.2.3.1.3.3 Burst Pressure

The DDV should not rupture with burst pressures of 2.5 times the nominal supply pressures on ports P, C1, and C2 (applied at a maximum rise rate of 25 000 psi/min (172 500 kPa/min) and usually at room temperature) with return open, followed by 1.5 times supply pressure applied simultaneously to all ports. The DDV shall not be required to operate after this test.

4.2.3.1.3.4 Pressure Impulse

Pressure impulse requirements for DDVs are occasionally specified as necessary to satisfy vehicle or system specifications. The following recommendations apply to a pressure impulse specification and demonstration testing when such is necessary.

A pressure impulse specification shall define the cyclic pressure conditions, DDV conditions during imposition of cyclic pressures, fluid and ambient temperatures, and required minimum number of pressure cycles. It is recommended that pressure impulses on the DDV supply port have the form of an overdamped square wave between limits of 0.33 x nominal supply and 1.50 x nominal supply. Maximum cycle rate shall be 5 Hz and dwell time at each pressure extreme shall be at least 10% of the cyclic period.

These recommended pressure limits encompass the pressure transients of most systems - the dwell time and rather slow cyclic rate allow stress equalization and total elastic deformation of components within the DDV. The overdamped waveform further provides a consistent test technique that avoids uncertainties of pressure peaks and the number of cyclic pressure stresses associated with underdamped pressure waveforms.

It is recommended that rated test conditions (other than operating pressures) be imposed during pressure impulse testing (see 4.2.3.2.1).

The DDV should withstand supply pressure impulse cycles in accordance with ARP1383 with no external leakage or other evidence of loss of structural integrity or permanent deformation of internal components. The DDV shall conform to specified performance tolerances following a pressure impulse test. One-half of the impulse cycles shall be applied with the input current at +50% rated, and the remaining half with -50% rated. DDV control ports shall be blocked during pressure impulse testing. Return pressure shall be the specified nominal.

Should it be necessary to impose a return pressure impulse requirement, the supply pressure should be the nominal specified. In any case, the magnitude of the return pressure shall not exceed that of the supply pressure during any portion of a pressure impulse cycle. It should be noted that excessive requirements for return impulse can adversely impact valve design.

Impulse pressure testing of a DDV is expected to impose severe fatigue cycles that permanently reduce useful valve life. As such, a DDV that has successfully completed pressure impulse testing should not be used for subsequent test evaluation, nor for normal field operation.

4.2.3.1.3.5 Fluid

The working fluid for the DDV should be specified. The exposure to other fluids, such as preservation oil or alternate test fluids, also should be noted.

4.2.3.1.3.6 External Leakage

Normally, the specification allows no external leakage, other than a slight wetting insufficient to form a drop, throughout all operational and environmental ranges.

4.2.3.1.3.7 Internal Leakage

Internal leakage should be specified as the maximum flow from pressure to return under rated test conditions with zero control flow. Internal leakage can vary with input current or voltage, but is usually specified as a value not to be exceeded throughout the command range. If necessary, this parameter can be specified both at null and at rated signal with different maximum limits at the two points.

The null leakage will vary greatly with the lap condition. More overlap will reduce null leakage, but will make the valve susceptible to silting with a possible adverse effect on threshold and hysteresis.

Internal leakage is usually specified and measured with no externally applied dither.

4.2.3.1.3.8 Intersystem Leakage (Tandem Valves)

Intersystem leakage on tandem valves should be specified with one system active and the other at system return. If systems are separated by a return pressure barrier, nominal expected return pressure differential pressure (50 to 200 psi) should be specified. This measurement is normally made with the valve held at null.

4.2.3.2 Performance Requirements

4.2.3.2.1 Rated Test Conditions

Unless otherwise stated, all DDV requirements apply to a set of standard test conditions as defined in this section. Any specification of performance over a range of conditions (i.e., over a range of temperatures, supply and return pressures, output loading, etc.) should be specified in 4.2.3.3. These environmental specifications are normally given as a maximum percentage variation of the particular parameter (flow gain, null, coil resistance, etc.) over the full specified range of each operating condition (valve pressure drop, temperature, etc.). If for some reason it is necessary to set the parameter tolerance at some nonstandard test condition or if some unusual environmental condition is expected, it should be so stated in this section. For example, if the valve is to be used primarily at elevated temperature, then it may be desirable to specify this temperature as a rated test condition. It should be noted that the normal tolerances given in 4.2.3.2 may not apply when the test conditions are non-standard.

The performance specifications given in 4.2.3.2 apply for operation of the DDV under the following standard test conditions:

Fluid: (Normally as specified in 4.2.3.1.3.5).

Operating pressure: (Normally as specified in 4.2.3.1.3.1).

Temperature: Normally 90 to 120 °F (32 to 49 °C) fluid and 65 to 90 °F (18 to 32 °C) ambient

Fluid Cleanliness: Conform with AS4059, Class 9 and cleaner

Command Signal: Test requirements should specify which coils are to be energized during testing. In some cases multiple coils may be energized at once.

4.2.3.2.2 Static

4.2.3.2.2.1 Rated Flow

Valve rated flow should be specified for the rated command and a particular load pressure drop. Rated flow is usually specified at no-load conditions since more accurate and more economical test methods can be employed. The tolerance for rated flow is generally ±10%.

4.2.3.2.2.2 Linearity

Linearity of the normal flow curve should be specified as maximum percent of rated command. If significant flow gain non-linearities are anticipated for a particular application, linearity should be specified over the range where linear operation is desired. Linearity, therefore, may be specified to a point less than rated signal. If direct drive servovalve specifications require a radical deviation from zero lap, it is usually advantageous to redefine linearity according to the unique requirement of the particular application. These cases are not considered in this document.

4.2.3.2.2.3 Symmetry

Symmetry of control flow on either side of null should be specified. Standard tolerance for this parameter is 10%. Intentional asymmetry can be specified, but this is a special requirement and is not considered in this document.

4.2.3.2.2.4 Hysteresis

When assessing the significance of hysteresis, the effect of direct drive servovalve hysteresis on system positional accuracy should be considered. In most systems, the magnitude of this error is sufficiently small due to electrical feedback gain such that 5% valve hysteresis is acceptable for an open loop DDV application. In closed loop applications, as a function of allowed loop gain, it should be easy to achieve a hysteresis of less than 2.5%.

Phase lag of the direct drive servovalve and of the test equipment increases the apparent hysteresis. Therefore it is important to specify and measure hysteresis under essentially static conditions. Plots of a full hysteresis loop are usually run at less than 0.03 Hz.

4.2.3.2.2.5 Threshold

Threshold should be specified as a maximum percent of rated command and the normal value is less than 2.0% for an open loop DDV application. In close loop applications, as a function of allowed loop gain, it should be easy to achieve a threshold of 1.0%. Hydraulic oil contamination will generally increase the tendency of valve parts to bind; therefore, it is important that this parameter be defined and tested according to a specified cleanliness standard. In typical positional systems, high valve threshold can cause static errors or limit cycle oscillations. In both cases it is only threshold in the flow null region of the DDV that is significant. Therefore, threshold specifications are considered to apply particularly to this region of DDV operation. If desired, specifications can require threshold measurements at additional points, usually one on either side of null. It should be recognized that additional test points are more of a check on DDV quality than performance measurements that can be related directly to system operation. In electrical feedback systems threshold is more related to loop gains, transducers used, and electronic signal condition.

4.2.3.2.2.6 Pressure Gain

Pressure gain is a parameter that must be considered when determining the accuracy of a DDV and actuator combination. Positional accuracy and static stiffness of the combination (amount of output deflection per unit of external load) are performance characteristics that relate to the DDV pressure gain.

Pressure output of the DDV is nonlinear with respect to input signal and saturation usually occurs at a small percent of rated command. Therefore, this parameter is defined over a limited range about null, usually ±40% of maximum load pressure drop. For a conventional four-way valve, maximum load pressure drop is equal to supply minus return pressure.

4.2.3.2.2.7 Flow Limit

Flow limit, when specified, is stated as a maximum flow which will not be exceeded for a peak DDV input. Load pressure drop must be defined and is usually specified as zero. Flow limit is specified only when the application requires control of this parameter. Electronic or mechanical spool stops can be employed to limit flow.

4.2.3.2.2.8 Flow Gain

Flow gain is a parameter that must be considered when determining the slew rate of the actuator. When specified, refers to the slope of the control flow versus input command in the region of normal flow control, usually defined under no-load condition. The standard tolerance for this parameter is ±10% for both open and closed loop DDV applications.

4.2.3.2.2.9 Control Flow versus Load Pressure Drop

This characteristic is usually not included in DDV specifications. When it is specified, it is generally not required as part of production acceptance tests since this characteristic is established by DDV design and is not subject to change by parts tolerance variation. Moreover, the generation of a family of load-flow curves for each unit is generally impractical from an economic point of view.

This characteristic of DDVs can be utilized to relate a loaded-flow system requirement to the corresponding no-load flow specification. The no-load characteristics are preferable for specification parameters to facilitate DDV testing. Correlation of loaded to unloaded flow is then established by special tests on a typical unit.

The specification can define the effect of varying load pressure on control flow for various constant input currents. Most DDVs present a constant orifice opening under these conditions so that increasing load pressure drop decreases the control flow by the square root relationship. For DDVs of this type, the specification can define a maximum deviation form the square root curve extending from no-load flow to zero flow (for varying load pressure drop) at a constant input current.

4.2.3.2.2.10 Null Coincidence

On valves that incorporate means to measure output element position, the difference between the zero position of such a measurement and hydraulic null expressed in displacement units.

4.2.3.2.2.11 Pressure Mismatch

Pressure mismatch is a critical parameter in tandem valve applications. A substantial mismatch will result in continuous force fighting between two power stages and may lead to actuator fatigue failures on tandem actuators. Excessive pressure mismatch can also result in system deadband that will impact system dynamics.

4.2.3.2.2.12 Flow Mismatch

Flow mismatch is not normally specified. Significant mismatch flow characteristics, however, can give rise to force fighting between power stages during actuator slewing.

4.2.3.2.2.13 Transducer Mismatch

The mismatch between the feedback transducer zero position and hydraulic null in a multi-channel system will have an impact on servo control loop steady state error and may have a significant effect on fault detection. Transducer zero position mismatch to hydraulic null, for each channel within the transducer, should be kept to a minimum and verified by test.

4.2.3.2.3 Null

4.2.3.2.3.1 Lap

Lap tolerances are independent of rated flow gain tolerances and establish the null pressure and the effective DDV gain in the null region. When a nominal zero lap condition is specified, the tolerance extends toward underlap and overlap in equal amounts.

Normally, servovalves are considered to be closed center, minimum overlap flow control valves. If significant departure from the zero lap case is intended, then unusual specification methods, not included in this document, would be required. However, it is possible to modify servovalve performance by small changes in lap conditions. These changes usually amount to tolerance relocation and have the following general effects on servovalve performance:

a. Underlap is usually specified by allowing the lap tolerance to extend between zero lap and some maximum underlap. Flow gain will vary between 100% and 200% of nominal flow gain in the null region. Pressure gain is normally higher and tendencies to silt are less than for the overlap condition. Internal leakage of the DDV at null increases as the underlap increases. Therefore, wear due to erosion of metering edges could be greater for the underlap case, and with mildly contaminated systems the internal leakage could increase more rapidly with time.

b. Overlap is usually specified by allowing the lap tolerance to extend between zero lap and some maximum overlap. Flow gain through the null region will be less than nominal gain, but will not go to zero due to clearance between the sliding member and its mating metering edge. Pressure gain will generally be lower and silting tendencies will be greater. DDV leakage at null will be low; effects of erosion wear will be less.

The total tolerance spread should be the same regardless of which lap condition is desired and is expressed in percent of rated current. This value will be the allowable variation at zero flow of the extrapolated normal flow curve-defining lap. The normal tolerances for lap are as follows:

a. Nominal zero lap = 2.5% overlap to 2.5% underlap.

b. Nominal underlap = 0% overlap to 5% underlap.

c. Nominal overlap = 5% overlap to 0% underlap.

4.2.3.2.3.2 Null Region Pressure

Lap tolerances will influence the degree to which control port pressure varies with spool position in the null region. This variation applies to four-way flow control valves and is typically measured under a zero load condition (control ports interconnected). The character is the resulting pressure plot can take a number of forms, several of which are depicted in Figure 11. Regardless of form, control pressure approaches a value midway between supply and return pressure as the spool is displaced beyond the null region, as long as the active metering slots are of equal width, as they are in most valves.

The precise trajectory of the pressure plot through null is dependent on the specific details of the output stage null cut, as well as the local variations in edge sharpness and spool clearance near the metering edges. In general though, control pressure will rise and fall according to the degree of overlap asymmetry between metering edge pairs, i.e., L_1 relative to L_3, and L_2 relative to L_4 (see Figure 11). A valve with identical metering slots, all of the same width and exactly equal overlaps at all four metering edges will produce a plot like that shown in Figure 11, Case 5. In practice, this degree of overlap uniformity is rarely achieved due to the practical difficulties of maintaining the necessary control over the individual lap dimensions.

Pressure variation through null is noteworthy because it can strongly affect the cyclic pressure loading imposed on system components controlled by the servovalve. This is due to the fact that, in most systems, the servovalve duty cycle is dominated by small amplitude excursions around null. Therefore, due consideration needs to be given to this phenomenon when specifying servovalve requirements, as well as those of system components subject to servovalve control pressure. Since valve production costs relate directly to the level of constraint imposed on the null characteristics, care needs to be taken when setting null region requirements. Table 1 provides some guidance (equal metering slot widths are assumed).

4.2.3.2.3.3 Null Bias

Many DDV designs are available which have no external null adjustments. The DDV null on these designs is set by the manufacturer and the maximum acceptable null bias should be specified. This parameter is usually set to within 2% of rated command under rated test conditions.

During the life of the DDV, the null bias at rated test conditions may change from its original setting. This is usually attributed to a continuing stress relief of the critical assemblies in the DDV and may be accelerated by the application of certain environments. As an example, a change in null bias at rated test conditions may occur as a result of the application of extreme temperature.

The long-term change in null bias is usually less than 3% of rated from its original setting. Because of the practical problem of separating the effects of initial setting and subsequent change, the specification normally requires a null bias within 5% of rated command over the useful life of the DDV. This parameter then includes the tolerance of initial setting and long-term variations. For electrical feedback DDVs, null bias is primarily a function of the feedback device adjustment. These values may usually be set lower than the normal beginning and useful life numbers previously given.

4.2.3.2.3.4 Null Pressure

In a nominal zero lap DDV, the control port pressures at valve null vary as described in 4.2.3.2.3.2.

In a tandem DDV the mismatch between the two system null pressures should be evaluated for the aspect it may have at the system level.

4.2.3.2.3.5 Null Shift

Null bias may change with the application of environments. Supply pressure, return pressure, and hydraulic oil temperature are three common variable environments and maximum allowable null shift for these environments is usually specified as a percent of rated current. When this parameter is specified, it should be defined as a maximum absolute value not to be exceeded throughout the required variation of the environments if they are determined to be critical to system performance.

4.2.3.2.4 Dynamic

NOTE: For DDVs without internal mechanical feedback, the dynamic performance requirements should be met when operating in conjunction with the loop closure electronics.

4.2.3.2.4.1 Amplitude Ratio

The dynamic transfer function of direct drive servovalves can be generally approximated by a second-order differential equation. However, since mathematical representation is approximate, the preferred method of specifying amplitude ratio is by defining graphical limits on a Bode plot. Usually, maximum and minimum limits are plotted through the frequency range of interest. For DDVs with multiple electrical channels, the performance requirements should also define the number of channels active during test.

DDV frequency response will vary with input command amplitude. Continuity of production is usually controlled by test at one particular set of operating conditions.

DDV dynamic response measured at large command amplitudes will saturate at higher frequencies due to limited voltage and/or current to the motor. Current saturation will result in an abrupt reduction in the amplitude ratio and increased phase angle. At low input command amplitude, valve threshold effects can result in a small reduction in the amplitude ratio and increased phase angle. The recommended amplitude of the input command for nominal dynamic response testing is ±25% rated command and an input amplitude of ±100% rated command for a dynamic response saturation test.

Amplitude ratio is usually normalized to a reference frequency of 5 to 10 Hz.

4.2.3.2.4.2 Phase Angle

This parameter is usually specified as a curve of maximum allowable phase lag, in degrees, plotted through the frequency range of interest. The general comments and specification recommendations of the previous paragraph apply equally to phase angle definitions.

4.2.3.2.4.3 Motor Current Limiting Frequency

The frequency of current saturation should be specified for ±100% rated command.

4.2.3.3 Environmental Requirements

Direct drive servovalves for aerospace applications are designed to meet certain specific environments and will perform their designed function fully in some, and to a limited degree in others. It is important to be aware of the environments in which limited performance is to be expected and also the specific performance parameter most affected by a particular environment.

Some of the environments which are normally encountered by DDVs and the specific areas of performance which are affected are the following:

a. Temperature: DDV performance, at various temperatures, will be greatly influenced by the viscosity of the fluid. As an example, only limited flow performance will be obtained below fluid temperatures of -20 °F (-29 °C) using MIL-PRF-83282 as the operating fluid.

b. Altitude: Normally, the only DDV characteristics that are affected by altitude are insulation resistance and dielectric strength.

c. Vibration, Acceleration, and Shock: Normally, the only DDV characteristics which are affected by these environments are null stability and structural integrity.

d. Humidity, Salt Spray, and Immersion: Normally, the only DDV characteristics that are affected by these environments are insulation resistance, dielectric strength, and integrity of protective finishes.

e. Fluid Contamination: Dependent upon the degree of contamination, a DDV may be expected to perform to specification for a limited period of time only. Care must be taken to be sure that the operating life desired and the contaminant level are compatible. With very high levels of contamination valves may be subject to “silt lock”.

f. Life: The performance of a DDV is a function of many factors that may reduce its life. These factors include extreme environments, fluid contamination, and frequency and magnitude of electrical and pressure overloads. A DDV is designed to perform many millions of cycles and should have a useful life exceeding 5000 h. However, dependent on the above factors, some degradation of performance is to be expected. In particular, high levels of fluid contamination will cause increases in internal leakage flow, increase nonlinearity through the null region, decrease pressure gain, and will probably increase both hysteresis and threshold. The other factors mentioned will tend to cause similar changes in performance. It is, therefore, very important that proper consideration be given to any life test conducted in view of the differences between the actual operating conditions and those employed during life testing. Additionally, if severe operating conditions are imposed during an extensive life test, some allowance for degradation of performance must be made.

DDV performance is not normally affected by such environments as sunshine, sand and dust, rain, and fungus. If exceptional environments, such as radiation or corrosive atmosphere, will be encountered in a particular application, then a special environmental requirement should be specified.

4.2.4 Quality Assurance Considerations

Quality assurance provisions are outlined to establish a means of test and inspection for a DDV in order to assure that all critical design parameters of the valve have been met and are maintained. These tests may be required at either or both vendor and procuring agency facilities, or in combinations as specifically outlined in each test specification.

4.2.4.1 Quality Assurance General Requirements

Information pertaining in general to test equipment, method of testing, or the inspection techniques may be outlined below to prevent redundant statements in the procedures. Where applicable, control documents should be included.

4.2.4.1.1 Classification of Tests

The types of tests that are necessary to establish and maintain control on the DDV design are generally described as:

Qualification Tests: See example in A.4.2

Acceptance Tests: See example in A.4.3

Life/Reliability Tests: See example in A.4.4

4.2.4.1.2 Calibration of Instrumentation

All measuring and testing equipment must be maintained in a calibrated condition to provide the standards that are necessary to define DDV operating characteristics. Tolerances in test measurements should be accounted for in defining the operating limits; therefore, it is imperative that these tolerances be held to a minimum. The standard test equipment used by a DDV manufacturer is equally scaled to obtain maximum readability and accuracy. If special test equipment is required, the method and equipment tolerances required should be specified.

4.2.4.1.3 General Test Notes

These notes should define all conditions, values, and procedures that will be standard throughout the majority of the tests. Items such as fluid type, filtration required, and ambient and fluid temperatures are described. Caution notes for cleaning test manifolds and bleeding air from the system may be detailed.

4.2.4.2 Qualification Tests

Qualification tests may be conducted on a sample group of units selected at random out of the first production valves from the manufacturer. These tests are normally conducted by the manufacturer per test procedures, which are approved by the buying agency. These tests are conducted to demonstrate compliance with design and performance requirements, particularly throughout extremes of environments.

The number of units subjected to a qualification test and the particular tests will depend on the final system requirements, previous experience with a particular valve model, and other test information and statistics available from the manufacturer.

The following are normally included in a DDV qualification test program:

Preparation of Test Unit
Proof Pressure Test
Acceptance Tests
Extreme Temperature Tests
Life Test
Burst Pressure Test
Altitude Test
Vibration Test
Shock Test
Humidity Test
Salt Spray Test
Immersion Test
Contamination Test
EMI Test

All information pertaining to the maintenance of parts, procedures, and data for these tests should be described. Such items as approvals required for the test procedures, rework and retest instructions in case of a failure, identification of the test parts, and the type and number of copies of final data required should be outlined.

4.2.4.3 Acceptance Tests

Acceptance tests are conducted on each unit delivered by the manufacturer. These tests prove conformance to design limits as established by the design specification. Testing is generally conducted on standard test equipment at ambient room temperature with the hydraulic fluid at normal operating temperature.

The following parameters are normally included in an acceptance test procedure:

Examination of Product
Coil Resistance
Insulation Resistance
Internal Leakage
Null Bias
Threshold
Null Pressure
Null mismatch (tandem valve)
Dynamic Performance
Symmetry
Pressure Gain
Dielectric Strength
Proof Pressure
Polarity
Rated Flow
Linearity
Hysteresis

4.2.4.4 Life/Reliability Tests

Reliability tests may be conducted on a periodic sampling basis throughout the production run to assure that the required level of reliability is maintained. Life tests may also be run to establish confidence in a new design or where a unit has unusual operating conditions or environment. Tests of this nature usually define life expectancy by imposing a given number of typical operating cycles with or without extreme environmental conditions.

4.2.5 Preparation for Delivery

This section should specify all delivery requirements. Standard items usually noted include container requirements, interior packaging, package markings, and wrapping. Requirements that are somewhat unique to DDVs, such as flushing, and use of preservative fluids also should be included in this section.

4.2.6 Notes

Miscellaneous ordering data are specified in this paragraph. If a definition of terms is included in the specification, it should be presented in the notes.

5. RECOMMENDED TEST METHODS

5.1 General

This section is intended to be a guide in establishing test procedures for performance measurements of electrohydraulic flow control DDVs. The characteristics covered include static and dynamic performance, but are limited to acceptance type of testing. Test methods for qualification tests (including performance under specific environments) are only to be covered in a general nature.

Most DDV performance characteristics can be obtained utilizing either continuous plotting equipment, automated discrete point testing against limits or manual point-by-point methods. For visual description, the use of continuous plotting is described herein. The use of overlays is discussed. In general, where alternate methods of testing are acceptable, one method will be described and the others mentioned. It should be noted that no order of testing is implied by the following sections except where specifically noted and reasons stated.

The acceptance parameters of applicable static performance characteristics are expressed as percentages of rated input command or current. However, it should be noted that these parameters may be expressed directly in current units. The test methods recommended are those in most general use. Conformance with these procedures will assure test uniformity, and will aid in the correlation of performance measurements.

5.2 Test Equipment

Figures 7 through 10 are sample schematics describing equipment that may be used to test DDVs for various parameters. These schematics are intended to show basic system operation. However, additional components are required to provide convenience or safety when constructing a test stand. In designing equipment for testing of DDVs, there are many aspects to be considered. These include:

a. Hydraulic lines should be placed to have a minimum number of bends. Sizing hydraulic lines to minimize pressure drop relative to flow requirements also is important. Care should be taken to minimize mechanical and hydraulic vibration of the test stand.

b. DDV mounting manifold should be of adequate design to assure rigidity and prevent deformation under application of pressure. For a face seal DDV the mounting surface of the test manifold should be adequately flat to prevent DDV body deflection during installation. Normally, the mounting manifold surface, in the sealing area, should have a 32 μin (0.8 μm) rms finish flat within 0.001 in (0.025 mm) total indicator reading and free of all burrs, nicks, and scratches.

5.3 Electrical Tests

5.3.1 Insulation Resistance and Dielectric Strength

The DDV need not be pressurized for this test; however, if internal electrical components are in contact with the fluid, the DDV must be filled with hydraulic fluid.

Apply specified voltage between the coil terminations (connected together) and the DDV body. Maintain the test voltage for specified time. With the test voltage still applied, measure the current. The applied voltage level divided by the measured current value gives the insulation resistance. (Equivalent electrical instruments may give the insulation resistance directly.) With a four-lead, two-coil configuration, this test may also be performed between the coils.

5.3.2 Coil Resistance

The DC resistance of the coil, or coils, should be measured and the ambient temperature recorded. If the recorded temperature is other than the specified temperature, a correction may be applied as follows:

$$R = R1 \times [1 + a1 \times (T - T1)] \quad \text{(Eq. 1)}$$

$$a1 = 1 / (390.1 + T1), \text{ for T in °F}$$

$$a1 = 1 / (234.5 + T1), \text{ for T in °C}$$

where:

a1 - Temperature coefficient of resistivity (copper conductor assumed), °F -1 (°C - 1)

R1 = Measured resistance, ohms

R = Corrected resistance, ohms

T1 = Actual temperature, °F (°C)

T = Specification temperature, °F (°C)

If the DDV has a three or four lead coil connection, the resistance of each coil should be measured separately. A conventional Wheatstone bridge type electrical test instrument is usually used. The DDV should not be supplied with pressurized fluid during this measurement, and time should be allowed to stabilize its temperature at room ambient.

5.3.3 Coil Impedance

Due to the large amount of DDVs and drive configurations available, a method to measure or calculate the coil impedance as a function of frequency is not provided herein.

5.4 Steady-State Performance Tests

After installing the DDV onto the test equipment and before any tests are performed, the unit should be cycled several times between rated input extremes with hydraulic pressure applied to the supply port, and the control ports interconnected. This eliminates air from the unit and the test system, and stabilizes the unit at the temperature of the fluid supplied.

5.4.1 Polarity

Apply rated supply pressure to the DDV supply port, and close the load valve(s) to block the control ports. If coils are so connected, and if desired, apply quiescent current of the polarity defined in the specification. Apply at least half rated input current with polarity as indicated in the specification. Observe the pressure at each control port. The specified control port should show a higher pressure than the other control port. If the force motor contains two coils, which are externally accessible (that is, three or four leads are brought out), this test should be conducted separately for each coil.

This test also may be conducted with the DDV control ports opened to the flow measuring cylinder by observing the direction of piston travel when input current is applied.

5.4.2 Proof Pressure and External Leakage

With the load valve(s) closed and return valve(s) open, apply the specified proof pressure to the DDV supply port at a maximum rise rate of 25 000 psi/min (172 500 kPa/min). Apply rated input current of either polarity and maintain for 2 min. Reverse the input current polarity and maintain for 2 min.

Reduce the input current and the supply pressure to zero, and close the return port shutoff valve. Apply specified return proof pressure to the supply port at a maximum rise rate of 25 000 psi/min (172 500 kPa/min) and maintain for 2 min. Open the return port shutoff valve and reduce the supply pressure to zero. During and after the application of the specified proof pressures, observe the DDV for permanent deformation and external leakage.

5.4.3 Flow Curve

The flow curve generated by the procedure described in this paragraph may be used to measure the following parameters: rated flow, hysteresis, symmetry, linearity, and null bias. Reference Figures 1 and 7.

To generate the flow curve, apply rated supply pressure to the DDV. Connect one input channel of the X-Y plotter to measure input current, and the other channel to measure control flow.

Generate zero flow and zero current lines on a sheet of paper installed onto the X-Y plotter, obtain zero flow and zero input current conditions, and align the X-Y plotter pen to the intersection of the lines. Connect the DDV load ports to opposite ends of the flow measuring cylinder, and cycle the input current between plus and minus rated input current. Complete at least one cycle with the X-Y plotter pen raised off the paper, and then lower the pen and plot one complete cycle. The rate of cycling should be slow enough to minimize any errors that might be generated in the plot as a function of speed. It is sometimes advisable to reduce the cycling speed as the unit passes through null to avoid producing a nonlinearity of the plot as the flow measuring piston reverses direction.

Except for null bias measurements, the hysteresis of the DDV will normally be sufficiently low that there will be negligible error in taking either side of the plotted flow curve loop as the Normal Flow Curve. Should this not be the case, construct the Normal Flow Curve by drawing a curve through the midpoints between the two sides of the plotted curve. Construct a Normal Flow Gain Line, on each half of the flow curve, from the point of zero flow of the normal flow curve. The normal flow gain line is a straight line drawn to minimize the deviation between itself and the normal flow curve.

5.4.3.1 Rated Flow

Measure the flow at plus and minus rated current. Rated current is measured from null and does not include null bias current.

5.4.3.2 Hysteresis

Disregarding plotter non-linearities or DDV lap effects in the null area, locate the section(s) of the flow curve of greatest width parallel to the current axis (zero flow line), and measure the current difference at this point. Divide this difference by the rated input current, and convert the result to a percent

Hysteresis of the DDV also may be measured from the pressure gain plot described in 5.4.7, when the plot is obtained by cycling between plus and minus rated current. This permits measurement in the null region of the unit (not generally advisable when using the flow plot), but is usually limited to this region because of the high-pressure gain of most flow control DDV.

5.4.3.3 Symmetry

Determine the flows at equal increments of current on both sides of the zero flow point of the normal flow gain lines. Calculate the symmetry of the DDV by dividing the difference between the two flows by the larger flow, and converting the result to a percent.

5.4.3.4 Linearity

Measure the maximum current difference between the normal flow curve and the normal flow gain line. Divide this difference by the rated input current, and convert the result to a percent.

5.4.3.5 Null Bias

Measure the current at the midpoint between the two sides of the flow curve at zero flow. This current is the null bias of the DDV.

The accuracy of this null bias measurement is adequate for most applications. If desired, however, null bias may be measured with greater accuracy by obtaining a flow plot with an expanded scale, after first cycling to eliminate residual hysteresis.

A pressure gain plot (see 5.4.7) also may be used to measure null bias. If the pressure gain plot is used, it is necessary to obtain a current zero and differential pressure zero in the same fashion as described above for the flow curve zeros. In this case, it is not necessary to establish a current zero on the flow curve.

5.4.3.6 Null Shift with Pressure

a. Supply Pressure: Increase supply pressure to the high value defined in the specification. Generate a flow (or pressure) curve. Measure the null bias. Reduce supply pressure to the low value defined in the specification and repeat the null bias measurement. Algebraically subtract each of the null bias values from that at rated test conditions. Convert the differences to percents of rated input current.

b. Return Pressure: Repeat the procedure described in step a. with supply pressure maintained at its rated value and with return pressure maintained at the high and low values defined in the specification.

5.4.4 Lap

Generate a flow curve of suitably expanded proportions to permit evaluation of the DDV lap condition. Locate the nearly straight portions of the normal flow curve (see Figure 3) and with straight lines extend them to intersect the zero flow axis. The points of intersection, if coincident, indicate a zero lap condition. Underlap or overlap causes a separation of the intersection points, which is measured and expressed as a percentage of rated input current. See Figures 6A, 6B, and 6C.

5.4.5 Threshold

DDV threshold may be evaluated in conjunction with either flow or pressure measuring equipment. In either case an expanded recording of the output versus input current is preferred. Input command to the DDV must be varied at a rate slow enough to avoid any dynamic effects and the equipment resolution must be sufficiently high to permit accurate observation of the DDV threshold.

Generate a plot by varying the input current to cause first increasing then decreasing DDV output. The DDV threshold is measured from the recording as the input current change necessary to cause DDV output to revert from increasing to decreasing and is expressed as a percentage of rated input command.

5.4.6 Internal Leakage

The total internal DDV leakage at rated pressure with control ports blocked is determined with flow measuring equipment as indicated in Figure 8. A recording of internal leakage versus input current from rated current of one polarity through zero to rated current of opposite polarity will enable the maximum leakage to be determined. Generally the recording sensitivity is increased to improve flow measuring accuracy. Recording speed should be sufficiently slow that an accurate flow measurement is obtained.

5.4.7 Pressure Gain

With control ports blocked, generate a plot of load pressure drop versus input current throughout the null region. When using conventional pen type recorders, it is important to achieve a very slow rate of input current variation and thereby avoid pen velocity effects.

5.4.8 Null Pressure

For a four-way DDV, null pressure is the control port pressure when the difference between C1 and C2 is zero, with both control ports blocked. For a three-way servovalve, null pressure is also measured with the control port blocked. The value of null pressure for a three-way valve is specified by the procuring activity, and is the pressure which results in zero flow to or from the control port, when the DDV is installed in the system.

5.5 Dynamic Response Tests

5.5.1 Test Circuit Considerations

a. The test circuit should be designed to minimize fluid compliance. Factors affecting compliance include:

   1. Volume of fluid and hydraulic line length between the DDV and the test actuator.

   2. Type of hydraulic line (rigid tubing or flexible hoses).

   3. Volume of fluid (total displacement) within the test actuator.

b. Fluctuations of supply or return pressure should be minimized

c. The test actuator should have low mass and friction so that the DDV will be tested at essentially no load

d. The resonant frequencies of the test actuator and test equipment should be significantly above the range of DDV test frequencies.

e. The test equipment servoamplifier design should consider the attenuation resulting from the DDV inductance. The servoamplifier should be capable of providing the same current across the required frequency range as the aircraft/user amplifier.

5.5.2 Conditions of Measurement

a. A constant amplitude undistorted sinusoidal input current should be provided to the DDV. The peak-to-peak amplitude of this signal should be adjusted to one-half rated input current.

b. The lowest test frequency or reference frequency is usually 5 or 10 Hz.

c. The frequency range of the test should be selected in accordance with the appropriate specification.

5.5.3 Performance of Test

a. Plot the amplitude ratio and the phase lag of the DDV versus the log of frequency throughout the frequency range of the test.

b. Recorder speed should be sufficiently slow to eliminate spurious dynamic effects of the instrumentation.

5.6 Use of Overlays

Assessment of DDV performance obtained by X-Y plots of both steady state and dynamic characteristics (see 5.4 and 5.5) are readily accomplished through the use of overlays showing acceptable performance limits. Overlays are particularly well suited to production acceptance testing and receiving inspection of DDVs where clear-cut acceptance or rejection of the DDV is the primary concern. Use of overlays can eliminate manual data reading and graphical construction. They provide convenient and rapid test criteria, which can be utilized by production personnel with a minimum of training and experience.

Overlays provide only a "go, no-go" acceptance criterion. Also, the most convenient overlays for assessing DDV linearity and lap do not represent precise interpretation of the terminology given in Section 3. However, overlays can be constructed which provide rigid control of these DDV parameters and often they give even tighter control of DDV performance.

Overlays should be prepared on a material having good dimensional stability such as translucent Mylar. Usually the overlays for all steady state performance tests can be contained on a single sheet, and overlays for dynamic performance tests on a second sheet. Typical acceptance test overlays are shown in Figure 12.

The overlays should contain both reference axes for careful alignment with the actual DDV data plot. It is recommended that actual plots be obtained with zero X and zero Y on each DDV data sheet for use in aligning the overlay (rather than trust to preprinted grid paper).

Part (A) of Figure 12A is an overlay for the no-load flow plot taken throughout the range ±100% rated current input. Alignment with either null point should confirm acceptable rated flow, polarity and null bias. The maximum separation of the no-load flow plot should be within the hysteresis limit of Figure 12A, Part (B).

Either side of the actual no-load flow plot is generally used to assess DDV linearity. Several different types of overlay limits can be used for linearity, and the most suitable type will depend upon the control needed for specific nonlinearities (for example, flow saturation, flow irregularities, servovalve lap, and symmetry). A convenient overlay is a pair of parallel lines drawn at a slope corresponding to rated flow and rated current (see Figure 12A, Part (C). These overlay limits define the straightness of the flow curve throughout the length of the overlay.

This length can be selected to control nonlinearities throughout any desired portion of the flow curve. The overlay shown in Figure 12A extends from about -10 to +100% of rated current, so includes flow saturation, flow irregularities in the normal control region, and nonlinearity of the lap region. A second pair of limits can be included and used in conjunction with the first for a check of symmetry (as illustrated).

The linearity overlay shown would be rotated as necessary for use with DDVs having rated flows throughout the allowable range. If DDV linearity, as defined in 3.3.8, Linearity, is measured from the overlay, there will be a small variation corresponding to rotation of the overlay. This variation will depend upon the scale factors selected for the flow plot and the range of rated flows allowed. Typically, the variation of the linearity limit due to rotation of the overlay will be ±5% of the specified linearity, or ±0.25% rated current for a ±5% linearity specification.

An alternate linearity overlay could be a pair of arrows similar to (B) in Figure 12A. This limit would be used in conjunction with a line drawn on the DDV flow plot. The line would be drawn parallel to the normal flow gain line and through a point of maximum nonlinearity.

An expanded current scale is generally used for the DDV pressure gain plot. Performance limits for pressure gain are shown in Part (D), Figure 12B. DDV threshold should also be measured with expanded scales, using suitable overlay limits (E) in Figure 12B. If flow gain at null is critical, then a separate overlay may be used to assess linearity through null. This overlay could be similar to the linearity overlay discussed previously, but would be used in conjunction with an expanded flow plot in the null region. An overlay can be used for checking DDV leakage, as shown in Part (F), Figure 12B.

Limits used for the overlays should reflect the intent of the specification requirements in areas where overlays do not give literal interpretation of performance terminology. In these cases both customer and supplier must agree upon actual overlay limits, and both should use duplicate overlays for their DDV test criteria. Often the DDV specification requirements can be expressed by overlay limits rather than by individual performance specifications.

It should be clearly understood what edge of the overlay limit lines constitute acceptable performance. Here, it is recommended that the outer edges of the limit lines be drawn to the performance limits, so that the DDV data, which is visible outside the limit lines, show unacceptable performance. Suitable allowance should be made for plotter pen effects.

5.7 Environmental Tests

Environmental tests are not usually run as a part of normal acceptance testing. They are most often conducted on a small sample, representative of production units, as a part of a development or qualification test program. If the specification can be satisfied by a standard DDV design, it may be possible to qualify by similarity. In this case, the DDV manufacturer may have sufficient applicable data already documented.

The environmental tests described in this section include all environments noted in this document. General test philosophy is presented and special precautions are noted. MIL-STD-810 or RTCA DO-160 may be used as a guide for environmental testing.

5.7.1 Temperature

Temperature environmental testing discussed in this section is intended to establish compliance with Type II requirements for hydraulic components, operating with the specified system fluid. The basic temperature range of -65 to +275 °F (-55 to +135 °C) is broken into three regions of interest:

a. Extreme low temperature, storage and start-up (-65 °F (-55 °C)).

b. Low temperature, operational (-20 °F (-30 °C)).

c. High temperature, operational (+275 °F (+135 °C)).

NOTE: Some hydraulic fluids, such as MIL-PRF-83282 fluid, at temperatures below 0 °F (-18 °C) have significantly higher kinematic viscosities than MIL-PRF-87257. Therefore, if such a fluid is used, the temperature boundaries defining these three regions will need to be revised upwards.

Equipment definitions will be the same as those noted in 5.2, as applicable, except that the fluid source must provide for fluid temperature control between -65 °F (-55 °C) and +275 °F (+135 °C). Some special precautions are necessary, however, in the fluid system. Care must be taken to remove all traces of water from the operating fluid. If ice particles form at low temperatures, DDV performance can be affected. Likewise, at high temperatures it is important to prevent fluid breakdown. Therefore, it is recommended that an inert gas head be maintained in the reservoir for operation above 150 °F (65 °C).

When conducting -65 °F (-55 °C) tests, the unit should be cold soaked until stabilized at this temperature. Prior to any performance test, the unit should be cycled with -65 °F (-55 °C) fluid, with control ports blocked, at ±50% rated signal for a maximum of 20 cycles at a maximum rate of 0.25 Hz.

At -20 °F (-29 °C) and +275 °F (+135 °C) some operational parameters are usually measured. It is important to stabilize the DDV and fluid at the test temperature prior to conducting the test. It is common practice to run tests under standard test conditions, before and after the tests at -20 °F (-29 °C) and +275 °F (+135 °C) so that performance changes, such as null shifts, can be determined.

5.7.2 Altitude

Since DDVs are designed to operate at very high absolute pressures, the change in external pressure due to altitude changes is insignificant and can be ignored. Insulation resistance, however, can be affected; especially where terminal connections are exposed to the environment. Therefore, only this test need be conducted during application of the environment. Since no permanent performance changes result from this environment it is not necessary to run pre and post-environmental performance tests. The insulation resistance test is conducted in accordance with 5.3.1 with the specimen placed in a suitable vacuum chamber.

5.7.3 Vibration

One purpose of this test is to prove that the DDV will maintain its structural integrity during and after application of the specified vibration levels. Another aspect is DDV performance during the presence of vibration (in particular, null shift and control flow caused by the vibration frequency). To determine DDV performance during vibration, it is necessary to operate the DDV and make appropriate measurements. It is impractical to perform tests for individual DDV parameters during the vibration test. Therefore, it is recommended that the DDV be cycled in a low gain closed loop during vibration with command, output, and error signal continuously recorded.

The amplitude and frequency of the command to the closed loop should be low so that flow saturation does not occur. Error signal traces will then reflect DDV threshold, null shift, or any DDV instabilities that may occur. The recommended procedure is to adjust the loop gain to about 40/s and apply a triangular command signal of 1/3 Hz, which calls for a velocity not to exceed the equivalent of 10% maximum DDV flow.

The DDV vibration fixture should be designed for low cross talk and so that no resonances occur below 3000 Hz. The fixture should allow the unit to be vibrated along each of the three mutually perpendicular axes and provide all hydraulic and electrical connections. In addition, the fixture shall contain provisions for accelerometer mounting near the attach point of the DDV for each of the three axes.

5.7.4 Sustained Acceleration

Sustained acceleration conditions allow for specific parameter measurements during application of the steady state environment. The pertinent DDV parameters that may be affected by this environment are threshold and null bias. Each of these parameters can be measured in the blocked load condition. Therefore, only supply and return connections need be provided, with pressure transducers in the two blocked control ports.

Special precautions should be taken in this test set-up to avoid DDV contamination. Since hydraulic fluid must be supplied to the test specimen through a rotary joint, it is important to carefully flush the entire system prior to DDV test. It is also advisable to include a filter in the supply line downstream of the rotary joint. Additionally, care must be taken to keep pressure instrumentation as physically close to the valve as possible to minimize errors resulting from accelerated columns of fluid.

5.7.5 Shock

Shock tests are intended to prove structural integrity during and after application of the specified shock level. Because the time of application is extremely short, it is virtually impossible to measure actual DDV performance during the shock test. The primary measurement consists of comparing DDV performance before and after the application of shock. Normally, the DDV is pressurized during this test.

If a measurement during the shock test is necessary, pressure transducers with high dynamic response can be placed in the blocked control ports and the unit pressurized during shock applications. If the shock wave causes a DDV oscillation, or null shift, this will be detected by the pressure transducers.

The shock test fixture should allow DDV orientation in three axes and should not have any significant resonances below 3000 Hz. In addition, the fixture should provide supply pressure and return connections to the DDV and, if required, contain the pressure transducers in the DDV control ports. Fluid volume in the blocked control ports should be kept to a minimum.

5.7.6 Humidity

This environmental test is classified as passive so the DDV need not be operated nor pressurized during application of the environment. The insulation resistance test per 5.3.1 should be run before and after this environment.

No special test equipment unique to DDV is required during this environmental test. Special precaution should be taken to seal the base ports of the DDV with a dummy manifold and insert the mating electrical connector prior to the humidity tests.

5.7.7 Salt Spray

This environmental test is classified as passive so the DDV need not be operated nor pressurized during application of the environment. The insulation resistance test per 5.3.1 should be run before and after this environment, and external leakage per 5.4.2. Again, caution must be taken to seal the base ports of the DDV and to insert the mating electrical connector during application of salt spray.

5.7.8 Fungus Resistance

This environmental test is classified as passive so the DDV need not be operated nor pressurized during application of the environment. The insulation resistance test per 5.3.1 should be run before and after this environment, and external leakage per 5.4.2. Base ports should be covered and the mating electrical connector inserted prior to testing.

5.7.9 Performance in Contaminated Fluid

This environment has not been standardized nor has acceptable performance of the DDV been clearly defined by past practice. Additionally, it is difficult to control the contamination conditions during this test in a manner that will ensure test repeatability.

DDV performance, as affected by contamination, is assessed in two ways:

a. Operation during application of the environment is continually monitored to measure general performance, threshold in particular.

b. Effects of fluid erosion are measured by complete performance tests before and after application of the environment.

SAE J2470, a contaminant sensitivity test procedure has been developed by the SAE. This procedure consists of tests, which measure sensitivity to silt lock (including magnetic particles for electrohydraulic servovalves). These short, standardized tests, with high levels of contamination, do not establish performance requirements. Rather, they provide a means for making repeatable comparisons of performance between servovalve designs. Performance requirements can be developed based on testing. Any performance requirements should reflect the specific requirements of the intended application. A test procedure to evaluate the wear characteristics of a valve using this test system and contaminants is under development.

5.7.10 Life

DDV life tests are directed towards establishing the extent of performance degradation after the specified life requirements. DDV output is continuously monitored to insure that the test unit remains operational during the entire life test schedule. Complete performance tests are run before and after life testing. Intermediate performance tests are optional.

The primary purpose of life tests is to assess performance degradation due to normal usage. Therefore, it is important that the DDV not be exposed to abnormal environments during the test program. In particular, fluid contamination during the test period should be carefully controlled to remain within levels expected for in-field service, since DDV wear is largely a function of contamination.

For the purpose of possible product improvements, it may be desirable to perform a complete disassembly and inspection of the DDV subsequent to the life test.

6. NOTES

6.1 A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

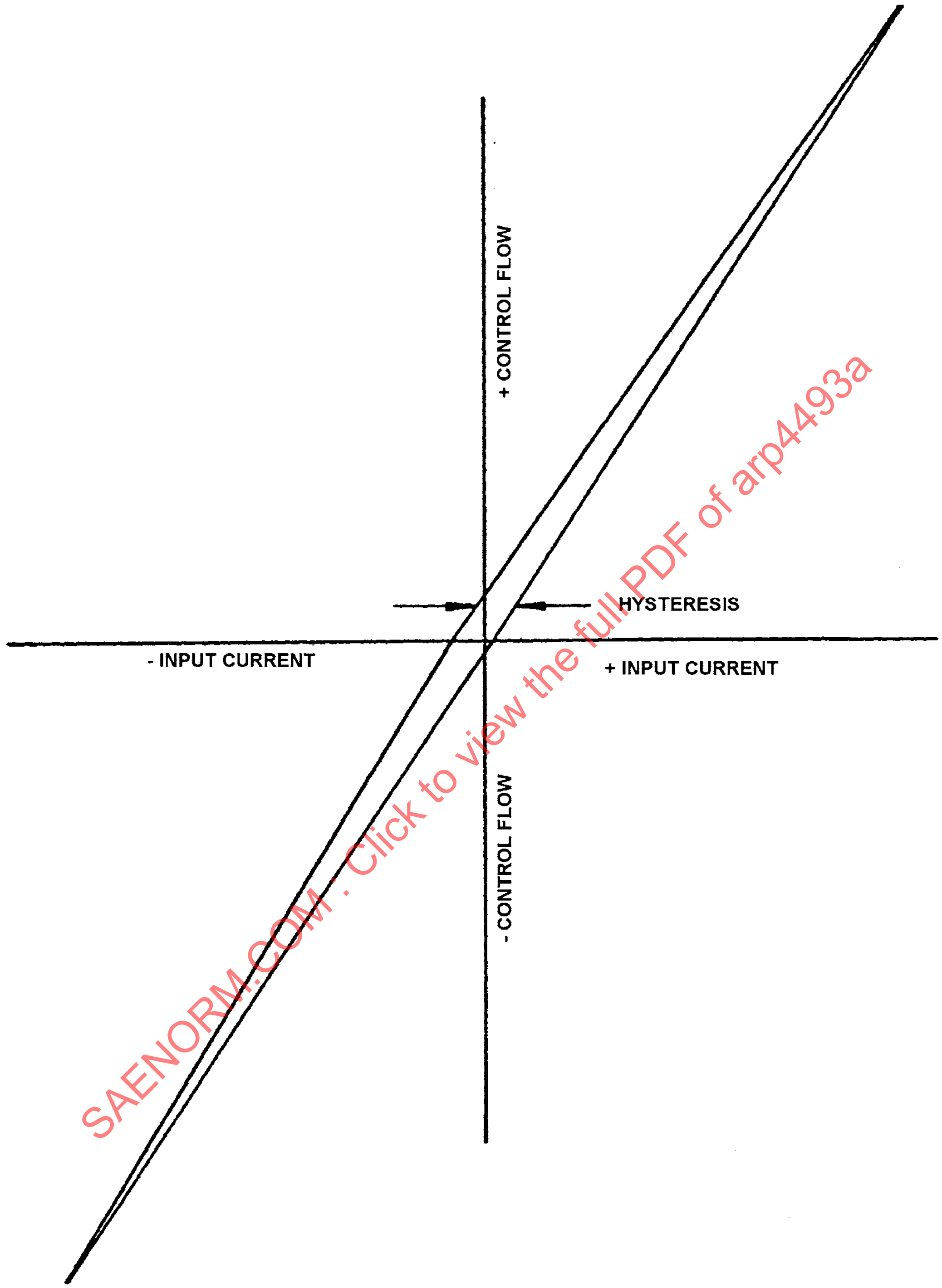


FIGURE 1 - FLOW CURVE

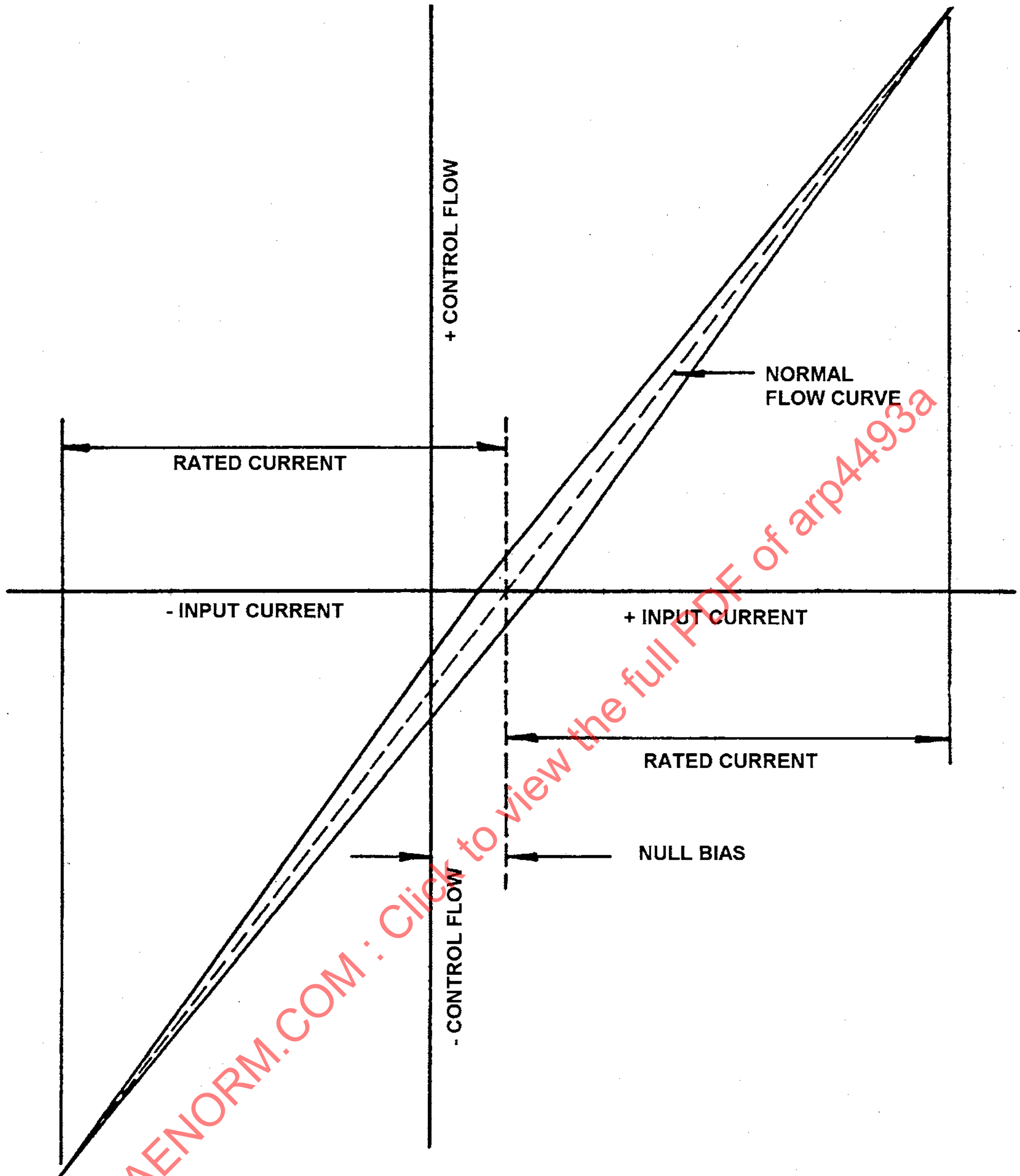


FIGURE 2 - NORMAL FLOW CURVE

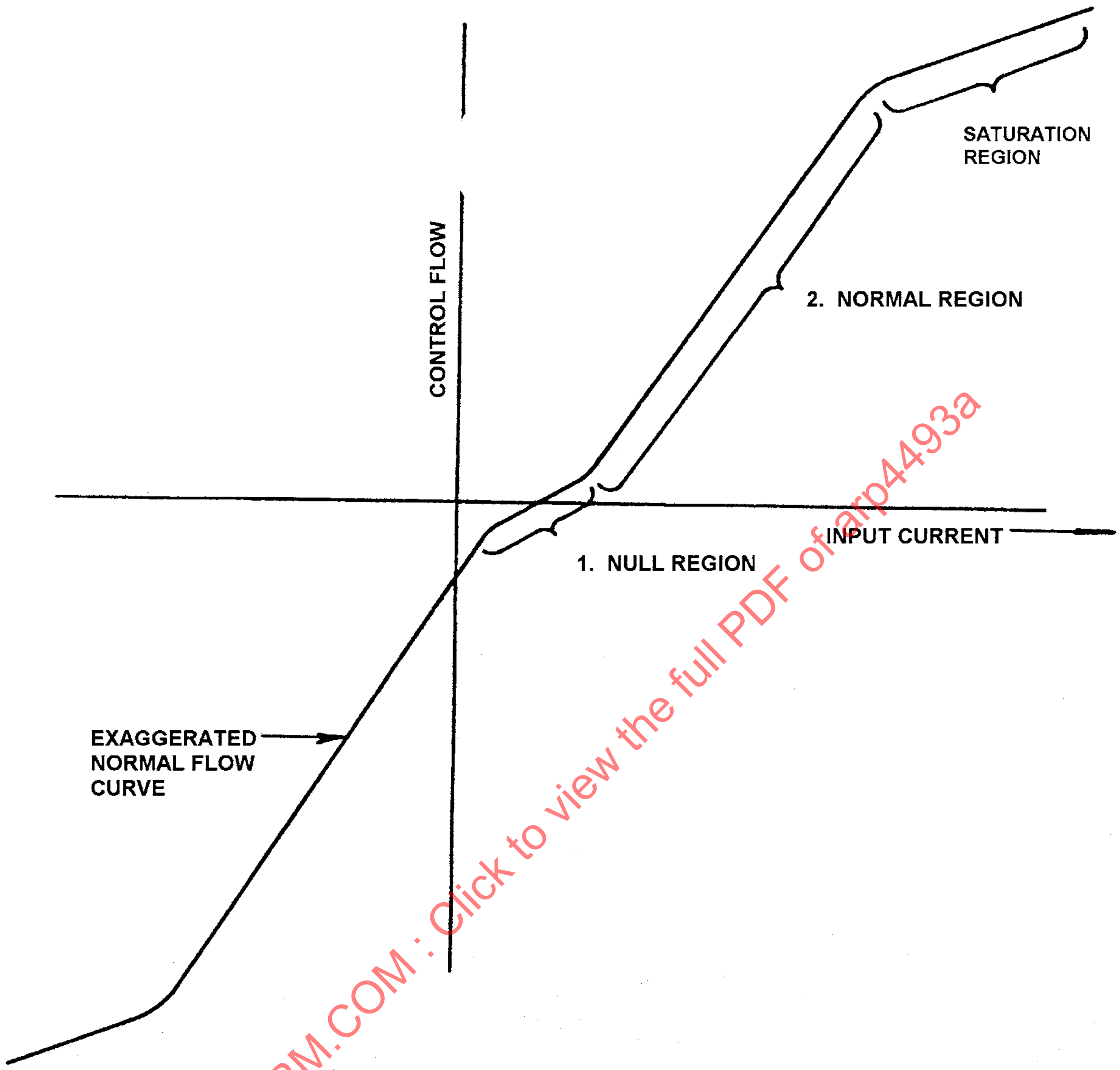


FIGURE 3 - OPERATING REGIONS

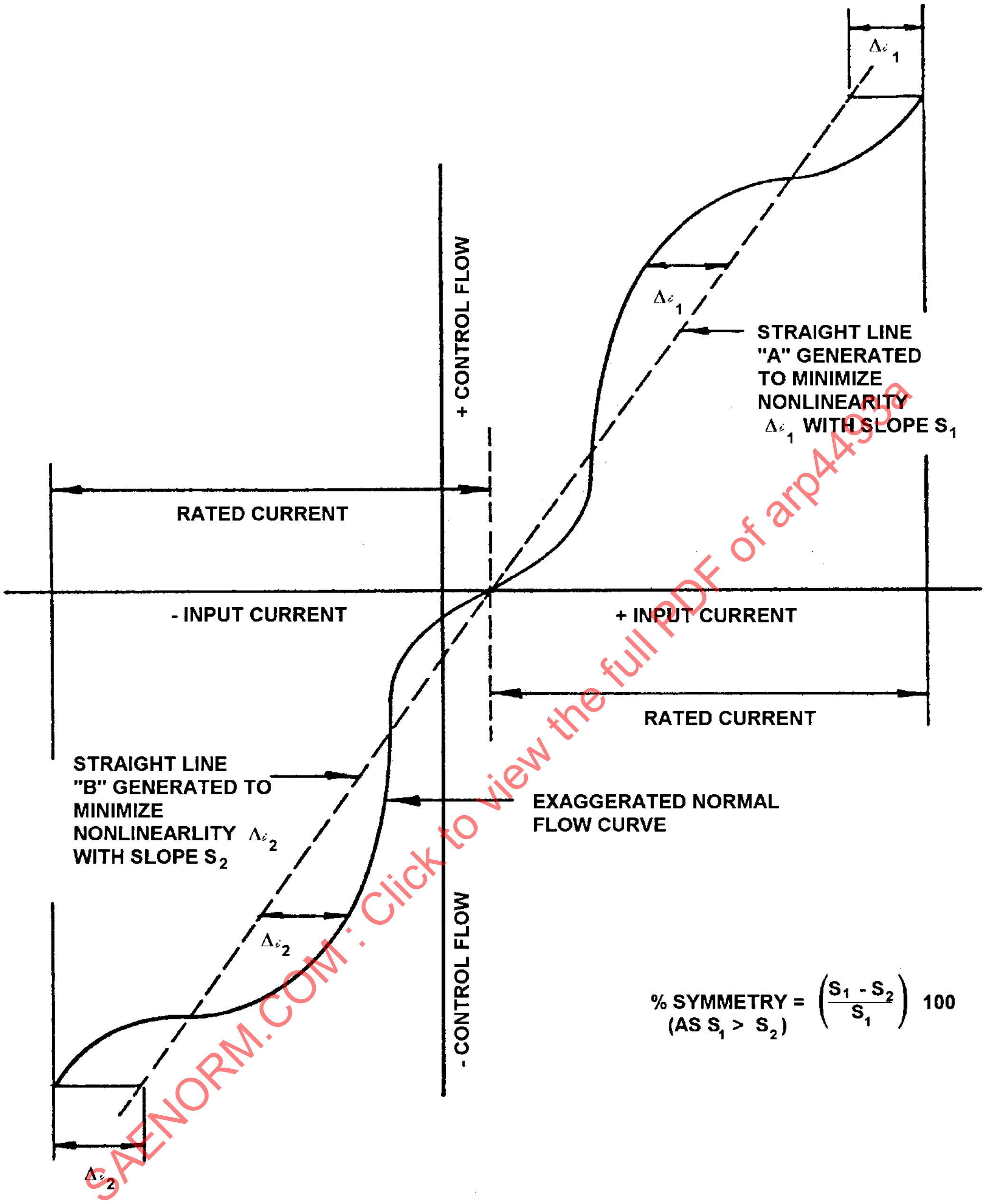


FIGURE 4 - LINEARITY/SYMMETRY

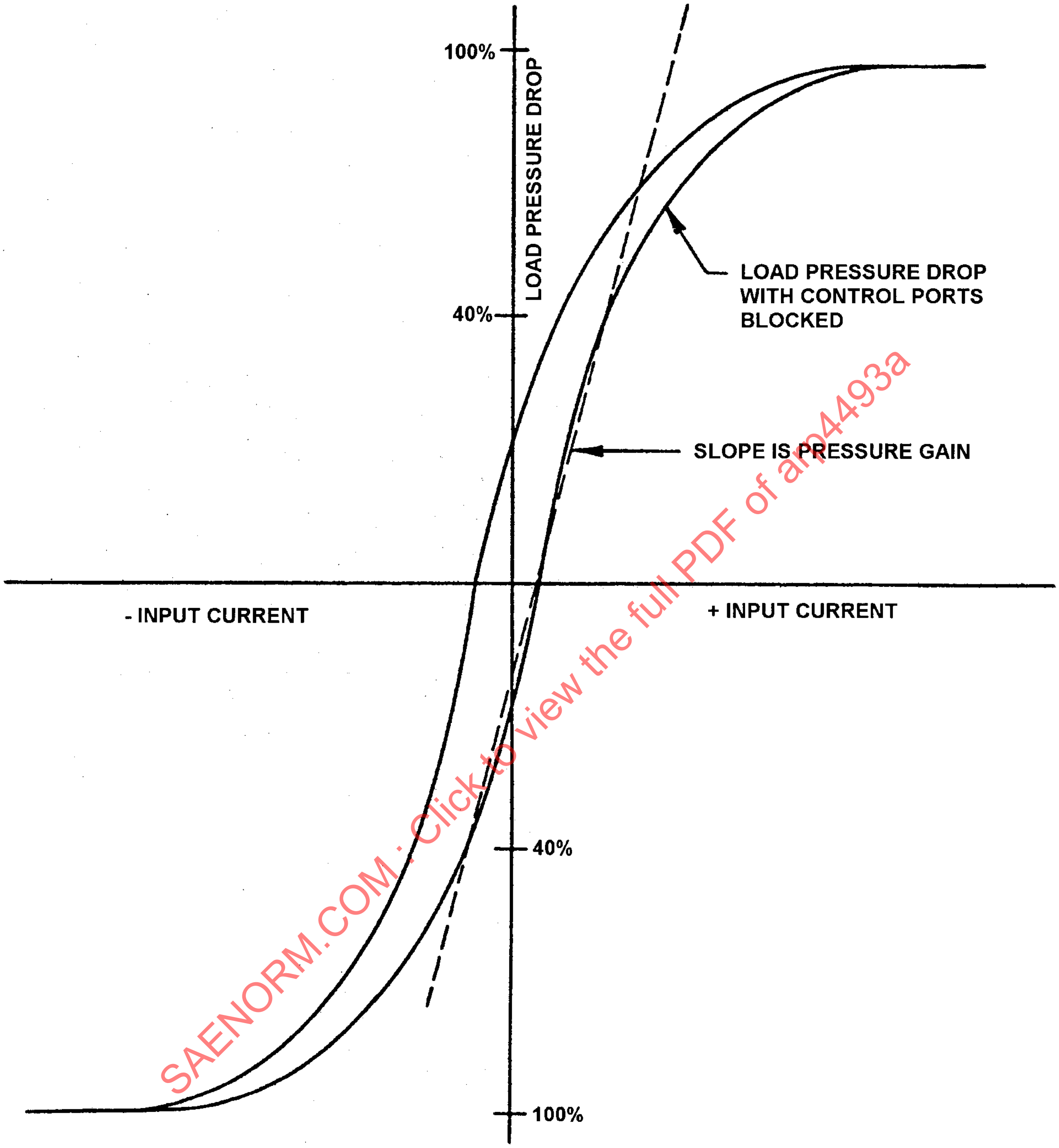
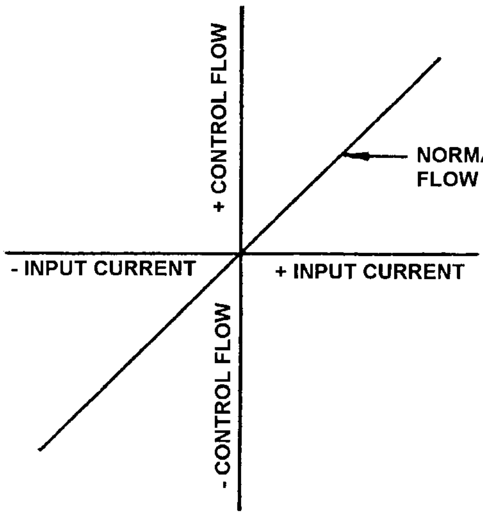
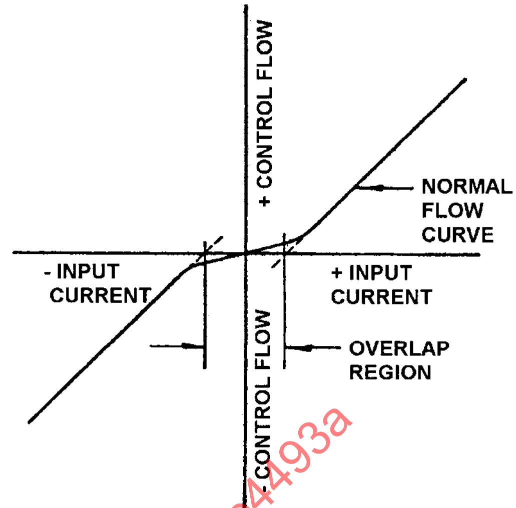


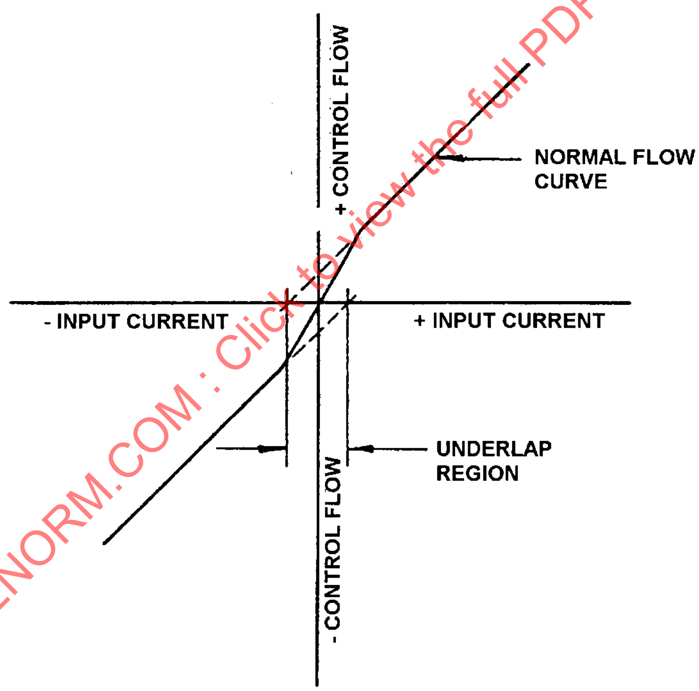
FIGURE 5 - PRESSURE GAIN



View A. Zero Lap



View B. Overlap



View C. Underlap

FIGURE 6 - LAP REGION

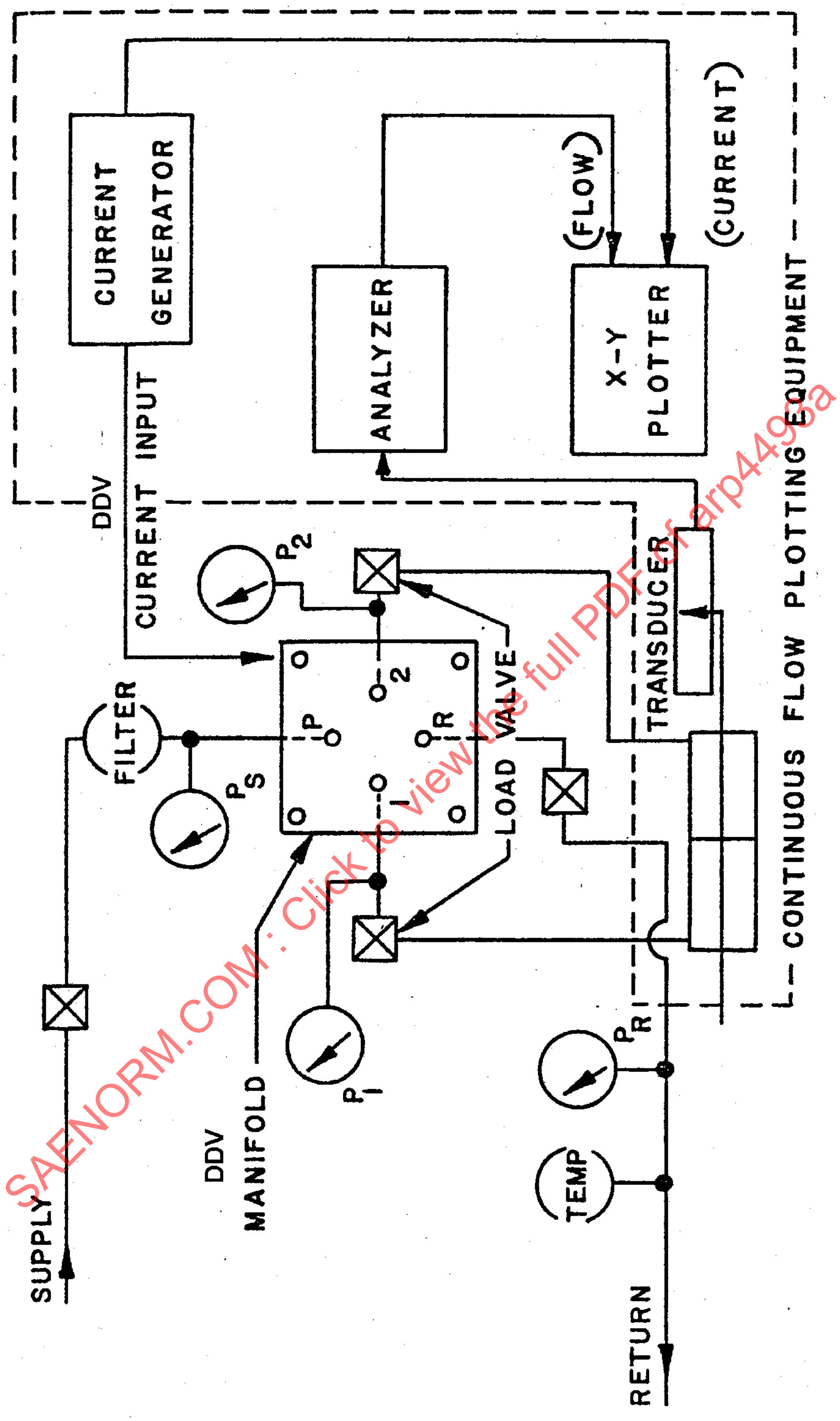


FIGURE 7 - FLOW CURVE EQUIPMENT SCHEMATIC

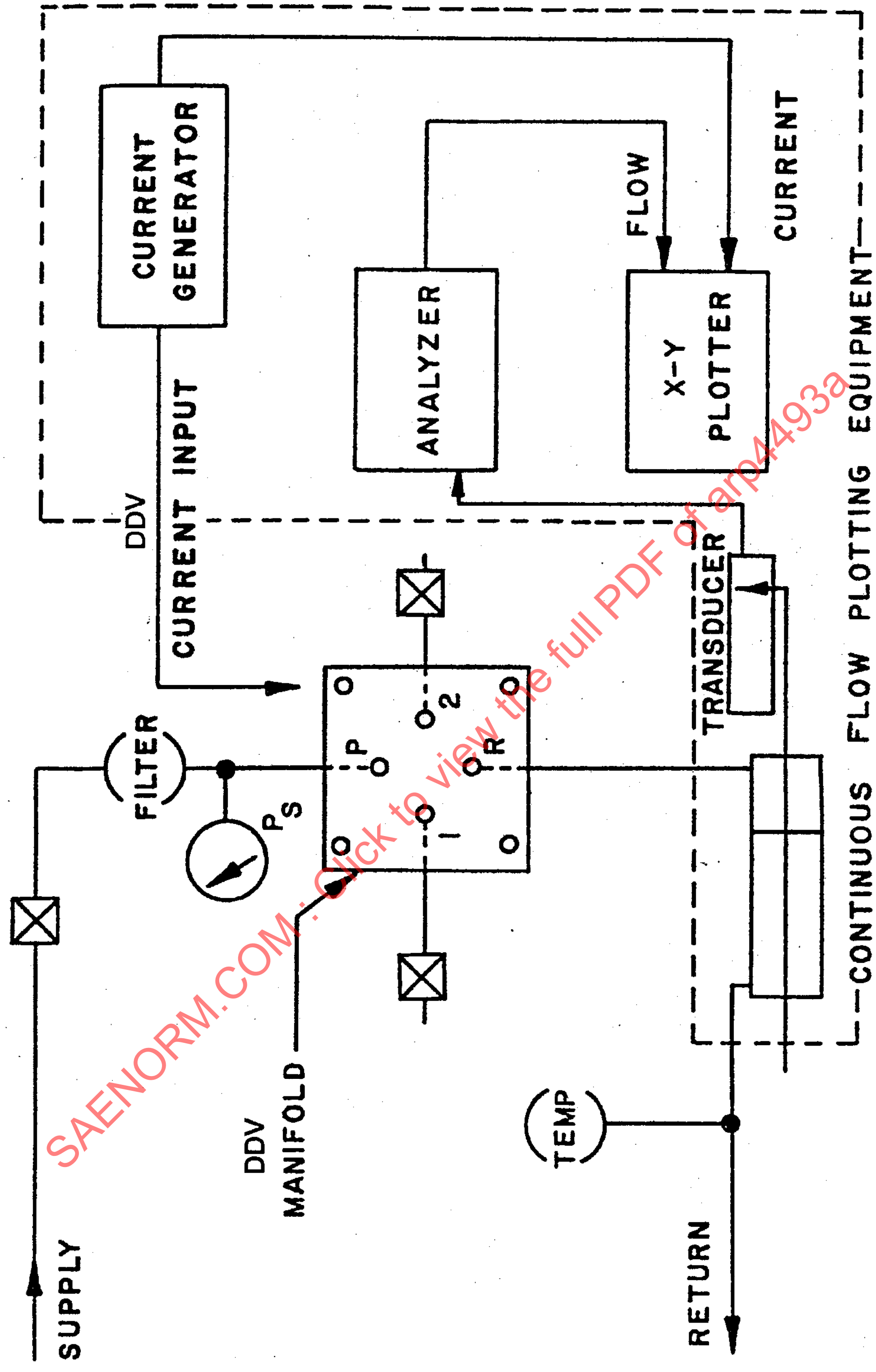


FIGURE 8 - INTERNAL LEAKAGE EQUIPMENT SCHEMATIC

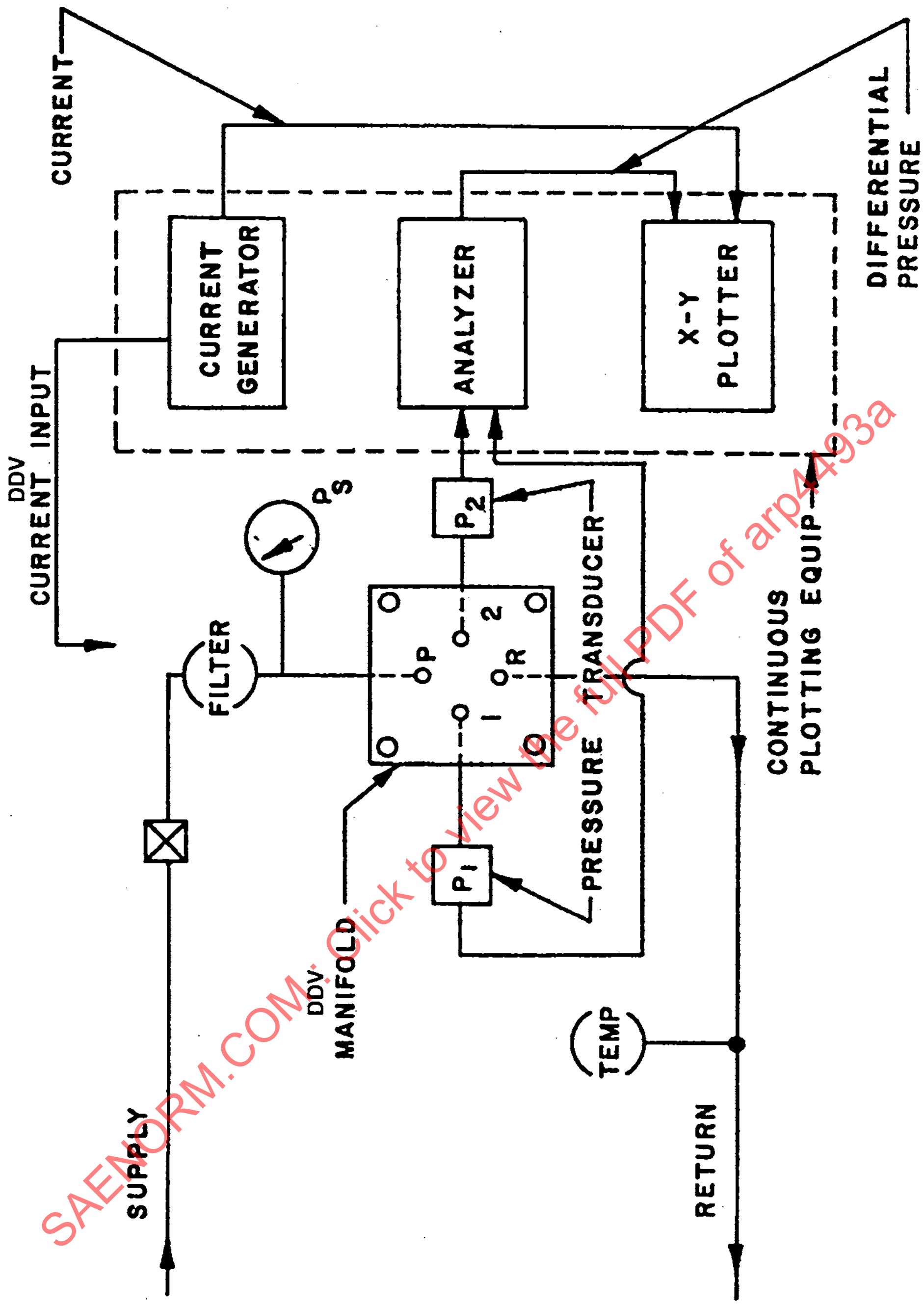


FIGURE 9 - PRESSURE GAIN EQUIPMENT SCHEMATIC

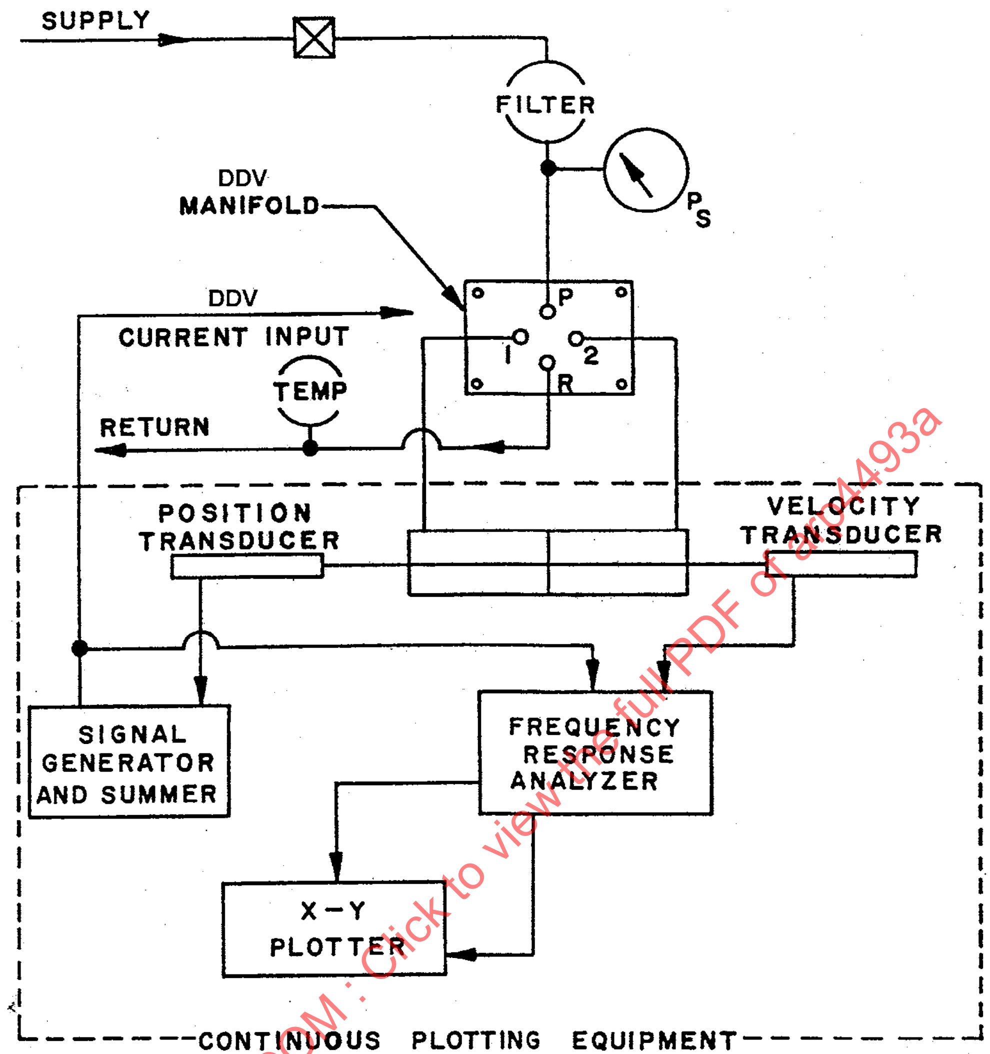


FIGURE 10 - FREQUENCY RESPONSE TEST SCHEMATIC

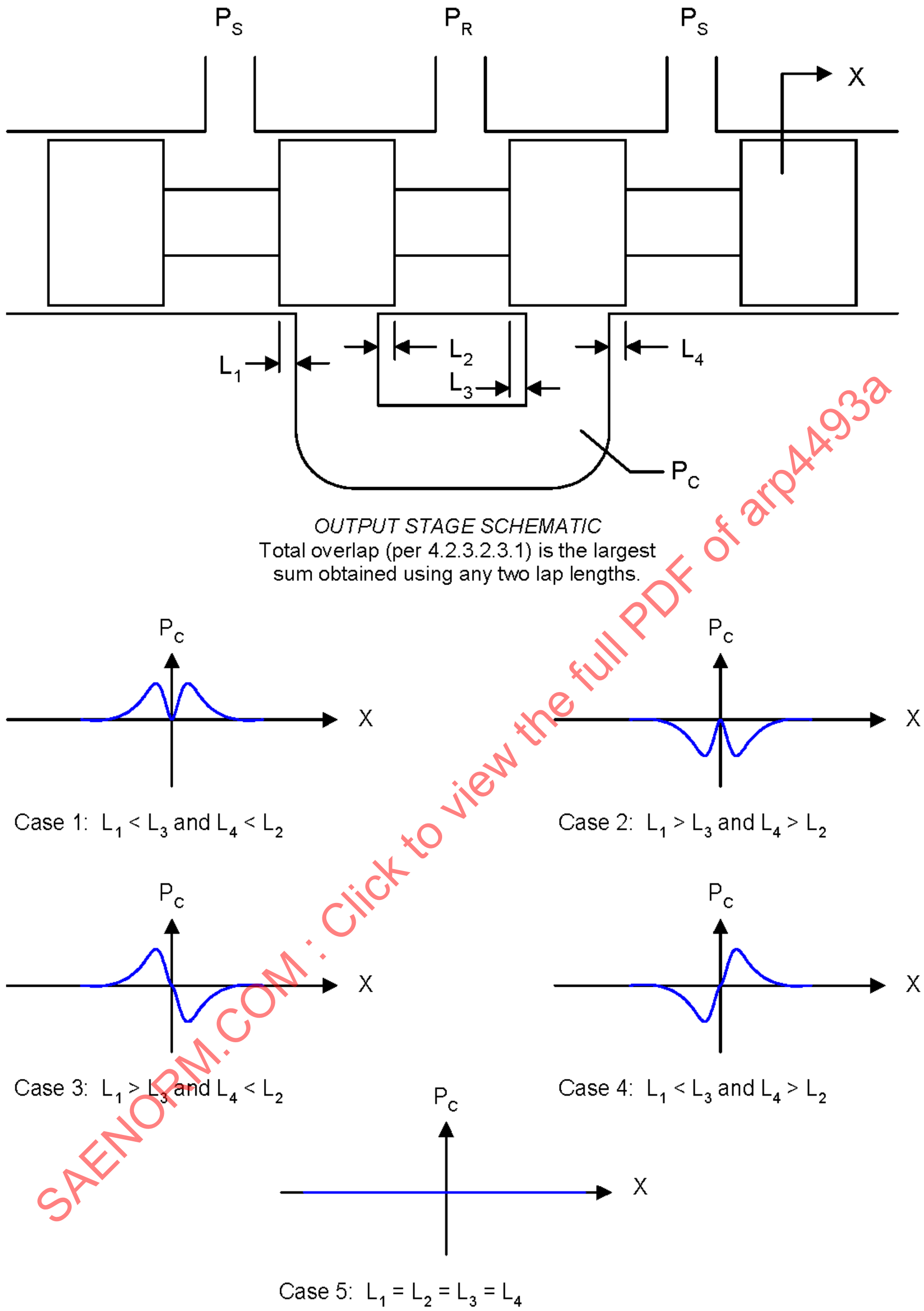


FIGURE 11 - NULL REGION CONTROL PRESSURE, UNLOADED FLOW CONDITION

VIEW 12A

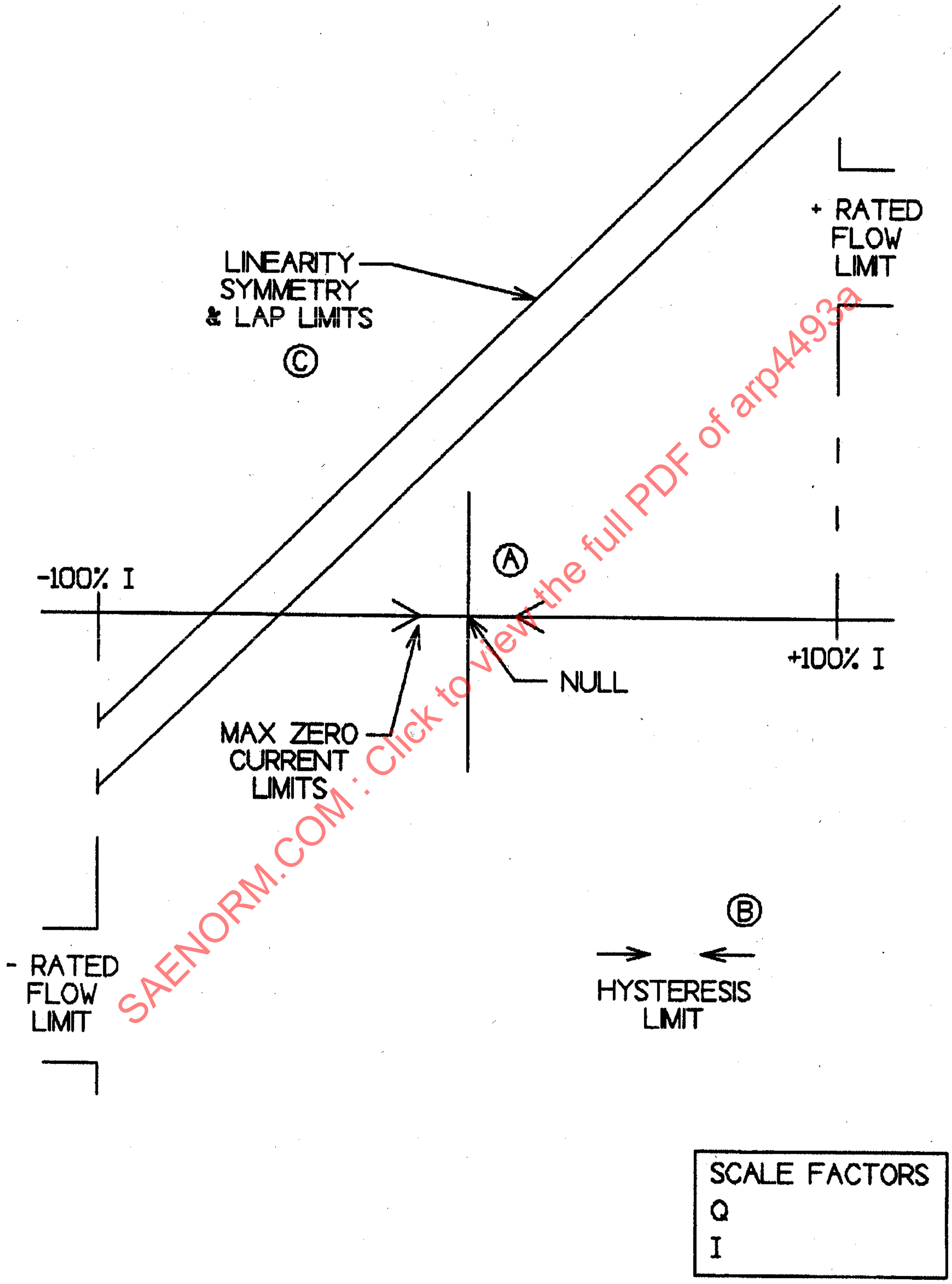


FIGURE 12 - SAMPLE OVERLAY

VIEW 12B

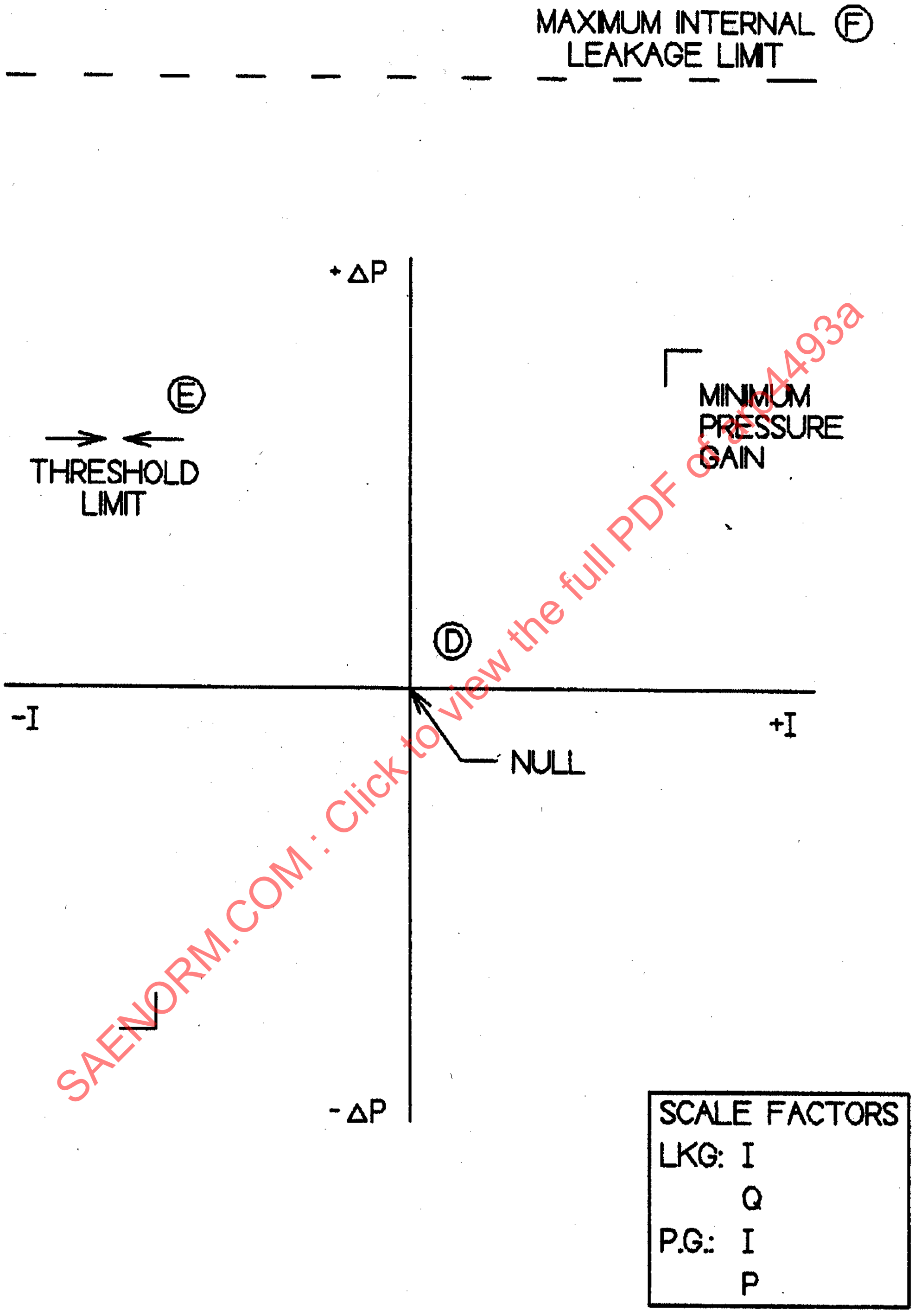


FIGURE 12 - SAMPLE OVERLAY (CONTINUED)

VIEW 12C

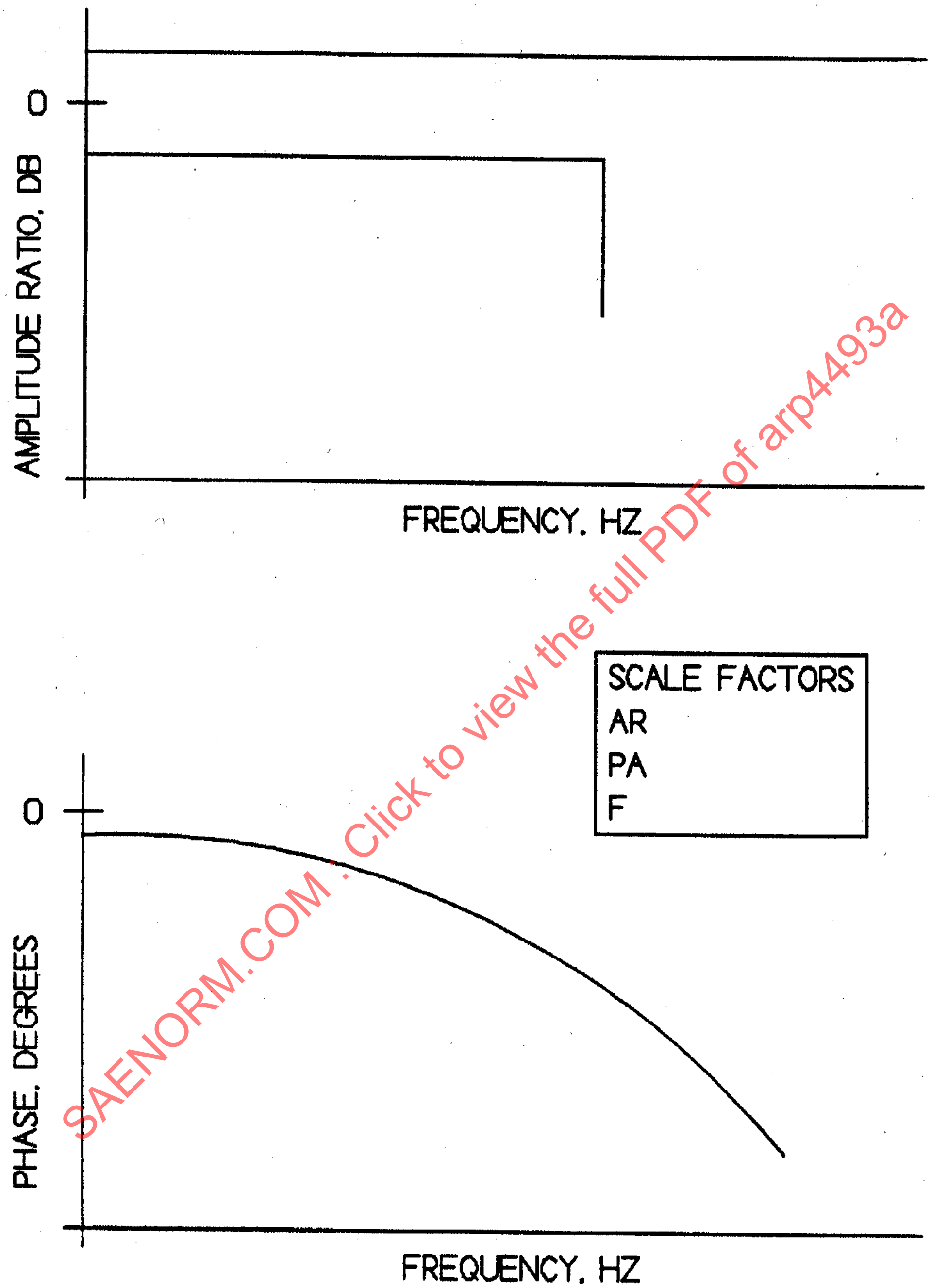


FIGURE 12 - SAMPLE OVERLAY (CONTINUED)

TABLE 1 - NULL REGION PRESSURE REQUIREMENTS

Control Level	Pressure Limits	Comments
1	Pc = (Ps + Pr)/2 ± 0.5 * (Ps - Pr)	Suitable for most applications. Least expensive to produce. Null pressure (3.3.15.2) is the controlling requirement.
2	Pc = (Ps + Pr)/2 ± 0.3 * (Ps - Pr)	Tighter control. Moderate cost penalty.
3	Other	Consult servovalve supplier concerning any stringent or unconventional pressure requirements. Significant cost impact is possible.

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