SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP490F

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Revised 2008-02

Superseding ARP490E

(R) Electrohydraulic Servovalves

RATIONALE

This revision of SAE ARP490 document is a result of a scheduled periodic document review. It incorporates changes recommended by the SAE A-6 Panel and committee members.

TABLE OF CONTENTS

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides definitions and background information for understanding the physical performance, and test procedures of electrohydraulic flow control servovalves.

The recommendations are confined to interface definition and input/output characteristics. This ARP does not restrict or attempt to define the internal characteristics of servovalves. As such, the recommendations are equally applicable to valves having different internal functioning, different ratings, different physical size, and valves used with different fluids. In certain instances, standards for valve design are recommended for the purpose of interchangeability, as for example, valve polarity, mounting bolt and fluid port locations.

The ARP provides extensive guidance for the preparation of Procurement Specifications and for functional testing. A sample Procurement Specification is provided in Appendix A. The primary focus of this ARP is on four-way valves. Three-way valves are discussed to a limited extent and terminology for pressure control valves is presented in Appendix B.

This ARP is applicable to fluid power systems in all types of flight vehicles, and it is applicable to Military, Civil and Space design/certification standards. Additional specifications or specialized test procedures may be necessary to define special requirements for specific control systems, and such considerations are beyond the scope of this ARP.

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.

AIR810 Degradation Limits of Hydrocarbon-Based Hydraulic Fluids, MIL-H-5606, MIL-H-6083, MIL-H-83282, and MIL-H-46170 Used in Hydraulic Test Stands

ARP1231 Gland Design, Elastomeric O-Ring Seals, General Considerations

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

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

AS4059 Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids

2.1.2 Non-Government Publications: Available from various commercial sources.

NHB 5300.4 Reliability Program Provisions for Aeronautical and Space System Contractors

NASM33540 Safety Wiring and Cotter Pinning, General Practices for

ANSI/NCSL Z540-1 General Requirements for Calibration Laboratories and Measuring and Test Equipment

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.3 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, http://assist.daps.dla.mil/quicksearch/.

MIL-PRF-83282 Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft, Metric, NATO Code Number H-537

MIL-PRF-87257 Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft & Missile

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

MIL-HDBK-1587 Materials and Process Requirements for Air Force Weapon Systems

2.2 Definitions

The following definitions describe recommended terminology for electrohydraulic flow-control servovalves. Terminology applicable to pressure-control servovalves can be found in Appendix B.

2.2.1 General

SERVOVALVE, ELECTROHYDRAULIC FLOW-CONTROL: An electrical input, flow-control valve, which is capable of continuous control. Output stage flow is a direct function of input current.

HYDRAULIC AMPLIFIER: A fluid valving device which acts as a power amplifier, such as a sliding spool, or a nozzle flapper, or a jet pipe with receivers.

STAGE: A hydraulic amplifier used in a servovalve. Servovalves may be single-stage, two-stage, three-stage, etc. (see 3.2.3.1.1.1).

OUTPUT STAGE: The final stage of hydraulic amplification used in a servovalve.

PORT: A fluid connection to the servovalve, for example, supply port, return port, control port.

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

THREE-WAY VALVE: A multiorifice flow-control component with supply, return and one control port arranged so that valve action in one direction opens supply to control port and reversed valve action opens the control port to return.

FOUR-WAY VALVE: A multiorifice flow-control component with supply, return, and two control ports arranged so that the valve action in one direction opens supply to control port #1 and opens control port #2 to return. Reversed valve action opens supply to control port #2 and opens control port #1 to return.

2.2.2 Electrical Characteristics

TORQUE MOTOR: The electromechanical transducer commonly used in the input stages of servovalves.

INPUT CURRENT: The current to the valve, expressed in mA, which commands control flow.

RATED CURRENT: The specified input current (expressed in mA) of either polarity to produce rated flow. The particular coil connection (differential, series, or parallel) must be specified in conjunction with the rated current. Rated current does not include null bias current.

QUIESCENT CURRENT: A DC current that is present in each valve coil when using a differential coil connection, the polarity of the current in the coils being in opposition such that no electrical control power exists.

ELECTRICAL QUIESCENT POWER: The dissipation required for differential operation when the current through each coil is equal and opposite in polarity.

ELECTRICAL CONTROL POWER: The power dissipation required for control of the valve. Control power is a maximum with full input signal, and is zero with zero-input signal. It is independent of the coil connection (series, parallel, or differential) for any conventional two-coil operation. For differential operation, the control power is the power consumed in excess of the electrical quiescent power. This power increase is a result of the differential current change.

TOTAL ELECTRICAL POWER: The sum of the instantaneous electrical control power and the electrical quiescent power, expressed in mW.

COIL IMPEDANCE: The complex ratio of coil voltage to coil current. It is important to note that the coil impedance may vary with signal frequency, signal amplitude, and other operating conditions due to back emf generated by the moving armature. The coil impedance is usually described in terms of impedance amplitude and phase angle plotted against the input signal frequency. An example of such a plot is shown in Figure 1.

COIL RESISTANCE: The DC resistance of each torque motor coil, expressed in ohms.

POLARITY: The relationship between the direction of control flow and the direction of input current.

DITHER: A low amplitude, relatively high frequency periodic electrical signal, sometimes superimposed on the servovalve input to reduce threshold. Dither is expressed by the dither frequency (Hz) and the peak-to-peak dither current amplitude (mA).

2.2.3 Steady State Characteristics

CONTROL FLOW: The flow through the valve control ports, expressed in cis or gpm (mL/s). 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 2.2.3, Load Pressure Drop.) Conventional test equipment normally measures no-load flow.

RATED FLOW: The specified control flow corresponding to rated current and specified load pressure drop. Rated flow is normally specified as the no-load flow.

FLOW CURVE: The graphical representation of control flow versus input current. This is usually a continuous plot of a complete cycle between plus and minus rated current values of no-load flow (see Figure 2).

NORMAL FLOW CURVE: The locus of the midpoints of the complete cycle flow curve, which is the zero hysteresis flow curve. Where valve hysteresis is sufficiently low, one side of the flow curve can usually be used for the normal flow curve (see Figure 3).

FLOW GAIN: The slope of the control flow versus input current curve in any specific operating region, expressed in cis/mA or gpm/mA (mL/s/mA). 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 (see Figure 4). Where this term is used without qualification, it is assumed to mean normal flow gain.

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 5).

RATED FLOW GAIN: The ratio of rated flow to rated current, expressed in cis/mA or gpm/mA (mL/ s/mA).

FLOW SATURATION REGION: The region where flow gain decreases with increasing input current.

FLOW LIMIT: The condition where control flow no longer increases with increasing input current. Flow limitation may be deliberately introduced within the servovalve.

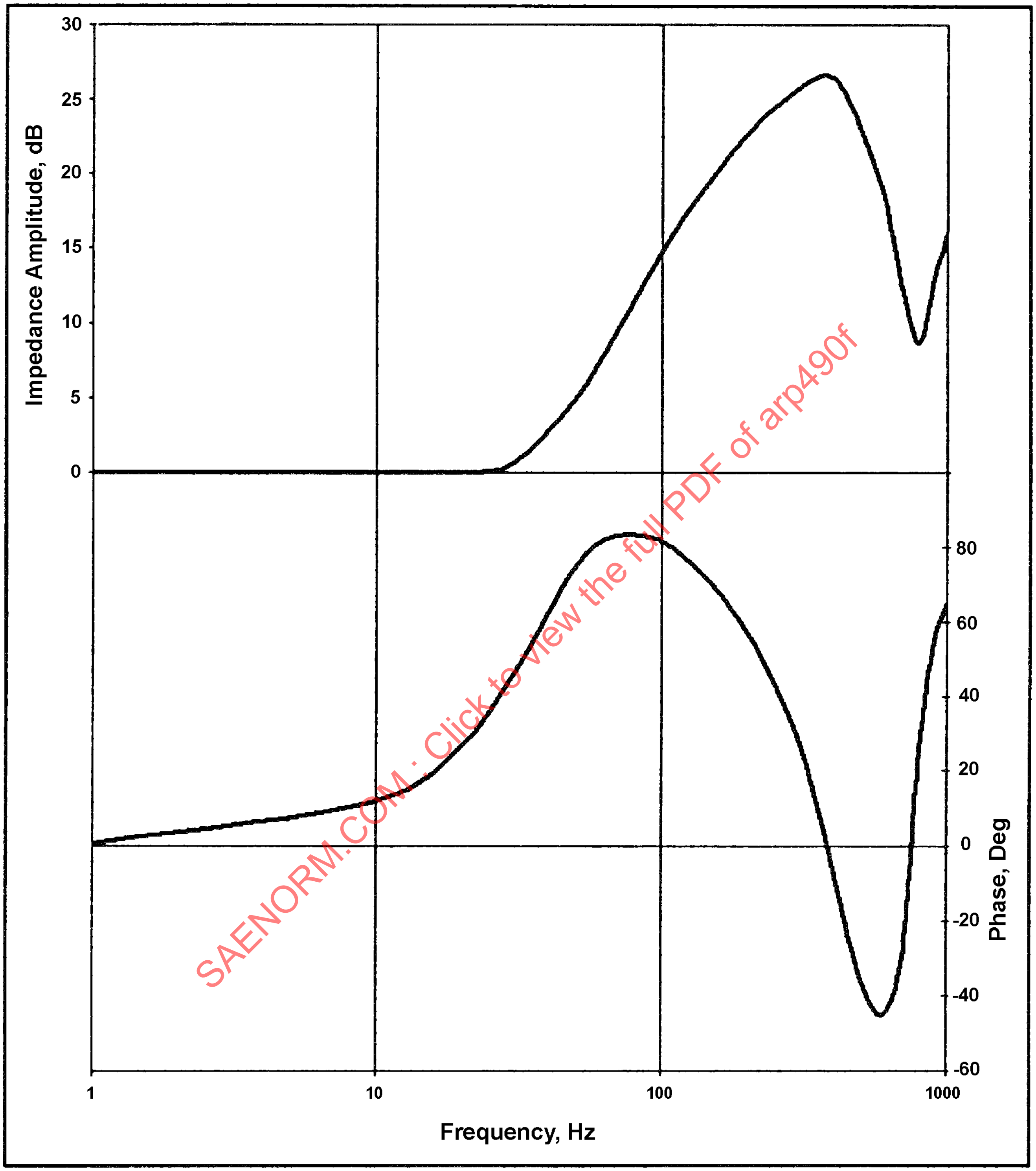


FIGURE 1 - COIL IMPEDANCE AMPLITUDE AND PHASE ANGLE

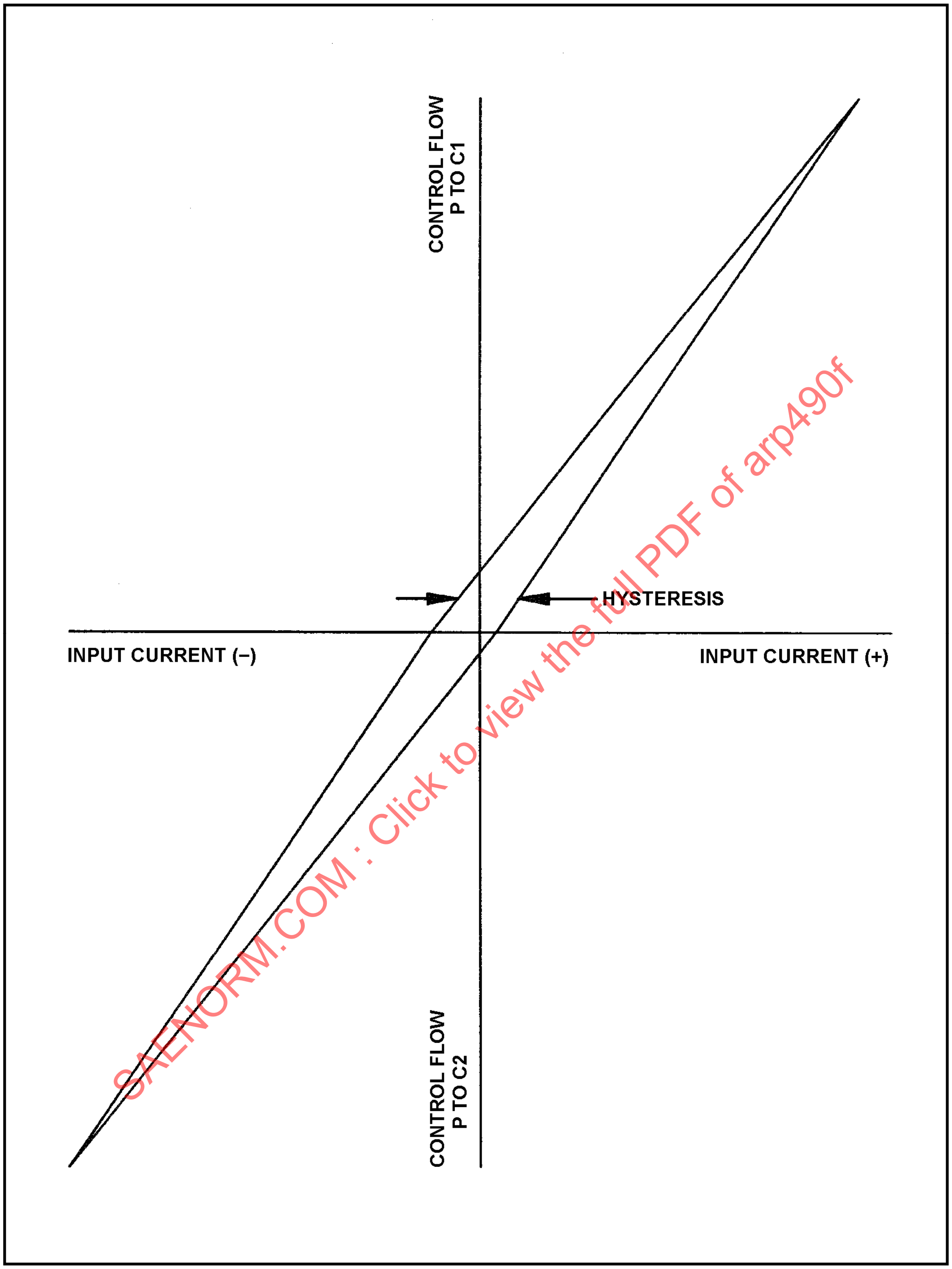


FIGURE 2 - FLOW CURVE

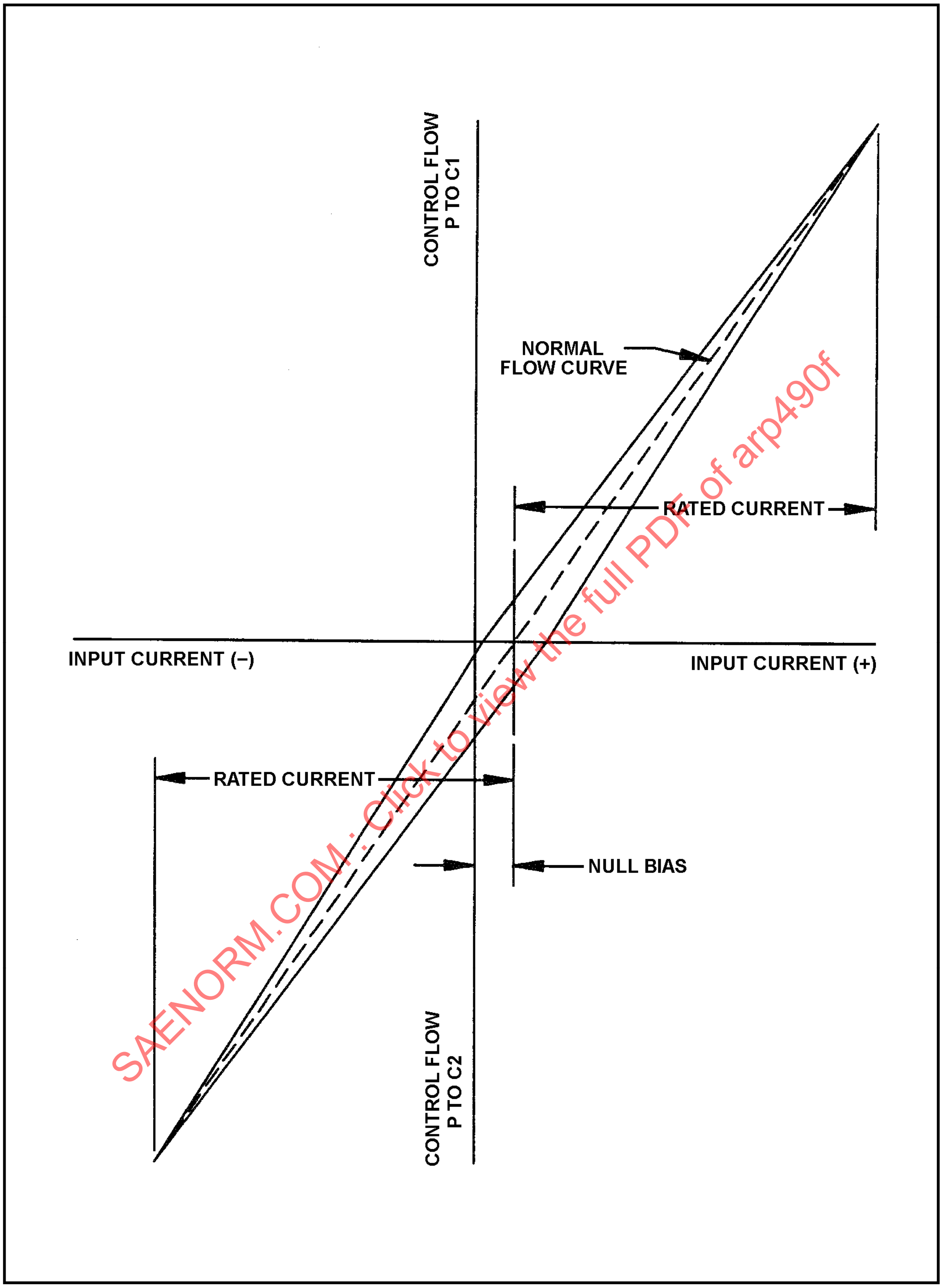


FIGURE 3 - NORMAL FLOW CURVE

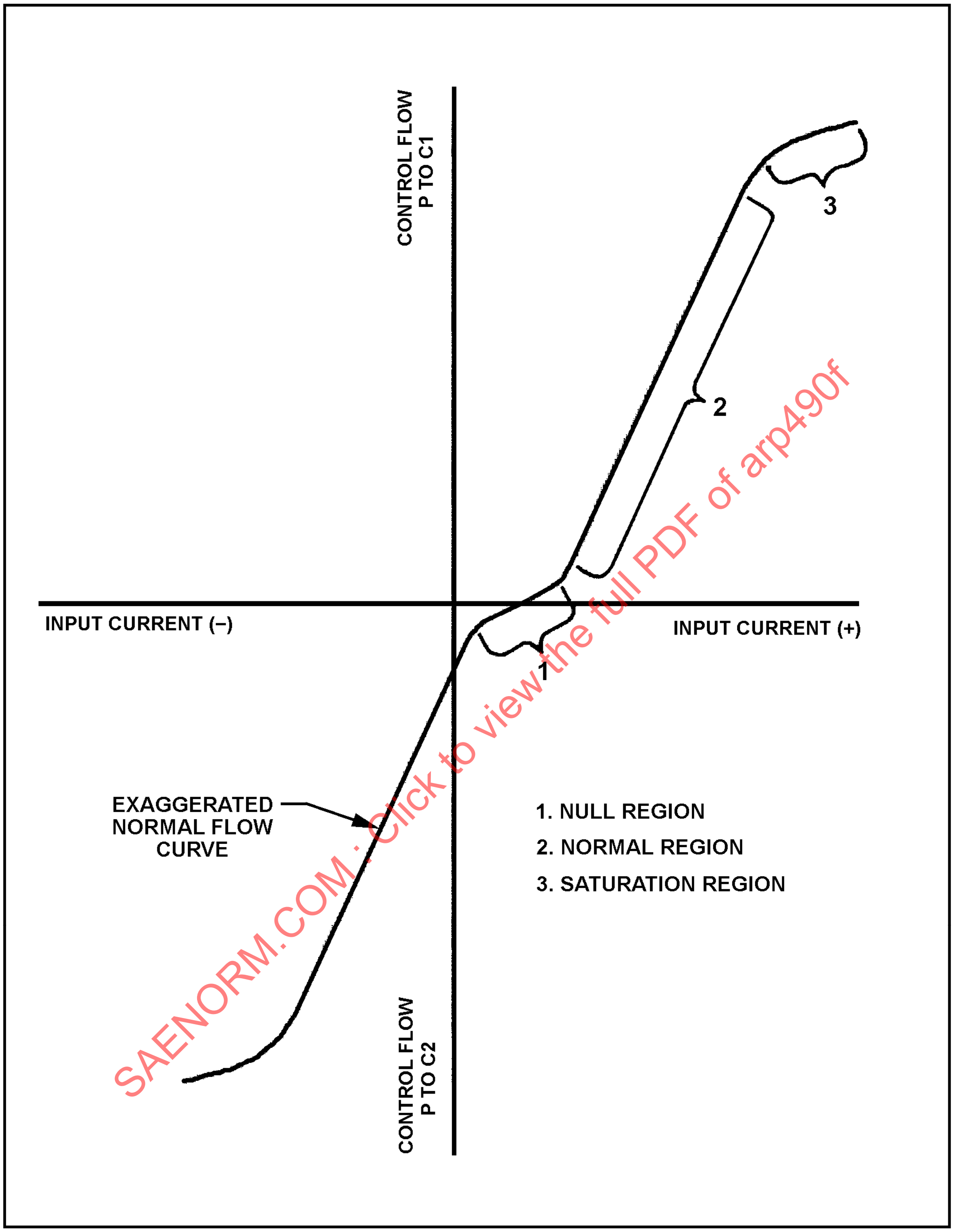


FIGURE 4 - OPERATING REGIONS

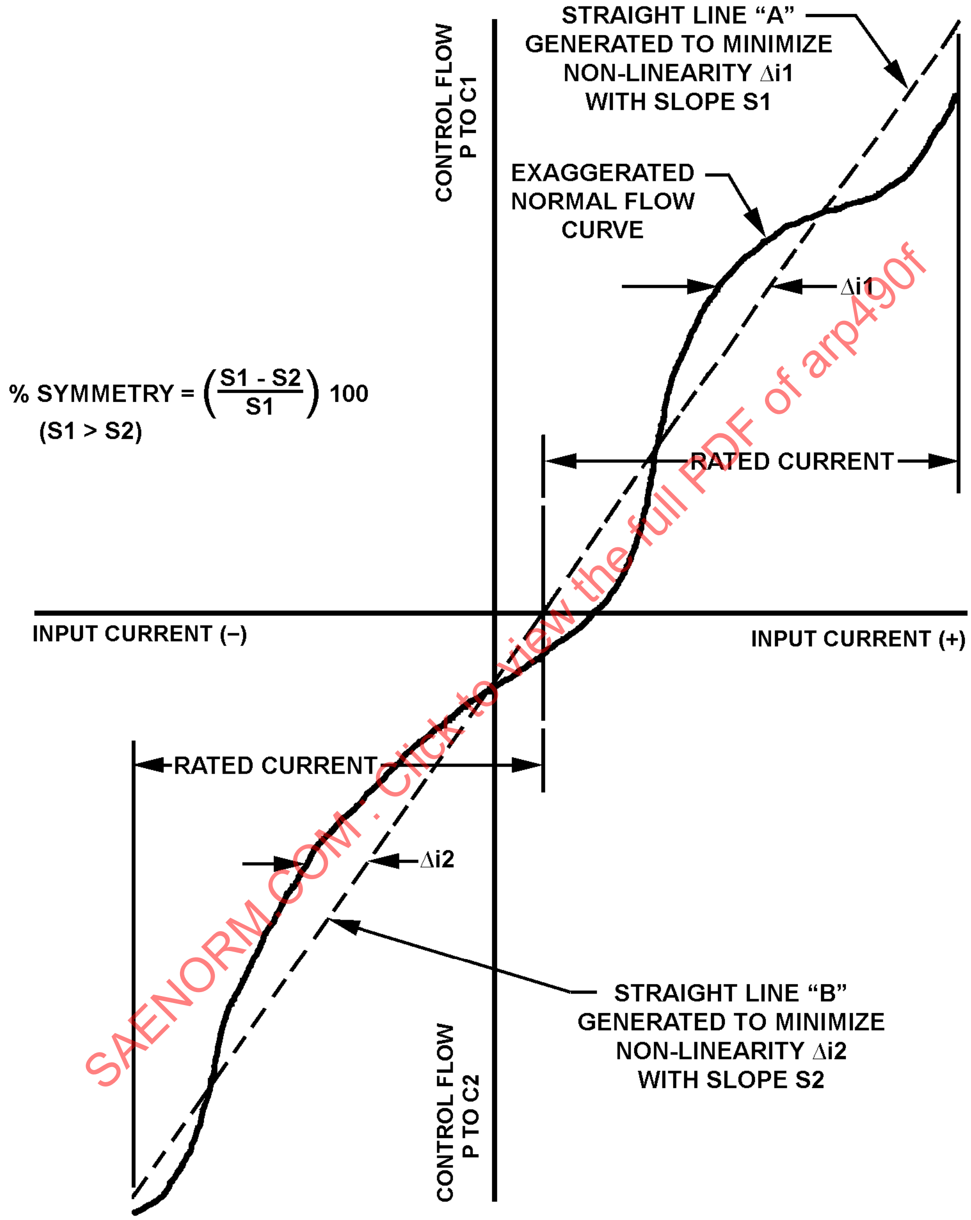


FIGURE 5 - LINEARITY/SYMMETRY

SYMMETRY: The degree of equality between the normal flow gain of one polarity and that of the reversed polarity. Symmetry is measured as the difference in normal flow gain of each polarity, expressed as a percent of the greater (see Figure 5 and 4.4.3.3).

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 current (see Figure 5).

HYSTERESIS: The difference in the valve input currents required to produce the same valve output during a single cycle of valve input current 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 curve throughout plus or minus rated current, and is expressed as a percent of rated current (see Figure 2).

THRESHOLD: The smallest increment of input current which will produce a change in valve output, expressed as percent of rated current. Threshold is normally specified as the current increment required to revert from a condition of increasing output to a condition of decreasing output, when current is changed at a rate below that at which dynamic effects are important.

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 (mL/s). Leakage flow will vary with input current, generally being a maximum at the valve null (null leakage).

LOAD-PRESSURE DROP: The differential pressure between the control ports, expressed in psi (kPa). In conventional three-way servovalves, load-pressure drop may be expressed as an equation, where it is equated to the supply pressure, less return pressure, and less the pressure drop across the single active control orifice. (Ps - Pr - Po = Pl).

VALVE PRESSURE DROP: The sum of the differential pressures across the control orifices of the output stage, expressed in psi (kPa). Valve pressure drop will equal the supply pressure minus the return pressure minus the load pressure drop.

PRESSURE GAIN: The rate of change of load pressure drop with input current at zero control flow (control ports blocked), expressed in psi/mA (kPa/mA). Pressure gain is usually specified as the average slope of the curve of load pressure drop versus current between 40% of maximum load-pressure drop (see Figure 6).

NULL REGION: The region about null where effects of lap in the output stage predominate.

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

NULL PRESSURE: The pressure existing at both control ports at null, expressed in psi (kPa).

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

NULL SHIFT: A change in null bias, expressed as percent of rated current. Null shift may occur with changes in supply pressure, temperature, and other operating conditions.

LAP: In a sliding spool valve, the relative axial position relationship between the fixed and movable flow-metering edges with the spool at null. For a servovalve, lap is measured as the total separation at zero flow of straight line extensions of the nearly straight portions of the normal flow curve, drawn separately for each polarity, expressed as percent of rated current.

ZERO LAP: The lap condition where there is no separation of the straight line extensions of the normal flow curve (see Figure 7A).

OVERLAP: The lap condition which results in a decreased slope of the normal flow curve in the null region (see Figure 7B).

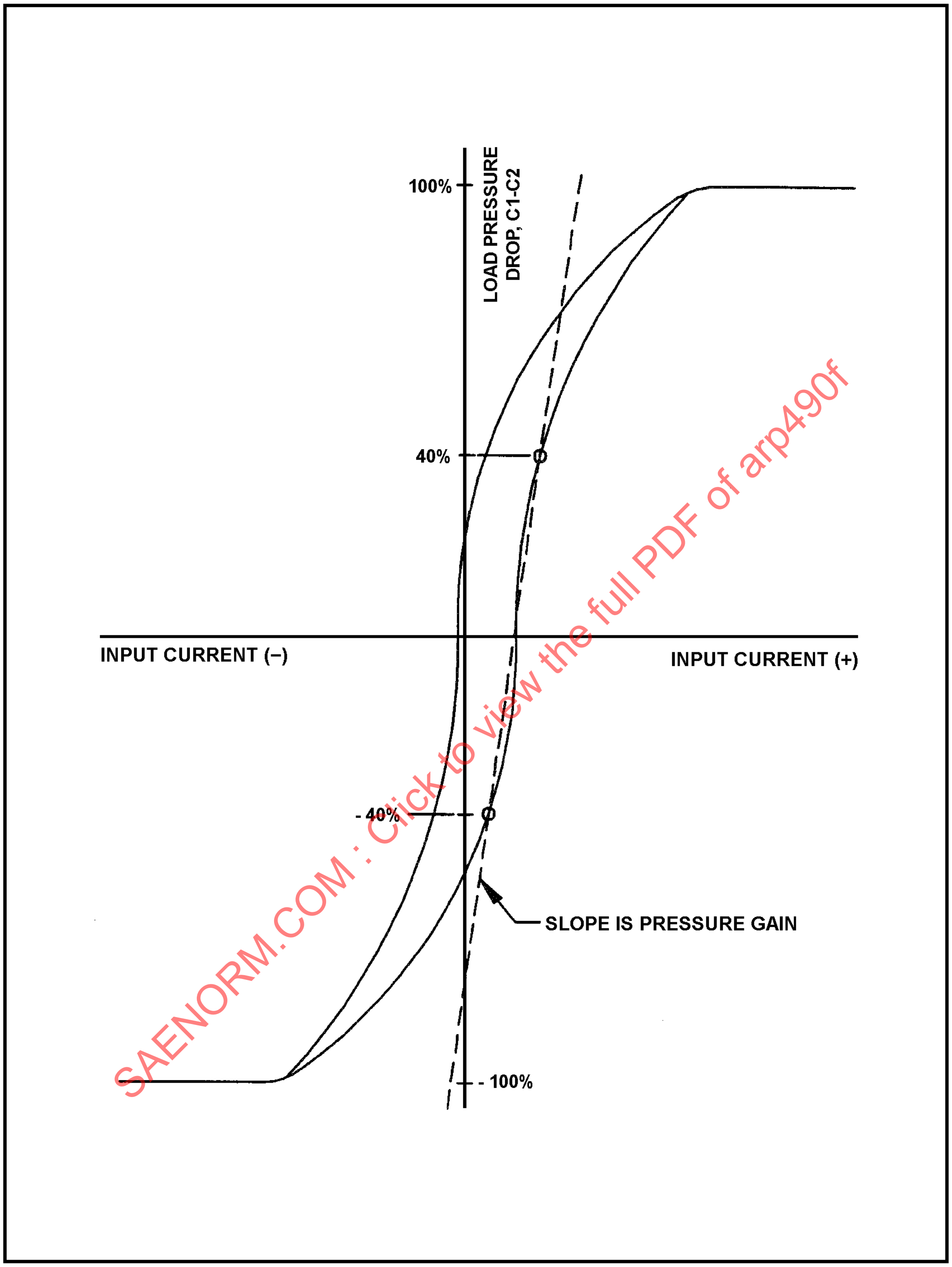


FIGURE 6 - PRESSURE GAIN

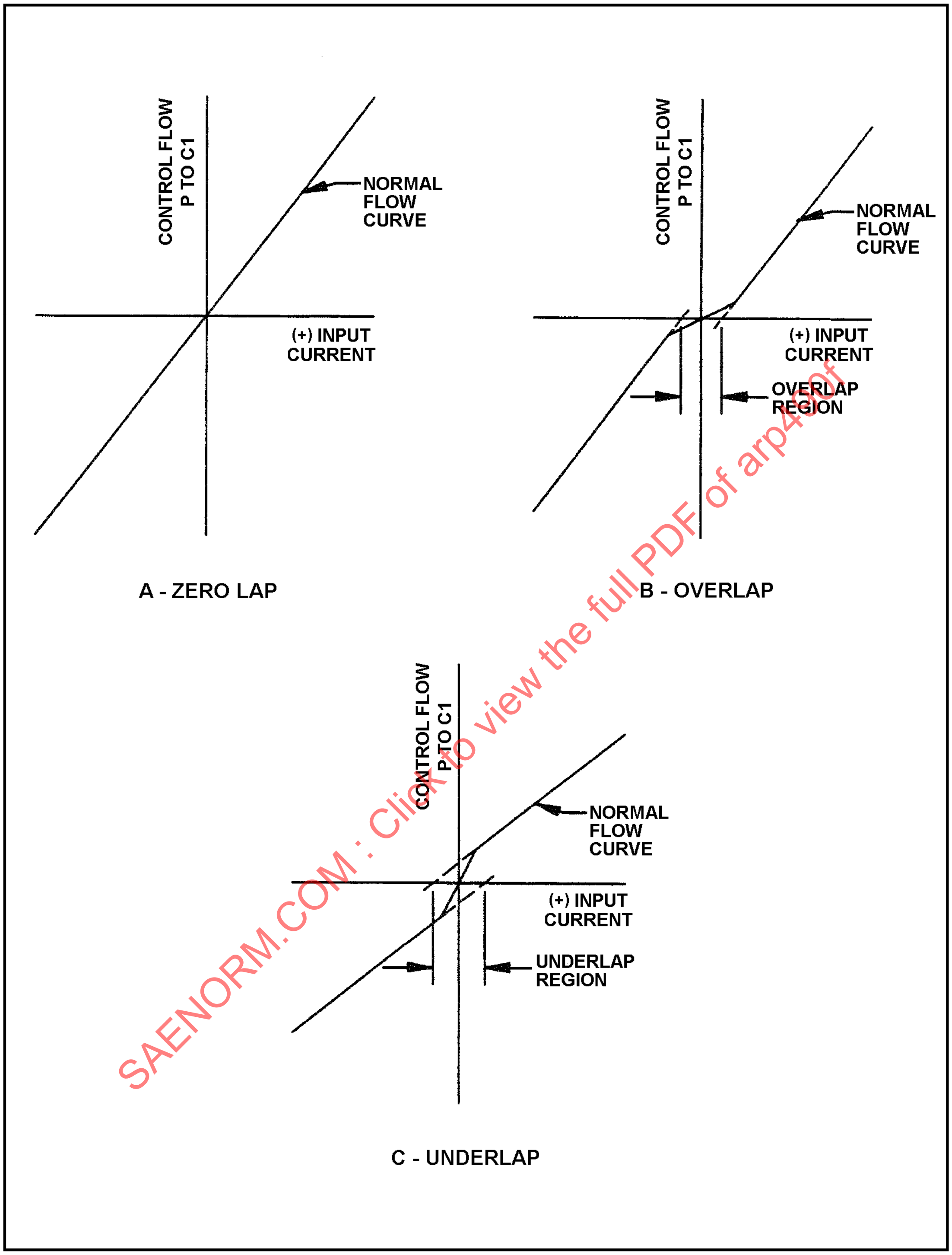


FIGURE 7 - LAP DEFINITIONS

UNDERLAP: The lap condition which results in an increased slope of the normal flow curve in the null region (see Figure 7C).

2.2.4 Dynamic Performance Characteristics

FREQUENCY RESPONSE: The complex ratio of flow-control flow to input current as the current is varied sinusoidally over a range of frequencies. Frequency response is normally measured with constant input current amplitude and zero load pressure drop, expressed as amplitude ratio, and phase angle. Valve frequency response may vary with the input-current amplitude, temperature, supply pressure, and other operating conditions.

AMPLITUDE RATIO: The ratio of the control-flow amplitude to the input-current amplitude at a particular frequency divided by the same ratio at the same input-current amplitude at a specified low frequency (usually 5 or 10 Hz). Amplitude ratio may be expressed in decibels where $dB = 20 \log_{10}(AR)$.

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

BODE DIAGRAM: A graphical depiction of servovalve frequency response, wherein phase lag and logarithmic amplitude ratio (usually expressed in dB) are plotted versus input signal frequency (see Figure A2).

2.3 Symbols and Abbreviations

Symbols and abbreviations used in this ARP are as listed below:

AC	alternating current
AR	amplitude ratio
°C	degrees Celsius
cis	cubic inches per second
dB	decibel
DC	direct current
deg	degree
emf	electromotive force
°F	degrees Fahrenheit
gpm	gallons per minute
h	hour
Hz	Hertz
in	inch
kg	kilogram
kPa	kilopascal
L	liter
lb	pound
M	mega (prefix)
m	meter
mA	milliampere
mL	milliliter
PA	phase angle
psi	pounds per square inch
s	second
V	Volt
Ω	Ohm
μ	micro (prefix)

3. PROCUREMENT SPECIFICATIONS

3.1 Introduction

This section is intended to be a guide for the preparation of specifications covering electrohydraulic flow control servovalves. Certain background information is presented in 3.2 to explain various considerations appropriate to such specifications. Supplementing this section is Appendix A, where a sample specification for a typical servovalve can be found.

3.1.1 Numbering System

The following numbering system is recommended for the organization of servovalve specifications. The numbers in parentheses to the right of each paragraph title in 3.2 correlate with this numbering system. The sample specification of Appendix A follows this system also.

- (1.) Scope
- (2.) Reference 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) Steady State
    - (3.2.3) Null
    - (3.2.4) Dynamic
  - (3.3) Environmental Requirements
- (4.) Quality Assurance Provisions
- (5.) Preparation for Delivery
- (6.) Notes

3.1.2 Valve Sizes

The specification information in 3.2 covers four common valve sizes, identified as Sizes I, II, III, and IV. Design requirements which affect interchangeability are specified for all four sizes, including maximum envelope, mounting details, electrical input configuration, hydraulic output configuration, and polarity. It is recognized that other valve sizes are commonly used. The information provided in this section is general enough to be applicable to most of these cases also.

3.1.3 Valve Variants

The recommended specification limits included in 3.2 and Appendix A are consistent with the requirements of most systems and can be met with reliable servovalve designs of proven producibility. It is important to understand and appreciate that compromises can be made in the specification of a flow-control servovalve. Specific performance parameters can often be improved by relaxing other performance requirements. For example, frequency response can normally be improved by allowing increased internal leakage. Likewise, valve internal leakage can be reduced by allowing overlap, but this will cause reduced valve flow gain in the null region.

3.1.4 Tolerances

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

In general, the specification information is directed towards servovalves for use in aircraft control systems. However, it should be recognized that the requirements of many other control systems will be essentially the same.

3.2 Specification Considerations

3.2.1 Scope (1.)

The introductory paragraph of the servovalve specification should identify specifically the type of component. 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 servovalve requirements. Any unusual design or performance requirements could be cited to indicate the general nature of the hardware to be procured by the specification (for example, high temperature, high response, three-way, etc.).

3.2.2 Reference Documents (2.)

Documents listed in this section should include those specifications or drawings, or both, specifically referenced in the text of the specification. All referenced specifications shall be applicable only to the extent specified in the text of the servovalve specification. Military specifications, standards, publications, etc., shall be listed by number and complete title, preceded by a statement as follows: "Unless otherwise specified in the solicitation, the applicable issue of documents shall be the issue in effect on the date of solicitation for bids." Contractors' specifications or drawings, or both, shall be listed under the contractors' name and shall always be identified by the specific date of issue which is applicable.

3.2.3 Requirements (3.)

3.2.3.1 Design Requirements (3.1)

3.2.3.1.1 Mechanical (3.1.1)

3.2.3.1.1.1 Design Configurations (3.1.1.1)

A major design variable in flow-control servovalves lies in the utilization of the electrical control power. When this control power is applied to a torque motor directly controlling the output stage, it is termed a single-stage servovalve. Servovalves employing one or more hydraulic amplifiers interposed between the output stage and the torque motor are termed two, three, etc., stage valves as applicable. For certain applications, sliding spool type hydraulic amplifiers are used for both single and multi stage servovalves. However, two-stage servovalves employing a spool type output stage and some form of frictionless variable orifice amplifier are used most extensively. Modern multi stage servovalves often employ some form of feedback from the output stage spool to the torque motor. This configuration is analogous to negative feedback systems employed in certain electronic amplifiers and has similar advantages.

3.2.3.1.1.2 Physical Description (3.1.1.2)

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

a. Envelope Drawing

b. Coil Connections

c. Mounting Details

d. Valve Polarity

e. Mating Electrical Connector

f. Dry Weight

The servovalve port connections should be legibly marked. Suitable locating pins may be provided to prevent incorrect connection of servovalve and manifold. The following identification of servovalve ports is recommended:

a. Supply Port: P

b. Return Port: R

c. Control Port 1: 1

d. Control Port 2: 2

The envelope given normally represents the installation space for the servovalve. It should indicate maximum dimensions and specify the location and dimensions of electrical connectors or other critical areas if applicable. The outline dimensions given in Figure 8 are furnished as a guide in the selection of servovalves. The cube-type envelopes shown reflect conditions which can be met within the industry. No allowance for electrical connectors has been made. Departure from the maximum dimensions shown can often be obtained in certain areas in order to meet more exacting space limitations.

The recommended mounting and porting configurations and methods of dimensioning these areas are given in Figure 9. Only four-way port configurations are indicated; however, three-way servo-valves should use the same basic mountings and dimensions except that one control port should be eliminated.

The flow capacity of commercially available servovalves most frequently employed may be classified broadly in terms of their respective port pattern dimensions as shown in Table 1.

It is not essential that these maximum ratings be rigidly followed since the allowable pressure drop within the servovalve at maximum required flow, or interchangeability requirements, often dictate the mounting configuration to be employed.

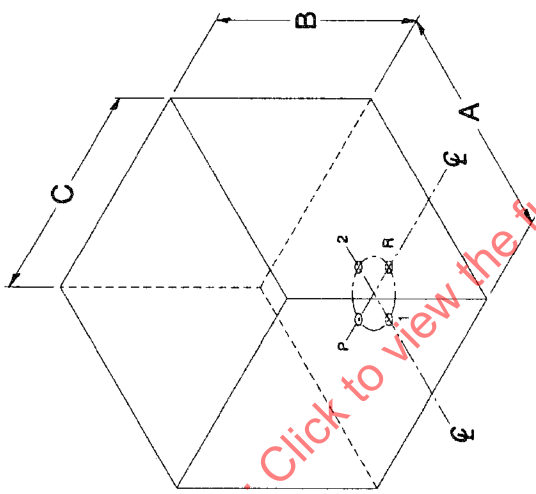
TABLE 1 - RATED FLOWS FOR STANDARD VALVE SIZES

	Size	Flow[1] gpm (mL/s)
IA	0.480 in x 0.300 in (12.19 mm x 7.62 mm)	2 (125)
IB	∅ 0.480 in (∅ 12.19 mm)	2 (125)
II	∅ 0.625 in (∅ 15.88 mm)	6 (375)
III	∅ 0.780 in (∅ 19.81 mm)	15 (950
IV	∅ 1.000 in (∅ 25.40 mm)	30 (1890)

[1]Maximum no-load flow at 3000 psid (20 000 kPa) using MIL-PRF-83282 fluid at 100 °F (38 °C). For alternate fluids and pressures, the applicable maximum flow can be estimated as:

$$Q' = (Q/6210) \times (P/\rho)^{1/2}$$

where:
- Q = Maximum flow, per the preceding table
- Q' = New maximum flow
- P = Valve pressure drop, psid
- ρ = Fluid mass density, lbf x s^2/in^4



	SIZE			
	I A & I B	II	III	IV
A	1.64 IN (41.66 MM)	3.12 IN (79.25 MM)	3.23 IN (82.00 MM)	4.5 IN (114.30 MM)
B	1.80 IN (45.72 MM)	2.54IN (64.50 MM)	2.54 IN (64.50 MM)	3.2 IN (88.90 MM)
C	1.64 IN (41.66 MM)	2.52 IN (64.01 MM)	2.52 IN (64.01 MM)	2.52 IN (64.01 MM)
WEIGHT	0.47 LB (0.213 KG)	1.0 LB (0.45 KG)	1.3 LB (0.59 KG)	2.15 LB (0.98 KG)

FIGURE 8 - STANDARD ENVELOPES

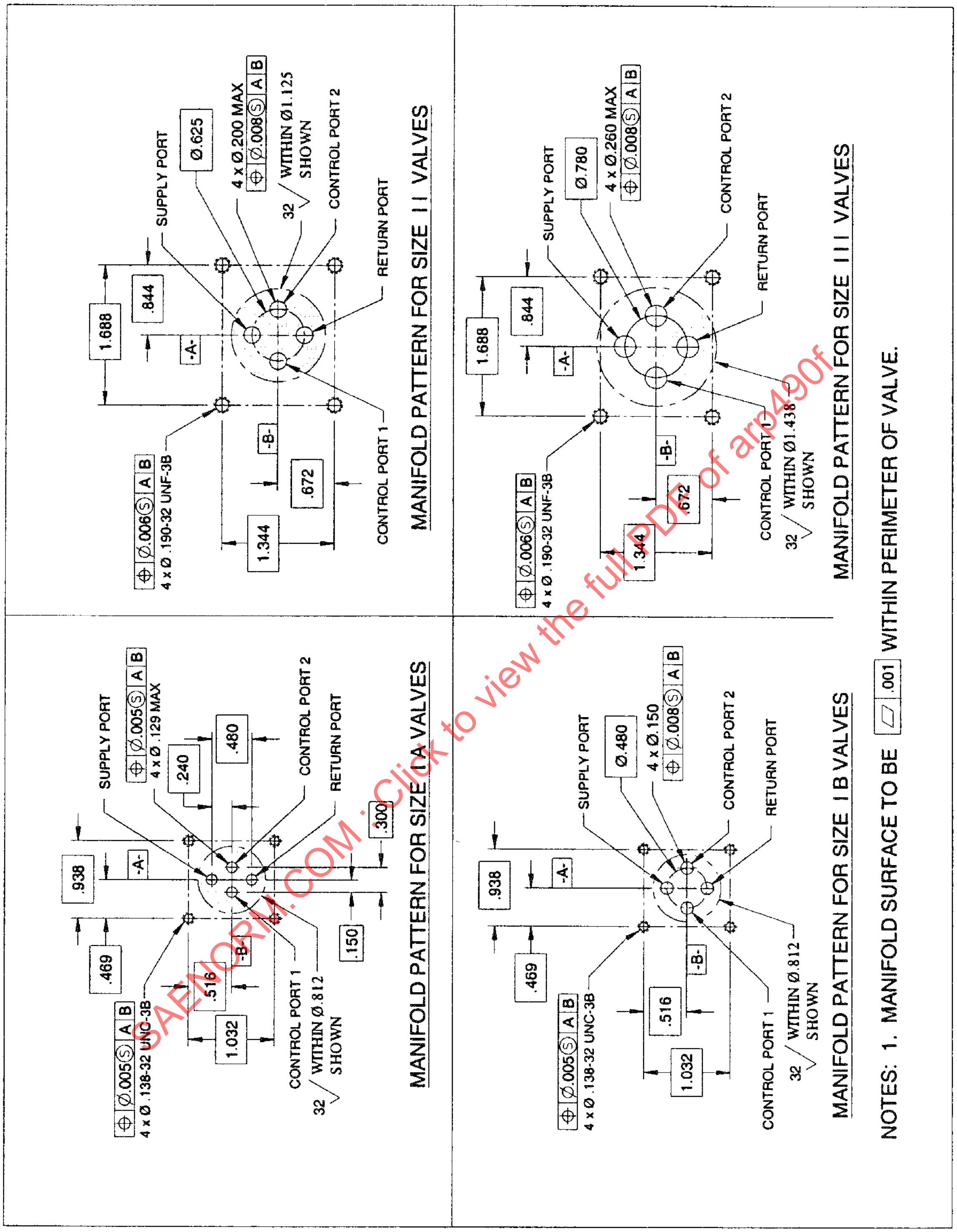


FIGURE 9 - STANDARD MOUNTING INTERFACES

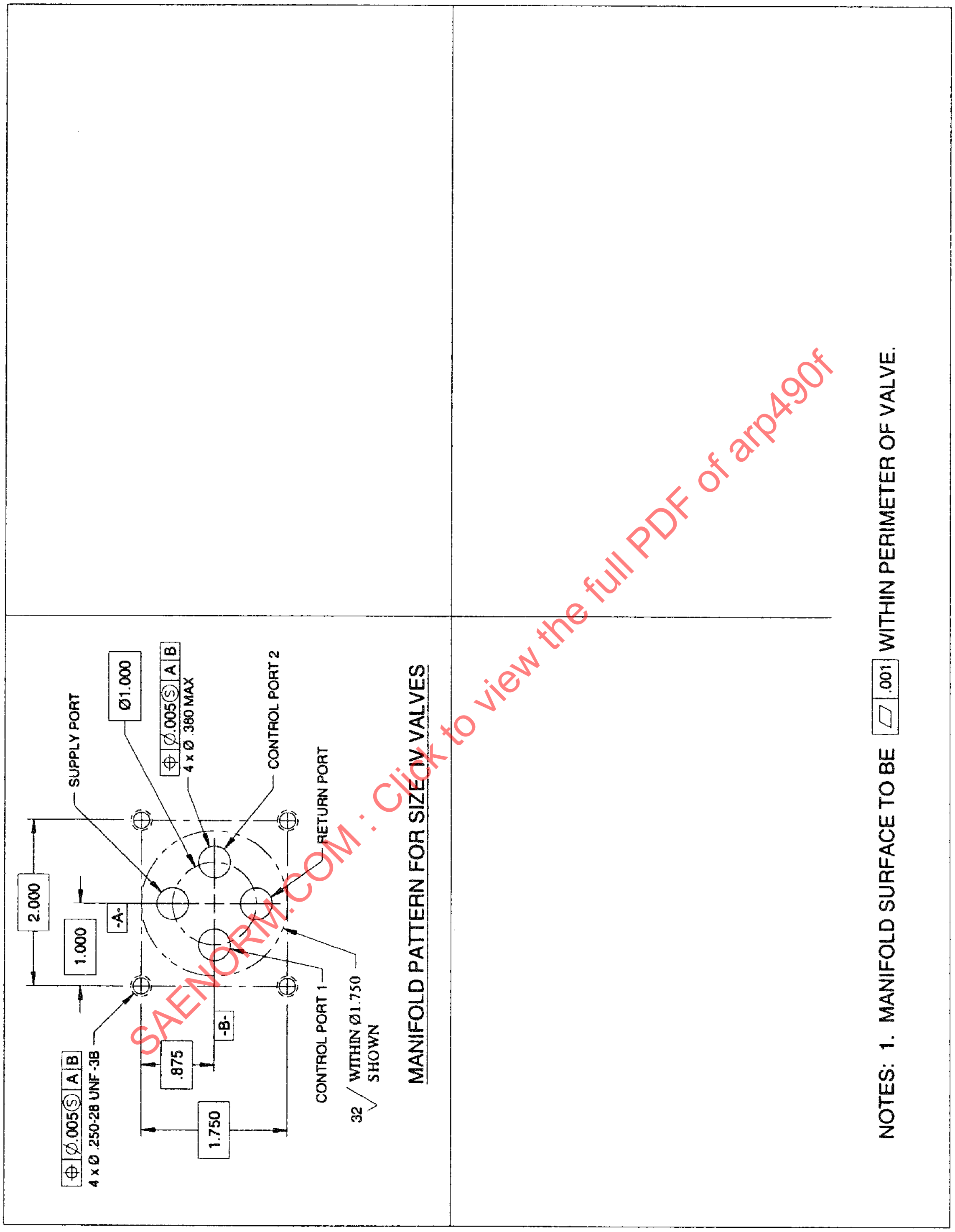


FIGURE 9 - STANDARD MOUNTING INTERFACES (CONTINUED)

3.2.3.1.1.3 Identification (3.1.1.3)

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

a. Manufacturer

b. Model Number (Supplier's Model or Part Number)

c. Serial Number

Additional information may also be included, such as the following:

a. Part Number (Customer)

b. Rated Pressure

c. Rated Current

d. Fluid

e. Contract number

f. Assembly date

3.2.3.1.1.4 Materials (3.1.1.4)

Materials 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. MIL-HDBK-1587 may be used as a guide in the selection of suitable materials.

3.2.3.1.1.5 Standard Parts (3.1.1.5)

Parts to industry and military standards, such as AS, MA, NAS, MS, or AN, should be used wherever they are suitable for the purpose.

3.2.3.1.1.6 Locking Devices (3.1.1.6)

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

3.2.3.1.1.7 Structural Strength (3.1.1.7)

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

3.2.3.1.1.8 Seals (3.1.1.8)

Seals should be of such composition and dimensions so as to satisfy the standardization and operating requirements of the applicable specifications. If a specific seal compound is desired for certain fluid or environmental conditions, the specification for the compound should be included. In aerospace servovalves it is often necessary to utilize nonstandard seals because of space and weight constraints. Therefore, while the use of standard size seals is desirable, the specification should permit the use of nonstandard seals when the concurrence of the procuring activity is obtained. Further, to assure adequate seal squeeze under the worst possible combinations of seal size, gland size, seal stretch, and gland eccentricities, the design of any nonstandard seal installations should follow the recommendations put forth in ARP1231.

3.2.3.1.2 Electrical (3.1.2)

3.2.3.1.2.1 Coil Connections (3.1.2.1)

The wiring configuration for the torque motor coils should be specified, together with the connector pin identification or lead wire color coding, as applicable. Recommended coil connections for single-ended, four-wire individual, and four-wire parallel applications are shown in Figure 10.

3.2.3.1.2.2 Rated Current (3.1.2.2)

Rated current should be stated in mA for the particular coil connection specified in 3.2.3.1.2.1. Specifying rated current and resistance combinations less than those recommended by the manufacturer may require the servovalve to be designed with less than optimum electrical control power. In general, a very low value for rated current requires the use of extremely small magnet wire, with resultant reliability hazards; so it should be avoided if possible.

3.2.3.1.2.3 Quiescent Current

If differential coil operation is specified, normal quiescent current values and polarity should be stated. Also, maximum anticipated quiescent current should be specified. If abnormal variations of quiescent current are anticipated, then the range of variation should be stated.

3.2.3.1.2.4 Insulation Resistance (3.1.2.3)

The minimum insulation resistance for valve coils and lead wires to the valve body should be specified. The recommended value is 50 MΩ under room temperature and humidity conditions following a 15 s application of a DC potential equal to 500 V, or five times the maximum anticipated coil voltage, whichever is less.

3.2.3.1.2.5 Dielectric Strength (3.1.2.4)

For systems where combined environmental effects are of concern, such as when ambient pressure, temperature, and moisture act together, an AC dielectric strength requirement should be specified.

For acceptance testing, a one time application of 1000 Vrms at 60 Hz for 15 s is recommended. To avoid undue insulation degradation, this test should not be repeated during the course of the valve's life. For subsequent tests, as may be desirable following repair, overhaul, or modification, a voltage of 800 Vrms at 60 Hz for 15 s is recommended. Even at this reduced level, the AC dielectric test represents a severe condition for the coil insulation and should not be repeated any more than necessary to demonstrate minimum compliance with the applicable quality assurance standards.

3.2.3.1.2.6 Coil Resistance (3.1.2.5)

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 coil pairs (usually within 10% of the nominal specified resistance).

3.2.3.1.2.7 Coil Impedance (3.1.2.6)

Coil impedance is a difficult parameter to measure accurately and normally will vary considerably from unit to unit. It is usually not specified where high output impedance servovalve driving amplifiers are used and the influence of valve complex impedance on servovalve input current is negligible. When impedance is specified, it is usually stated as a vector quantity, together with a tolerance. Since coil impedance will change considerably with slight variations in servovalve design, it is recommended that the individual servovalve manufacturers be consulted before this parameter is specified.

The apparent impedance of servovalve coils will be influenced markedly by operation of the torque motor. This influence is due to back emf's generated by the moving armature, so it will depend upon supply pressure, input current amplitude, and frequency. Therefore, the magnitude of each of these parameters should be included with a coil impedance specification.

Figure 1 provides a representative example of the kind of variation that can be expected as the servovalve input current frequency is varied. Because this variation can be significant, it is generally recommended that the drive electronics have the following characteristics:

- High output impedance current source.
- Sufficient bandwidth to maintain high output impedance characteristic beyond the servovalve impedance notch frequency.
- Voltage capability consistent with desired operating frequency range.

3.2.3.1.3 Hydraulic (3.1.3)

3.2.3.1.3.1 Operating Pressures (3.1.3.1)

The system supply pressure should be specified together with the nominal return pressure. Servovalves are in service for systems with operating pressures as low as 200 psig and as high as 5000 psig.

3.2.3.1.3.2 Proof Pressure (3.1.3.2)

The servovalve 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 * supply pressure applied for 2 min to ports P, 1, and 2, with return open, followed by supply pressure applied simultaneously to all ports for 2 min. Normally, proof pressure tests are applied at room temperature for production acceptance tests 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).

3.2.3.1.3.3 Burst Pressure (3.1.3.3)

The servovalve should not rupture with burst pressures of 2.5 * supply pressure on ports P, 1, and 2 (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 * supply pressure applied simultaneously to all ports. The servovalve shall not be required to operate after this test.

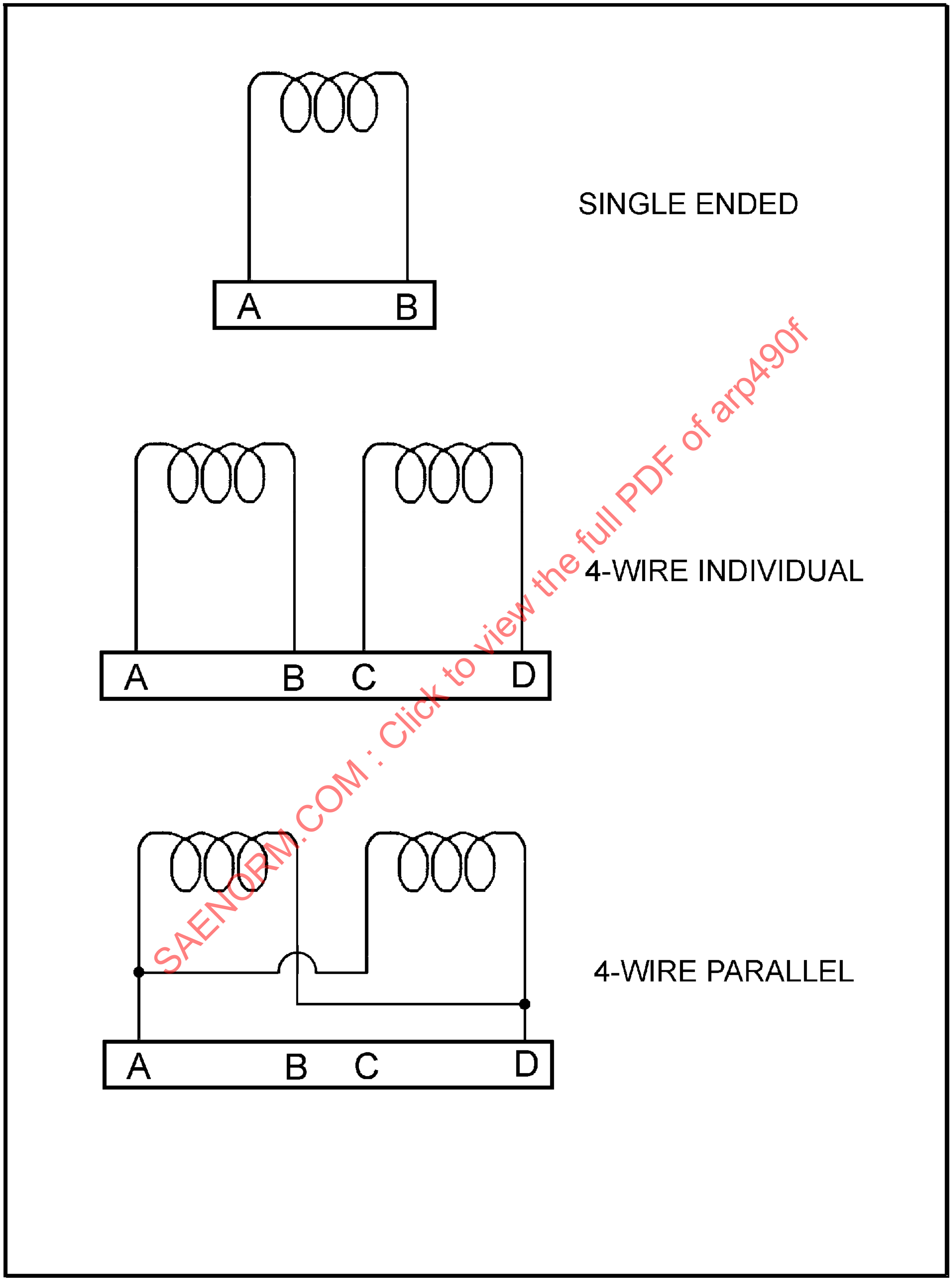


FIGURE 10 - STANDARD COIL CONNECTIONS

3.2.3.1.3.4 Pressure Impulse

Pressure impulse requirements for servovalves are occasionally specified as necessary to satisfy vehicle or system specifications. They are commonly specified to ensure adequate component fatigue life and proper elastomeric seal design. The following recommendations pertain to the specification of pressure impulse requirements and demonstration testing, when such is necessary.

The requirements of ARP1383 should be followed, except as appropriate to simulate any significant application-specific characteristics or concerns, such as fluid temperature, number of cycles, etc. It is recommended that half of the impulse cycles be applied with the servovalve input current at +50% of rated and the remaining half with -50% of rated. It is also recommended that standard test conditions (other than operating pressures) be imposed during pressure impulse testing (see 3.2.3.2.1).

The servovalve should conform to specified performance tolerances following a pressure impulse test. However, because impulse pressure testing is expected to impose severe fatigue cycles that permanently reduce useful servovalve life, a servovalve that has successfully completed pressure impulse testing should not be used for subsequent structural test evaluation, nor for normal field operation.

3.2.3.1.3.5 Fluid (3.1.3.4)

The working fluid for the servovalve should be specified. Hydrocarbon based fluids per MIL-PRF-83282 and MIL-PRF-87257 are typically used in military and space applications while phosphate ester based fluids per AS1241 are used in most commercial aircraft. The exposure to other fluids, such as preservative oil or alternate test fluids should also be noted.

3.2.3.1.3.6 External Leakage (3.1.3.5)

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

3.2.3.1.3.7 Internal Leakage (3.1.3.6)

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, but is usually specified as a value not to be exceeded throughout the current range. If necessary, this parameter can be specified both at null and at rated signal with different maximum limits at the two points.

In general, servovalve first-stage leakage can be reduced, but at the expense of dynamic response. Also, the null leakage of the second stage 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. Dither will generally cause the servovalve to appear slightly underlapped, so the internal leakage normally increases as dither is applied.

3.2.3.2 Performance Requirements (3.2)

3.2.3.2.1 Rated Test Conditions (3.2.1)

Unless otherwise stated, all servovalve specifications apply to a set of standard test conditions as defined in this section. Any specification of performance over a range of conditions (that is, over a range of temperatures, supply and return pressures, output loading, etc.) should be specified in accordance with 3.2.3.3. 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 3.2.3.2 may not apply when the test conditions are nonstandard.

The performance specifications given in 3.2.3.2 apply for operation of the servovalve under the following standard test conditions:

a. Fluid - Normally as specified in 3.2.3.1.3.5

b. Operating pressure - Normally as specified in 3.2.3.1.3.1

c. Rated current - Normally as specified in 3.2.3.1.2.2

d. Temperature - Normally 90 to 120 °F (32 to 50 °C) fluid and 65 to 90 °F (18 to 32 °C) ambient

e. Fluid cleanliness - Conform with AS4059 Class 5 or cleaner

3.2.3.2.2 Steady State (3.2.2)

3.2.3.2.2.1 Rated Flow (3.2.2.1)

Valve rated flow should be specified for the rated current 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%.

3.2.3.2.2.2 Linearity (3.2.2.2)

Linearity of the normal flow curve should be specified as a maximum percent of rated current. Standard tolerance for this parameter is 7.5%. If significant flow gain nonlinearities 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 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.

3.2.3.2.2.3 Symmetry (3.2.2.3)

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.

3.2.3.2.2.4 Hysteresis (3.2.2.4)

Hysteresis, as defined, includes threshold and electromagnetic effects. Therefore, hysteresis loop width is a function of input amplitude plus some constant value. Standard tolerance for this parameter is 5% of rated current.

When assessing the significance of this parameter, the effect of 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% servovalve hysteresis is acceptable.

Phase lag of the servovalve and of the test equipment increases the apparent hysteresis. Therefore, it is important to specify and measure servovalve hysteresis under essentially steady state conditions. Plots of a full hysteresis loop are usually run at less than 0.1 Hz.

3.2.3.2.2.5 Threshold (3.2.2.5)

Threshold should be specified as a maximum percent of rated current and the normal value is 1%. In standard two-stage servovalves, this parameter is essentially a measure of the static friction of the moving elements in the second stage. Hydraulic fluid contamination will generally increase the tendency of these parts to bind; therefore, it is important that this parameter be defined and tested according to a specified cleanliness standard. Electrical or externally applied mechanical dither is usually not included in the definition and test of this parameter.

In typical positional systems, high servovalve threshold can cause static errors or limit cycle oscillations. In both cases it is only threshold in the flow null region of the servovalve that is significant. Therefore, threshold specifications are considered to apply particularly to this region of servovalve 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 a check on servovalve quality than performance measurements which can be related directly to system operation.

3.2.3.2.2.6 Pressure Gain (3.2.2.6)

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

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

Pressure gain will normally exceed 20% of maximum load pressure drop for a change in signal input of 1% rated current.

3.2.3.2.2.7 Flow Limit (3.2.2.7)

Flow limit when specified is stated as a maximum flow which will not be exceeded for any servovalve 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.

3.2.3.2.2.8 Control Flow Versus Load Pressure Drop (3.2.2.8)

This characteristic is usually not included in servovalve specifications. When it is specified, it is generally not required as part of production acceptance tests since this characteristic is established by servovalve 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 servovalves 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 servovalve 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 servovalves present a constant orifice opening under these conditions so that increasing load pressure drop decreases the control flow by the square root relationship. For servovalves of this type, the specification can define a maximum-deviation from the square root curve extending from no-load flow to zero flow (for varying load pressure drop) at a constant input current.

3.2.3.2.3 Null (3.2.3)

3.2.3.2.3.1 Lap (3.2.3.1)

Lap tolerances are independent of rated flow gain tolerances and establish the null pressure and the effective servovalve 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 servovalve 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. Servovalve 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

3.2.3.2.3.2 Null Region Pressure (3.2.3.2)

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 of 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 pressures as the spool is displaced beyond the null region, so 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 whose metering slots are all the same width and that has 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. The Table 2 below provides some guidance (equal metering slot widths are assumed).

3.2.3.2.3.3 Null Bias (3.2.3.3)

Many servovalve designs are available which have no external null adjustments. The servovalve 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 current under rated test conditions.

During the life of the servovalve, 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 servovalve 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 current 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 of 5% of rated current over the useful life of the servovalve. This parameter then includes the tolerance of initial setting and long-term variations.

3.2.3.2.3.4 Null Shift (3.2.3.4)

Null bias may change with the application of environments. Supply pressure, return pressure, and hydraulic fluid 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 environment. Null shift may be specified for other environments if they are determined to be critical to system performance.

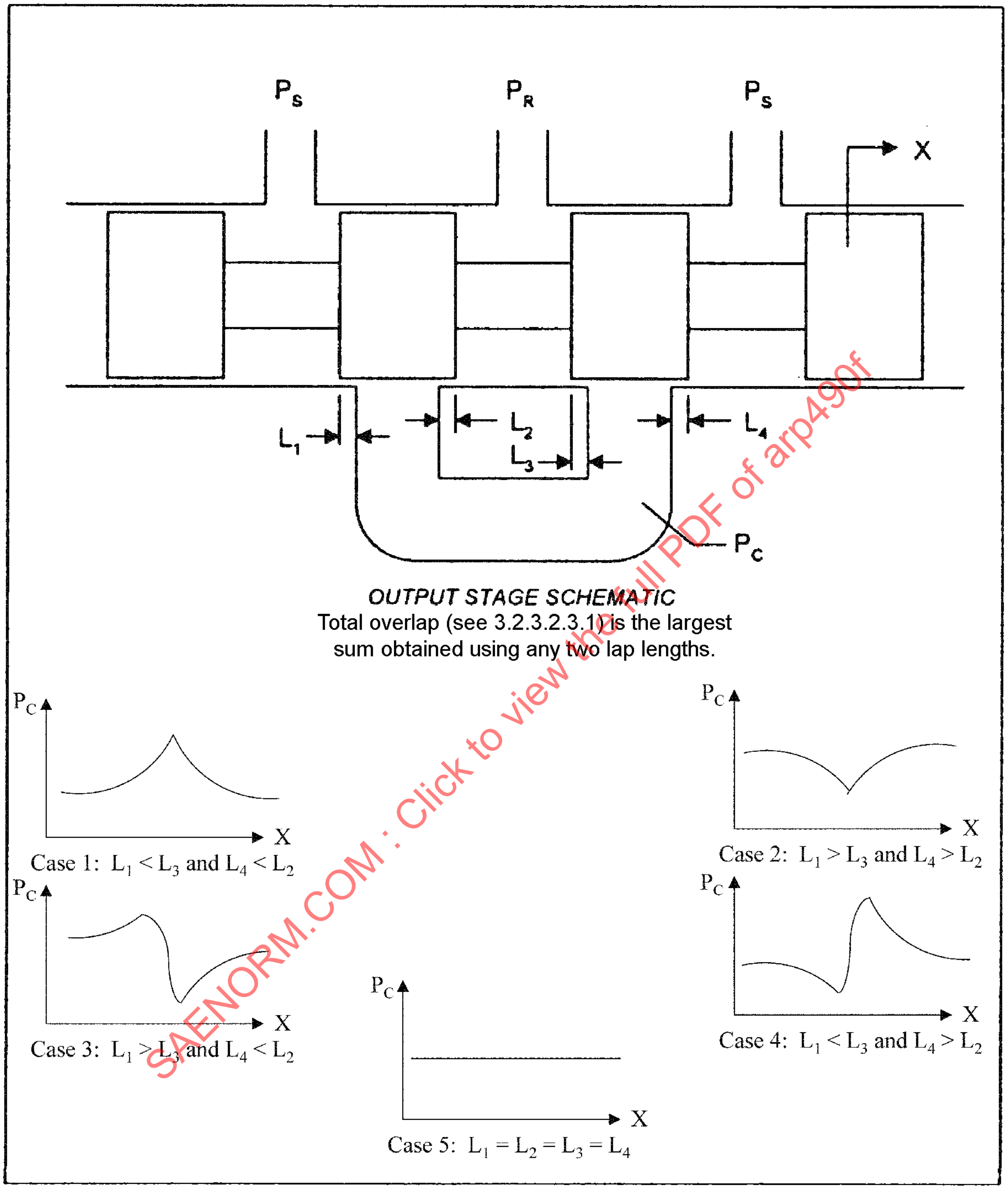


FIGURE 11 - NULL REGION CONTROL PRESSURE, UNLOADED FLOW CONDITION

TABLE 2 - INTERCONNECTED CYLINDER PORT PRESSURE

Control Level	Pressure Limits	Comments
1	Pc = (Ps + Pr) / 2 ± 0.5 x (Ps - Pr)	Suitable for most applications. Least expensive to produce. Null pressure (see 4.4.8) is the controlling requirement.
2	Pc = (Ps + Pr) / 2 ± 0.5 x (Ps - Pr)	Tighter control. Moderate cost penalty.
3	Other	Consult servovalve supplier concerning any stringent or unconventional pressure requirements. Significant cost impact is possible.

3.2.3.2.4 Dynamic (3.2.4)

3.2.3.2.4.1 Amplitude Ratio (3.2.4.1)

The dynamic transfer function of servovalves can generally be 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 diagram. Usually, maximum and minimum limits are plotted through the frequency range of interest.

Servovalve frequency response will vary with fluid temperature, supply and return pressures, and input current amplitude. Therefore, predictions of servovalve response at extremes of these operating conditions are generally unreliable and should be measured on a prototype model if performance requirements are critical. Continuity of production is usually controlled by test at one particular set of operating conditions.

Servovalve dynamic response measured at large current amplitudes will saturate at higher frequencies due to limited output of the torque motor and intermediate stages. At low input current amplitude, servovalve threshold effects produce distorted waveforms. In either case, departure from sinusoidal waveforms can produce ambiguous and even meaningless response data. The recommended peak-to-peak amplitude of the input current for dynamic response testing is one-half the rated current.

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

3.2.3.2.4.2 Phase Angle (3.2.4.2)

Phase angle should be specified on the same Bode diagram as amplitude ratio. This parameter is usually specified as a curve of maximum allowable phase lags, 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.

3.2.3.3 Environmental Requirements (3.3)

Standard 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 servovalves and the specific areas of performance which are affected are the following:

a. Temperature: Servovalve performance, at various temperatures, will be greatly influenced by the viscosity of the fluid. As an example, only limited performance will be obtained below fluid temperatures of -20 °F (-29 °C) using MIL-PRF-87257 as the operating fluid. At -65 °F (-55 °C) fluid servovalve performance sufficient for system start capability should normally be expected. Servovalve pressure gain and null shift can be important at this temperature (see 4.7.1).

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

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

d. Humidity, Salt Spray, and Immersion: Normally, the only servovalve 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 servovalve may be expected to perform to specification for a limited period of time only. Care must be taken to be sure that the operating time desired and the contaminant level are compatible.

f. Life: The performance of a servovalve is a function of many factors which, regardless of excellence of design, may reduce its life. These factors include extreme environments, fluid contamination, and frequency and magnitude of electrical and pressure overloads. A servovalve is designed to perform many millions of cycles. However, dependent upon 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 probable 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.

Servovalve 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.

3.2.4 Quality Assurance Considerations (4.)

Quality assurance provisions are outlined to establish a means of test and inspection for a servovalve 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.

3.2.4.1 Quality Assurance General Requirements (4.1)

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, Government Control Documents should be included.

3.2.4.1.1 Classification of Tests (4.1.1)

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

a. Qualification Tests

b. Acceptance Tests

c. Reliability Tests

3.2.4.1.2 Calibration of Instrumentation (4.1.2)

All measuring and testing equipment must be maintained in a calibrated condition to provide the standards which are necessary to define servovalve 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 servovalve manufacturers is usually scaled to obtain maximum readability and accuracy. If special test equipment is required, the method and equipment tolerances required should be specified.

3.2.4.1.3 General Test Notes (4.1.3)

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

3.2.4.2 Qualification Tests (4.2)

Qualification tests (first article 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 procuring 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 is a partial list of tests which the procuring agency may elect to include in a qualification test program.

a. Preparation of Test Unit

b. Vibration

c. Proof Pressure

d. Shock

e. Acceptance

f. Humidity

g. Extreme Temperature

h. Salt Spray

i. Life

j. Immersion

k. Burst Pressure

l. Altitude

m. Contamination Sensitivity

n. Impulse

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 procedure, 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.

3.2.4.3 Acceptance Tests (4.3)

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:

a. Examination of Product

b. Coil Resistance

c. Insulation Resistance

d. Dielectric Strength

e. Proof Pressure

f. Polarity

g. Rated Flow

h. Linearity

i. Symmetry

j. Pressure Gain

k. Internal Leakage

l. Null Bias

m. Threshold

n. Hysteresis

o. Dynamic Performance

3.2.4.4 Reliability Tests (4.4)

Reliability tests may be conducted on a periodic or a sampling basis throughout the production run to assure that the required level of reliability is maintained. Reliability 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.

3.2.4.5 Preparation for Delivery (5.)

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 servovalves such as flushing and use of preservative fluids should also be included in this section.

3.2.4.6 Notes (6.)

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.

4. RECOMMENDED TEST METHODS

4.1 General

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

Most servovalve performance characteristics can be obtained utilizing either continuous plotting equipment or manual point-by-point methods. Although the point-by-point methods are recognized, the use of continuous plotting equipment is recommended and 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.

In order to be consistent with the definitions of this document, the acceptance parameters of applicable steady state performance characteristics are expressed as percentages of rated 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.

4.2 Test Equipment

Figures 12 through 15 are simple schematics describing equipment necessary to test servovalves 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 servovalves, there are many aspects to be considered. These include:

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

b. Mounting manifold dimensions are provided in Figure 9 for the standard valve sizes identified in 3.2.3.1.1.2. All mounting manifolds should be adequately flat to prevent servovalve 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.

c. Manually operated valves should be of high quality to ensure zero leakage.

d. Use of magnetic material including the servovalve manifold or presence of magnetic fields in the proximity of the servovalve may affect its performance.

e. Care should be taken to have elastomers compatible with operating fluids and temperatures.

f. Care should be taken to maintain proper cleanliness in the test stand. Except for the possible special requirements of life and contamination testing, test stand fluid cleanliness requirements should at least meet the cleanliness requirements for the system in which the valve is to be used. AS4059, Class 5 or cleaner cleanliness is recommended. The system should initially be flushed until the recommended contamination level is attained (before servovalves are tested). Periodic sampling of fluid is also recommended.

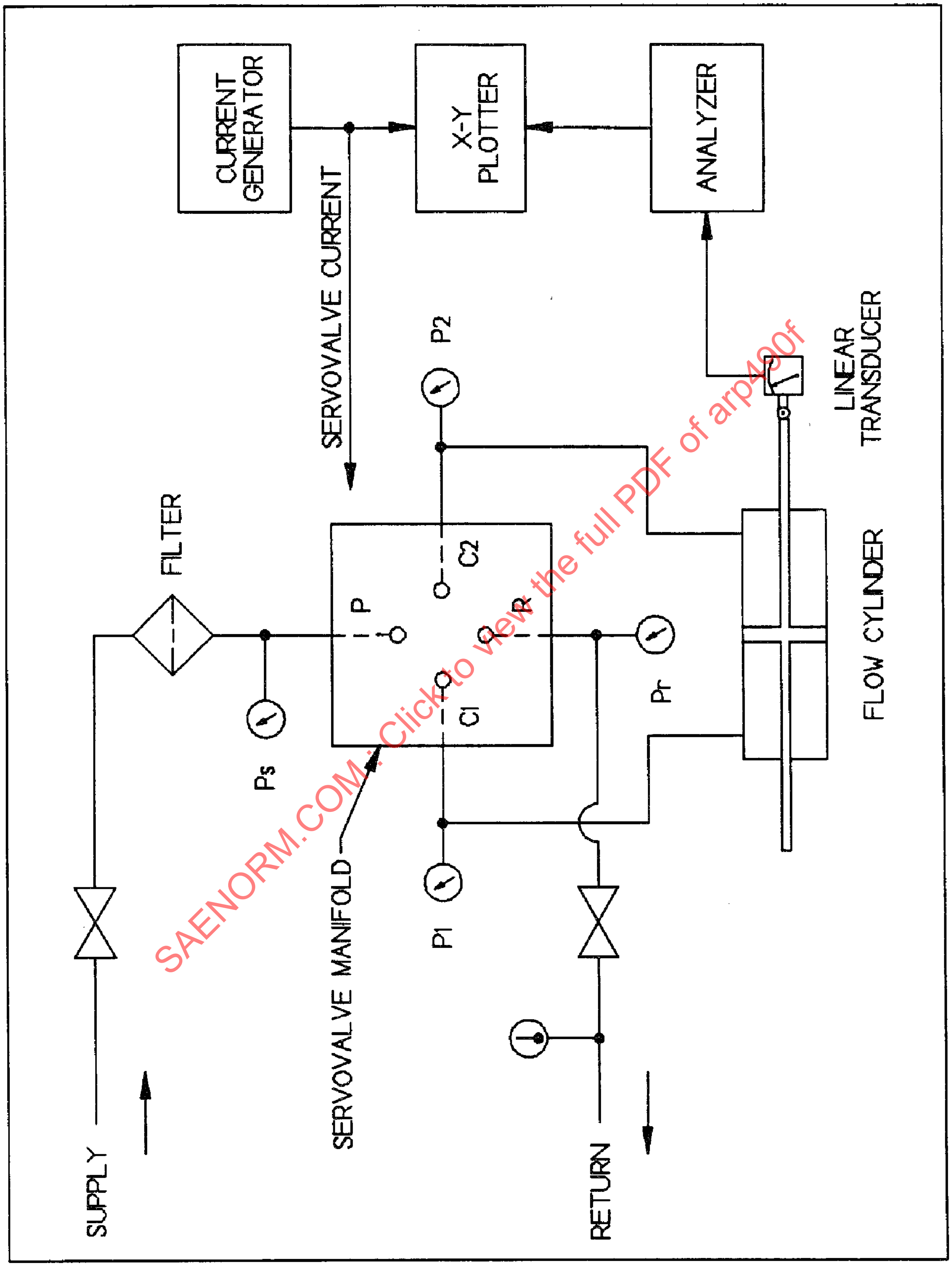


FIGURE 12 - FLOW CURVE EQUIPMENT SCHEMATIC

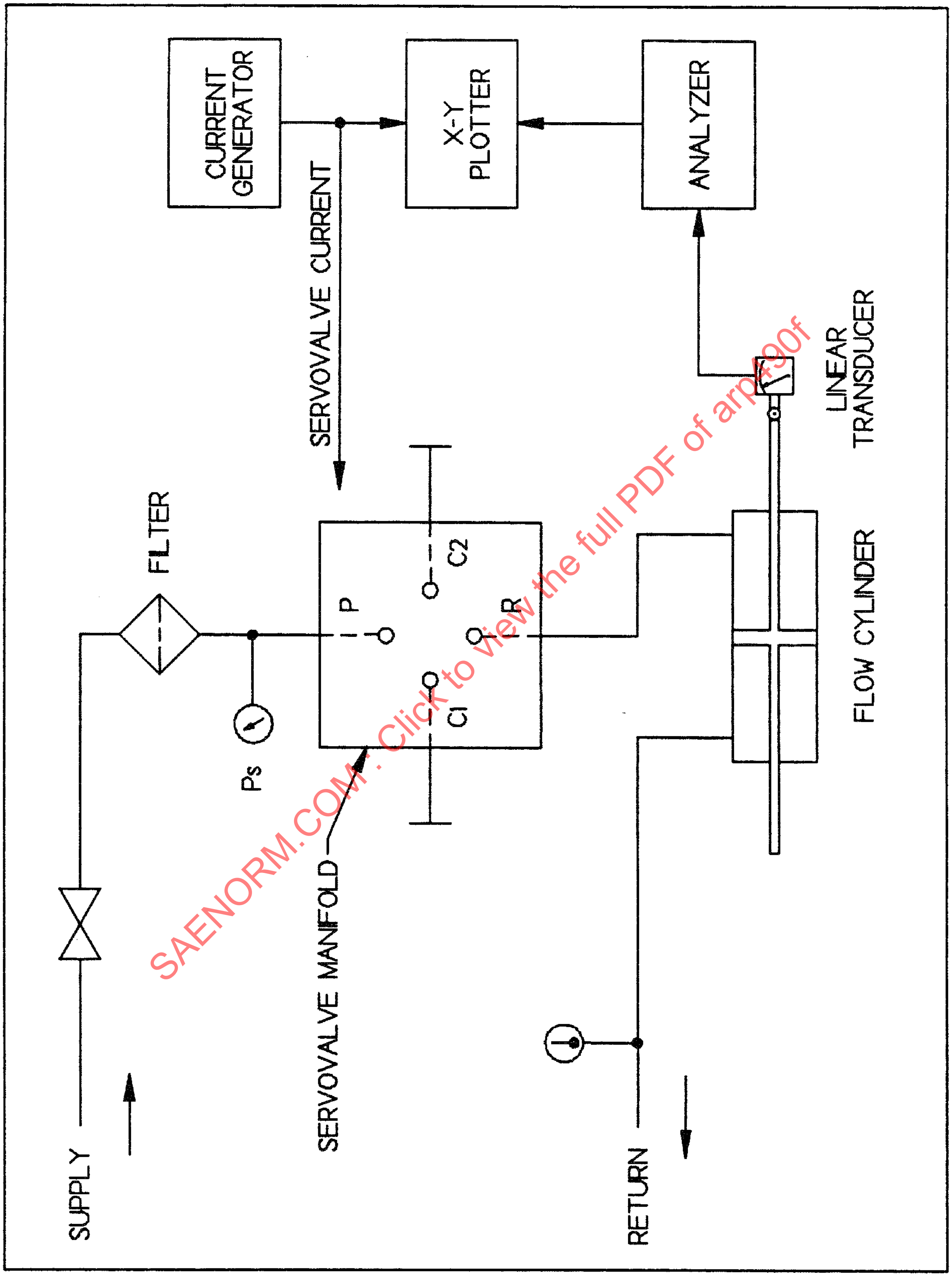


FIGURE 13 - INTERNAL LEAKAGE EQUIPMENT SCHEMATIC

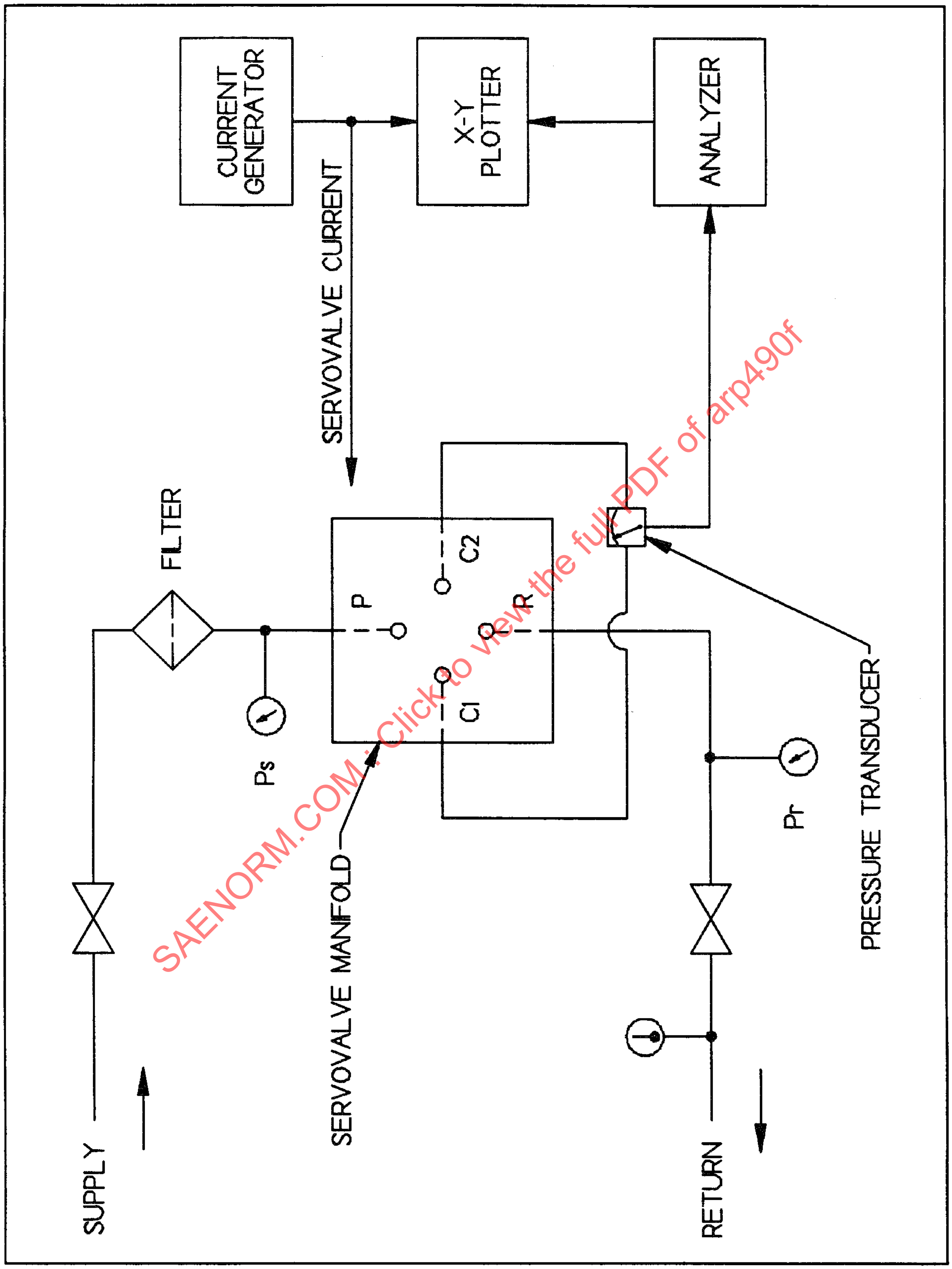


FIGURE 14 - PRESSURE GAIN EQUIPMENT SCHEMATIC

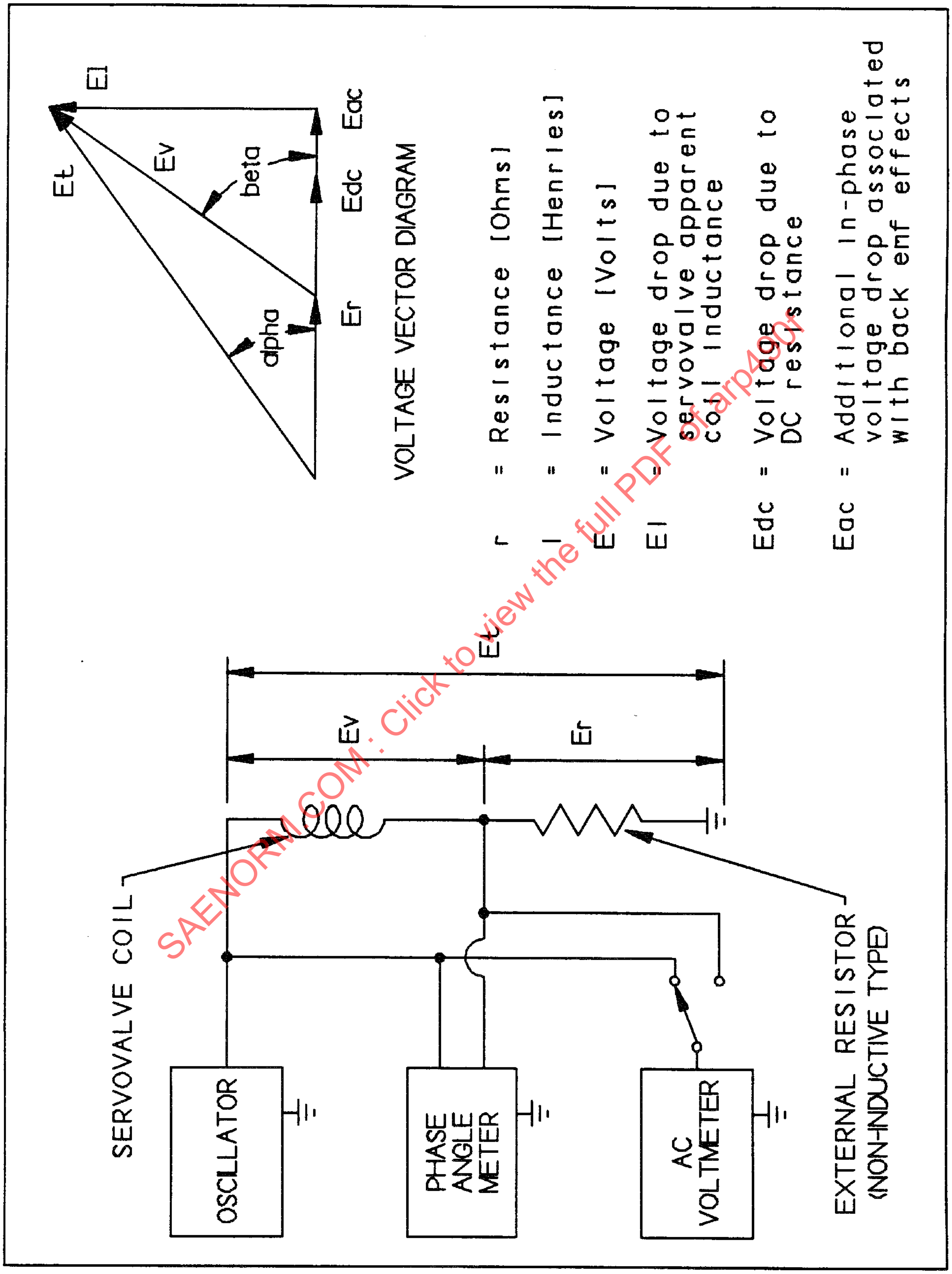


FIGURE 15 - SERVOVALVE COIL IMPEDANCE TEST

g. Actuators used for test should be selected to be compatible with flow and dynamic requirements of the servovalve being tested. Actuator leakage should be sufficiently low to have a negligible influence on test measurements.

h. Instrumentation should be selected to be compatible with required ranges under test. Test equipment tolerances should be compatible with specified servovalve parameter tolerances.

i. To minimize the effect of compliance, pressure transducers used in the pressure gain schematics should be placed as close to the valve manifold as possible. Compliance of the fluid and transducers in the servovalve control lines should be minimized for pressure gain measurements.

j. The existence of ripple in either the electrical current source or the hydraulic supply should be minimized to reduce the influence of dither on test results.

4.3 Electrical Tests

4.3.1 Insulation Resistance and Dielectric Strength

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

Apply specified voltage between the coil terminations (connected together) and the servovalve 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.

4.3.2 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.

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

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

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

where:

α_1 = temperature coefficient of resistivity (copper conductor assumed), °F-1 (°C-1)

R_1 = measured resistance, Ohms

R = corrected resistance, Ohms

T_1 = actual temperature, °F (°C)

T = specification temperature °F (°C)

If the servovalve 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 servovalve should not be supplied with pressurized fluid during this measurement, and time should be allowed to stabilize its temperature at room ambient.

4.3.3 Coil Impedance

A suitable oscillator is connected to drive the servovalve coil (or coils) connected in series with a noninductive resistor. The oscillator is set at the desired frequency and the amplitude adjusted to give a peak-to-peak current of one-quarter servovalve rated current. The oscillator should have sufficient output to supply undistorted input current. The servovalve should be supplied with fluid at rated pressure during this measurement. When the servovalve has two coils they are usually connected in series, with appropriate change in current amplitude.

A test schematic, as well as the vector relationship of the voltages, is indicated in Figure 15. To determine the vector impedance, first measure the AC voltages Er and Et. Then measure the angle α between Er and Et. Coil impedance characteristics are given by the following expressions:

Phase Angle:

$$\beta = \tan^{-1}\{Et \times \sin(\alpha) / [Et \times \cos(\alpha) - Er]\}, \text{ degrees} \quad \text{(Eq. 2)}$$

Coil impedance:

$$Z = R \times Et \times \sin(\alpha) / (Et \times \sin(\beta)) = R \times Ev / Er, \text{ Ohms} \quad \text{(Eq. 3)}$$

Apparent inductance:

$$L = R \times Et \times \sin(\alpha) / (2 \times \pi \times f \times Er), \text{ Henries} \quad \text{(Eq. 4)}$$

4.4 Steady State Performance Tests

After installing the servovalve 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.

4.4.1 Polarity

Apply rated supply pressure to the servovalve 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 torque 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 may also be conducted with the servovalve control ports opened to the flow measuring cylinder by observing the direction of piston travel when input current is applied.

4.4.2 Proof Pressure and External Leakage

With the load valve(s) closed and return valve(s) open, apply the specified proof pressure to the servovalve 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 servovalve for permanent deformation and external leakage.

4.4.3 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 2 and 12.

To generate the flow curve, apply rated supply pressure to the servovalve. 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 servovalve 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, then lower the pen and plot one complete cycle. The rate of cycling should be slow enough to minimize any errors which 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 non-linearity of the plot as the flow measuring piston reverses direction.

Except for null bias measurements, the hysteresis of the servovalve 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.

4.4.3.1 Rated Flow

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

4.4.3.2 Hysteresis

Disregarding plotter non-linearities or servovalve 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 servovalve may also be measured from the pressure gain plot described in 4.4.7, 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 servovalves.

4.4.3.3 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 servovalve by dividing the difference between the two flows by the larger flow, and converting the result to a percent.

4.4.3.4 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.

4.4.3.5 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 servovalve.

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 4.4.7) may also 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.

4.4.3.6 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.

4.4.4 Lap

Generate a flow curve of suitably expanded proportions to permit evaluation of the servovalve lap condition. Locate the nearly straight portions of the normal flow curve (see Figure 4) 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 7A, 7B, and 7C.

4.4.5 Threshold

Servovalve 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 current to the servovalve 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 servovalve threshold.

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

4.4.6 Internal Leakage

The total internal servovalve leakage at rated pressure with control ports blocked is determined with flow measuring equipment as indicated in Figure 13. 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.

4.4.7 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.

4.4.8 Null Pressure

For a four-way servovalve, 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 servovalve is installed in the system.

4.5 Dynamic Response Tests

4.5.1 Test Circuit Considerations (See Figure 16)

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 servovalve 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 servovalve 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 servovalve test frequencies.

4.5.2 Conditions of Measurement

a. A constant amplitude undistorted sinusoidal input current should be provided to the servovalve. 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.

4.5.3 Performance of Test:

a. Plot the amplitude ratio and the phase lag of the servovalve 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.

4.6 Use of Overlays

Assessment of servovalve performance obtained by X-Y plots of both steady state and dynamic characteristics (see 4.4 and 4.5) is readily accomplished through the use of overlays showing acceptable performance limits. Overlays are particularly well suited to production acceptance testing and receiving inspection of servovalves where clear-cut acceptance or rejection of the servovalve 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 servovalve linearity and lap do not represent precise interpretation of the definitions given in 2.2. However, overlays can be constructed which provide rigid control of these servovalve parameters and often they give even tighter control of servovalve performance.

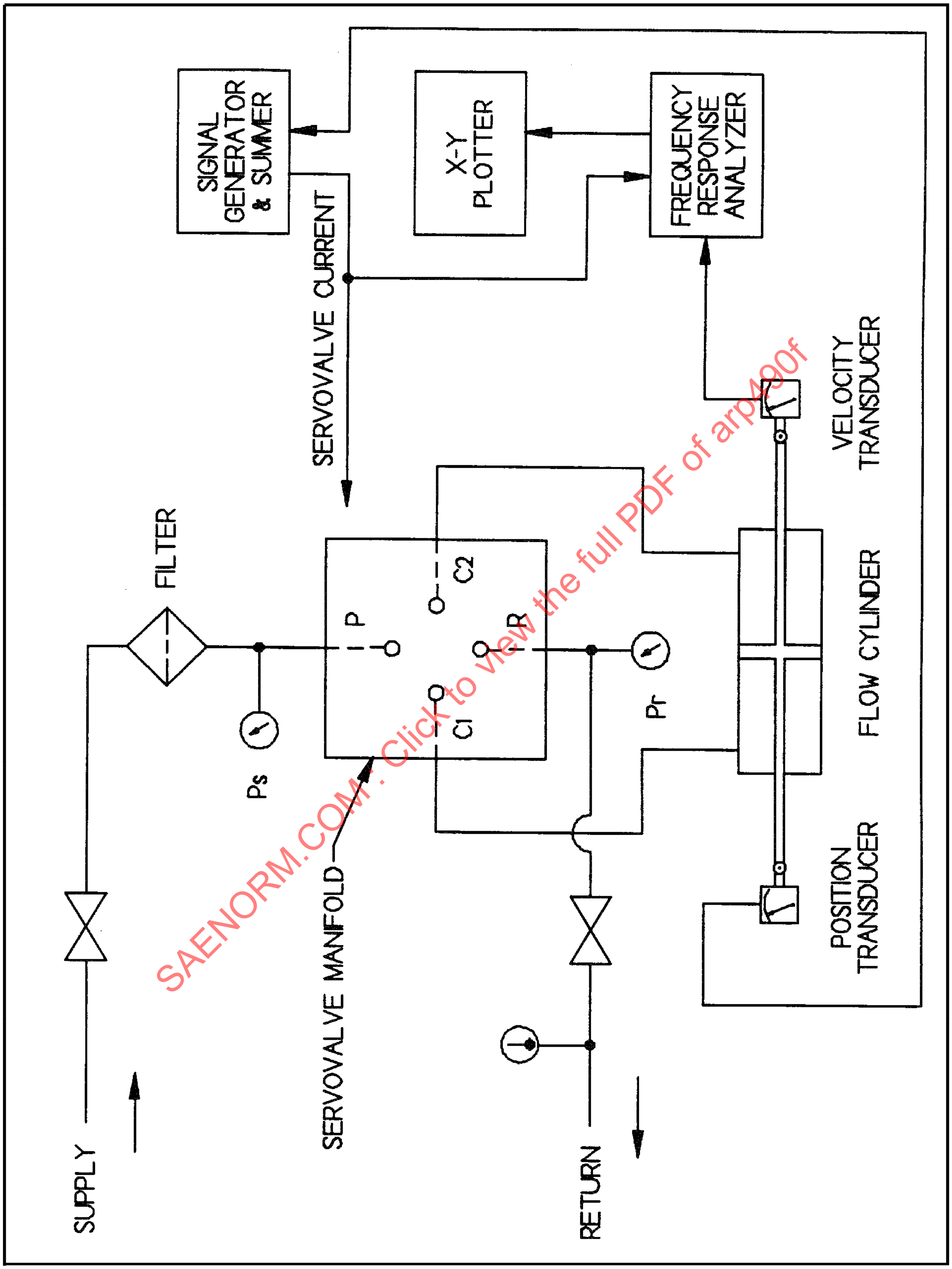


FIGURE 16 - FREQUENCY RESPONSE TEST EQUIPMENT

Overlays should be prepared on a material having good dimensional stability such as translucent mylar[1]. 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 17.

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

Part (A) of Figure 17A 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 17A, Part (B).

Either side of the actual no-load flow plot is generally used to assess servovalve 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 17A, 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 17A 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 servovalves having rated flows throughout the allowable range. If servovalve linearity, as defined in 2.2.3, 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 17A. This limit would be used in conjunction with a line drawn on the servovalve 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 servovalve pressure gain plot. Performance limits for pressure gain are shown in Part (D), Figure 17B. Servovalve threshold should also be measured with expanded scales, using suitable overlay limits (E) in Figure 17B. 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 servovalve leakage, as shown in Part (F), Figure 17B.

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 servovalve test criteria. Often the servovalve 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 servovalve data which is visible outside the limit lines show unacceptable performance. Suitable allowance should be made for plotter pen effects.

[1] Registered trademark of DuPont.

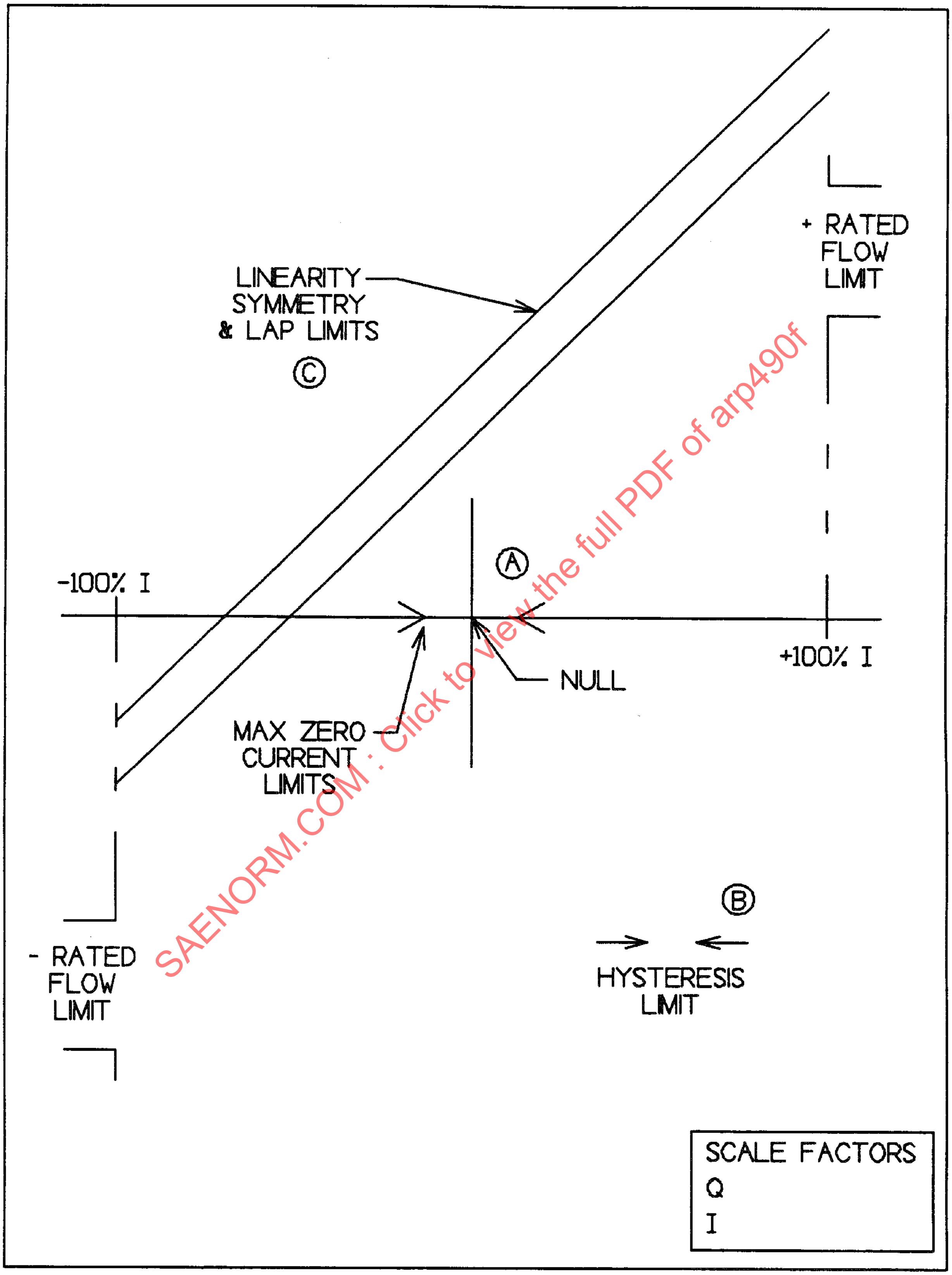


FIGURE 17A - RATED FLOW, LINEARITY, SYMMETRY, LAP LIMITS, AND HYSTERESIS

FIGURE 17 - SAMPLE OVERLAY

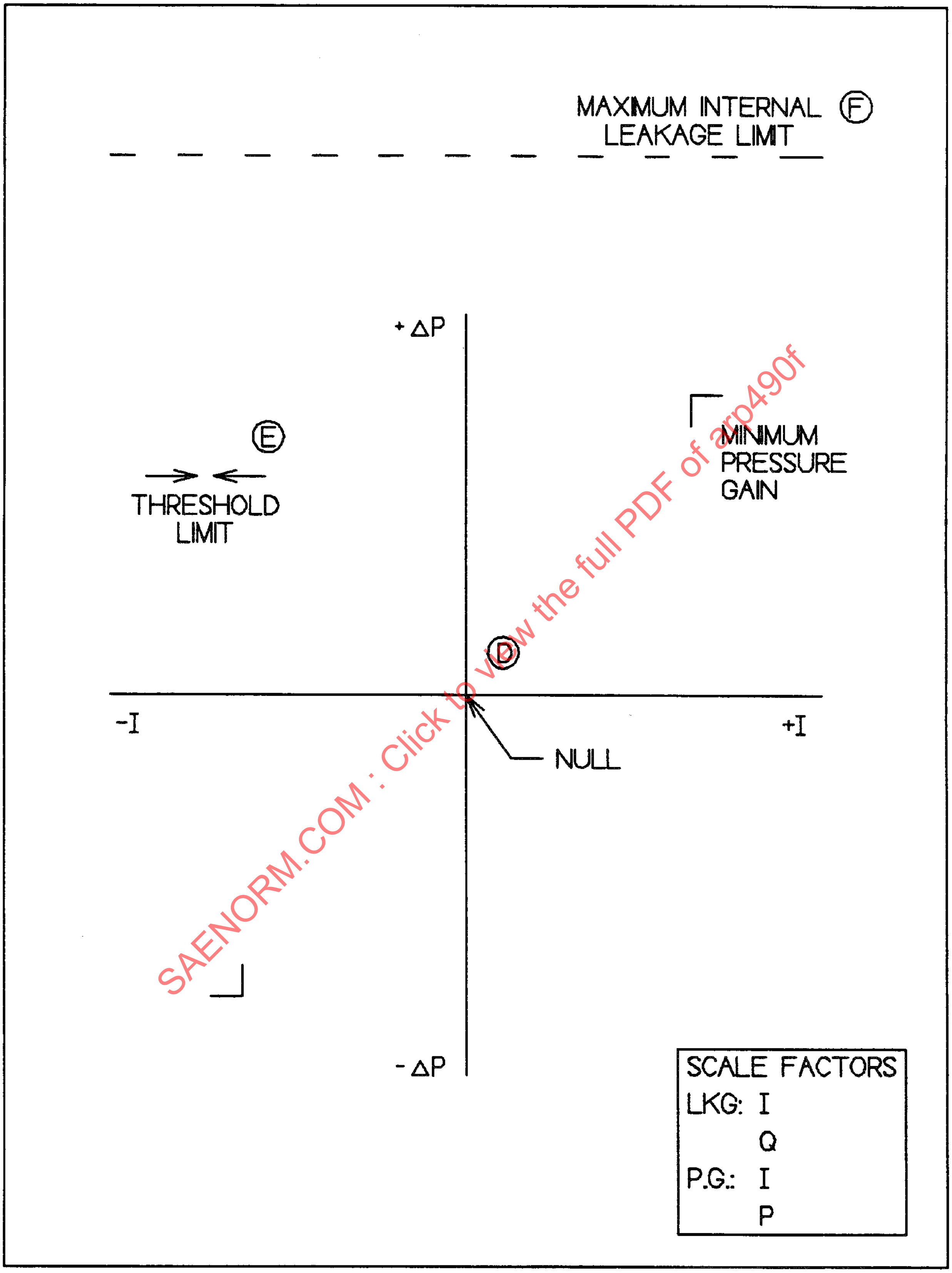


FIGURE 17B - PRESSURE GAIN, THRESHOLD, AND INTERNAL LEAKAGE

FIGURE 17 - SAMPLE OVERLAY (CONTINUED)

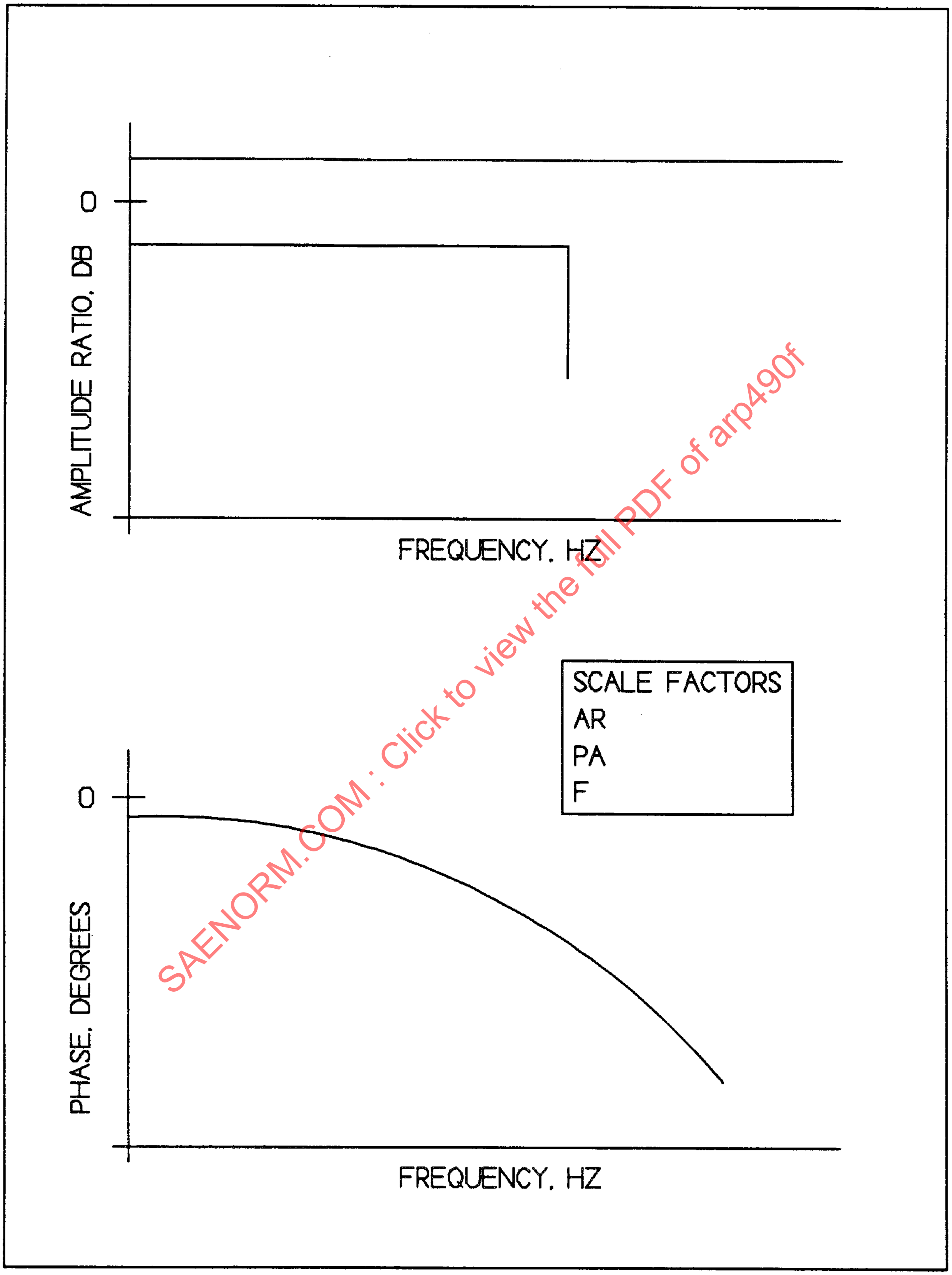


FIGURE 17C – AMPLITUDE RATIO AND PHASE

FIGURE 17 - SAMPLE OVERLAY (CONTINUED)

4.7 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 servovalve design, it may be possible to qualify by similarity. In this case, the servovalve 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.

4.7.1 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 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 4.2, 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, servovalve 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 (see 3.2.3.3.a), 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 (-30 °C) and +275 °F (+135 °C) some operational parameters are usually measured. It is important to stabilize the servovalve 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 (-30 °C) and +275 °F (+135 °C) so that performance changes, such as null shifts, can be determined.

4.7.2 Altitude

Since servovalves 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 4.3.1 with the specimen placed in a suitable vacuum chamber.

4.7.3 Vibration

One purpose of this test is to prove that the servovalve will maintain its structural integrity during and after application of the specified vibration levels. Another aspect is servovalve performance during the presence of vibration (in particular, null shift and control flow caused by the vibration frequency). To determine servovalve performance during vibration, it is necessary to operate the servovalve and make appropriate measurements. It is impractical to perform tests for individual servovalve parameters during the vibration test. Therefore, it is recommended that the servovalve 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 servovalve threshold, DC null shift, or any servovalve 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 servovalve flow.

The servovalve 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 servovalve for each of the three axes.

4.7.4 Sustained Acceleration

Sustained acceleration conditions allow for specific parameter measurements during application of the steady state environment. The pertinent servovalve 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 servovalve 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 servovalve 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.

4.7.5 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 servovalve performance during the shock test. The primary measurement consists of comparing servovalve performance before and after the application of shock. Normally, the servovalve 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 servovalve oscillation, or null shift, this will be detected by the pressure transducers.

The shock test fixture should allow servovalve 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 servovalve and, if required, contain the pressure transducers in the servovalve control ports. Fluid volume in the blocked control ports should be kept to a minimum.

4.7.6 Humidity

This environmental test is classified as passive so the servovalve need not be operated nor pressurized during application of the environment. The insulation resistance test per 4.3.1 should be run before and after this environment.

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

4.7.7 Salt Spray

This environmental test is classified as passive so the servovalve need not be operated nor pressurized during application of the environment. The insulation resistance test per 4.3.1 should be run before and after this environment, and external leakage per 4.4.2. Again, caution must be taken to seal the base ports of the servovalve and to insert the mating electrical connector during application of salt spray.

4.7.8 Fungus Resistance

This environmental test is classified as passive so the servovalve need not be operated nor pressurized during application of the environment. The insulation resistance test per 4.3.1 should be run before and after this environment, and external leakage per 4.4.2. Base ports should be covered and the mating electrical connector inserted prior to testing.

4.7.9 Fluid Contamination

This environment has not been standardized nor has acceptable performance of the servovalve 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.

The recommended maximum contamination level for meaningful testing of servovalves which operate on hydraulic fluid is that corresponding to the maximum particle count limits of AS4059 Class 8 fluid.

Servovalve 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.

As of this revision, a contaminant sensitivity test procedure is being developed by the SAE. This procedure consists of tests which measure sensitivity to silt lock (including magnetic particles for electrohydraulic servovalves) and contaminant wear/erosion. These short, standardized tests do not establish performance requirements. Rather, they provide a means for making repeatable comparisons of performance between servovalve designs. If, in addition to these tests, performance requirements are invoked, they should reflect the specific requirements of the intended application.

4.7.10 Life

Servovalve life tests are directed towards establishing the extent of performance degradation after the specified life requirements. Servovalve 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 servovalve 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 servovalve 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 servovalve subsequent to the life test.

5. QUALITY ASSURANCE AND RELIABILITY CONSIDERATIONS

5.1 Quality Assurance Considerations

5.1.1 Scope

It is the intent of this section to discuss quality considerations unique to servovalves and to complement, rather than to recommend, a quality assurance program. It is presumed that both servovalve manufacturers and their users maintain effective quality assurance programs, planned and developed in conjunction with their other functions.

5.1.2 Contamination Control

5.1.2.1 Built-in Contamination

Control of sources of contamination during the assembly of a servovalve requires the application of stringent controls to assure all parts are free of burrs and residual contamination from previous manufacturing processes. Assembly areas must be well controlled to minimize airborne contamination and be isolated from equipment which can generate contamination.

5.1.2.2 Hydraulic Fluid Contamination

The control of the contamination and properties of the hydraulic fluid are extremely important in the manufacture and use of servovalves. Contamination not only contributes to operational failures but can result in decreased life and erroneous test results.

5.1.2.2.1 Filtration

The importance of adequate hydraulic system filtration cannot be minimized. The filtration system should be capable of controlling the particle count and distribution within a prescribed tolerance range. Contamination below 5 µm can have a significant effect upon the silting characteristics of a unit utilizing lapped spools and sleeves having diametral clearances of this same order of magnitude.

5.1.2.2.2 Sampling

The proper sampling of a hydraulic system is a vital factor in the control of contamination. Proper design and placement of sampling valves coupled with controlled sampling procedures are necessary to minimize the introduction of contamination by the sampling procedure.

5.1.2.2.3 Analysis

Once a representative sample has been obtained, the analysis of this sample is of prime importance. Methods, both manual and automated, have been devised to determine contamination levels of a fluid. The chosen method should comply with the requirements of AS4059.

5.1.2.2.4 Hydraulic Fluid Properties

The control of the physical properties of the hydraulic fluid is important in obtaining consistent performance characteristics from a servovalve. Duplication of test results from one facility to another can be influenced by differences in the fluid's properties. See AIR810.

5.1.2.2.4.1 Viscosity

Fluid viscosity is influenced principally by temperature and system degradation of viscosity improvers. Shearing motion between hydraulic system components (e.g., spool valves) is the primary cause of cumulative viscosity improver damage. Control of viscosity is significant in obtaining consistent leakage measurements.

5.1.2.2.4.2 Degradation

Excessive water content can produce gelatines in some fluids. Also, particulate contamination can accelerate fluid degradation by acting as catalysts to form harmful by-products.

5.1.3 Test Equipment and Gaging Calibration Tolerance

The manufacturers of servovalves will normally maintain a calibration system in conformance to ANSI/NCSL Z540-1. However, it should be understood that within practical limits and state-of-the-art boundaries, calibration tolerance ratios of 10:1 will be sought as a goal. The calibration ratio is the accuracy of the calibrating standard to the accuracy of the equipment being calibrated. In the cases of extreme accuracy the standard is sometimes used as the measuring instrument, resulting in a 1:1 ratio.

5.2 Reliability

5.2.1 Scope

It is the intent of this section to discuss reliability considerations unique to servovalves and to complement, rather than to recommend, a reliability program. Reliability requirements in the form of either a numerical value or a reliability program, or both, are sometimes specified for a servovalve. When specified, reliability requirements should be well defined and should reflect boundary conditions particular to the system in which the servovalve will be installed. This requires consideration of certain aspects pertaining to servovalves as discussed in the following paragraphs.

5.2.2 Considerations

5.2.2.1 Application

The application will normally govern whether reliability requirements are specified, and the extent of these requirements. This may be decided by failure consequence in a higher level equipment, by a higher level equipment contract requirement, or by other factors.

Considerable divergence exists with regard to operating characteristics, environmental conditions, and duty cycles. For this reason, a universal reliability requirement for servovalves is not considered feasible.

Where it is deemed necessary to specify reliability requirements, the following factors should be considered:

a. Servovalve failure consequence in higher equipment application.

b. Vulnerability of anticipated designs to malfunction.

c. Available service experience, applicable to the servovalve being specified, as to demonstrated reliability.

d. Demonstrated reliability versus required reliability.

e. Practical potential for improving servovalve reliability.

f. Intentions for employing servovalves redundantly, or for providing other redundant features.

g. Constraints of program (that is, number of servovalves procured, procurement lead time, span time of application, cost, etc.).

h. Operational and environmental conditions particular to the system in which the valve is to be installed.

5.2.3 Numerical Reliability Requirements

When a numerical reliability requirement is specified, it should be expressed as a requirement which can be realistically measured. Therefore, when a numerical requirement is stipulated, demonstration test requirements should be defined to permit the servovalve manufacturer to assess the ability of the particular servovalve to comply with the specified numerical reliability requirement. Performance of reliability demonstration test may not be required.

It may be possible to employ similarity data to indicate compliance with the reliability requirement. In any event, evidence submitted to verify compliance with specified reliability should be based upon test or other empirical data, or both, and not on reliability predictions based upon questionable arbitrary assumptions and numerical data.

5.2.4 Reliability Program Requirements

Formal programs such as those specified in NASA document NHB 5300.4 are all inclusive and are intended to be applied to complex systems. These programs are not normally applicable to components such as servovalves.

If a reliability program is required, a practical, direct approach is recommended. A program plan, tailored specifically to the servovalve under consideration, should be prepared and effected to direct reliability task. This program plan should specify specific tasks to be accomplished rather than to catalog reliability principles. A reliability program may be applied whether or not a new design is involved, to assure the effectiveness of the design and quality assurance efforts. Some reliability program considerations are listed below:

a. If a new design is required, inherent reliability can most effectively be achieved through a concentrated reliability design effort performed by experienced designers, started in initial design concept phase and continuing through design completion. A failure possibility analysis is recommended as the initial step, to serve as a guide for reliability design review.

b. Program should provide actions to minimize degrading effects of human factors, tolerances, process variances, and other manufacturing limitations.

c. Special tests on materials, processes, component elements, subassemblies, etc., may be desirable to determine or verify reliability of these elements or processes prior to production incorporation.

d. Production sampling tests may be desirable on certain elements or assemblies, or on the complete servovalve assembly, depending upon the potential for and degree of production variance.

e. Reliability program should include provisions for failure analysis, data feedback, and design or manufacturing correct on for reliability retention and/or growth.

5.2.5 Reliability Test

Where a numerical reliability requirement is specified, it is desirable to also specify a high-confidence, statistical reliability demonstration test to verify achievement. If this is deemed impractical, consideration for de-rating, such as application of endurance cyclic multiplication, is suggested to provide a qualitative level of high confidence. Other types of hybrid (nonrepresentative) reliability tests may be specified, depending upon application and funds available.

5.2.6 Reliability Prediction

Due to unavailability of applicable servovalve piece part failure rate data and due to critical interfaces, reliability predictions using the generic failure rate method or other analytical techniques do not provide valid indication of compliance with specified reliability requirements. Therefore, actual service or test data should be used when possible, in performing reliability predictions.

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.

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APPENDIX A - SAMPLE SPECIFICATION: SERVOVALVE, ELECTROHYDRAULIC FLOW-CONTROL

A.1 SCOPE

This specification defines the requirements for a two-stage four-way electrohydraulic flow-control servovalve. In application, the servovalve will be used in a closed loop hydraulic actuation system for the control of position of an aerodynamic surface. Physically, the servovalve will be mounted directly upon a linear hydraulic actuator.

The following is a sample Procurement Specification as may be written by the Procuring Activity. A Specification Control Drawing, defining envelope interface requirements is also typically provided as part of the Procurement Specification. Additional special requirements pertinent to the application may also be included. Details of tests and method of tests are typically the responsibility of the Servovalve Supplier.

A.2 APPLICABLE DOCUMENTS

The following documents of the issue in effect on the date of invitation for bids form a part of this specification to the extent specified herein. In the event of conflict between this specification and any referenced specification, standard, drawing or publication, the requirements of this specification shall govern.

A.2.1 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.

AMS-P-83461 Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275°F (135°C)

AMS-P-83461/1 Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275°F (135°C) Sizes and Tolerances

ARP490 Electrohydraulic Servovalves

ARP1231 Gland Design, Elastomeric O-Ring Seals, General Considerations

AS4059 Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids

AS4716 Gland Design, O-Ring and Other Elastomeric Seals

AS5857 Gland Design, O-Ring and Other Elastomeric Seals, Static Applications

AS8775 Hydraulic System Components, Aircraft and Missiles, General Specification for

A.2.2 Non-Government Publications

Available from various commercial sources.

ANSI/NCSL Z540-1 General Requirements for Calibration Laboratories and Measuring and Test Equipment

NASM20995 Wire, Safety or Lock

NASM33540 Safety Wiring, Safety Cabling, and Cotter Pinning, General Practices for

A.2.3 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, http://assist.daps.dla.mil/quicksearch/.

MIL-STD-2073-1 Standard Practice for Military Packaging

MIL-PRF-87257 Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hhydrocarbon Base, Aircraft and Missile

MIL-STD-810 Environmental Test Methods and Engineering Guidelines

MS3106 Connector, Plug, Electric, Straight, Solder Contacts, AN Type

A.2.4 Drawings

Available from XYZ Aircraft Corp.

0001 Servovalve, Electrohydraulic Flow-Control, Specification Control

A.3 REQUIREMENTS

A.3.1 Design Requirements

A.3.1.1 Mechanical

A.3.1.1.1 Design Configuration

A.3.1.1.1.1 Classification

The servovalve shall be a two-stage, four-way electrohydraulic flow-control servovalve. It shall conform to the physical requirements of a size II servovalve, as defined in ARP490 and the temperature requirements of a type II hydraulic system (-65 to +275 °F (-54 to +135 °C)) per AS8775.

A.3.1.1.1.2 External Null Adjustment

The null shall be properly adjusted before delivery. If an external adjustment is used, it shall be sealed with an inspection stamp to permit detection of unauthorized adjustment.

A.3.1.1.1.3 Special Tools

Installation and removal of the servovalve shall not require the use of special tools.

A.3.1.1.1.4 Internal Filtration

The servovalve shall incorporate a first stage filter, if required, to assure satisfactory performance with the system fluid. See A.3.1.3.5.

A.3.1.1.2 Physical Description

A.3.1.1.2.1 Envelope

The servovalve envelope shall be held to a minimum, not exceeding that of specification control drawing 0001 (Figure A1).

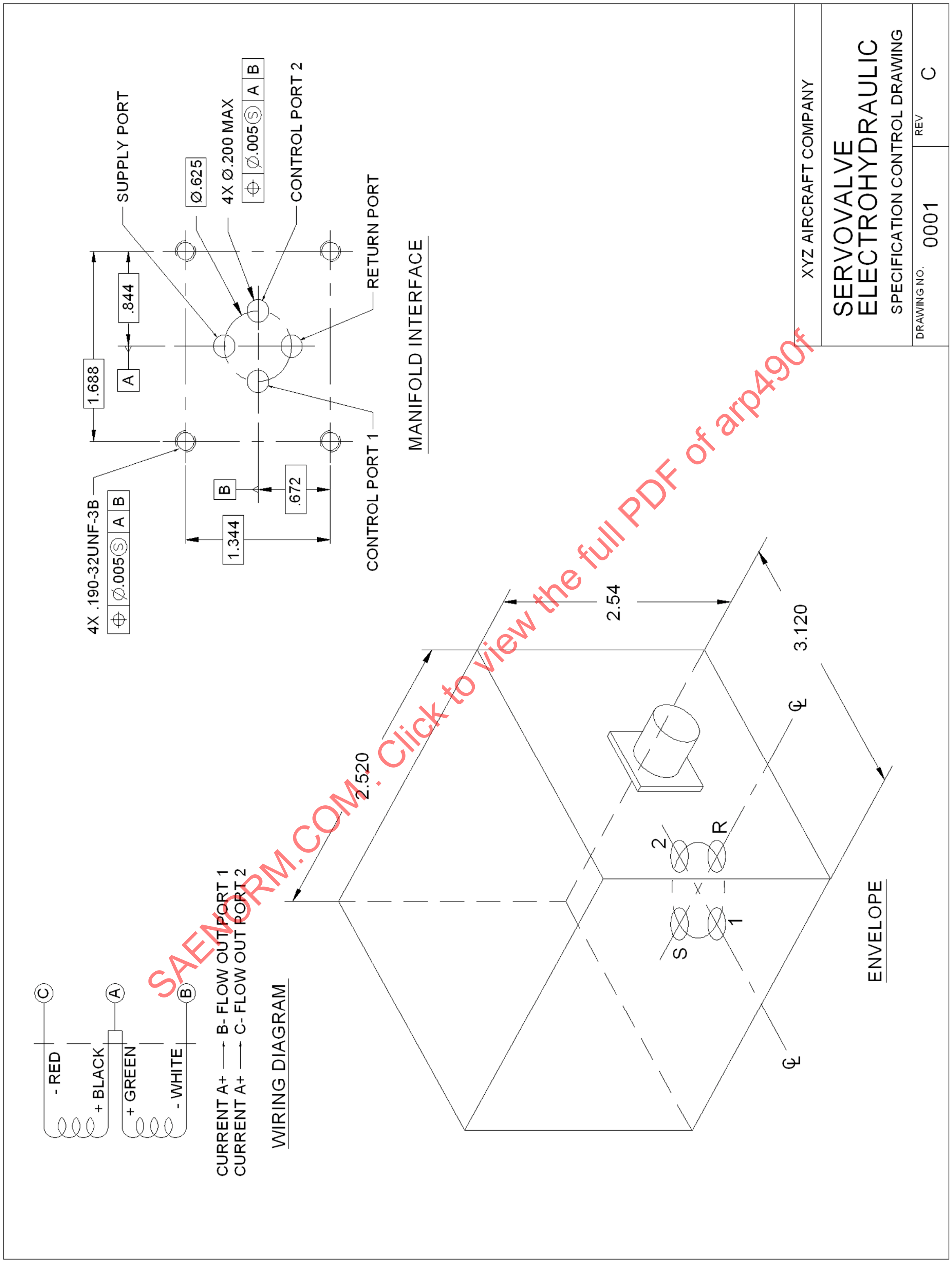

FIGURE A1 - SPECIFICATION CONTROL DRAWING

A.3.1.1.2.2 Mounting

The servovalve shall be designed to mate with the manifold as specified on drawing 0001.

A.3.1.1.2.3 Electrical Connector

The servovalve connector shall mate with a MS3106-10SL-3S plug.

A.3.1.1.2.4 Weight

The dry weight of the servovalve shall not exceed 1.0 lb (0.45 kg).

A.3.1.1.3 Identification

The servovalve shall include permanent identification showing the following:

a. Manufacturer's Name

b. Model Number

c. Serial Number

A.3.1.1.4 Materials

All materials used in the manufacture of this servovalve shall be of suitable quality and type to assure compliance with the requirements of this specification.

A.3.1.1.5 Standard Parts

Industry and military standard parts, such as AS, MA, NAS, MS, or AN, should be used wherever they are suitable for the purpose.

A.3.1.1.6 Locking Devices

All threaded parts shall be securely locked or safetied by safety wiring, self-locking nuts, or other approved methods. Safety wire shall be applied in accordance with standard NASM33540 and shall conform to NASM20995.

A.3.1.1.7 Structural Strength

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

A.3.1.1.8 Seals

Except where the use of nonstandard sizes is considered advantageous from a size and weight standpoint, all seals shall conform to AMS-P-83461 and AMS-P-83461/1, and all glands shall conform to AS4716 and AS5857. The configuration of any non-standard seals or glands shall comply with the recommendations of ARP1231 and shall be subject to the approval of the procuring activity.