SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP988 REV. A

Issued 1972-06
Revised 2003-09

Superseding ARP988

Electrohydraulic Mechanical Feedback Servoactuators

FOREWORD

Changes in this revision are format/editorial only.

1. SCOPE:

The recommendations contained herein are confined to the input and output characteristics of electrohydraulic mechanical feedback servoactuators. The information presented should be useful for standardizing the terminology and for specification of physical and performance parameters.

The recommendations do not restrict nor attempt to define the internal design characteristics of servoactuators. As such, the material is equally applicable to servoactuators having different internal functioning, different ratings, different physical size, etc. In certain instances, standards for actuator design are recommended to increase interchangeability as, for example, pigtail color-coding and actuator polarity.

The specifications contained herein should be adequate to describe electrohydraulic mechanical feedback servoactuators used for position control. Additional specifications may be necessary to define special requirements for specific control systems. Certain dynamic compensation methods will be discussed.

1.1 Purpose:

This recommended practice is intended as a guide for the specification of electrohydraulic mechanical feedback servoactuators used for position control.

2. REFERENCES:

MS33540
NAS 1638
MIL-H-5606

3. RECOMMENDED ABBREVIATIONS:

ac	alternating current
AR	amplitude ratio
C	degrees Celsius
cis	cubic inches per second
cm	centimeters
cw	clockwise
ccw	counterclockwise
db	decibels
dc	direct current
deg	degrees
emf	electromotive force
F	degrees Fahrenheit
gpm	gallons per minute
hp	horsepower
Hz	hertz
in	inch(es)
k	kilo (prefix)
lb	pounds
lb-in	pound-inches (torque)

3. (Continued):

lpm	liters per minute
M	mega (prefix)
m	meters
m	milli (prefix)
ma	milliamperes
mfb	mechanical feedback
min	minutes
mw	milliwatts
N	newtons (force)
Nm	newton-meter (torque)
PA	phase angle
Pa	pascals = newtons per square meter
psi	pounds per square inch
rad	radians
sec	seconds

4. RECOMMENDED TERMINOLOGY:

4.1 Servoactuator, Electrohydraulic Mechanical Feedback:

An electrical input, hydraulic powered position control servoactuator which is capable of continuous control.

4.1.1 Servovalve, Electrohydraulic: An electrical input servovalve which controls the position, rate of change of position, and force or torque output of the actuator.

4.1.2 Actuator, Hydraulic: A piston(s) or vane(s) type mechanism which utilizes hydraulic power to position a load. The output shaft of the hydraulic actuator is capable of control displacement which may be either rectilinear or rotary.

4.1.3 Feedback, Mechanical: A mechanical device which transmits the actuator output shaft position to the servovalve. Normally this position feedback is converted to a torque which is applied to the torque motor armature.

4.2 Electrical Characteristics:

4.2.1 Torque Motor: The electromechanical transducer commonly used in input stages of mfb actuators.

4.2.2 Input Current: The current to the mfb servoactuator, expressed in ma, which commands actuator position.

4.2.3 Rated Current: The specified input current (expressed in ma) of either polarity to produce rated stroke. 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.

4.2.4 Quiescent Current: A dc current that is present in each torque motor 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.

4.2.5 Electrical Quiescent Power: The power dissipation required for differential operation when the current through each coil is equal and opposite in polarity.

4.2.6 Electrical Control Power: The power dissipation required for control of the servoactuator. 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.

4.2.7 Total Electrical Power: The sum of the instantaneous control power and the quiescent power, expressed in mw.

4.2.8 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 of the torque motor.

4.2.9 Coil Resistance: The dc resistance of each torque motor coil, expressed in ohms.

4.2.10 Polarity: The directional relationship between actuator motion and input current.

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

4.3 Static Performance Characteristics:

4.3.1 Control Position: The magnitude and direction of actuator output shaft displacement from the mechanical null position. Rectilinear actuator position is expressed in inches (or cm) extend (+) and inches (or cm) retract (-). Rotary actuator position is expressed in deg (or rad) cw (+) and deg (or rad) ccw (-) as viewed from the output shaft side of servoactuator.

4.3.2 Mechanical Null: The specified zero reference point for actuator position.

4.3.2.1 Null Bias: The input current required to bring the servoactuator to mechanical null excluding the effects of hysteresis, expressed as percent of rated current.

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

4.3.3 Rate Stroke: The specified displacement of the actuator output shaft from mechanical null corresponding to the rated current with no external load applied. Normally, maximum displacement is limited by fixed mechanical stops. The maximum displacement is not necessarily the same as rated stroke. Rated stroke for rectilinear actuators is expressed in inches (or cm) extend (+) and inches (or cm) retract (-). Rated stroke for rotary actuators is expressed in deg (or rad) cw (+) and deg (or rad) ccw (-) as viewed from the output shaft side of servoactuator. In most applications the positive and negative rated strokes are symmetrical.

4.3.4 Position Curve: The graphical representation of actuator control position vs input current. This is usually a continuous plot of a complete cycle between plus and minus rated current values with no external load applied. See Figure 1.

4.3.4.1 Normal Position Curve: The locus of the midpoints of the complete cycle position curve, which is the zero hysteresis position curve. Usually servoactuator hysteresis is sufficiently low such that one side of the position curve can be used for the normal position curve. See Figure 1.

4.3.5 Position Gain: The slope of the actuator control position vs input current curve in any specific operating region expressed in in/ma (cm/ma) or deg/ma (rad/ma). When this term is used without qualification, it is assumed to mean normal position gain.

4.3.5.1 Rated Position Gain: The gain determined by dividing rated total actuator displacement between plus and minus rated currents by the total change in current between plus and minus rated currents.

4.3.5.2 Normal Position Gain: The gain determined by dividing actual total actuator displacement between plus and minus rated currents by the total change in current between plus and minus rated currents.

4.3.6 Linearity: The degree to which the normal position curve conforms to a reference line drawn through the mechanical null point of the normal position curve throughout a specified current range, and drawn to minimize deviations in current of the normal position curve from the straight line. Linearity is measured as the maximum deviation of the normal position curve from the reference line, expressed as percent of rated current. See Figure 2.

4.3.7 Hysteresis: The difference in the servoactuator input currents required to produce the same actuator output during a single cycle of 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 position curve throughout plus and minus rated current. See Figure 1.

4.3.8 Threshold: The increment of input current required to produce a change in control position, expressed as percent of rated current. Threshold is normally specified as the current increment required to reverse the direction of output motion when the current is cycled at a rate sufficiently low to minimize dynamic effects.

4.3.9 Internal Leakage:

4.3.9.1 Unloaded Internal Leakage: The total internal flow from pressure to return with the actuator stationary expressed in cis, gpm, or lpm. The actuator is unloaded and not bottomed.

4.3.9.2 Loaded Internal Leakage: The total internal flow from pressure to return with the actuator stationary expressed in cis, gpm, or lpm. Maximum design operating differential pressure is applied across the piston.

4.3.10 External Leakage:

4.3.10.1 Static External Leakage: External leakage with the actuator stationary.

4.3.10.2 Dynamic External Leakage: External leakage with the actuator in motion, usually expressed in cycles per drop.

4.3.11 External Load: The total load on the actuator including mass, damping, spring, and static loads.

4.3.12 Static Load: A constant external force or torque applied in one direction to the actuator output shaft expressed in lb (N) or lb-in (Nm).

4.3.12.1 Rated Load: The specified staic load which the servoactuator has capability of overpowering at rated velocity expressed in lb (N) or lb-in (Nm).

4.3.12.2 Static Compliance: The steady state control position deviation generated by a specified static load less than stalled load with other operational variables held constant, expressed in in/lb (m/N) or deg/lb-in (rad/Nm).

4.3.12.3 Stall Load: The minimum level of static load which the servoactuator cannot overpower, expressed in lb (N) or lb-in (Nm).

4.3.13 Actuator Stiffness: The open loop spring rate of the actuator due to fluid compressibility and structural deflections, expressed in lb/in (N/m) or lb-in/degree (Nm/rad).

4.4 Dynamic Performance Characteristics:

4.4.1 Rated Velocity: Maximum velocity of actuator output shaft with specified static load applied, expressed in in/sec (cm/sec) or deg/sec (rad/sec).

4.4.2 Saturation Velocity: Maximum velocity of actuator output shaft with no external load applied, expressed in in/sec (cm/sec) or deg/sec (rad/sec).

4.4.3 Frequency Response: The complex ratio of control position 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 is expressed as amplitude ratio and phase angle. Servoactuator frequency response may vary with input current amplitude, temperature, supply pressure, external load (including inertia and stiffness) and other operating conditions.

4.4.3.1 Amplitude Ratio: The ratio of the control position amplitude to the input current amplitude at a particular frequency divided by the same ratio at the same input current at static conditions. For convenience a low frequency reference is commonly used. Amplitude ratio may be expressed in decibels where $dB = 20 \log_{10} AR$.

4.4.3.2 Phase Lag: The instantaneous time separation between the input current and the corresponding control position variation, measured at a specified frequency and expressed in degrees (time separation in seconds x frequency in Hz x 360 degrees per cycle).

5. SPECIFICATION CONSIDERATIONS:

5.1 Scope:

The introductory paragraph of the specification for a mechanical feedback servoactuator should identify the type of component and give a brief description of the application. Any unusual design or performance requirements may be cited to indicate the general nature of the unit to be procured by the specification (e.g., rotary output, tandem piston, high temperature, load damping, etc.).

5.2 Reference Specifications:

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

The priority of any specified documents shall be clearly indicated to avoid misunderstanding. Some parts of applicable government documents may be incompatible with the particular application. In these cases, if written deviations and approvals are necessary, it shall be so noted. Otherwise such specification inconsistencies may be disregarded.

5.3 Requirements:

5.3.1 Mechanical Design Requirements:

5.3.1.1 Configuration: The design configuration of the servoactuator should be specified such that necessary physical and functional requirements are explicit; however, the specification should allow fullest latitude for equivalent design implementations of these requirements. It is recommended that a simplified schematic or block diagram be included in the specification to identify the functional interconnection of subcomponents within the servoactuator. These subcomponents generally include a torque motor, a servovalve (one or more stages), an actuator (translational or rotary with one or more hydraulic supplies), and a mechanical feedback mechanism. In addition the mfb servoactuator may include various auxiliary components such as a filter, flushing valve, actuator mechanical lock, piston bypass valve, velocity limiter, force or torque limiter, snubbers, load pressure feedback mechanism, instrumentation transducers, etc. The design and performance requirements for each auxiliary component should be included in the servoactuator specification. Recommendation of specifications for such auxiliary components is beyond the scope of this ARP.

5.3.1.2 Driven Load: It is recommended that design parameters of the external load to be driven by the mfb servoactuator be stated in the servoactuator specification. The mfb servoactuator is a closed loop positioning device in which internal loop gains, dynamic compensation and other design choices are made to achieve specified accuracies and dynamic response. Generally the performance of a mfb servoactuator is influenced markedly by the nature of the driven load, so the specification of load parameters is necessary to ensure proper design.

It is recommended that specification of the driven load be given as equivalent lumped parameters of mass, viscous damping, dry friction and stiffness, as appropriate. A simple schematic diagram may be used to show the location of load parameters with respect to the actuator output and mounting.

5.3.1.3 Physical Description: The envelope and installation requirements for the servoactuator should be defined by a specification control drawing. This drawing should include: (a) mounting details, (b) details of the actuator attachment at the moving output, (c) preferred and alternate locations for the hydraulic and electrical connections, (d) available space for packaging of auxiliary components, and (e) stroke or displacement range of the actuator output.

5.3.1.4 Weight: The maximum weight of the servoactuator when filled with hydraulic fluid, but with any and all non-operational shipping and/or installation accessories removed, should be specified.

5.3.1.5 Identification: An area on each servoactuator and major subcomponent thereof should be available for engravement or secure attachment of identifying information. As a minimum this identification should include: manufacturer, model number (supplier's model or part number), and serial number. The following additional information may also be included on the servoactuator nameplate: customer part number, rated pressure, rated current, rated load, rated stroke, and fluid.

5.3.1.6 Materials: Any specific restrictions for materials and/or finishes due to special environmental conditions (such as nuclear, chemical, electrical, or organic) should be defined. Likewise, material preferences due to special operational requirements or previous program experience (for example, to minimize magnetic influences or to reduce stress corrosion tendencies) should be included in the specification.

5.3.1.7 Structural Strength: All component parts of the servoactuator shall have sufficient strength to withstand all loads or combinations of loads resulting from hydraulic pressure, temperature, actuation, vibration, and acceleration imposed during installation and operation under rated conditions.

5.3.1.8 Standard Parts: Standard MS or AN parts should be used whenever suitable.

5.3.1.9 Locking Devices: 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 MS33540. Snap rings should not be used as retainers unless they are positively retained in their installed position.

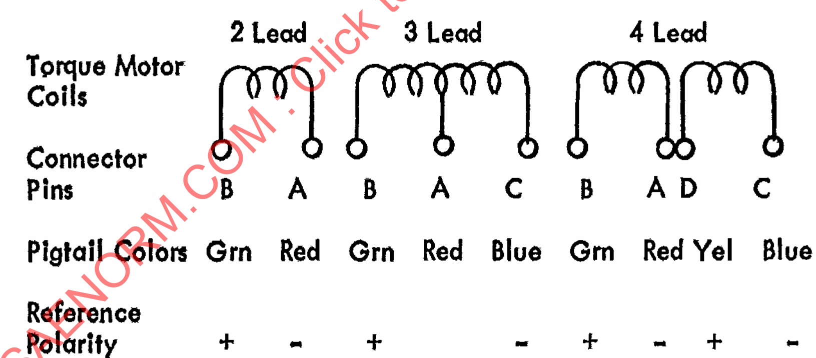
5.3.1.10 Seals: When possible, seals, gaskets and packings should be of such composition and installation as to satisfy the requirements of all applicable military specifications and specified tests. If a specific seal compound is desired for certain fluid or environmental conditions, the specification for the compound should be included.

Servoactuators sometimes employ so-called "non-standard" packings and installations due to space limitations. These intallations, while at times in conflict with certain military standards, have been proven to be highly successful.

5.3.2 Electrical Design Requirements:

5.3.2.1 Electrical Connections: The internal wiring configuration for the servoactuator should be specified, together with the pin identification of electrical connectors or color coding for pigtails, as applicable. It is recommended that a separate wiring diagram be included in the specification and that wiring connections for all electrical components within the servoactuator be given in this diagram.

Recommended connections for the torque motor coils are shown below.



5.3.2.2 Polarity: Application of dc potential voltage of the polarity indicated in 5.3.2.1 shall act to cause a positive servoactuator displacement as defined in 4.3.1.

5.3.2.3 Rated Current: Rated current for the mfb servoactuator should be stated in ma for the particular torque motor coil connection specified in 5.3.2.1. In general, for constant electrical control power, the lower the rated current, the smaller the magnet wire will be in the torque motor coils. In addition, with lower input currents, the coil impedance is increased.

5.3.2.4 Quiescent Current: If a differential connection of the torque motor coils is specified, the normal value and polarity of the quiescent current should be stated. Also, the maximum anticipated value of quiescent current should be specified. If wide variations of quiescent current are anticipated, then the range of quiescent current should be stated.

5.3.2.5 Insulation Resistance and Dielectric Strength: Minimum insulation resistance of the electrical wiring and connections within the servoactuator should be specified. It is recommended that this value be 50 megohms under room temperature and humidity conditions following a 15-second application of a dc potential equal to 1000 volts or five times the maximum anticipated voltage, whichever is less. Repeated applications of high voltage may eventually break down the electrical insulation, so a maximum number of insulation resistance tests should be specified. The recommended number of tests is not more than ten times on one servoactuator.

5.3.2.6 Coil Resistance: The dc resistance of the torque motor coil or coils should be specified. A ±10% tolerance for individual coil resistance is recommended. The temperature at which resistance is measured should be stated (usually 68 F or 20 C). 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).

5.3.2.7 Coil Impedance: Coil impedance is a difficult parameter to measure accurately; also, coil impedance may vary considerably from unit to unit. It is usually not specified where servoamplifiers having high output impedance are used. When coil impedance is specified it is usually stated as a maximum value of the apparent coil inductance, together with the specification of dc coil resistance. Since coil impedance will change considerably with slight variations in torque motor design, it is recommended that manufacturers be consulted before this parameter is specified.

The apparent inductance of the torque motor coils will depend upon supply pressure, input current amplitude, and frequency. Therefore, the magnitude of each of these parameters should be included if a coil inductance specification is necessary.

The coil impedance presented to low frequencies is more pertinent for control system dynamic considerations than are measurements made with a conventional 1000 Hz impedance bridge. Since torque motor coil impedance will vary with frequency, it is recommended that this parameter be specified and measured at a low frequency. Usually 50 Hz is chosen for specification purposes, as measurements at lower frequencies are subject to test equipment inaccuracies. Measurements at 60 Hz should be avoided because of line frequency interaction, and frequencies above 60 Hz are generally of less interest in electrohydraulic servosystems.

5.3.2.8 Electrical Driving Servoamplifier: The output impedance of the electrical servoamplifier used to supply input current to a mfb servoactuator can have a pronounced effect on actuator characteristics such as threshold and frequency response. In addition, an unfortunate mismatch of servoamplifier and servoactuator impedance characteristics may cause undesirable actuator limit cycling, erratic motion, or high frequency instability. Such effects may be aggravated when operating at the extremes of temperature and pressure. Since the impedance characteristics of both the servoactuator and servoamplifier are extremely difficult to define, measure and control, it is recommended that the performance of mfb servoactuators be measured as driven by the actual output circuitry of the servoamplifier to be used in the end application.

5.3.3 Hydraulic Design Requirements:

5.3.3.1 Operating Pressures: The servoactuator supply and return pressures should be specified together with the anticipated pressure variations. These pressures should be specified for the applicable requirements of static and dynamic performance.

5.3.3.2 Inlet Proof Pressure: The servoactuator should withstand without evidence of external leakage (other than slight wetting at seals insufficient to form a drop), excessive distortion or permanent set, the following proof pressures applied at the inlet port: 5 psi (0.35 bars or 35 kPa) for 3 minutes followed by 1-1/2 times the nominal operating pressure or the applicable proof pressure, whichever is greater, for a period of 3 minutes. These pressures should be applied with the maximum input signal and the piston fully extended. The test should be repeated in the fully retracted direction. Proof pressure should be applied at a maximum rise rate of 25,000 psi/min (1700 bars/min or 170 MPa/min).

5.3.3.3 Return Proof Pressure: The servoactuator should withstand without evidence of external leakage (other than slight wetting at seals insufficient to form a drop), excessive distortion or permanent set, the following proof pressures applied simultaneously at the inlet and return ports: 5 psi (0.35 bars or 35 kPa) for 3 minutes followed by the specified return proof pressure for a period of 3 minutes. Proof pressure should be applied at a maximum rise rate of 25,000 psi/min (1700 bars/min or 170 MPa/min). Normally the return proof pressure is equal to nominal system supply pressure.

5.3.3.4 Burst Pressure: The servoactuator should not rupture with burst pressure of 2-1/2 times supply pressure at the inlet port applied at a maximum rise rate of 25,000 psi/min (1700 bars/min or 170 MPa/min) with return open. These pressures shouuld be applied with the maximum input signal and the piston fully extended. The test should be repeated in the fully retracted direction. This test should be followed by return burst pressure applied simultaneously to inlet and return ports. The servoactuator shall not be required to operate after this test. Return burst pressure is normally equal to 1-1/2 times the nominal system supply pressure applied to 2 minutes for each test.

5.3.3.5 Fluid: The working fluid for the servoactuator should be specified. The exposure to other fluids, such as preservative oil or alternate test fluids, should also be noted.

5.3.4 Performance Requirements:

5.3.4.1 Rated Test Conditions: Unless otherwise stated, all servoactuator specifications apply to a set of standard test conditions as defined in this section. Any specification of performance over a range of conditions (i.e., over a range of temperatures, supply and return pressures, output loading, etc.) should be specified in 5.3.5. These environmental specifications are normally given as a maximum percentage variation of the particular parameter (position gain, null, coil resistance, etc.) over the full specified range of each operating condition (supply pressure variation, temperature, etc.). If for some reason it is necessary to set the parameter tolerance at some non-standard test condition, or if some unusual environmental condition is expected, it should be so stated in this section. For example, if the actuator 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 5.3.4.2 and 3 may not apply when the test conditions are non-standard.

The performance specifications given in 5.3.4.2 and 3 apply for operation of the servoactuator under the following standard test conditions:

Fluid: (Normally as specified in 5.3.3.5)
Operating pressure: (Normally as specified in 5.3.3.1)
Quiescent current: (Normally as specified in 5.3.2.4)
Temperature: Normally 90 to 120 F (32 to 50 C) fluid and 65 to 90 F (18 to 32 C) ambient
Filtration: Conform with National Aerospace Standard 1638, Class 6 or better

5.3.4.2 Static Performance Characteristics:

5.3.4.2.1 Rated Stroke: Servoactuator rated stroke should be specified for the rated current and a particular output load condition. For ease of testing rated stroke is usually specified at no-load conditions. The tolerance for rated stroke is generally ±4 to ±7%.

5.3.4.2.2 Linearity: Linearity of the normal position curve should be specified as a maximum percent of rated current. A normal limit for this parameter is ±5%. If a non-linear feedback arrangement is inherent in a particular application, linearity should be defined according to the unique requirement of the particular application.

5.3.4.2.3 Hysteresis: Hysteresis, as defined, includes the static inaccuracies associated with threshold and electromgnetic effects. Therefore the hysteresis loop width obtained with quasi-static cycling of the actuator is a function of input amplitude plus some constant value. Plots of the full hysteresis loop are usually run at less than 0.01 Hz so as to minimize phase lag effects of the servoactuator and test equipment. The normal limit for hysteresis measured in this manner is 4% of rated current.

Mechanical feedback servoactuators may exhibit larger values of hysteresis if the variation of input current causes velocity saturation of the actuator. This "saturation hysteresis" can be measured by applying the following sequence of input current:

(a) 0% input current

(b) apply step input current of +100% rated and hold until actuator comes to rest

(c) slowly change input current from +100% to the value that gives actuator null

(d) apply step input current of -100% rated and hold until actuator comes to rest

(e) slowly change input current from -100% to the value that gives actuator null

The difference in input currents that correspond to the actuator null in steps (c) and (e) is saturation hysteresis. A normal limit for hysteresis measured in this fashion is 5% of rated current.

An alternate method of measuring saturation hysteresis is to run a normal hysteresis cycle but deliberately overdrive the input signal to the point of saturation of the servovalve.

5.3.4.2.4 Threshold: Threshold should be specified as a maximum percent of rated current and the normal limits is 1.0%. The threshold of a mfb servoactuator can be considered to comprise the servovalve threshold plus the frictional breakout characteristic of the actuator. However, due to the normal high pressure gain of a servovalve output spool, the minimum breakaway spool movement will usually result in actuator motion. Consequently, threshold will be affected by hydraulic oil contamination and an oil cleanliness standard should be specified. Electrical or externally applied mechanical dither is usually not included in the definition and test of this parameter.

Mfb servoactuator threshold will also include the effects of friction and backlash in the feedback mechanism. Depending on the type of feedback mechanization employed, the threshold may be a maximum at the mechanical null point of the actuator. For some servoactuators threshold measurements may be desired near the full displacement points in each direction of travel.

5.3.4.2.5 External Leakage: Static external leakage from any seal shall be insufficient to form a drop. Dynamic external leakage is normally specified for each dynamic rod or shaft seal as the number of cycles of specified amplitude and frequency per drop of leakge oil (typically 25 cycles per drop). The amount of external leakage will be determined by such factors as rod size, actuator stroke, and type of dynamic seals (e.g. single or two-stage). It may be necessary to specify a run-in period for the actuator prior to the external leakage measurement to allow for the filling of seal cavities (such as the cavity formed by a scraper ring), so that a valid leakage measurement can be made. The nature and duration of such run-in can be established only from test experience with a number of actuators of a given design.

External leakage should be monitored during the proof pressure test with the actuator in a static condition. The dynamic measurement of external leakage should be made at the completion of all other acceptance testing on an actuator.

5.3.4.2.6 Internal Leakage: Internal leakage with a balanced area servoactuator at no load will normally comprise that of the servovalve at its null condition. It is desirable to measure this leakage on an actuator to ensure that any other seals between pressure and return are functioning properly.

Since spring loaded Teflon rings are commonly used as piston seals, their leakage characteristics under load will be significant for most servoactuator applications. To detect this leakage a signal should be applied which causes the actuator to bottom out at each end in succession, thereby applying full system pressure across the piston seal in each direction. It should be noted that valve spool null leakage is not present in this test.

Other specific internal leakage measurements may be required to test the operation of load-limiting or bypass valves, as well as unbalanced actuator designs.

5.3.4.2.7 Stall Load: The stall load is normally used to determine the actuator effective piston area based on specified differential pressure and crank arm length for a rotary actuator. Some allowance for actuator friction will normally be made.

5.3.4.2.8 Rated Load: The rated load will be one of the parameters considered in determining the flow rating of the servovalve. While rated load and velocity are usually the primary power parameters of a servocontrol system, the measurement of these characteristics is normally not included in the acceptance testing of an actuator because of the cost and complexities associated with such testing. It is generally sufficient to measure the saturation velocity with an actuator whose stall force characteristic is established from the dimensional effective piston area.

5.3.4.2.9 Static Compliance: The static compliance of the servoactuator can be an important parameter affecting the positional accuracy of a servocontrol system. The servoactuator compliance is determined by the piston area, loop gain, servovalve pressure gain, and actuator structural compliance. Some servocontrol systems do not require the measurement of actuator static compliance.

5.3.4.2.10 Saturation Velocity: The saturation velocity of a servoactuator determines the full flow rating of the servovalve and flow passage sizing. It can be measured by recording the positional response of an actuator to the input current applied in a step fashion. This input current is typically in excess of rated current. The saturation velocity can be measured at the steepest section of the position plot where the servovalve is in its saturated flow condition.

5.3.4.2.11 Null Bias: Many mechanical feedback servoactuator designs have no external null adjustment. The null of these designs is set by the manufacturer and an acceptable maximum for null bias should be specified. This parameter is usually less than ±2% of rated current under rated test conditions.

During the life of the servoactuator the null bias measured with rated test conditions may change from the initial setting. This change is usually attributed to continuing stress relief of critical subassemblies and may be accelerated by the application of certain environments. The long-term change in null bias is usually less than ±3% of rated current from the original null bias value. Because of the practical problem of separating the effects of initial null setting and subsequent change, the specification normally requires a null bias of ±5% of rated current throughout the useful life of the servoactuator. This parameter then includes the tolerance for initial null setting and for long-term null bias variations.

5.3.4.2.12 Null Shift: The servoactuator null bias may change with variation of the operating environment. 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.

The torque motor and first-stage of the servovalve mechanism used in the mechanical feedback servoactuator will generally contribute most of the actuator null shift. Also, the amount of null shift contributed by the torque motor and servovalve first stage (measured as percent of rated current) is the same whether these components are used in a servovalve or mechanical feedback servoactuator. Therefore, the specification allowance for null shift is only slightly higher for a mechanical feedback servoactuator than it is for a servovalve.