AEROSPACE RECOMMENDED PRACTICE

ARP5879™	REV. A
Issued 2010-04 Revised 2024-05 Superseding ARP5879	

(R) Recommended Test Requirements for Electrohydrostatic Actuators

RATIONALE

This revision aligns the document with the terminology of ISO 22072 and includes test requirements relevant to EHAs.

TABLE OF CONTENTS

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

For more information on this standard, visit
https://www.sae.org/standards/content/ARP5879A

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides recommended test requirements for electrohydrostatic actuators (EHAs).

NOTE: This document does not address tests and issues of a higher system level, such as the primary flight control surface level where multiple EHAs and or electrohydraulic servoactuators (EHSAs) may be integrated.

1.1 Purpose

The purpose of this document is to facilitate the generation of test specifications, plans and procedures for EHAs covering Integration, Acceptance, and Qualification testing.

1.2 Field of Application

This document focuses on EHA issues for both military and commercial aircraft applications.

NOTE: It should be the user's responsibility to ensure that particular qualification or certification requirements, or applicable specifications, standards, or regulations for the intended application are satisfied by the EHA design, and the tests and test methods that are developed.

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 +1 724-776-4970 (outside USA), www.sae.org.

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

ARP1383 Aerospace - Impulse Testing of Hydraulic Components

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

ARP5007 Development Process - Aerospace Fly-By-Wire Actuation System

ARP6154 Aerospace Fluid Power Electrohydrostatic Module, Design, Performance and Test Recommendations

ARP7490 Recommended Guidelines for the Specifications of Motor Control Electronics for Electrically Powered Actuators

AS4941 Aerospace - General Requirements for Commercial Aircraft Hydraulic Components

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

2.1.2 ISO Publications

Copies of these documents are available online at https://webstore.ansi.org/.

ISO 22072 Aerospace - Electrohydrostatic actuator (EHA) - Characteristics to be defined in procurement specifications

2.1.3 RTCA Publications

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

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

2.1.4 U.S. Government Publications

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

MIL-STD-704 Aircraft Electric Power Characteristics

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

2.2 Related Publications

The following publications are provided for information purposes and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

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

ARP6025 Duty Cycle Considerations for Electrohydrostatic Actuators

2.3 Terminology

Refer to ARP4386 and ISO 22072 for EHA specific terminology.

2.4 Abbreviations

ACE actuator control electronics

ATP acceptance test procedure

BIT built-in test

CE control electronics

EBHA electrical backup hydraulic actuator

EHA electrohydrostatic actuator

EHAS electrohydrostatic actuation system

EHM electrohydrostatic module

EHSA electrohydraulic servoactuator

EMI electromagnetic interference

ESD	electrostatic discharge
HIRF	high-intensity radiated field
ICD	interface control document
IAP	integrated actuator package
MCE	motor control electronics
MDE	motor drive electronics
PDE	power drive electronics
REU	remote electronics unit
SOV	solenoid operated valve
UUT	unit under test

3. GENERAL

An EHA incorporates a linear or rotary hydraulic actuator and a variable speed, bidirectional electric servomotor driving a fixed displacement hydraulic pump for actuator control, and associated power drive electronics (PDE). The tests and the issues documented in this ARP are not necessarily all-inclusive.

An EHA is typically comprised of the motor control electronics (MCE) or motor drive electronics (MDE), a variable-speed bidirectional electric motor, a bidirectional hydraulic pump, a manifold (with the functionality required by the system), and a hydraulic actuator. Refer to ARP7490 for alternate terms used for MCE. In some applications, the function of the Test Console and MCE may be physically combined or separated.

An electrohydrostatic module (EHM) is typically comprised of the MCE, variable speed bidirectional electric motor, and bidirectional hydraulic pump. Refer to ARP6154 for details of the design performance and test recommendations for an EHM.

To test an EHA, a test setup is required and is comprised of a Test Controller, a Test Console, including a Data Acquisition System, and a Loading Actuator. The unit under test (UUT) in Figure 1 represents a typical EHA. Additional connections may be required depending on the specific UUT and Test Stand. Mechanical and hydraulic interfaces are not included in Figure 1. The Test Controller may be fabricated from actuator control electronics (ACE) or a remote electronics unit (REU) depending on the system and hardware availability.

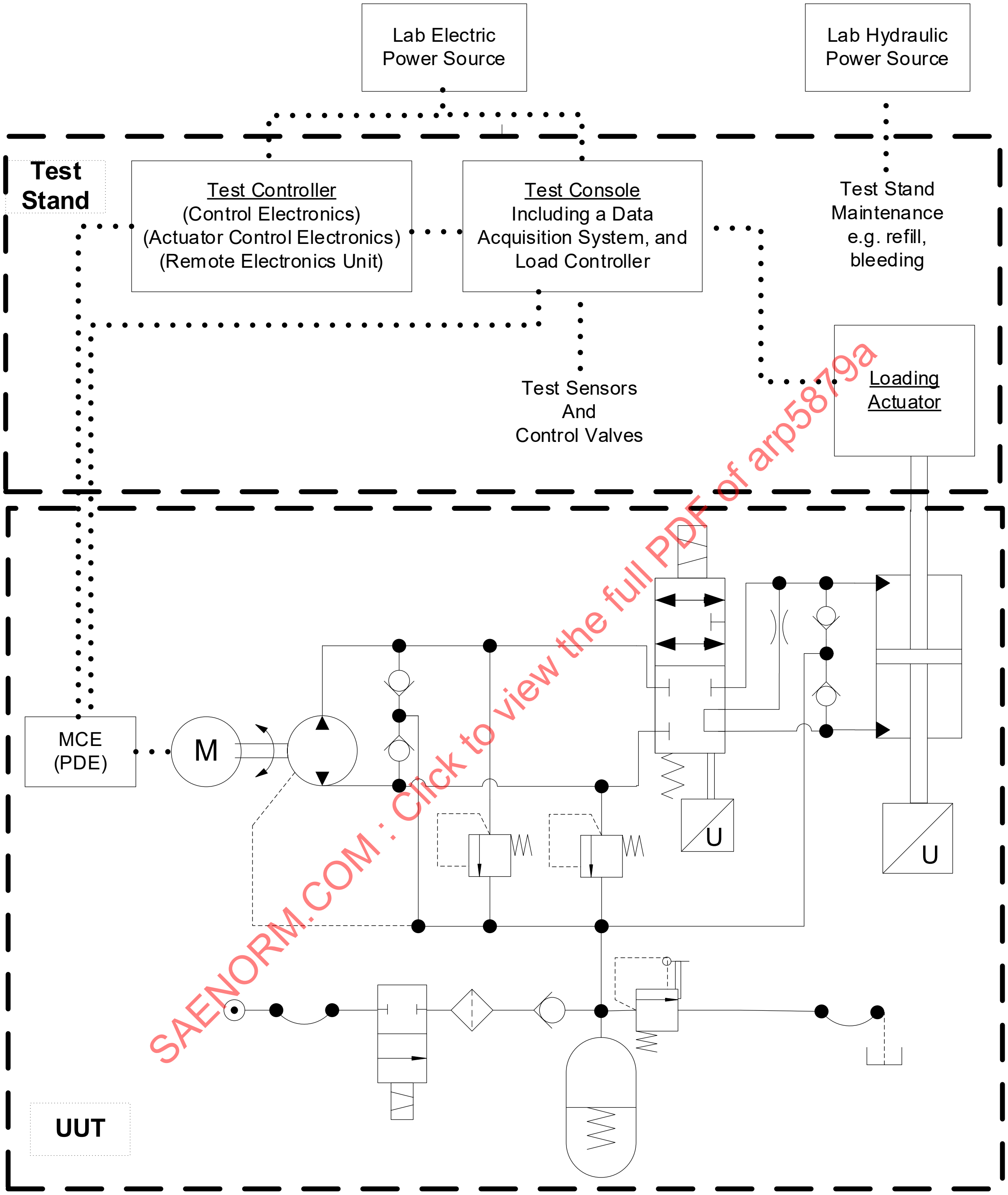

Figure 1 - EHA and test stand schematic diagram

If this document does not list a test applicable to both EHAs and EHSAs, the reader may refer to ARP1281, which addresses test issues applicable to EHSAs.

In the discussion of the tests and test methodologies contained in this document, the numerical definition or specification of the test parameters to be imposed or measured is not included. These definitions or specifications should be developed to conform to the requirements of the applicable EHA technical specification document, considering the usual influencing factors such as instrumentation accuracy, test temperature, etc.

4. TEST CONSIDERATIONS

4.1 System Considerations

The performance of an EHA is heavily dependent upon the associated electronics – both the power drive for the electric motor, as well as the associated control loop closures. The EHA includes the MCE, whether mounted locally on the actuator itself, or at a remote location (refer to ARP4386, ARP7490, or ISO 22072). ACE or an REU, by definition, are not a part of the EHA. While this definition of an EHA facilitates isolation of the discussion of the critical EHA elements, physical separation between the MCE and Test Controller may or may not be distinct.

This document is intended to discuss issues related to testing of the EHA and includes issues related to the MCE. While this document is not intended to discuss issues related to the Test Controller, it is to be recognized that the planning and execution of several, if not most, tests on an EHA needs to be undertaken with full consideration of the impact that the Test Controller used to test the EHA will have on the EHA under test.

For example, the EHA has performance capability dependent upon the motor capability, the capability of the MCE and the supply voltage, power control algorithms built into the MCE, and all loop closures around the MCE, the motor, and the EHA. Similarly, the failure transient performance of the EHA is dependent upon the performance of any mode select valves within the EHA, the electrical energization/de-energization of electrically actuated mode select valves and the motor, and the control algorithms that govern various EHA functions.

The test methods should also consider balanced and unbalanced actuator configurations. For example, unbalanced actuators may introduce unique test requirements based on the direction of travel and the capability of the compensator.

As such, in all those instances where an EHA is subjected to a test that necessitates electronics for its operation and the electronics have an impact on the performance of the EHA, the Test Controller will be either:

a. The actual electronics to be used with the actuator (e.g., the ACE or REU),

or

b. The test electronics that are used to test the EHA, which should be validated separately and independently as being of the required configuration and capability, to ensure accurate EHA test results. Such electronics may be termed validated electronics (or a validated Test Controller).

4.2 Component Considerations

4.2.1 Motor Control Electronics (MCE)

A critical safety consideration in handling the MCE in a test environment is to ensure that the MCE is discharged before handling it. While a typical MCE contains bleed resistors or other devices to ensure the internal charge on capacitors has been depleted, the time over which the discharge occurs can vary, and in the event of failure of the bleed device, may not discharge at all. It is imperative that before handling the MCE, the voltage from source to return be verified to be at a safe level, usually below 30 V.

4.2.2 EHA Mechanical Components

In addition to the usual importance of component cleanliness before assembly for EHSAs, EHA mechanical components require additional considerations. Due to the relatively small, closed hydraulic circuit of EHAs, ensuring that components are adequately cleaned before assembly and any reassembly during a test program is very important to preclude adverse impacts on EHA fluid cleanliness and integrity.

For any disassembly that may be required during a test program, the disassembly procedure should carefully consider minimizing fluid loss, recovery, storage and reuse, or replenishment of any fluid that may be lost.

An important safety consideration in the disassembly of the EHA in a test environment is to ensure that the EHA reservoir is depressurized or discharged before opening the hydraulic circuit of the unit.

4.2.3 Fluid – Fill and Bleed, Integrity, Replenishment

4.2.3.1 Fluid Fill and Bleed

Proper filling and bleeding of the EHA are crucial to its performance. A fill and bleed test procedure and tooling/fixtures for the UUT and test stand are often developed to ensure adequate fill and bleed in the test environment. Before beginning EHA tests and as necessary during an extended test program, it should be verified that the EHA has been adequately filled and bled.

4.2.3.2 Fluid Integrity

In an extended test program, the need to monitor the condition of the EHA fluid periodically should be examined. The method to obtain a sample of the EHA fluid, and its replenishment if required, should be documented in the test procedure.

4.2.3.3 Fluid Replenishment

In an extended test program, the EHA fluid may need to be replenished due to external leakage, or due to the fluid lost during disassembly and reassembly that may be required of the UUT mechanical components. The test program should address the implications of such replenishment. The cleanliness of the fluid used for replenishment should comply with the applicable EHA specification.

4.2.3.4 Other Considerations

Depending upon the configuration of the EHA, some specific tests may result in internal temperature increases, excessive internal pressurizations, or external fluid loss. In such cases, unless such internal pressurization or overboard fluid loss is intended, consideration should be given to conducting such tests with the EHA reservoir partially filled to accommodate expected changes in fluid volume.

4.3 Test Fixture and Setup Considerations

In addition to the usual considerations given to the design of the required test fixtures and setups for EHSAs, EHA test fixtures and setups may require additional issues to be addressed depending upon the planned tests. The following is an illustrative list of such considerations:

- Environmental considerations for the required heat transfer for the EHA, including the PDE. The considerations or requirements may not be the same for all the EHA elements.

- Endurance and duty cycle testing: Need for synchronizing the load system to EHA commands and/or PDE operating parameters.

- Duty cycle testing: Worst case requirements for the EHA may or may not be the worst case for the PDE. There may be a need for separate tests for each component.

- The rate at which EHA endurance testing is conducted may be impacted by the EHA and/or electronics temperatures.

- Consideration of undertaking an EHA endurance test with validated electronics instead of the PDE intended to be used with the EHA on the aircraft.

- Careful consideration of performance test stress on the actuator and the PDE. Due to losses such as the motor and the PDE electrical losses and the energy required to accelerate/decelerate the motor-pump inertia, the duration of testing such as stall force and frequency response, among others, may need to be limited to avoid causing thermal damage to the motor or the PDE.

4.3.1 Instrumentation

During certain tests, it may be necessary to install sensors in addition to the sensors that may already be a part of the EHA. Consideration of such sensors should ensure that the sensors or their attachment hardware do not impact the EHA function or performance in a manner that may invalidate the test.

4.3.2 Electric Power Supply

The electric power supply system used during EHA testing should be sufficiently representative of the power supply of the intended application of the EHA. As such, it should conform to several important requirements. The impedance characteristics (resistance, inductance, and capacitance) of the power supply system and wiring, and the circuit breaker characteristics should be representative of the intended application.

In addition, the electric power supply system should be of sufficient capability to provide the maximum anticipated power to the EHA. If the power supply has capability above what the EHA requires, or the capability is more than the power supply in the intended application of the EHA, it may be necessary to ensure that the EHA is not commanded to an operating point where it delivers more power than its design capability.

Further, the dynamic response characteristics of the power supply should be evaluated to ensure that the power supply will not limit the dynamic performance of the EHA. A power supply that can supply sufficient steady state voltage and current may not provide enough capability during transient operation typical of testing aerospace EHAs.

If the PDE has been designed to provide regenerative power back to the supply bus during aiding load conditions or rapid motor deceleration, it should be ensured that the electric power supply being used for EHA testing can absorb regenerative power, and the electric power quality on the supply bus is measured under a regenerative mode of operation consistent with the applicable bus power quality requirements. The need for a load bank or batteries for use in parallel with the supply to the PDE to absorb the worst case regenerative energy should be evaluated.

Test procedure documentation should include a detailed wiring diagram to instruct test personnel on accurate connections to avoid ground loops, ensure maximum protection from electric shock, and avoid equipment damage from unintended misconnection.

4.4 Documentation

In developing a test plan or procedure for an EHA, documents relevant to the EHA requirements and design such as the following may be referenced as necessary.

- EHA Technical Specification

- EHA Hydraulic Schematic Diagram

- EHA Test Controller Schematic Diagram

- EHA Interface Control Document (ICD), Electrical

- EHA Interface Control Document (ICD), Mechanical

Such documents will have document numbers per the requirements of the corresponding supplier or procurement activity.

5. SCOPE OF TESTS AND METHODOLOGY

In 5.1 through 5.3, three categories of tests are described as they apply to EHAs: Integration Tests, Acceptance Tests, and Qualification Tests. These categories, following the terminology generally used in the industry, are defined as follows:

Integration Tests: These tests are designed to subject the EHA to a series of tests to verify that it functions per its design requirements. These tests may be limited to functional verification at a relatively higher level or could include lower level performance verification. These tests generally precede formal qualification tests and are not counted as a part of the formal qualification.

The integration tests discussed in this document are EHA level integration tests, which usually are the responsibility of the EHA manufacturer. Higher level aircraft system integration tests, including verification of proper integration of a set of EHAs with the aircraft flight control system, power generation, etc., are beyond the scope of this document.

Acceptance Tests: These tests are designed to subject the EHA to a series of tests to verify that individual EHAs meet the performance requirements. Acceptance tests verify a part of the entire set of design requirements and are generally conducted at laboratory ambient conditions.

Qualification Tests: These tests, designed to verify the flightworthiness of the EHA design, subject the EHA to a series of tests to verify that the EHA meets all its performance and life requirements, over all extremes of environmental and other requirements. These tests constitute a verification of the entire set of design requirements. The term verification tests may also be used to describe the qualification tests.

All test results and observations should be recorded on an appropriate test data sheet.

For guidance regarding the development of test plans and procedures for EHAs, refer to AS4941, AS8775, and ARP5007 as applicable.

5.1 Integration Tests

Integration tests generally consist of three types of tests – performance, thermal, and failure transient tests. The purpose of these tests is to ensure that the EHA functions per its design requirements, with the associated loop closures implemented per the design requirements.

5.1.1 Integration Performance Tests

Integration performance tests are designed and conducted to evaluate the performance of the EHA. These tests may be based on steady state and/or dynamic performance requirements of the EHA, either designed specifically for integration, or they may be a relatively small subset of the performance tests required for acceptance tests (see 5.2.6).

5.1.2 Integration Thermal Tests

Integration thermal tests are designed and conducted to evaluate the thermal performance of the EHA. These tests may be based on steady state and/or dynamic performance requirements of the EHA, either designed specifically for integration, or they may be a relatively small subset of the duty cycle test requirements. See 5.3.7 for duty cycle tests that include a discussion of the thermal tests.

5.1.3 Integration Failure Mode Tests

Integration failure mode tests are designed and conducted to evaluate the failure transient performance of the EHA. These tests should be designed based on the specific failure transient performance that is important to evaluate as a part of the integration. See 5.3.5 for failure transient tests that include a discussion of the various issues related to failure transient performance tests.

5.2 Acceptance Tests

See 5.2.1 through 5.2.8 for a description of the recommended EHA acceptance tests and test methodologies. These tests are conducted at the ambient and unit operating temperatures specified in the applicable test procedures. All test results and observations should be recorded on an appropriate test data sheet.

5.2.1 Examination of Product

Carefully examine the EHA to determine conformance with the requirements of the applicable specifications, standards, and engineering drawings for workmanship, marking, and any visible defects.

5.2.2 Software/Firmware Version Verification

As applicable, it is recommended to implement a method to verify the correct version of the software or firmware is loaded into the PDE. Such verification could be via a direct query of the software or firmware, or through build documents, and marking on the associated nameplate.

5.2.3 Weight

Since an EHA that is ready for acceptance test procedure (ATP) would be filled and bled, the wet weight should be recorded. If an EHA is comprised of separate elements, then these elements should be filled, bled, and weighed separately.

5.2.4 Proof Pressure

5.2.4.1 High Pressure Proof

For an EHA, if it is not feasible to generate the high pressures required to conduct the high pressure proof test with the EHA pump and motor, then the high pressure proof test may be conducted with the required high pressure introduced from an external source through a suitable port of the EHA. To prevent excessive pressurization of the return cavities of the EHA during a high pressure proof test, the pressure of the return circuit may be controlled by an appropriate external hydraulic circuit specifically designed for that purpose.

When high pressure is introduced from an external source to either the extend or retract cavities, the effects of the resulting differential pressure at the pump and the de-energized motor should be considered. To preclude uncontrolled pump rotation or other possible damage, the pump and the motor may be removed from the EHA, replacing them with a test block of the required functionality. The high pressure proof tests on the pump and motor in this case may be conducted separately at the pump and motor assembly levels, consistent with the applicable specification.

During high pressure proof test of an EHA, a component such as a relief valve that is not designed to be functional at the proof pressure, or which may significantly affect the ability to execute the proof pressure test, may either be disabled or removed from the EHA (similar to the industry practice for EHSAs).

While an EHA design may require the removal of one or more components for a proof pressure test, it is highly desirable to preclude or minimize the need for such component removal to the maximum extent possible. This intent may be satisfied, for example, by increasing the return pressure to preclude operation of the relief valve with the high proof pressure, if the applicable requirements document so permits.

If components of the EHA were disassembled for high pressure proof testing, then the EHA should be reassembled, filled, bled, and subject to an acceptance test, except for the high pressure proof testing portions of the acceptance test.

5.2.4.2 Return Pressure Proof

Return pressure proof test of an EHA is conducted with the required pressure introduced from an external source through a suitable port of the EHA in its return or reservoir circuit, using appropriate tooling. During this test, the hydraulic circuit subject to high pressure proof test may be subject to the return proof pressure.

During return proof pressure test, in general, it is not necessary to remove either the pump, the motor, or any other components of the EHA.

If components of the EHA were disassembled for return pressure proof testing, then the EHA should be reassembled, filled, bled, and subject to an acceptance test, except for the return pressure proof testing portions of the acceptance test.

5.2.5 Verification of Fill and Bleed

Verification of the correct level of fluid fill of the EHA should be accomplished using an appropriate applicable technique and procedure, which may include utilizing the sensors on the EHA.

Verification of the efficacy of the bleed process executed on the EHA to purge any entrained or entrapped air is an important step before subjecting the EHA to performance testing and completion of ATP. The appropriate verification technique and procedure may be unique to a particular EHA design and should be the designer's responsibility. Common methods to verify the efficacy of the bleed process are described below and may be used as applicable.

5.2.5.1 EHA Fluid Stiffness Test

The following method describes one approach to determine the stiffness of the fluid in an EHA. Other methods may also be considered.

This approach utilizes the effect of entrained air on the stiffness (or compressibility) of the EHA fluid. Permitting expansion of a known volume of EHA fluid and monitoring the change in EHA fluid pressure, provides a means to determine the efficacy of the EHA bleed process. Figure 2 illustrates this test method.

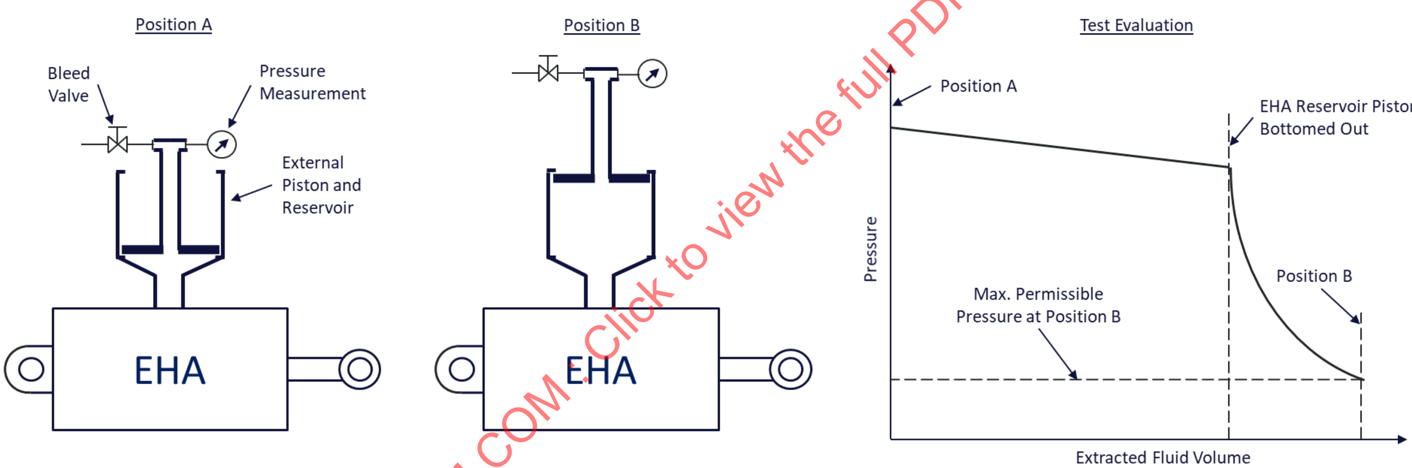

Figure 2 - EHA fluid stiffness test

An apparatus such as that illustrated in Figure 2 is connected to one of the EHA fluid circuits through a suitable hydraulic port (for example, the EHA reservoir circuit). This apparatus enables controlled extraction (expansion) and re-insertion (re-compression) of the EHA fluid using an external piston and reservoir. Without extracting any EHA fluid with this apparatus (position A), the EHA is filled and bled to the correct EHA reservoir level, and the bleed valve is closed. The bleed valve is opened, and the external piston is then moved to position B while monitoring the fluid pressure. The fluid pressure in position B, after allowing sufficient time for it to stabilize, must not exceed a specified value corresponding to an acceptable efficacy of the bleed process. The test is completed by returning the apparatus to position A condition and disconnecting it from the EHA. This test can be used to determine the total amount of gas or air in the EHA fluid.

5.2.5.2 EHA Dynamic Stiffness Test

This approach also utilizes the effect of entrained air on the stiffness (or compressibility) of the EHA fluid but utilizes the measurement of EHA dynamic stiffness to determine the efficacy of the bleed process. It relies upon prior establishment of the expected dynamic stiffness at a specific frequency or frequencies of the EHA under known bleed conditions, and adequate control of the parameters relevant to dynamic stiffness. See 5.3.4.

5.2.6 Acceptance Performance Tests

During and as a part of the acceptance performance tests, relevant input electrical and other parameters may be measured as required by the applicable specifications, to establish the acceptability of the measured performance during the tests. Such parameters may include the motor current, line current, line voltage and power, motor revolutions per minute, etc.

5.2.6.1 Static External Leakage

Throughout all ATP testing, no static external leakage is expected for EHAs. For a definitive and rigorous test, in addition to monitoring the static external leakage with nominal reservoir pressure, it may also be monitored while the EHA is subjected to a relatively low reservoir pressure such as 5 psig (34.5 kPa gauge) for a sufficiently long time such as 12 hours, at ambient temperature and pressure.

5.2.6.2 Dynamic External Leakage

Throughout all ATP testing, no dynamic external leakage is generally expected for EHAs. For a definitive test, an acceptable set of test requirements consistent with specification requirements are recommended, such as 100 full stroke cycles at the maximum rate: the success criterion typically being no single drop of external leakage during or after this test. The ATP should include the loads on the EHA which may affect the dynamic external leakage.

5.2.6.3 Uncommanded Motion (Chatter, Instability)

During acceptance testing, the output motion of the EHA should be monitored for evidence of uncommanded motion, adverse noise, chatter, or instability. A specific or special test, or monitoring of other internal EHA parameters such as the pump-motor speed, if required, should be conducted as specified in the applicable specification.

5.2.6.4 Verification of Operating Modes

Verification of all operating modes of the EHA should be performed as required by the applicable requirements or specifications.

5.2.6.5 Positioning Accuracy and Stroke

Positioning accuracy, rated stroke, and total stroke of the EHA should be measured as required by the applicable requirements or specification.

5.2.6.6 Maximum Operating Load

The maximum operating load test verifies the EHA is capable of reacting or holding the commanded actuator position for a specified time against a load equal to the specified maximum operating load, as well as moving the actuator at a low velocity in both directions in the following conditions. Particular attention should be given to the duration of the test. A portion of the internal heat generated by actuators powered by an external hydraulic system (e.g., hydraulic servoactuators) is removed by the hydraulic system. However, power-by-wire actuators (e.g., electromechanical actuators and EHAs) are prone to continuously increasing temperatures under constant load conditions because heat is primarily removed by thermal convection which has limited dissipation capability. This characteristic can make the thermal balance a sizing driver.

A recommended test method to achieve the above objective is as follows:

Command the EHA to mid-stroke or the specified position. Gradually increase the load to the specified maximum operating load. The successful ability to react to the maximum operating load is demonstrated by the ability of the EHA to maintain the commanded position within the specified acceptable range.

With the EHA holding the commanded position at the maximum operating load, slowly command a position change to the EHA. The successful ability to move against the maximum operating load is demonstrated by the ability of the EHA to achieve the new commanded position within the acceptable range.

With the EHA holding the commanded position at the maximum operating load, command a position change to the EHA with a sufficiently low frequency and amplitude sinusoidal position command that ensures, over a cycle, actuator movement with both positive and negative velocity, as well as pump-motor rotation with both positive and negative rotational velocities. Successful ability to move against the maximum operating load is demonstrated by the ability of the electrohydrostatic actuation system (EHAS) to achieve the new commanded position within the acceptable range, including direction reversals of the actuator and the pump-motor.

It is recommended that the above test be conducted with both opposing and aiding loads, for both retract and extend actuator movement. Also, in the case of multichannel systems, all modes of operation that can affect output force should be evaluated.

It is also recommended that the duration of the maximum operating load test be limited as required to ensure that the EHA does not exceed the temperatures allowed in the specification.

5.2.6.7 Continuous Force

The continuous force test verifies that the EHA is capable of reacting to the specified continuous force for a specified time without overheating.

In this test, the EHA should be required to hold a commanded position against the required external load, for the required time duration, while monitoring and recording the critical EHA temperatures. The ability to withstand the specified load for the specified duration with the critical temperatures remaining within their specified acceptable limits constitutes successful completion of the test. The test should take into account the worst case environmental and heat generation conditions, e.g., in flight at higher altitudes where the ambient air is cold and convection rates are low, or on the ground where the ambient air can be hot and heat dissipation is improved.

It is recommended that the above test be conducted with both compressive and tensile loads. Also, in the case of multichannel systems, all modes of operation that can affect output force should be evaluated.

5.2.6.8 Constant Load Limitation Test

The load limitation test verifies the ability of the EHA to limit the constant maximum external load it can react.

EHA load limitation capability may be limited by the use of a device such as a relief valve in the hydraulic schematic of an EHA, or specific control system implementation. This test verifies the operation of such a device or control implementation.

For an external load equal to or greater than the specified maximum load, the EHAS should not be able to hold the commanded position, and the EHA will move in a direction dependent upon the external load, at a rate consistent with the design of the EHA or EHAS.

A recommended method to verify the EHA load limitation capability is as follows:

With zero external load, command the EHA to hold a position required by the applicable specification, or within the range of its operating stroke, such that sufficient stroke capability remains to adequately measure the rate at which the EHA moves under the maximum load.

Gradually, or as required by the applicable specification, increase the external load to the specified load limitation requirement, while monitoring the EHA position and velocity, along with all other parameters of interest.

The test is successful if at the specified load limitation requirement, the EHA should cease to hold its commanded position and move in a direction consistent with the direction of the applied load, at a rate within the performance specification of the EHA. The application of the maximum external load should be discontinued upon achieving a rate consistent with the requirement, or before the EHA runs into its internal stop.

As required by the applicable specification, the external load may be reduced gradually, and the load at which the EHA stops its movement in the uncommanded direction and regains position loop control should be measured.

An alternate approach that may be used for this test consists of developing a continuous Load versus Rate performance characteristic curve of the EHA, over the range of load the test is required to be conducted.

The above test should be conducted for both compressive and tensile external loads, according to the applicable specification.

During this test, the EHA may be monitored for excessive pressure oscillations and/or erratic noise.

It should be noted that during this test the EHA temperature may increase rapidly due to high force generation and high energy dissipation.

For this test, the load should be limited by the pressure relief valves and not limited by the EHA control law.

5.2.6.9 Internal Leakage

Measurement of EHA internal leakage in its active or normal operating mode at a specified load may be accomplished by commanding the EHA to hold position against the specified load and monitoring the motor-pump rotational velocity required to maintain the actuator position (at zero actuator velocity). The known pump displacement and the measured motor-pump revolutions per minute permits the calculation of the actual internal leakage for the specified load and test temperature.

5.2.6.10 No Load Velocity

EHA no-load velocity test should be conducted with zero external load, by commanding the EHA with an appropriate position and/or velocity command to achieve the required EHA output velocity, in each direction of operation, while monitoring and recording all parameters of interest. The command may be a sine waveform or a lowpass filtered command (to round the speed reversal), with constant magnitude and increasing frequency below the position bandwidth.

For an EHA, it is recommended to preclude end-of-stroke bottoming of the actuator during this test. The EHA command may be limited or tailored as necessary for this purpose.

5.2.6.11 Loaded Velocity

EHA loaded velocity test should be conducted with the specified external load, by commanding the EHA with an appropriate position and/or velocity command to achieve the required EHA output velocity, imparting the required load by an appropriate load system, and monitoring and recording all parameters of interest.

Depending upon the design of the EHA loading fixture, the load control system, and/or the dynamics of the EHA and the load system, the load system and/or the EHA may not be able to achieve and maintain a constant load or velocity during the test. In this case, a recommended approach to accomplish a valid test is to utilize an average velocity and load over a certain stroke of the EHA for an indication of the EHA performance. The use of such an approach should be consistent with or permitted by the applicable EHA specification.

The loaded velocity test should be conducted in each direction of operation, with both opposing and aiding loads.

For this test, it is recommended to preclude end-of-stroke bottoming of the actuator at a sufficiently large velocity, particularly under significant loads. The EHA command may be limited or tailored as necessary, consistent with the applicable specification requirements, for this purpose.

5.2.6.12 Frequency Response

Similar to EHSAs, EHA frequency response tests should be conducted for the specified external load and variable position amplitude commands.

EHA frequency response testing should ensure that the test procedure precludes EHA temperatures that exceed expected in-service or specification values and includes consideration of the required dissipation of regenerative power and energy. These aspects may require due consideration of the number of test points per decade or per sweep and the duration of the test, for the required amplitude and frequency range, and/or additional ventilation or cooling of the EHA. Because the method used to calculate the amplitude and phase impacts can be sensitive, the method should be reviewed with the customer. The EHA or the test system regenerated electrical energy management system should be of the required capability.

5.2.6.13 Run-Up Time

EHA run-up time test measures the time between the issuance of a command to the EHA and the instant the required EHA velocity is achieved, under specified operating conditions. The issuance of the command should be based on the EHA specification and could be the time at which the REU or the MCE receives the command.

Consistent with the applicable requirements document, the issued command to the EHA may be a mode select discrete, a solenoid operated valve (SOV) command to the EHA, or similar. An associated, specified EHA velocity command per the applicable requirements document should be applied. The test should be conducted with the specified external load.

5.2.6.14 Regenerative Mode Operation

EHA regenerative mode operation test verifies the performance of the EHA while being back-driven, reacting aiding loads, or while operating at sufficiently high deceleration rates.

The regenerative mode test should be conducted per the applicable requirements document relative to the EHA input position command and external load, as a function of time.

The regenerative mode operation test should be structured to preclude temperatures of EHA components greater than those expected in service or allowed by the specification of EHA components during the test.

5.2.6.15 Hysteresis

EHA hysteresis test should be conducted for the specified stroke amplitude and at the specified rate, with zero external load, and if required by the applicable requirements document, for the specified external loads, which may include opposing and aiding loads.

5.2.6.16 Threshold

EHA threshold test may be conducted for the specified stroke amplitude and at the specified rate, with zero external load, and if required by the applicable requirements document, for the specified external loads, which may include opposing and aiding loads.

5.2.6.17 Mode Transition Time

EHA mode transition time test measures the time between the issuance of a command to the EHA to initiate a mode change, and the instant the EHA accomplishes a mode change, under specified operating conditions.

Consistent with the applicable requirements document, the issued command to the EHAS may be a mode select discrete, an SOV command to the EHA, or similar. If required by the applicable requirements document, an associated, specified EHA velocity command should be applied. The test should be conducted with the specified external load.

5.2.6.18 Fail-Safe Mode Operation

As required by the applicable requirements document, the EHA fail-safe mode test should verify the ability to engage the fail-safe mode and meet the associated applicable performance requirements.

5.2.6.19 Degraded Mode Performance

As required by the applicable requirements document, the EHA degraded mode performance test should verify its performance under the specified degraded mode operating conditions.

5.2.6.20 Bearing Backlash

A recommended method to measure the total bearing backlash is as follows:

With the EHA in powered or active mode, command the EHA to a specified position (usually mid-stroke). An external load is gradually applied to start from zero, increasing to its maximum required tensile and then the maximum required compressive value and then returning to the initial state for this test. Dial indicators or suitable equipment should be used to measure the resulting gap between the bearing housing and the spherical bearing at the maximum tensile and maximum compressive load. The total bearing backlash is the sum of the bearing backlash of all bearings in the primary load path.

The maximum tensile and the maximum compressive load to be applied in the test above should be determined from the known characteristics of the EHA bearings so that while those loads positively result in movement over the backlash of the bearings, they do not result in significant deflections due to either the bearing structural compliance or EHA stiffness.

5.2.6.21 Bearing Rotational Torque

The rotational (or breakout) torque of the EHA bearing(s), such as rod end bearings, should be measured as required by the applicable specification.

5.2.7 Electrical Tests

The electrical tests listed below should be conducted per the applicable EHA requirements specification.

- Dielectric Strength
- Insulation Resistance
- Bonding Resistance

5.2.8 Damping Mode Performance

The damping mode performance test verifies the EHA can meet the specified minimum damping when it is in damped mode.

The test methodology should be consistent with the applicable requirements document. Testing can be done as a function of resisting force versus actuator velocity or delta pressure between the extend and retract side of the actuator versus actuator velocity. In some cases, testing with a defined sinusoidal position oscillation correlated to real-time resisting force is needed to fully characterize the damping performance of the actuator.

In cases where multiple actuators or power sources are used on a control surface, it is also important to characterize and test the maximum damping forces that the actuator can produce because those forces increase the opposing load on the active actuator of an Active-Damped control surface.

Damping mode performance should be tested at temperature extremes because minimum damping performance can be lowest at maximum temperatures due to fluid viscosity, fluid bulk modulus, and friction from seals and bearings. Similarly, maximum damping can be highest at minimum temperatures for the same reasons.

Care should be taken to prevent the EHA from overheating during damping mode performance testing. Overheating can result from repeatedly cycling the damped actuator at a rate higher than the specified duty cycle. Such overheating may result in degradation of seals and reduced damping performance due to reduction of the fluid viscosity and bulk modulus. It is recommended to monitor the actuator temperature during damped mode testing in the region of the dynamic piston rod seals to ensure that the actuator operating temperatures remain within design limits.

5.3 Qualification Tests

Sections 5.3.1 through 5.3.16 describe the recommended EHA qualification tests and test methodologies. These tests should be conducted under environmental conditions and at unit operating temperatures specified in the applicable test specifications.

Throughout all qualification testing, similar to an EHSA, it is important that the operation of the EHA be periodically verified for acceptable operation and performance, to preclude the possibility of unacceptable degradation or failure.

5.3.1 Proof Pressure (High Temperature)

The EHA high temperature proof pressure test should be conducted similarly to the acceptance proof pressure test described in 5.2.4, except that it should be conducted at the high ambient and/or the high unit temperature specified in the applicable requirements document, after stabilizing the unit temperature at the specified conditions.

If the EHA under test utilizes a gas charged fluid reservoir, the reservoir pressure should be monitored during the test to ensure that excessive pressurization due to the high temperature does not occur.

5.3.2 High Temperature Performance

EHA performance should be verified at the high temperature specified in the applicable requirements document, through all applicable tests listed in 5.2.6 and 5.2.7 of the acceptance tests.

For all high temperature EHA performance tests, concern relative to EHA thermal overstress or overheating for certain tests may require greater attention compared to acceptance testing. Appropriate modifications to the test procedures should be implemented if required, which otherwise could have been similar to the corresponding acceptance test procedures.

5.3.2.1 Stability Margins

The EHA should be tested for its stability margins (gain and phase) of the position loop at the high temperature specified in the applicable requirements document, for the specified input command magnitudes, load, and supply voltage.

During this test, EHA thermal overstress or overheating and the regenerative device capability may be a concern similar to the frequency response test described in 5.2.6.12; it should be taken into account and addressed.

5.3.2.2 Degraded Mode Performance

EHA degraded mode performance test should be conducted similarly to 5.2.6.19, at the specified high temperature.

5.3.3 Low Temperature Performance

EHA performance should be verified at the low temperature specified in the applicable requirements document, through all applicable tests listed in 5.2.6 and 5.2.7 of the acceptance tests.

While concern relative to EHA thermal overstress or overheating may be none or much less during low temperature performance tests, a different but related concern may need to be addressed. There may be sufficient local heating within the EHA during low temperature tests, such that during tests of sufficiently long duration, internal components may not be at the low temperature required by the applicable requirement. This aspect may need to be addressed and may require structuring the test methods or procedure so that such local heating is minimized or mitigated.

5.3.3.1 Stability Margins

The EHA should be tested for its stability margins (gain and phase) of the position loop at the low temperature specified in the applicable requirements document, for the specified input command magnitudes, load, and supply voltage.

During this test, EHA thermal overstress or overheating and the regenerative device capability may be a concern similar to the frequency response test described in 5.2.6.12; it should be taken into account and addressed in the test specification.

5.3.3.2 Degraded Mode Performance

EHA degraded mode performance test should be conducted similar to 5.2.6.19, at the specified low temperature.