



AEROSPACE RECOMMENDED PRACTICE

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Duty Cycle Considerations for Electrohydrostatic Actuators

RATIONALE

There is a need to provide a method of characterizing Electrohydrostatic Actuator (EHA)/Electrohydrostatic Module (EHM) duty cycles in order to compare the severity of different EHA/EHM applications and to define parameters for endurance testing of EHA's. This document meets this need.

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1. SCOPE

This recommended practice provides a method of characterizing Electrohydrostatic Actuator (EHA)/Electrohydrostatic Module (EHM) duty cycles for the following purposes:

- a. To enable the comparison of the severity of different EHA/EHM applications. This allows the use of previously qualified designs without the need for repeat testing.
- b. To define parameters for endurance-test design of EHAs; e.g., a way of executing a life-equivalent test in a shorter duration by increasing the speed of cycles and/or the level of applied loads.

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

AIR1922 System Integration Factors Affecting Hydraulic Pump Life

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

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org

ASTM E1049 Standard Practices for Cycle Counting in Fatigue Analysis

2.2 Definitions

Refer to ARP4386 for the EMA/EHM terms that are used in this Aerospace Recommended Practice.

3. TECHNICAL DISCUSSION

3.1 EHA Component Life-Limiting Factors

Assuming that the failure modes of a hydraulic linear actuator are well known and covered elsewhere, this document only considers the long-term failure modes endemic to the unique EHA/EHM components. These are the life-limiting mechanisms (wear and fatigue) of the EHM components, exclusive of the actuator including the wear of sliding parts and fatigue of rolling-element bearings.

NOTE: This document does not address the following considerations that are important in design of the EHA, but not considered related to long-term wear:

- a. Ambient operating temperature
- b. Minimum or average reservoir (pump inlet) pressure
- c. Electrical power quality
- d. Thermal Cycles (other than directly associated to number of flights)

3.1.1 Hydraulic Pump Life Factors

The pump is the main life-limiting component of the EHA/EHM. Wear analysis must be performed, and endurance testing designed, to satisfy users of the technology that pump life is adequate for the intended application. Refer to AIR1922. Failure modes of the pump occur in three general categories:

3.1.1.1 Normal Wear

The wear of mating components under load with relative motion. The classic “Archard Wear Equation” relates material loss to the product of load and distance traveled. If failure is defined as a given amount of material lost from a critical interface in the pump, then the parameter of interest is the total work output of the device over time. For a fixed-displacement pump, this quantity is the same as the fluid volume passed times pressure rise. For a fixed displacement device this measure is equivalent to shaft revolutions times ΔP . Most wear surfaces within the pump can be assessed on this basis.

3.1.1.2 Bearing Fatigue

The rolling-element bearings of the pump are subject to compressive-fatigue failure. Bearing manufacturers and technical associations devoted to bearings have devised approaches for predicting the useful life of a bearing based on its loading and number of revolutions. In these formulations the load is generally raised to the third power. Thus, with bearing loads being generally proportional to pressure, the parameter associated to pump bearing life is revolutions times the cube of differential pressure.

3.1.1.3 Low Speed Wear

A pump may fail due to extended loaded operation near zero speed, where the absence of hydrodynamic lubrication between the component parts results in an accelerated wear mechanism. The typical EHA application has many low-speed loaded conditions, which can contribute to earlier-than-expected pump failure. Consequently, the total number of “zeroes” (shaft speed stoppages and reversals of direction) constitute a useful counting parameter.

3.1.2 Electric Motor Life Factors

Typically, EHA/EHM designs utilize externally-commutated brushless DC motors. Consequently, without the wear associated with brushes, the motor is rarely the life-limiting component of the EHA/EHM design. For EHA, electric motors are generally considered low-risk and are not subject to component-level endurance testing.

Motor failures, when they do occur, are commonly the result of one-time events – excessive voltage, current, or temperature. As long as the motor operates within its normal limits, it remains viable. Bearings in a motor are generally loaded continuously by springs, rather than having a load proportional to actuator force, as in an EHA pump. Motor bearing wear must be considered as a function of the design of the prevailing installation loads and the applied number of revolutions.

The life-limiting factors for the Electric Motor are then generally confined to two considerations:

1. Total Work (leading to long-term breakdown)
2. Number of revolutions (bearings)

3.1.3 Power Electronics Life Factors

The life-limiting factors for the Electronics Module (Motor Control Electronics) are generally confined to two considerations:

1. Thermal Cycles (including startups)
2. Total Work (long-term breakdown of insulation, resistors, etc.)

Thermal cycling is associated to duty cycles in terms of the number of flights. Failure of electronic components as a result of thermal cycling should be considered separately from the operational duty cycles.

3.1.4 Summary of Component Life-Limiting Factors

The variables below in Table 1 are written in terms of a linear actuator (force and stroke); however, the principles apply to components of the EHA, and can be understood equally well in terms specific to each component. (The severity of a pump test or duty cycle, for example, could be specified in terms of pressure differential and numbers of shaft revolutions.)

Table 1 - Component life limiting factors

			Relevant To:			
			Hydraulic Pump	Electric Motor	Power Electronics	Complete EHA/EHM
Summations	Σx	Total Stroke Distance (mileage)		x		x
	ΣFx	Total Work (integrated or summed force times distance)	x	x	x	x
	ΣF^3x	Bearing-Wear Summation	x			x
	Σz	Direction Reversals (Zeroes)	x			x
	N_f	Number of Flights (start/stop cycles)	(*)		x	x
Maxima	F_{max}	Load	x	x	x	x
	V_{max}	Rate	x	x	x	x
	a_{max}	Acceleration	x			x
	P_{max}	Power	x	x	x	x

* N_f is associated with pump cold-starts, separate from Endurance testing.

3.2 Duty Cycle Analysis, Reduction, Comparison, and Classification

3.2.1 Analysis and Reduction Methods

3.2.1.1 Synthetic Method

The Synthetic Method is based on the above summations and maxima. It offers the user and manufacturer of the EHA a rational way of translating aircraft duty cycle data into useful values for comparison of the relative severity of different applications, or to design an equivalent test regimen.

Because it tends to compress test duration by trading cycle count for increased average loads, the Synthetic Method is not recommended for situations where long-term operation at elevated loads presents a significant departure from “normal” operating conditions. Examples may include designs that have very low thermal margins. The Synthetic Method does not preserve some actuator duty cycle information, most notably mean loads and velocities.

The Synthetic Method generates a group of summations and maxima that characterize the duty cycle data being analyzed. These are considered to define the duty cycle in a useful way.

A full description of the Synthetic Method, including a sample calculation, is presented in Appendix A.