AEROSPACE RECOMMENDED PRACTICE

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Superseding ARP777

Gas Actuators (Linear and Vane Rotary Type)

RATIONALE

1) Majority of aircraft and missiles use hydraulic or electrical actuators and 2) Material is still valuable in the event a gas powered actuator becomes desirable.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE A-6B1 Hydraulic Servo Actuation Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

1. PURPOSE:

1.1 General - It is intended that this ARP will set down guidelines for the development and test of reliable rotary vane and/or linear gas actuators. Specific operational and test requirements shall be specified in a detail specification.

1.2 Specific - The areas to be discussed are: Requirements (performance, environment, life, and reliability), design and fabrication, and test considerations.

2. SCOPE:

2.1 Definitions

2.1.1 Gas: Gas, for the purpose of this ARP, shall be defined as the gaseous product(s) resulting from the decomposition, dissociation, or combustion of liquid or solid mono or bi-propellants. Where other gases such as heated N_2, H_2, H_2O (steam), etc., which may have similar physical and/or chemical properties as the defined "gas", are used to effect testing economies, they may be considered as being included in this ARP.

2.1.2 Linear Actuator: For the purpose of this ARP, a linear actuator shall be considered to be any gas powered device, generally consisting of a piston and cylinder, which in its energy converting stage changes gas energy to a directional (push and/or pull type) mechanical power.

2.1.3 Vane Actuator: For the purpose of this ARP, a vane actuator shall be considered to be any gas powered device, generally consisting of a rotating shaft, with one or more vanes, enclosed in a housing, which provides an inlet and outlet port. In its energy converting stage the vane actuator changes gas energy to rotary mechanical power with generally less than one complete revolution.

2.1.4 Exclusions: To be considered in the development of the "gas actuator" but not a part of this ARP, are such devices as the servo control valve, speed reducer, output conversion devices, servo loop feedback mechanisms, and dynamic characteristics of the driven load.

2.2 Design Considerations

2.2.1 Life: This ARP will generally define the life requirements of "gas actuators" for three broad categories of flight vehicles.

2.2.1.1 Long Range Air Breathing Vehicles - The actuators for this type vehicle generally will have both a long operational and ground checkout life.

2.2.1.2 Manned Re-entry Vehicles - Actuators for this type vehicle generally will have a moderately long operational life, but will be significantly less than their ground checkout life.

2.2.1.3 **Single** Use Vehicles - Actuators for this type vehicle have a long ground checkout life with a short operational life. The operational life may range from a few seconds to several hours.

2.2.2 Environment and Performance: This ARP will be confined to discussing the environments and gas temperatures most likely to be encountered, listing some of the performance parameters without numerically defining them, and to specifying tests to show compliance with the performance and reliability requirements under the expected environmental conditions. This ARP will not define a specific "gas actuator".

3. DESIGN AND FABRICATION:

3.1 Materials - All materials must be carefully selected to insure against wide variations of thermal expansion between adjacent members.

3.1.1 All materials under highly stressed conditions must be carefully selected so that stress-creep at temperature is held to a minimum, as governed by their life requirements.

3.1.2 Factors to be considered for the selection of materials at the operating temperature for a given time shall include: thermal coefficient of expansion, stress level at that temperature, creep, corrosion and heat resistance, erosion, and nuclear environment.

3.1.3 Protective coatings to guard against oxidation and corrosion of the base metal must be used wherever the base metal may be subjected to levels and durations of temperatures above its upper limit of oxidation resistance, depending upon life requirements.

3.1.4 Solid-phase dry lubricants to reduce friction forces and increase life may be advisable where the temperature range is such that they may be used. At temperatures beyond the usefullness of dry type lubricants consideration may be given to soft oxides of mating materials.

3.1.5 Organic materials for seals, diaphragms, etc., may be used with caution with special consideration given for application and life.

3.1.6 The use of material combinations whose chemical reactions to each other are accelerated by high temperature shall be avoided.

3.2 Design and Construction - Design and construction of the actuator shall be such that the errosion or build up due to the reaction of the gases and the materials will not result in reduced reliability or abnormal operation at the required temperature for specified time.

3.2.1 Rotating members shall be mounted in bearings of adequate size to carry the maximum loads for the design life of the unit.

3.2.2 Inasmuch as no handbook data exists on bearing operations at highly elevated temperatures, cautious judgement should be exercised at all times, even at the possible expense of added weight, to insure against seizure or galling.

3.2.3 In applications where output shaft seals may be required, low-force, pressure-balanced seals should be employed. If shaft seal leakage is critical, as outlined in the detail requirements, there may be some advantage in dual shaft seals.

3.2.4 All actuator clearances should be selected so that a minimum quiescent flow is attained when the unit is motionless under a static load, or unloaded, as specified in the detail requirements.

3.2.5 All moving members shall be mounted in such a manner that G loadings and shock do not deteriorate performance and life, and so that they do not cause destructive vibrations in themselves or to the rest of the actuator and related and/or attached equipment.

3.2.6 The Moment of Inertia of the rotating members of the vane actuator, and the piston and rod of the linear actuator, shall be as low as possible consistant with ruggedness, reliability, and good design practice. For any specific application the maximum allowable Inertia should be specified.

3.2.7 Due to the high weight penalty for the hot gas to be used in most cases the actuator's overall gas consumption shall be as low as possible. However, gas consumption at maximum output horsepower may not, in many cases, be as critical as low gas consumption at either low output torque, low output speed, or even under quiescent conditions. In all probability a large amount of the actuator usage will be at less than 10 per cent of peak power, with high system pressure on the actuator.

3.2.7.1 The choice in selection between linear type actuators and vane rotary type actuators is dependent upon a careful review of rated conditions and operational environments.

3.2.7.2 In all cases the volume of the pressurizing gas, not doing useful work, shall be held to a minimum. This means that stroke displacements, clearances, and volumes must be minimized.

3.2.8 In the event that any dynamic spring-mass systems are used in either type actuator system, they shall be sufficiently damped to insure against adverse operation under conditions of anticipated vibration.

3.2.9 The design of the rotary actuator bearings should generally not require the vane motor to withstand any loads other than the torsional and thrust loads resulting from rotational operation. The rotary actuator shall be mounted in such a manner to the speed reducer or other use function that the misalignment load imparted to the output shaft is minimized.

3.2.10 In many cases the actuator may be designed to operate with a servo valve of specific performance characteristics. In the design of the servo, the entire servo loop must be considered to the extent that the actuator dynamics match the dynamics of the valve, speed reduction, driven member, and necessary feedback circuitry.

3.2.11 Because of the high reliability requirements, a high degree of workmanship must be exercised in fabricating the actuator. In particular, care must be exercised to avoid free particles, hanging burrs, or other contaminants which may dislodge during operation and initiate a malfunction within the actuator or within the system in which it will operate. In addition, great care must be taken to insure that the correct surface finishes and clearances are specified and accomplished so that random failures, premature wearout, and/or unnecessary loss of efficiency can be minimized. Quality control inspection of the highest caliber, most rigid integrity, and utmost thoroughness must be exercised on even the most insignificant seeming component of the actuator to insure against faulty workmanship.

3.3 Static Performance - For vane type rotary actuators the following three tests shall apply: Applicable tests shall also apply to other types of actuators.

3.3.1 Stall Torque: The maximum allowable stall torque shall be defined in inch pounds. Since the stall torque will have a significant effect on the weight of the unit, it should be optimized based on a trade between servo torque response, rate, and supply pressure.

3.3.2 Friction: The maximum allowable breakout friction shall be defined in inch pounds. Since the breakout friction will have a significant effect on servo resolution, it should be minimized within the clearance limits required for low leakage.

3.3.3 Quiescent Leakage: The maximum allowable quiescent leakage flow shall be defined in pounds per minute of gas. It will occur in two forms, leakage across the load ports and external leakage to the ambient atmosphere. Here again, a trade study must be made to determine the optimum condition. All leakage is detrimental from a fuel consumption standpoint, but leakage across the load ports adds damping to the servo.

3.4 System Dynamics - The actuator with its speed reducer, driven function, input servo valve, amplifiers, command input, and feedback network shall comprise the control servo system. In considering the actuator dynamics, the entire system must be integrated. The dynamic values should be those for the whole actuation loop.

3.4.1 The inertia loads shall be specified in lb.in.-sec. 2 for rotary motion, in lb.sec.^{2}/inch for linear motion and reflected to some specified point in the system.

3.4.2 The maximum load shall be specified in in-lbs/radian for rotary actuator and in lbs/inch for the linear actuator and reflected to some specified point in the system.

3.4.3 The aerodynamic spring rate shall be specified in in.-lbs/radian.

3.4.4 The maximum surface deflection shall be specified in $\pm$ radians.

3.4.5 The output motion shall be specified in radians per second in the case of rotary motion, and inches per second in the case of sliding motion or a combination thereof.

3.4.6 The frequency response shall be specified as the ratio of output to input in db versus frequency with a corresponding phase lag envelope, and measured at some fixed and specified input signal amplitude.

3.4.7 Assuming a rigid attachment point to structures, the minimum allowable natural frequency shall be specified in radians/sec.

3.4.8 The static stiffness, assuming a rigid attachment point, shall be specified in in-lbs/radian reflected to the output shaft.

4. ENVIRONMENTAL CONDITIONS:

4.1 Vehicle Environment - The vehicle environment is that environment to which the actuator will be subjected due to the requirements of the vehicle mission profile. Such environmental parameters as ambient temperature, atmospheric pressure, vibration, acceleration, shock, etc., fall into this category.

4.1.1 Ambient Temperature: The ambient temperatures shall be based on the anticipated mission profile and shall be defined for each specific application in a detail specification. These may vary in the neighborhood of 500°F to 2000°F.

4.1.2 Vibration: The amplitude, frequency, and **g** loads of the vibrational spectra to which the actuator will be subjected depend on the type of vehicle and the profile of the mission in which it will be used. Some applications may require that a Random Excitation Spectrum be specified as well as a Sinusoidal Envelope.

4.1.3 Shock: The actuator shall be capable of withstanding the required impact shocks along any axis without compromising its performance. The specified shock load represents the maximum condition to be expected in the handling and transportation of missiles and/or missile and aircraft components and/or subsystems.

4.1.4 Acceleration: The maximum acceleration along any axis shall be specified for each actuator application in a detailed specification.

4.1.5 Atmospheric Pressure: The atmospheric pressure to which the actuator will exhaust shall be specified in terms of time vs. altitude. It is of importance, especially for low pressure units, that an atmosphere pressure vs. actuator power curve be included so that the actuator can be properly sized to suit the power use function requirements at the various operational altitudes. In many cases the maximum power requirement will occur at sea level or slightly above.

4.2 Actuator Environment - The actuator environment is that environment resulting from the use of the gas actuator itself. Parameters such as gas temperature and pressure are the principle ones to be considered in this case, although actuator noise generation and unbalanced vibration are important.

4.2.1 Hot Gas Temperature: The temperature of the pressurizing gas for the actuator will be largely dependent on the fuel selected to provide the gas. Other factors such as vehicle ambient temperature can influence the gas temperature in cases where it is much higher or much lower than the gas temperature and the uninsulated tubing runs are quite long. The actuator shall be designed so that it will perform satisfactorily from a gas source of the temperature to be encountered in service. Various types of fuels will provide pressurizing gas at different temperatures depending on how they are used.

4.2.1.1 A hydrogen-oxygen fuel-oxidizer combination can provide good fuel efficiency at gas temperatures as low as 700°F. Lower SFC's can be obtained by increasing the temperature, but the overall advantages are somewhat dubious in that a greater proportion of oxygen is required. This reduces the amount of hydrogen available for a heat sink, and as the ratio of hydrogen to oxygen decreases to the stoichiometric combustion condition the actual gas temperature rises above 4000°F.

4.2.1.2 Liquid monopropellants such as hydrogen peroxide and hydrazine have decomposition temperatures in the 1200°F to 1300°F range. In the case of hydrazine, the lower limit (1200°F) can be approached without a great penalty by causing a relatively high ammonia dissociation to occur in the decomposition chamber.

4.2.1.3 Most of the solid propellants, either single base or double base, have combustion temperatures in excess of 2000°F. These temperatures will undoubtedly be tempered somewhat by the time the gas reaches the actuator if they travel for any distance through uninsulated tubing in a lower vehicle ambient temperature.

4.2.2 Rated Gas Pressure: This document will not specify the rated gas pressure, as this will be entirely dependent on the propellant and system selected. The actuator type chosen will in turn depend, to a large extent, on the rated pressure and the work function selected. The rated gas pressure and its upper and lower limits shall be clearly specified in the detail specification.

4.2.3 Noise Generation: The upper limit of allowable noise generation radiated by the actuator to the vehicle shall be specified.

4.3 Storage Environments - The complete storage environments shall be reviewed and considered in the actuator design.

5. TEST REQUIREMENTS:

5.1 Functional Tests - Functional tests may be run on the actuator alone without the other portions of the servo loop.