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DESIGN AND VERIFICATION REQUIREMENTS FOR SPACEFLIGHT VALVES

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FOREWORD

This NASA Technical Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This Standard establishes uniform design and verification requirements for spaceflight valves whose correct operation is required for safety or mission success.

For additional information on this standard, submit a request via “Email Feedback” at <https://standards.nasa.gov>.

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DESIGN AND VERIFICATION REQUIREMENTS FOR SPACEFLIGHT VALVES

1. SCOPE

1.1 Purpose

This NASA Technical Standard establishes uniform design and verification requirements for spaceflight valves.

Historically, valve design and verification requirements have been an accumulation of requirements levied by various disciplines to satisfy higher level system performance. Lessons learned have shown that this approach results in requirement gaps and inconsistently applied requirements that have led to costly valve failures.

The objective of this Standard is to create a single, consistent source of requirements to be applied to valves to ensure that valves are properly designed and verified for their applications.

1.2 Applicability

1.2.1 This Standard applies to all instances of all types of valves, including servo valves, engine valves, quick disconnect valves, regulators, couplers, ordnance-operated valves, and hand-operated valves, used in any application on spacecraft or launch vehicles.

1.2.2 This Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program, and other Agency documents. This language applies to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center), other contractors, recipients of grants, cooperative agreements, or other agreements only to the extent specified or referenced in the applicable contracts, grants, or agreements.

1.2.3 References to “this Standard” refer to NASA-STD-5023; references to other documents state the specific document information.

1.2.4 Verifiable requirement statements are designated by the acronym “VDVR” (Valve Design and Verification Requirement), numbered, and indicated by the word “shall.” This Standard contains 105 requirements. To facilitate requirements selection by NASA programs and projects, a Requirements Identification Matrix is provided in Appendix C.

1.2.5 Explanatory or guidance text is indicated in italics beginning in section 4. The terms “may” or “can” denote discretionary privilege or permission, “should” denotes a good practice and is recommended but not required, “will” denotes expected outcome, and “is/are” denotes descriptive material or a statement of fact.

1.3 Tailoring

Tailoring of the requirements in this Standard for application to a specific program or project is acceptable when formally approved by the delegated NASA Technical Authority in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements, and documented in program or project requirements.

2. APPLICABLE DOCUMENTS

2.1 General

2.1.1 Documents listed in this section contain provisions constituting requirements of this Standard as cited in the text. Latest issuances of cited documents apply unless specific versions are designated. Obtain approval from the delegated NASA Technical Authority to use a version other than as designated.

2.1.2 Access applicable documents at <https://standards.nasa.gov> or obtain documents directly from the Standards Developing Body, other document distributors, information provided or linked, or by contacting the office of primary responsibility for this Standard.

Note: References are provided in Appendix B.

2.2 Government Documents

NASA

NPR 7120.5, NASA Space Flight Program and Project Management Requirements

2.3 Non-Government Documents

Not applicable.

2.4 Order of Precedence

2.4.1 The requirements and standard practices established in this Standard do not supersede or waive existing requirements and standard practices found in other Agency documentation.

2.4.2 Conflicts between this Standard and other requirements documents will be resolved by the delegated NASA Technical Authority.

3. ACRONYMS, ABBREVIATIONS, SYMBOLS, AND DEFINITIONS

3.1 Acronyms and Abbreviations

ABMA	American Bearing Manufacturers Association
ACD	adiabatic compression detonation
AIAA	American Institute of Aeronautics and Astronautics
BLDC	brushless direct current
BP&G	best practices and guidelines
EEE	electrical, electronic, and electromechanical
EHD	elastohydrodynamic
FOD	foreign object debris
HRC	Rockwell C hardness
ISO	International Organization for Standardization
JSC	Johnson Space Center
ksi	thousand pounds per square inch
MDP	maximum design pressure
MEOP	maximum expected operating pressure
MPa	megapascal
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NC	normally closed
NO	normally open
PCA	primer chamber assembly
PIV	positive isolation valve
SMC	Space and Missile Systems Center
SPEC	specification
STD	standard
TWPB	thin wall pressure boundaries

3.2 Definitions

3.2.1 Definitions of Variables

τ	motor torque
F_a	force needed to achieve a specified acceleration of the driven component
F_{avail}	minimum available force generated by the driving or holding component
F_f	individual fixed resistive forces that are not strongly influenced by environmental conditions and cycles

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F_v	individual variable resistive forces that may be strongly influenced by environmental conditions and cycles
FS_a	safety factor applied to the torque or force needed to achieve a specified acceleration of the driven component
FS_f	safety factor applied to the “fixed” resistive torques that are not strongly influenced by environmental conditions and cycles
FS_v	safety factor applied to the “variable” resistive torques that may change with environmental conditions and cycles
I	current drawn by a motor
K_m	motor constant
K_t	torque constant
P	resistive power loss
R_t	electrical resistance across motor terminals
T_a	torque needed to achieve a specified acceleration of the driven component
T_{avail}	minimum available torque generated by the driving or holding component
T_f	individual fixed resistive torques that are not strongly influenced by environmental conditions and cycles
T_v	individual variable resistive torques that may be strongly influenced by environmental conditions and cycles

3.2.2 Definitions of Terms

Actively Actuated Valve: A valve that is controlled via the application of external power. *Note: An actively actuated valve is, in effect, any valve that is not passively actuated (see definition of “Passively Actuated Valve” below). Hand-operated valves are considered actively actuated valves.*

Bearing Preload: The equal and opposite axial load on each of two bearings or bearing sets mounted on a common axis.

Chatter: A sustained instability usually encountered only in passively actuated valves (e.g., check valves, pressure relief valves, and regulators) that arises when the pressure fluctuations created by valve opening and closing create a rapid cycling of the valving element or occur in resonance with it.

Cold Welding: An unintentional joining of very clean metallic surfaces that can occur when under load for a length of time, usually occurring under vacuum conditions. *Note: Some materials are more susceptible to cold welding than others, especially inert metals like gold and silver. Vacuum is not required for cold welding to occur, but it facilitates cold welding because a vacuum inhibits surface oxide formation and contaminant transfer (i.e. it helps keep the surfaces very clean).*

Contact Ellipse: The area of contact between a bearing ball and raceway that occurs as a result of elastic deformation of both parts under load.

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Cogging Torque: See “Detent Torque.”

Compression Set: The percent of a compressed material's deflection that is unrecovered after being subjected to a specified force or deflection for a specified time and temperature. *Note: See ASTM D 395 – Standard Test Methods for Rubber Property—Compression Set*

Creep: A time- and temperature-dependent response of solid materials under persistent load in which strain increases over time.

Detent Torque: The amount of magnetic torque that a motor produces to resist rotation when it is not energized. Also known as “cogging torque.”

Dimensional Analysis: A systematic calculation addressing how the dimensions or clearances of a part or assembly vary due to the accumulated effects of specified dimensions, manufacturing tolerances, environmental exposure, and applied loads.

Dynamic Clearance: The minimum distance between two valve parts when the valve parts are subjected to the environments encountered during the valve's service life.

Dynamic Torque (or Force) Margin: A measure of the excess torque (or force) available to provide acceleration to a driven component.

Galling: A form of surface damage arising between sliding solids, distinguished by macroscopic, usually localized, roughening and creation of protrusions above the original surface often including plastic flow or material transfer or both.

Holding Torque (or Force) Margin: A measure of the excess torque (or force) available to maintain position in the presence of disturbances.

L0.05 Life: The life at which 0.05 percent of the bearings in an application can be expected to have failed due to rolling contact fatigue or, alternatively, the life at which 99.95 percent of the bearings will still be operating. *Note: The L0.05 life of the bearing is theoretical and may not represent actual service life of the bearing.*

Leak: An unintentional flow of operating medium past flow-blocking barriers, typically specified to not exceed a "maximum acceptable leak rate". *Note: leaks can be classified into two types: an "external leak" in which the operating media exits the valve and an "internal leak" in which the operating media stays inside the valve. Internal leaks may be further classified into "forward leaks" and "reverse leaks" with regard to the intended flow direction through the valve.*

Lubricant: A material with low shear resistance that reduces friction and wear. *Note: Lubricants can include gases, liquids, and solids.*

Mechanical Stop: A feature intended to prevent a mechanism component from traveling beyond a prescribed travel limit by physically impeding motion of the component, also known as a hard stop.

Mechanism: An assembly in which one mechanical part moves relative to another mechanical part.

Motor Constant: A figure of merit used to evaluate a motor's ability to transform electrical power to mechanical power and to compare the relative efficiencies and output power capabilities of different motors, defined as

$$K_m = \frac{\tau}{\sqrt{P}} \quad \text{or} \quad K_m = \frac{K_t}{\sqrt{R_t}}$$

where K_m is the motor constant, τ is the motor torque, P is the resistive power loss, K_t is the torque constant, and R_t is the electrical resistance across the motor terminals.

Operating Medium: Any fluid whose flow the valve is intended to stop, start, or otherwise regulate. *Note: Operating media includes:*

- a. *the intended flight operating medium, which may contain migrated fluids from other system components, and*
- b. *other media that will flow through the valve during testing or ground processing.*

Passively Actuated Valve: A valve that is actuated by the pressure differential in the operating medium, rather than being actively commanded, controlled, or regulated by an external source.

Note: Common examples of passively actuated valves include check valves, pressure relief valves, and regulators.

Performance Test: A test conducted to demonstrate whether specified performance requirements are met.

Pull-in Torque: The maximum constant externally applied resistive torque for a given speed, driven inertia, and set of drive electronics against which a stepper motor rotor will accelerate from rest to operating speed, stop, or reverse direction, in synchronism with electrical input pulses (i.e., without loss of steps). *Note: Pull-in torque is determined using 100 percent pulse duty cycle unless defined otherwise.*

Pull-in Torque Margin: A measure of the excess torque (or force) available to accelerate a stepper motor rotor from rest to operating speed, stop, or reverse direction, in synchronism with electrical input pulses (i.e., without loss of steps) for a given speed, driven inertia load, and set of drive electronics.

Pull-out Torque: The torque at which a stepper motor operating at its desired speed begins to lose synchronism with electrical input pulses as an externally applied resistive torque is

increased. *Note: Typically, a curve plotting applied resistive torque versus step rate (or rotor speed) is produced. This curve represents the maximum torque that the stepper motor can supply at any given speed. Any torque or speed demand that exceeds this curve will cause the motor to lose steps. Pull-out torque is affected by drive voltage and phase switching techniques.*

Redundant Seal System: A seal configuration having a primary seal and a secondary seal and possibly additional (tertiary, etc.) seals arranged so as to provide sequential barriers to leakage of the operating medium. Note that a primary seal is sometimes referred to as a "main seal", and non-primary seals are sometimes referred to as "backup seals" or "redundant seals".

Reseating Pressure: The value of decreasing inlet static pressure at which the valving element reestablishes contact with the valve seat and flow ceases.

Seatless Valve: A valve having a grooved or ported valving element that slides or rotates against the valve body to open and close flow passages through a shearing rather than a seating action.

Service Life: The period beginning with manufacture of a component and ending with completion of its specified use. All significant loading cycles or events during testing, transportation, storage, launch preparation, liftoff, ascent, on-orbit operations, entry, descent, landing, recovery, refurbishment, reacceptance, and reuse are considered part of service life.

Servomechanism: An automatic device that uses error-sensing negative feedback to improve the performance of a mechanism.

Set Pressure: The value of increasing inlet static pressure at which the valving element in a pressure relief valve loses contact with the valve seat and flow begins.

Static Clearance: The minimum distance between two parts when the parts are at rest.

Static Torque (or Force) Margin: A measure of the excess torque (or force) available to overcome resistance to initiating motion.

Stepper Motor Step Response Analysis: An analytical method of quantifying stepper motor system performance and stability by evaluating dynamic response to electrical input pulses.

Stress Relaxation: A time- and temperature-dependent response of solid materials under constant strain in which stress decreases over time.

Surface Lay: The direction of the predominant surface pattern, ordinarily determined by the method used to produce the surface.

Torque Constant: The ratio of the motor torque to the current drawn by the motor, defined as

$$K_t = \frac{\tau}{I}$$

where K_t is the torque constant, τ is the motor torque, and I is the current drawn by the motor.

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Torque (or Force) Margin: A measure of the excess torque (or force) of a mechanism available to impart, maintain, or prevent motion, or to provide acceleration.

Torque Ripple: A periodic variation in shaft torque as a motor shaft rotates.

Truncation: The condition created when applied loads cause a portion of a bearing ball's contact ellipse to extend beyond the edge of the raceway.

Valve: A device that stops, starts, or otherwise regulates the flow of the operating medium by means of a movable element that obstructs or opens a flow passage.

Valve Body: The exterior structure of the valve that contains the operating medium and houses the other valve elements.

Valve Maximum Design Pressure (MDP): The maximum pressure for which the valve pressure boundary is to be designed and after which the valve is expected to meet operational requirements.

Valve Maximum Expected Operating Pressure (MEOP) - The maximum pressure at which the valve is expected to meet its specified performance requirements (i.e., open, close, and seal).

Note: The Valve MEOP may be different than the MEOP for the fluid system containing the valve.

Valve Seat: The portion of the valve body against which the valving element rests to regulate or prevent flow. *Note: Although a valve seat can also double as a seal, a distinction should be made between the seat and the sealing device, which is commonly inserted either in the seat or in the valving element and used to control leakage in the closed position.*

Valving Element: The moving element of a valve that controls flow either by its proximity to a seat or its relationship to a closure port, as in the case of a seatless valve. *Note: The valve industry uses the following terms synonymously with valving element: control element or member, closure element or member, metering element, and loss-producing element.*

Yield Design Load: The product of the design limit load and the yield factor of safety.

4. REQUIREMENTS

4.1 Mechanism Design Requirements

4.1.1 Dimensional Analysis

4.1.1.1 [VDVR 1] A dimensional analysis of all moving parts and intentional interference-fit parts **shall** be performed and documented to ensure that specified functional performance is maintained under worst-case environmental conditions and configurations.

[Rationale: Dimensional analysis is important for ensuring internal and external clearances and establishing manufacturing tolerances. Dimensional analysis should be performed as part of the design process prior to part manufacturing. A documented dimensional analysis helps elucidate the effects of fits, tolerances and other factors, avoids tolerance stack-up conditions that can adversely affect hardware performance, ensures parts will assemble, and allows for easy review and revision later.]

4.1.1.2 [VDVR 2] The dimensional analysis **shall** account for the following:

- a. Manufacturing, assembly, and alignment tolerances.
- b. Temperature- and temperature-gradient-induced deformations or structural instabilities.
- c. Pressure- and pressure-gradient-induced deformations.
- d. Deflections due to vibration.
- e. Deformations or structural instabilities due to external loads, including gravity effects.
- f. Deflections due to operational loads.
- g. Deflections due to changes in pressurization.
- h. The full range of adjustability of the valve parts.
- i. Dimensional changes of non-metallic parts due to exposure to operating media.
- j. Dimensional changes due to corrosion and wear.

[Rationale: Dimensional analysis is sensitive to these factors.]

Guidance: Additional factors may be appropriate for consideration based on individual applications. Verification that these factors have been considered is expected to include line items in the analysis documentation for each factor in the dimensional analysis, or rationale for why a particular factor does not apply in a given situation.

4.1.2 Clearances

4.1.2.1 [VDVR 3] The valve dimensional envelope **shall** be specified in the valve's engineering documentation.

[Rationale: Specifying the valve's dimensional envelope helps ensure that no valve components interfere with nearby equipment.]

4.1.2.2 [VDVR 4] Valve internal allowable clearance ranges **shall** be established, documented, and maintained throughout the service life of the flight unit and throughout the life test.

[Rationale: Maintaining clearances within valves is necessary to maintain proper valve function.]

4.1.2.3 [VDVR 5] The established clearances **shall** account for the following:

- a. The results of dimensional analysis per section 4.1.1.
- b. Environments arising from transportation.
- c. Allowable particulate contamination.

[Rationale: Because many of the factors affecting the clearance are not present when inspections are performed, these effects need to be accounted for and included in allowable clearance ranges. Motion under transportation loads is often not considered, but clearances are also important in that situation.]

Guidance: Individual applications may consider additional factors as appropriate. Verification that these factors have been considered is expected to include line items in the analysis documentation for each factor in the clearance analysis, or rationale for why a particular factor does not apply in a given situation.

4.1.3 Torque and Force Margins

Guidance: Torque or force margin is a measure of the excess capability of a mechanism to impart, maintain, or prevent motion, or to provide acceleration. Torque margin and force margin are intended to ensure that a mechanism retains reserve torque or force that can be applied in the event of an unforeseen effect that increases resistive torque or force, or reduces motive torque or force within the mechanism.

Torque margin is not applicable to valve components that must provide a specific torque or force value within a narrow tolerance range to perform their basic function, such as a spring controlling the set point of a regulator or pressure relief valve.

Torque margin and force margin are defined in Equations 4-1 and 4-2 as follows:

$$\text{torque margin} = \frac{T_{\text{avail}}}{\sum FS_f T_f + \sum FS_v T_v + \sum FS_a T_a} - 1 \quad (\text{Equation 4-1})$$

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$$\text{force margin} = \frac{F_{\text{avail}}}{\sum FS_f F_f + \sum FS_v F_v + \sum FS_a F_a} - 1 \quad (\text{Equation 4-2})$$

T_{avail} and F_{avail} are the minimum available torque or force, respectively, generated by the driving or holding component (e.g., spring, motor, pyrotechnics, solenoids, heat-actuated devices, pneumatic or hydraulic systems, etc.). The minimum available torque or force from an energized motor is typically understood to include “magnetic losses” (e.g., hysteresis and eddy current drag torques and forces), “mechanical losses” (e.g., bearing, brush, and windage drag torques or forces), and “ripple” caused by detent (cogging) torque or forces, asymmetry in motor design and construction, commutation strategy, etc.

For static and dynamic torque and force margins, T_v and F_v are the individual maximum “variable” resistive torques and forces, respectively, that may be strongly influenced by environmental conditions and cycles (e.g., friction torques and forces, viscous drag torques, wire harness torques or forces due to flexing or set). For holding torque and force margins, T_v and F_v are used to denote the individual maximum disturbing torques or forces regardless of their degree of variability.

T_f and F_f are the individual maximum “fixed” resistive torques and forces, respectively, that are not strongly influenced by environmental conditions and cycles (e.g., vehicle maneuver-induced torques, return spring torques, unbalanced pressure loads limited by pressure relief devices).

T_a and F_a are the torque and force, respectively, needed to achieve a specified acceleration of the driven component.

FS_v , FS_f , and FS_a are safety factors applied to each individual torque or force in the denominator of Equations 4-1 and 4-2 prior to summation. Table 1, Minimum Safety Factors for Torque Margin Equation 4-1 and Force Margin Equation 4-2, specifies the minimum safety factors to be used in Equations 4-1 and 4-2. The safety factor applied should be higher than given in Table 1 if:

- a. The designs involve an unusually large degree of uncertainty in the characterization of resistive torques or forces.
- b. Torque or force margin testing is not performed in the required environmental conditions, or the test results are not repeatable (have high variability).
- c. Torque or force margin testing is performed only at the component level.

Table 1 – Minimum Safety Factors for Torque Margin Equation 4-1 and Force Margin Equation 4-2

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Source of Torque Data	FS_v	FS_f	FS_a
Theory or analysis	3.00	1.50	1.25
Qualification test at environmental extremes ¹	See Note 1		
Acceptance test at expected environmental extremes	2.00	1.25	1.10
Test evaluation of one-spring-out case ²	1.00	1.00	1.00

¹ If the qualification unit undergoes acceptance testing before the qualification test campaign and meets the required torque or force margin with the acceptance test factors applied, then factors of safety of 1.0 applied to all resistive torques and forces are sufficient during operation under qualification environments. When qualification is performed without the qualification article first undergoing acceptance testing, a factor of safety is applied during the qualification testing. However, the margined environments under which qualification testing is performed will often add resistive torques or forces beyond that which will be encountered during acceptance testing or flight, and in some cases these additional resistive torque and forces can be large. In such cases, factors of safety less than the values listed for acceptance test may be appropriate. Analysis should be performed to determine the factors of safety to apply during qualification testing to ensure the torque and force margins demonstrated during qualification testing matches or exceeds the torque and force margins demonstrated during acceptance testing. In the absence of such analysis, use the factors of safety for acceptance test at expected environmental extremes.

² When the torque or force margin of spring-driven mechanisms that use multiple springs in parallel to provide torque or force is evaluated by test for cases in which one of the multiple springs fails (the “one-spring-out case”), a minimum FS_f , FS_v , and FS_a of 1.0 may be used. Prior to a spring failure, the factors in the first three rows of Table 1 apply. Note that because using multiple springs in parallel for redundancy is distinct from designing a system to tolerate a failure of some portion of a single spring, the torque margin or force margin for a failure-tolerant single spring is evaluated with the same factor after failure as prior to failure. The one-spring-out factors do not apply to any case other than the use of redundant springs in parallel.

There are many forms of torque and force margin equations in use in various standards. Each can be reformulated to appear like the others; the only difference among them is in the magnitude and nature of the different safety factors applied to the terms. This form was chosen due to its relative simplicity, its ability to handle several types of torque and force margin calculations with a single equation, and its suitability for application of maturity-based safety factors.

The required reserve torque is included in the equation in the form as the safety factors, so a torque or force margin greater than or equal to zero indicates that requirements are met. Setting the FS_f , FS_v , and FS_a safety factors to unity represents the torque or force at which no reserve is available.

The “Theory or analysis” safety factors listed in Table 1 are not intended to be used—to borrow the terminology of NASA-STD-5001, Structural Design and Test Factors of Safety for Spaceflight Hardware—as “design factors” in a “no-test option.” Such an approach is prohibited by the requirement to verify torque margins during an acceptance test in section 4.1.3.1.3. The “Theory or analysis” safety factors are intended to compensate for higher uncertainty in initial sizing and calculations until torque or force values can be obtained by test. This approach allows the required torque or force to be reduced as confidence in the system characteristics grows through testing. The values FS_v , for FS_f , and FS_a are chosen such that higher factors are applied to torque or force sources with higher variability.

When assessing the torque or force margin of failure tolerant mechanisms that use multiple springs in parallel to provide torque, it is important to recognize that to show a positive torque

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or force margin after a spring failure the torque or force margin without a spring failure can be excessive. For those cases, reduced conservatism in the safety factors is appropriate. Redundancy will often be achieved with elements such as redundant motor windings or redundant actuators. These elements do not normally work together at full power to provide torque or force. These types of implementations still require using the FS_f , FS_v , and FS_a values from the first three rows of Table 1. Note that if the failed actuator produces a resistive torque or force after failure, this torque or force is to be included in the torque or force margin calculation for the failure case.

Note that the use of multiple springs in parallel for redundancy is distinct from designing a system to tolerate a failure of some portion of a single spring (e.g., a broken coil of a guided helical compression spring designed and restrained per the guidance in NASA-STD-5017B, Appendix A, section A.2.5, or one broken leaf in a multi-leaf spring) and still maintain functionality with reduced performance. The mass penalty in this scenario is not as great as adding an entirely redundant spring, so the one-spring-out safety factors are not appropriate in such a case. See NASA-STD-5017B, Appendix A, section A.2.5 for further discussion on spring redundancy.

4.1.3.1 General Torque and Force Margin Requirements

Guidance: *Torque and force margins are not applicable to mechanisms that are intended to provide a specific torque or force value within a narrow tolerance range to perform their basic function; therefore, passively actuated valve functions are exempted from torque and force margin requirements.*

4.1.3.1.1 [VDVR 6] All torque and force margin requirements **shall** be applied under worst-case conditions throughout the valve's life, including throughout life testing.

Guidance: *Worst-case conditions are defined as those that result in a combination of minimum driving torque or force and maximum resistive torque or force over the range of qualification environmental limits (e.g., temperature, pressure, acceleration, vibration, radiation, humidity), operating limits (e.g., pressure of the operating media, supply voltage, motor drive electronics parameters), and design parameters (e.g., material properties, manufacturing tolerances, spring force variability).*

Only those worst-case combinations that can occur simultaneously need to be considered. For example, if the minimum driving torque or force occurs at hot conditions and the maximum resistive torque or force occurs at cold conditions, then the two should not be combined to calculate a torque or force margin. As another example, if the minimum driving torque or force and maximum resistive torque or force do not occur at the same point in a valve mechanism's range of motion, then the two should not be combined to calculate a torque or force margin.

The following are examples of conditions that should be accounted for when calculating torque margin and force margin:

- a. *Material property variations.*

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- b. *Dimensional tolerances.*
- c. *Environmental conditions.*
- d. *Frictional effects.*
- e. *Changes in static and kinetic friction due to storage time, operating medium exposure, or exposure to vacuum.*
- f. *Alignment effects.*
- g. *Latching forces.*
- h. *Return springs, including stress relaxation (see NASA-STD-5017B, Appendix A, section A.2.5.1).*
- i. *Damper drag.*
- j. *Thermally induced distortions, both recoverable (e.g., coefficients of thermal expansion) and non-recoverable (e.g., creep).*
- k. *Load-induced distortions.*
- l. *Pressure-induced distortions.*
- m. *Variations in lubricity.*
- n. *Supply voltage, voltage drops, current limit.*
- o. *Motor drive electronics parameters (e.g., gains, sampling rate, bandwidth).*
- p. *Acceleration due to vehicle motion or maneuvers that can retard motion.*
- q. *Loading due to vibroacoustic environment.*
- r. *Effects of exposure to operating media or operating media vapor, directly or via permeation (e.g., corrosion, dimensional changes of soft goods such as seal swell or shrinkage).*
- s. *Effects of compression set of non-metallic materials.*
- t. *Magnetic saturation (see NASA-STD-5017B, Appendix A, section A.2.1.1).*
- u. *Torque needed when swapping between primary and redundant actuators and/or drive electronics.*
- v. *Environments and worst-case loads occurring in redundant modes of operation.*
- w. *Adherence of conforming surfaces similar to that of gauge blocks wrung together.*

- x. *Side loading from annular flow effects.*
- y. *Startup and shutdown pressure transients.*
- z. *The effects of permissible leakage and permeation.*

Whether or not to include inertial torques or forces as resistive torques or forces in a torque or force margin calculation depends on the type of torque or force margin being calculated and the duration of the actuation event compared with the duration of the inertial torques or forces. Inertial torques or forces arise when inertias are accelerated. Quasi-static accelerations (e.g., acceleration due to launch vehicle thrust) have durations long enough to warrant inclusion in all torque and force margin calculations. However, transient accelerations (e.g., accelerations due to vibration or shock) may generate a small enough response in some mechanisms that they may be neglected in some torque or force margin calculations.

For example, the static torque margin calculation for an actuator whose inertia is large may be able to neglect the inertial torque or forces due to high-frequency vibration exposure if the vibratory forces cannot accelerate the inertia enough to generate significant resistive torques or forces. However, exposure to the same high-frequency vibration may be important in the holding torque calculation of a valve because, even if transient, vibratory forces can induce small motions that lead to undesirable effects such as leakage or valve seat damage.

Torque and force margins for hand-operated valves are assessed against the minimum torques and forces that a human can be expected to be able to apply per applicable human-system integration standards such as NASA-STD-3001, NASA Spaceflight Human-System Standard. Human-applied limits such as the torques and forces able to be applied by deconditioned crew members may have extra knockdowns included. Care should be taken not to accidentally apply a higher overall factor of safety than intended in these cases. The combined factor of safety when taking into account the human-applied torque limits need not exceed the values in Table 1.

4.1.3.1.2 [VDVR 7] Torque and force margins **shall** be calculated at both the input and output of devices multiplying or reducing torques or forces (e.g., gearboxes, strain wave gear drives, lever arms).

[Rationale: Torque and force margins are calculated at both positions because torque and force multipliers and reducers are not 100 percent efficient, and because some resistive torques and forces can have a more detrimental effect on torque and force margin when considered prior to multiplication. Basing torque and force margins on the overall output can give a false impression of the true torque or force margin.]

4.1.3.1.3 [VDVR 8] All torque and force margins **shall** be verified during an acceptance test at the highest possible level of assembly.

[Rationale: Torque and force margins are intended to ensure that a mechanism retains reserve torque or force that can be applied in the event of unforeseen circumstances. Therefore, as with any other capability of the valve, the minimum torque or force margin is verified prior to placement into service. Testing at the highest level of assembly possible ensures the assembly

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process, installation process, or differing boundary conditions do not reduce torque or force margin.]

Guidance: Often, it is not possible to test torque and force margins directly, in which case the individual torque or force terms in Equations 4-1 and 4-2 are to be individually acceptance-tested and the torque or force margin calculated using these tested values. Attempts to calculate torque and force margins at higher levels of assembly (subsystem or vehicle) can be more complex because of the potential inability to discriminate between different torque or force sources in the denominator of Equations 4-1 and 4-2. See NASA-STD-5017B, Appendix A, section A.2.1.2, for a methodology to calculate torque and force margins at higher levels of assembly.

4.1.3.2 Static Torque and Force Margin

[VDVR 9] For all actively actuated valve functions, static torque and force margin per Equations 4-1 and 4-2 and Table 1 **shall** be greater than zero within the valve mechanism's full range of motion.

Guidance: Static torque or force margin is a measure of the excess torque or force available to overcome resistance to motion. T_{avail} and F_{avail} are the minimum available torque or force generated by the prime mover, respectively. Static friction and static resistive torque or force values are used for T_v and T_f or F_v and F_f in this calculation. T_a or F_a and FS_a are not used in static torque and force margin calculations.

4.1.3.3 Dynamic Torque and Force Margin

[VDVR 10] For all actively actuated valve functions, dynamic torque and force margins per Equations 4-1 and 4-2 and Table 1 **shall** be greater than zero within the valve mechanism's full range of motion.

Guidance: Dynamic torque and force margins are a measure of the excess torque or force available to provide acceleration to an object. Such a requirement can take many forms such as a specified acceleration, a specified minimum time, or a specified minimum velocity. This requirement is only applicable to mechanisms that are required to provide a minimum acceleration to an object.

T_{avail} or F_{avail} is the minimum available torque or force generated by the prime mover. Friction and resistive torque or force values appropriate for the specified motion profile are used for T_v and T_f or F_v and F_f in this calculation, and the torque or force needed to achieve the minimum acceleration is used for T_a or F_a , respectively. Values of moment of inertia and mass (linear inertia) used in dynamic torque and force margin calculations may need to include allowances for system growth over the duration of a program.

4.1.3.4 Holding Torque and Force Margin

[VDVR 11] For all actively actuated valve functions, holding torque and force margins per Equations 4-1 and 4-2 and Table 1 **shall** be greater than zero at the specified positions within the valve mechanism's full range of motion.

Guidance: Holding torque and force margin are a measure of the excess torque or force available to maintain position in the presence of disturbances. This requirement is applicable to mechanisms that are required to maintain position in the presence of external disturbances. T_{avail} and F_{avail} are the minimum powered or unpowered holding torque or force, respectively, that is intentionally provided to hold position from sources such as brakes, springs, motors, pneumatic or hydraulic systems, or detents. Incidental, unreliable, and/or uncharacterized contributors to holding torque or force (e.g., joint friction) should be excluded from T_{avail} and F_{avail} . The maximum disturbing torque or force values are used for T_v or F_v in this calculation. T_v and F_v are used in holding torque and force margin calculations for two reasons. First, although the disturbing torques or forces may not be highly variable in nature, the holding torques or forces of the T_{avail} and F_{avail} terms can contain a high degree of variability. Second, using a mechanism to hold position is inherently more variable than using a structure; therefore, a higher factor of safety than would be applied to a structure is appropriate. T_f and T_a or F_f and F_a are not used in holding torque and force margin calculations.

4.1.3.5 Stepper Motor Margin

4.1.3.5.1 [VDVR 12] Stepper motor torque margin **shall** be greater than zero within the valve mechanism's full range of motion, using the appropriate allowable margin calculation method per Table 2, Stepper Motor Margin Calculation Methods.

Table 2 – Stepper Motor Margin Calculation Methods

Case	Allowable Margin Calculation Methods
When all of the following conditions are met: - The resistive torque due to friction is much greater than the torque needed to drive the inertia - The natural frequency of the spring-mass-damper system comprised of everything in the closed torque path is at least ten times greater than the stepping frequency - The driven inertia is not driven into a hard stop or spring stop - The stepper motor winding current flows for the full period of the step - A pull-in torque test is performed in the operating environments - The stepping frequency is not under closed-loop control	- Pull-in torque margin analysis per Equations 4-1 and 4-2 and Table 1 or - Torque margin analysis per Equations 4-1 and 4-2 and Table 1 with T_{avail} derived from a stepper motor step response analysis

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All other cases	• Torque margin analysis per Equations 4-1 and 4-2 and Table 1 with T_{avail} derived from a stepper motor step response analysis
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[Rationale: The dynamic response to a commanded step can result in unstable stepping. The bulleted cases in Table 2 are intended to bound the circumstances in which stable stepping can be expected. When those circumstances are not in place, a stepper motor step response analysis is needed to guarantee stable stepping.]

Guidance: Pull-in torque margin is a measure of the excess torque available to accelerate a stepper motor from rest to operating speed, stop a stepper motor, or reverse stepper motor direction in synchronism with electrical input pulses (i.e., without loss of steps) for a given speed, driven inertia, and set of drive electronics. For pull-in torque margin, the pull-in torque for a given speed is used for T_{avail} , and the total resistive torque seen by the stepper motor is used for T_v . For torque margin using a stepper motor step response analysis, the minimum torque produced under stable stepping is used for T_{avail} , and the total resistive torque seen by the stepper motor is used for T_v . T_f and T_a are not used when calculating stepper motor torque margin.

A further discussion of stepper motor performance and stability analysis can be found in NASA-STD-5017B, Appendix A, section A.2.4.2.

4.1.3.5.2 [VDVR 13] When stepper motor detent torque is used to maintain rotor position in the presence of vibratory disturbances, detent stiffness and motor damping **shall** be considered when determining the holding torque margin.

[Rationale: The spring-damper nature of the detent torque needs special consideration when used in a holding torque application.]

4.1.3.6 Servomechanism Margins

[VDVR 14] For servomechanism applications, control system performance margins **shall** be calculated in addition to meeting the applicable static torque and force margin, dynamic torque and force margin, holding torque and force margin, and stroke margin requirements.

[Rationale: Servomechanism performance requirements may necessitate motor performance that far exceeds that required by the torque margin or force margin equations alone. Though applicable torque and force margins should still be calculated and documented, servomechanisms need a control system performance analysis (e.g., phase and gain margin analysis) to fully assess performance and margin. The specific control system margins for a given application are outside the scope of this document and therefore cannot be specified here. It is important to successful servomechanism functionality that these be calculated and evaluated by control system experts.]

4.1.4 Stroke Margin

Stroke margin is defined in Equation 4-3 as follows:

$$\text{stroke margin} = \frac{\text{output stroke of the actuator}}{\text{stroke required to achieve desired function}} - 1 \quad (\text{Equation 4-3})$$

4.1.4.1 [VDVR 15] Stroke margins per Equation 4-3 **shall** be greater than zero for all valve mechanisms.

[Rationale: Stroke margin helps guarantee enough linear or rotary travel exists in a mechanism to accomplish its function in the presence of uncertainty.]

Guidance: Some applications may warrant higher minimum stroke margins; every application should be evaluated to determine whether larger stroke margins should be specified. In applications where stroke of the driven component is physically limited by a mechanical stop, this requirement still applies to the actuator (i.e., the actuator itself is to have stroke remaining when the mechanical stop is reached by the driven component). Continuously rotating mechanisms are exempt from this requirement.

4.1.4.2 [VDVR 16] Stroke margin **shall** account for worst-case credible combinations of the following:

- a. Environmental effects.
- b. Misalignments.
- c. Dimensional tolerances.
- d. Load-induced distortions.
- e. Trapped fluids.
- f. Dimensional changes of non-metallic parts due to exposure to operating media.
- g. Dimensional changes due to corrosion and wear.

[Rationale: Like torque and force margins, stroke margin ensures that adequate travel is available to account for unforeseen effects, which can increase the stroke needed. A variety of factors, including those specified in the requirement, can affect the dimensions of the assembly and stroke needed. Therefore, these various factors are important considerations when determining the necessary travel for actuators.]

Guidance: Worst-case conditions are defined as those that result in the minimum stroke over the range of qualification environmental limits (e.g., temperature, pressure, acceleration, vibration, radiation, humidity), operating limits (e.g., pressure of the operating media), and design parameters (e.g., material properties, manufacturing tolerances).

In applications where stroke of the driven component is physically limited by a mechanical stop, this requirement still applies to the actuator (i.e., the actuator itself is to have stroke remaining when the mechanical stop is reached by the driven component). Assurance that a linear actuator remains engaged prior to actuation is covered by holding torque or force margin (see section 4.1.3.4), tolerancing (see section 4.1.1), and adherence to structural requirements.

4.1.5 Indication of Status

[VDVR 17] A direct indication of the critical states of each actively actuated valve **shall** be provided over the full range of valve operating and environmental conditions.

[Rationale: Knowledge of a valve's critical states (i.e., any state necessary for adequate operational use or hazard control) is important for mission success. Direct measurement ensures that reliable information is provided.]

Guidance: *It is recognized that this requirement may be difficult to meet for small valves or may not be necessary in some applications. However, this requirement is considered important enough to warrant dedicated consideration for every valve. If rationale for not implementing indication of critical states exists for a particular application then it should be removed from the valve's requirement set and the rationale documented as part of the tailoring process.*

The necessary state information will vary depending on the valve, the application, the concept of operations, and any hazards posed by failure to achieve or maintain the intended valve state. Examples of state indications include open and closed for valves with binary states, and position for valves with a variable metering function.

Direct indication, as opposed to indirect indication, is achieved when the function of interest is itself indicated unambiguously rather than some other related function. An example of direct indication of the valve's state would be measuring the position of the valve disc or its shaft. An example of indirect indication of the valve's state would be measuring the position of a component in a valve gear train, since such an indication could be erroneous if the gear train has structurally failed or has enough backlash or flexibility to allow the measured component to turn with respect to the valve disc itself.

Evaluation of the proposed means of state indication is recommended to determine whether a proposed state indication should be considered direct or indirect.

Valve positioning systems should always provide absolute positioning capability, either in the form of absolute position indication or the ability to command the component to a specific known position. This allows for periodic calibration or recovery in the event of an anomaly that introduces a discrepancy between the commanded and true positions.

4.1.6 Chatter

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[VDVR 18] Valves **shall** not chatter within the range of operational conditions, including primary mission conditions as well as those encountered during component acceptance testing and processing conditions (e.g., purges).

[Rationale: Valve chatter can have adverse effects on the valve such as damage to the valving element and valve seat, and accelerated wear. Valves not susceptible to chatter under flight conditions will sometimes be susceptible under conditions that significantly differ from flight conditions, like lower flow rates, lower pressures, or different flow media, that can be experienced during ground testing or processing events (e.g., fills, drains, purges).]

Elimination of chatter in systems using pure oxygen or oxygen-rich operating media is extremely important. Current oxygen compatibility analysis methods only consider one ignition mechanism at a time. Chatter can create multiple simultaneous ignition mechanisms that can interact in detrimental ways, which can invalidate the assumptions inherent in these oxygen compatibility analysis methods and result in unexpected ignition.]

Guidance: Valve chatter is usually encountered only in passive valves (e.g., check valves, pressure relief valves, and regulators). Valve chatter is usually audible but can also be detected with accelerometers or pressure transducers, and chatter-induced damage can be identified after disassembly and inspection.

The dynamics of the valving element and other moving parts of passively actuated valves should be analyzed during the design phase and should include all flow conditions and environments to which those parts will be exposed over their service life. This includes flushing, purging, and tests at the component level and at higher levels of assembly, in which conditions outside the normal operating conditions may easily occur that can cause damaging chatter. Designers may adjust factors like the spring preload or orifice size to prevent chatter, or they might recommend making changes to the range of flow rates used in the system.

The proper design of inlet piping to pressure relief valves is very important. Pressure relief valves are sometimes located away from the hardware to be protected so that the pressure relief valve can be more accessible. In such a case, there may be a considerable length of inlet piping, often with bends, that may create a significant nonrecoverable pressure drop during the pressure relief valve's operation. When a direct acting pressure relief valve is closed, the pressure throughout the system is uniform. The inlet piping configuration will not change the set pressure of the pressure relief valve. However, when the valve opens, the frictional losses created by the inlet pipe will cause a difference between the pressure at the pressure relief valve inlet and the pressure in the rest of the system. A direct acting pressure relief valve will reseal when the pressure relief valve inlet pressure reaches the resealing pressure for the valve. It is important that the non-recoverable inlet line pressure drop be less than the difference between the set pressure and the resealing pressure of the valve so there is a higher probability of a stable opening and a single reclosure cycle. Non-recoverable inlet losses in excess of the difference between the set pressure and the resealing pressure of the valve can be a cause for valve chatter or rapid cycling. A good guideline is to design for a maximum inlet pressure loss of no more than 3% of the pressure relief valve set pressure.

Similar to how improper inlet piping design can contribute to pressure relief valve chatter, an oversized pressure relief valve can also cause the inlet pressure to drop significantly below the valve's reseal pressure. When the inlet pressure falls below the resealing pressure during flow, the valve becomes unstable and cycles open and closed, resulting in chatter.

Pilot-operated pressure relief valves with the pilot pressure sensing line connected to the pitot tube at the main valve inlet can experience chatter due to high non-recoverable inlet losses in a similar manner.

4.1.7 Mechanical Stop Incorporation

[VDVR 19] Non-jamming mechanical stops **shall** be incorporated into all valves where excess motion will result in detrimental effects to the valve or the overall fluid system.

[Rationale: Stops ensure that mechanical devices do not travel farther than intended and cause problems or end up in an unrecoverable state. Soft stops (e.g., software logic, open-loop control, and limit switches) can be implemented in an unreliable manner, and the electronics or components they rely on can be unreliable, so mechanical stops are important for maximum reliability. In addition, soft stops are not always in place or implemented correctly for testing at lower levels of assembly, which adds potential for problems or damage.]

Guidance: Compression springs or bellows reaching their solid height should not be used as a mechanical stop.

4.1.8 Ground Operations and Environments

[VDVR 20] Ground operations and ground environments **shall** be accounted for by one of the following:

- a. Incorporating ground operations and ground environments into the valve specification.
- b. Creating a ground operations constraints document.
- c. A combination of a and b.

[Rationale: Ground operations and ground environments can be more severe than the flight environments if unconstrained. Therefore, the valve needs to be either designed for the ground operations and environments, or the ground operations need to be constrained so that design limits are not exceeded during ground operations.]

4.1.9 Valve Contamination and Debris Tolerance

[VDVR 21] The valve **shall** meet all performance requirements after being exposed to the following:

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- a. The materials, quantities, and size distributions of the contaminants entering the valve with the operating media as defined in the valve specification or provided by the program's technical authority, and
- b. The materials, quantities, and size distributions of the debris generated internally within the valve.

[Rationale: Valves must operate in the real world, which is dirty. Understanding the materials, quantities, and size distributions of debris will help size valve components such as filters and seals, select materials for valve seats and other valve parts, and plan cleaning methods.]

4.2 Structural Requirements

Guidance: *This section addresses aspects of structural design that may be unique to valves or may not be widely understood to be applicable to valves. Requirements for structural design and test factors of safety are documented in NASA-STD-5001, Structural Design and Test Factors of Safety for Spaceflight Hardware. Fracture control requirements are documented in NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware. Pressure system requirements are documented in AIAA S-080, Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components. Strength and life requirements for valves used in liquid-fueled rocket engines are documented in NASA-STD-5012, Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines. Other structural requirements documents may also be applicable.*

4.2.1 Valve Boundary Conditions

[VDVR 22] Valve engineering design and analyses **shall** account for the boundary conditions imposed by the installation of the valve, including:

- a. Stiffness.
- b. Mounting alignment tolerances.
- c. Temperature-induced distortions.
- d. Distortions induced by installation, rework, or externally applied loads, including from lines connected to the valve.
- e. Load-induced distortions.
- f. Pressure-induced distortions.
- g. Interface friction.

[Rationale: Idealized representation of boundary conditions (planar, rigid, with joints modeled as either continuous or frictionless) can give misleading results due to factors such as different load-induced distortions, different frequency response, or different flow characteristics. Failures

can occur in service when real interfaces create different environments than the idealized interfaces considered in the analysis.]

Guidance: *Deflection is an important factor in mechanical performance. A detailed analysis of displacements and related loads through all ranges of motion and environments will help identify problems early in the development cycle. Valve qualification testing should be conducted with mounting interface boundary conditions that replicate the flight boundary conditions whenever possible. When verified by test, verification that these influences have been accounted for is expected to include explicit description of how these boundary conditions are addressed in the test plan or, if the condition does not apply in a given situation, the rationale for this inapplicability. When verified by analysis, the accounting for these items in the structural analysis documentation is expected to include a discussion of each of these items and how they were modeled or why they were not modeled.*

4.2.2 Stall Conditions

[VDVR 23] Valves **shall** remain functional after exposure to actuator stall conditions at any point in their travel.

[Rationale: It is possible for valves to experience actuator stall torque or force, intentionally or unintentionally, either in testing or in flight. Designing the valve with sufficient structural and thermal capability to withstand actuator stall torque or force ensures that the valve is undamaged by this exposure and allows steps to be taken to recover valve function.]

Guidance: *Where stall duration is important, it is recommended that actuator stall torque or force be applied at each point of interest for at least 1 minute when assessing compliance. It is recommended that actuator stall torque or force conditions be applied for a duration of two (2) minutes during qualification testing and one (1) minute during acceptance testing under worst-case environmental conditions.*

The program-specified factors of safety apply to this actuator stall condition (i.e., the factors of safety applied for structural analysis are not to be reduced for this situation). Valve function is defined by the valve's specification. The actuator stall condition load case should include the worst-case torque or force that could be applied in that condition, which could include transient loading. In cases in which no recovery would be possible after actuator stall regardless of valve functionality, this ability may no longer be useful and may be a candidate for tailoring.

4.2.3 Mechanical Stops

[VDVR 24] Valve components **shall** maintain positive structural margins of safety with the full design factors of safety applied when subjected to worst-case loads from contacting a mechanical stop, including structural dynamic effects.

[Rationale: Contacting a mechanical stop can create elevated loads on other parts of the mechanism, and these loads need to be accounted for in the structural analysis. The contact of mechanical stops is often rapid enough that quasi-static analysis approaches based on peak contact force can give invalid results, necessitating the use of dynamic analysis approaches.

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Guidance: *A bounding worst-case load would include impact at maximum speed combined with stall torque or force, including the effects of drive electronics faults. A quasi-static load may be appropriate if the contact speed is low or if the load includes the influence of momentum and energy transfer and contacting part dynamic response, otherwise a transient analysis is needed.*

4.2.4 Creep and Stress Relaxation of Non-Metallic Parts

[VDVR 25] The effects of creep and stress relaxation of non-metallic parts on valve performance **shall** be analyzed or tested and accounted for in the valve design.

[Rationale: *Non-metallic parts are more prone to experiencing creep or stress relaxation than metallic parts. The time- and temperature-dependent flow of material in these phenomena can manifest in a number of ways in valves, leading to unacceptable leakage, seal extrusion, increased friction, or compression set, and can be affected by exposure to operating media. Valve seals and bushings are typically of most concern.*]

Guidance: *Analyses and tests should account for the combined effects of exposure to operating media, temperature, and the duration of loading and operating media exposure on creep and stress relaxation. Consideration of creep and stress relaxation is important for metallic parts as well, particularly for springs, but this is addressed by other requirements. The requirement to consider stress relaxation of springs in force and torque margins can be found in section 4.1.3.1.1.*

4.2.5 Specification of Valve Maximum Expected Operating Pressure (Valve MEOP) and Valve Maximum Design Pressure (Valve MDP)

[VDVR 26] The Valve Maximum Expected Operating Pressure (Valve MEOP) and Valve Maximum Design Pressure (Valve MDP), as defined by this document, **shall** be identified in the valve specification.

[Rationale: *There is often confusion regarding the meaning of these two terms as they pertain to valves, and different documents in different applications can have confusing or contradictory definitions. Explicitly specifying these values will help eliminate confusion.*]

Guidance: *See section 3.2.2 for definitions of “Valve MEOP” and “Valve MDP”.*

MEOP and MDP are often used inconsistently and interchangeably in the primary standards that are typically levied on flight hardware, usually in the context of the overall fluid system. The Valve MEOP and Valve MDP will not necessarily be the same as the system MEOP and system MDP. In a valve, these terms represent physical values that are very important to the valve design and are not interchangeable. Valve MEOP is an operational requirement (i.e., the maximum pressure at which the valve is expected to open, close, and seal) and Valve MDP is a structural requirement (i.e., the maximum pressure that the pressure boundary is to contain without detriment to later valve operation within Valve MEOP). Both values are essential for valve design, but in different ways. For example, in a solenoid valve, Valve MEOP is a primary driver in the design of the coil and plunger (i.e., the actuation force), while Valve MDP is the

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primary driver in the design of the valve body (i.e., the pressure boundary design strength). In other words, the valve needs to survive Valve MDP without incurring detrimental yielding or fatigue failure but must operate under the Valve MEOP. The application of Valve MDP to pressure boundaries can also include poppet-seat seal systems where excessive leakage or unintended flow could lead to a catastrophic hazard, such as thruster control valves. There are applications when Valve MEOP and Valve MDP will be the same, but each valve within a system needs to be assessed individually to determine the Valve MEOP and Valve MDP.

After the pressure at which the system requires the valve to operate is determined, the Valve MEOP can be specified. Transients may need to be included if the valve is expected to operate during the transient. For example, a monopropellant thruster valve may not need to open against transient pressure waves if the system can tolerate the time delay needed for the valve inlet pressure to decay to the point at which the valve has enough force to open. However, in the case of a bipropellant thruster with independent valves, it may be necessary for the valve to operate during the transient pressure waves to ensure that both valves open simultaneously and are not affected by the out-of-phase transient pressure waves. When transient pressures are included in Valve MEOP, clearly state the maximum steady-state pressure. The maximum steady-state pressure will govern seal stress and drive the seat design (e.g., material, geometry, etc.). In some cases, a separate Valve MEOP may need to be specified for the inlet and outlet (or a differential pressure) to ensure that the valve can open under the required system conditions.

Valve MDP is a structural requirement on the pressure boundary to ensure margin against external leakage. In some cases, the valve inlet and outlet may have different MDPs. For example, a regulator inlet MDP accounts for the full inlet pressure, but the outlet MDP may be based on the pressure relief valve full flow pressure. For systems used in human spaceflight, Valve MDP should include pressure transients for water hammer or surge. For robotic systems, Valve MDP does not need to include pressure transients for water hammer or surge, but the transients are to be enveloped by the proof pressure. Proof and burst pressures are multiplying factors applied to Valve MDP and are established by governing documents as determined by the project.

4.3 Electrical Requirements

Guidance: *Requirements for soldered joints are documented in IPC J-STD-001, with space addendum, Space and Military: Space and Military Applications Electronic Hardware Addendum to IPC J-STD-001H Requirements for Soldered Electrical and Electronic Assemblies. Electrical, Electronic, and Electromechanical (EEE) parts requirements are contained in NASA-STD-8739.10, Electrical, Electronic, and Electromechanical (EEE) Parts Assurance Standard, but other specifications such as MSFC-3012, EEE Parts Management and Control for MSFC Space Flight Hardware, are sometimes specified in its place. The red plague requirements of the EEE parts standards may be appropriate for tailoring for smaller, more risk-tolerant programs.*

4.3.1 Electrical Interfaces

4.3.1.1 Wire Color

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[VDVR 27] All lead wires and insulated conductors in an electrical cable **shall** have different colored insulation specified on the engineering drawings.

[Rationale: Using distinct colors helps ensure proper connection at the interface.]

4.3.1.2 Electrical Connectors

[VDVR 28] Valves using multiple electrical connectors **shall**:

- a. Use connectors configured to prevent incorrect mating (e.g., keyed connectors, different size connectors, etc.), and
- b. Have each connector permanently marked with the identifier of the correct mating connector.

[Rationale: Using distinct, labeled connectors helps ensure proper connection at the interface.]

4.3.2 Electrical Bonding

Electrical bonding requirements are documented in NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.

4.3.2.1 [VDVR 29] Gears **shall** not be used to carry electrical current.

4.3.2.2 [VDVR 30] Bearings **shall** not be used to carry electrical current.

[Rationale: These requirements are meant to preclude gears and bearings from being used as part of an intentional electrical distribution circuit or to carry other currents such as ground return currents, lightning currents, or plasma-induced surface currents. These components are not designed to carry electrical current, and their geometry and lubrication make it difficult for them to do so. Other current paths should be provided.

***Guidance:** Electrical currents produced by unintentional charging of bearing-supported hardware should be considered when evaluating this requirement. Gears and bearings should not be assumed to be electrically insulative or conductive.*

4.4 Materials and Process Requirements

***Guidance:** This section addresses aspects of valve materials that may be unique to valves or may not be widely understood to be applicable to valves. Materials compatibility requirements and test procedures are located in NASA-STD-6001, Flammability, Offgassing, and Compatibility Requirements and Test Procedures. Materials and process requirements are documented in NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft. Care should be taken when evaluating methods for fabricating joints made from dissimilar materials.*

4.4.1 Permeation Through Seals

[VDVR 31] Materials in regions of the valve that may be exposed to permeates **shall** be included in the material compatibility assessment of the valve.

[Rationale: Unless hermetically sealed, certain operating media (e.g., hypergolic propellant vapors and hydrogen) and service environments (e.g., humid air) will permeate through seals into non-wetted portions of the valve. It is important to recognize and assess the interactions between permeates and the valve, such as corrosion of valve parts and degradation of lubricants, which can reduce torque and force margins and affect clearances.]

Guidance: Materials compatibility assessments and usage agreements for reactive and hazardous fluids are required per NASA-STD-6001, Flammability, Offgassing, and Compatibility Requirements and Test Procedures; and NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft. Secondary and tertiary media interactions (media mixed with air/moisture/lubricant) should be investigated against the corrosion resistance of valve material choices. The influence on compatibility that may result from the presence of contaminants in the operating medium, such as corrosion products that may be present after long-duration exposure of the larger fluid system to the operating medium, should be considered in the assessment of material compatibility.

4.4.2 Galling Resistance

[VDVR 32] Sliding contacts in which material compatibility or contamination requirements prohibit lubrication **shall** use materials selected to minimize the potential for galling and cold welding.

[Rationale: Cases in which lubrication cannot be used need extra precautions to prevent galling.]

Guidance: If dissimilar metallic materials are used, consideration should be given to the potential for galvanic corrosion.

4.4.3 Interference Fits

[VDVR 33] Interference fitted joints **shall** employ the following process controls:

a. Either

(1) Dimensional verification that:

- A. the measured dimensions of every part being assembled meet drawing requirements, and
- B. the assembled parts are in the correct position and orientation.

or

- (2) Logging of force versus distance during force fits, followed by comparison with acceptable force versus distance envelopes,

and

- b. Proof load testing, when a proof load can be applied in the direction of disassembly.

[Rationale: When interference-fitting small parts, ten-thousandths of an inch matter, so precise dimensional inspection is important. When force fitting parts, understanding the force magnitude and how the force magnitude changes as the parts assemble can identify interference-fitted joints made from parts that are misaligned, undersized, oversized, tapered, the wrong material, or improperly heat treated, as well as ensure that parts are not seizing and have been inserted to the desired distance. Careful inspection of every force-versus-displacement plot is an important step in determining whether a force-fitted assembly is fit for service. Proof loading is important to screen for defects in workmanship and material quality and to verify structural integrity. Relative motion between parts of the assembly indicates a proof load test failure.]

Guidance: Interference fits include force fits and thermal fits. Whenever possible, interference fitted joints should use the interference to eliminate clearance (also known as play or slop) rather than to react axial forces or torques through friction. When interference fit joints react axial forces or torques through friction, use ample design factors and experimentally verify the slip loads and slip torques for the minimum interference case under appropriate environmental conditions. For highest reliability, the design should include features that lock or cage the interference-fitted part so it will still carry load and not become a loose part that could jam a mechanism if the interference fit pressure is lost.

4.4.4 Adhesive Bonding

[VDVR 34] Adhesive bond verification **shall** include a proof load test on witness specimens that use the same materials and processes and are processed at the same time as the hardware being verified.

[Rationale: Adhesive bonds can be sensitive to variations in materials and process parameters. Performing proof load tests on witness specimens provides additional assurance that the bond materials and processes for a given bond application are able to perform as intended.]

Guidance: General adhesive bonding requirements are located in NASA-STD-6016 and MSFC-SPEC-445, Requirements for Adhesive Bonding Process and Inspection. Per these documents, adhesive bond application processes for valves are to be developed and validated prior to implementation to ensure adhesives cure, adhere, and function as expected. Proof load testing of adhesively bonded joints is recommended wherever possible.

4.4.5 Verification of Cleanliness

[VDVR 35] A valve cleanliness plan that describes how valve cleanliness requirements will be achieved and verified, and how cleaned valve hardware cleanliness will be maintained, **shall** be

developed and maintained by the valve provider and approved by the program technical authority.

[Rationale: Achieving, verifying, and maintaining needed cleanliness of valves is one of the most challenging aspects of developing a valve. The effectiveness of different manufacturing operations, cleaning methods, cleaning media, and verification approaches will vary depending on the application, rendering it necessary for each application to be evaluated independently.]

Guidance: Common subassembly operations that are likely to produce contaminants include:

- a. Installation of sliding or interference-fit parts.
- b. Installation of threaded parts.
- c. Welding, brazing, or soldering.
- d. Valve actuator armature hard-stop adjustment.
- e. Operations performed in environments that do not meet the required cleanliness.

Cleaning should be performed, and cleanliness verified, after subassembly operations that are likely to produce contaminants. This helps prevent difficult-to-remove contaminants from becoming lodged in the final valve assembly.

After acceptance testing, cleanliness is most effectively verified by flowing a liquid medium through all flow paths and then testing the medium for its contaminants. Gas media are less capable of transporting contaminants than liquid media and may give falsely optimistic results.

4.4.6 Platings and Coatings

[VDVR 36] The use of platings and coatings to meet operating medium material compatibility requirements **shall** be approved by the specifying program technical authority.

[Rationale: Platings and coatings can be susceptible to wear, cracking, and loss of adhesion which may expose the incompatible substrate to the operating medium.]

4.4.7 Radiation Susceptibility

[VDVR 37] Valves that will experience a high radiation environment **shall** be evaluated for potential performance degradation with a radiation susceptibility assessment that includes:

- a. A detailed analysis to determine the location-specific radiation exposure levels of valve components given the expected mission-specific radiation environment, intrinsic radiation shielding by the spacecraft, and valve body itself,
- b. Materials testing before and after radiation exposure if the calculated total ionizing dose is greater than the allowable material limit, and

c. Valve-level radiation testing to determine in-situ performance degradation if the valve function is needed for safety or mission success.

[Rationale: High radiation doses can degrade materials commonly used in valve components, resulting in valve performance degradation or failure.]

Guidance: Location-specific radiation exposure levels should be performed by ray tracing with the appropriate radiation design factors.

4.5 Valve Components and Features

4.5.1 Seals

Guidance: Seal material selection should be consistent with the internal and external environments as required in NASA-STD-6016. Applicable space environments include atomic oxygen, solar ultraviolet (UV) radiation, ionizing radiation, plasma, vacuum, thermal cycling, and contamination. Applicable planetary environments, such as dust and planetary atmospheres, may also apply. Meteoroids and orbital debris should also be considered in the analysis of long-term degradation. Exposure to environments can affect material properties and seal performance.

4.5.1.1 [VDVR 38] Dynamic sealing surfaces for primary seals **shall** be axially separated from dynamic sealing surfaces for any backup seals and/or surfaces supporting loads by a distance larger than the stroke of the linear motion.

[Rationale: To minimize leak rates, sealing surfaces should be pristine. Axial separations larger than the valve stroke ensure the rod or cylinder sealing surface is not contacted by more than one seal during actuation or by bearing surfaces supporting loads. Seals and bearings tend to wear surfaces they rub, and degraded surfaces increase leak rates.]

4.5.1.2 [VDVR 39] All seal counterfaces **shall** be inspected to verify drawing requirements for dimensions, flatness, and surface texture (roughness, waviness, and lay) parameters are met.

[Rationale: Surfaces contacted by seals need specific characteristics to achieve proper seal performance. Improper sealing surface characteristics can lead to increased leakage, premature wear, damage, and particulate generation.]

Guidance: Surface texture parameters of importance to seals often include mean roughness and surface lay for static seals with the addition of roughness peak height, roughness total height, and roughness skewness for dynamic seals. Dynamic seals may not function well if the mean roughness is too high or too low. The surface should be rough enough to retain a small amount of lubricant. Such surfaces can often be obtained via honing, lapping, polishing, or electropolishing.

Different surface lays are appropriate for different seal applications. For example, an O-ring may provide an acceptable static seal against a surface produced by lathe turning, which has a

lay perpendicular to the delta-P direction, but may not provide an acceptable static seal against a surface produced by end milling, which has a lay in the delta-P direction.

4.5.1.3 [VDVR 40] All seals **shall** be inspected prior to installation.

[Rationale: Seal flaws and other improper seal characteristics can lead to increased leakage, premature wear, damage, improper function, and particulate generation. Non-conformances can be very common in some types of seals.]

Guidance: *The appropriate level of inspection for a given seal will depend on seal type, application, accessibility, consequence of failure, and the mission risk posture. The level of inspection and seal inspection procedures for each seal should be agreed upon by the specifying program technical authority before implementation. Commonly used seal inspection standards include ISO 3601-3, Fluid power systems - O-rings - Part 3: Quality Acceptance Criteria and SAE AS5752, Visual Inspection Standard for Elastomeric Sealing Elements Other than O-Rings.*

4.5.1.4 [VDVR 41] The installation process of each seal in a valve **shall** be witnessed to ensure that it conforms to the procedure established for its installation.

[Rationale: Proper installation of seals into a valve is crucial for performance, and seals are easily damaged if not installed with the appropriate methods. Witnessing seal installation helps ensure that the seal will either be properly installed without damage or that damage during installation will be caught before further assembly of the valve.]

Guidance: *Seals and sealing surfaces should be lubricated with a compatible lubricant prior to seal installation. Specialized seal installation tools such as “bullets” should be used during seal installation to prevent damaging seals.*

4.5.1.5 [VDVR 42] Valves with redundant seal systems **shall** demonstrate required performance and margins in the cases where the primary seal is functioning properly, where the primary seal has failed, and the case where operating medium is trapped between the seals.

[Rationale: Test or analysis is performed under the conditions backup seals will experience after primary seal failure to ensure that backup seals will perform adequately in a failed primary seal case. As one example, leakage that causes pressure to be trapped between seals can result in high-friction forces to operate the valve, even when applied pressure is low. Seal extrusion may increase seal drag forces. As another example, leakage of a primary face seal will increase the pressurized area and thus increase the joint separation force. The effect of temperature changes on the pressure of any trapped fluids should be considered.

4.5.1.6 [VDVR 43] Qualification and acceptance test plans that include a description of how redundant seal system performance will be qualification and acceptance tested **shall** be developed and maintained by the valve provider and approved by the program technical authority.

[Rationale: It is important to understand whether the performance of each seal in a redundant seal system is to be independently verified, and if so, whether it is to be independently verified

during qualification testing only or during both qualification and acceptance testing. Independent verification of seals in a redundant seal system can be difficult to implement and may necessitate specific design accommodations. The strategy used will depend on the application, the consequence of leakage, and the overall risk posture of the program. The considerations listed in AIAA S-080A section 5.1.2 Service Category may help select a strategy.]

4.5.1.7 [VDVR 44] When leakage of seals in a redundant seal system is independently verified during acceptance testing, a leak check port between seals **shall** be used.

[Rationale: Having a leak check port between seals allows for the most direct verification of individual seal performance and eliminates the need to break configuration during testing.]

4.5.1.8 [VDVR 45] When leakage of seals in a redundant seal system is independently verified only during qualification testing without independent verification during acceptance testing, the following **shall** be performed for each seal used in the redundant seal system:

- a. Vibration qualification testing and subsequent leak testing that qualify the seal for the predicted ground and flight vibration level and duration.
- b. Thermal cycle qualification testing and subsequent leak testing that qualify the seal for the predicted thermal cycle magnitudes and life, including thermal transients.
- c. Pressure cycle qualification testing and subsequent leak testing that qualify the seal for the predicted pressure cycles from normal operation and surge.
- d. Operational life testing that qualifies dynamic seals for the predicted cycle life in applicable environments and with the flight operating medium, including the appropriate life test factor per section 4.6.1.2.

[Rationale: Omitting the independent verification of seals in redundant seal systems during acceptance testing can increase the risk of unacceptable leakage during service. The specified testing and analyses address specific environments and conditions to which seals are known to be sensitive and help establish confidence in the individual seals.]

4.5.1.9 [VDVR 46] An analysis of the gland design of each seal used in the valve **shall** be provided as part of verification documentation.

[Rationale: Proper gland design is crucial for proper seal function. A variety of design parameters are involved in gland design, and providing an analysis of the gland design will help ensure proper seal function.]

4.5.1.10 [VDVR 47] Moving parts **shall** be supported by bearings or guides designed to carry all operational loads, including vibration-induced loads, pressure-induced forces, and thermally-induced loads.

[Rationale: Uncontrolled radial displacement of rods and pistons is the most common cause of seal leakage and failure. Seal life and performance depend on accurate alignment between

rods/shafts, pistons, valve bodies, and seal surfaces. Excess clearance between parts can lead to seal extrusion.]

Guidance: *Compliant seals are not adequate or intended for carrying loads other than those needed for proper seal function, such as loads from spring energizers, pressure that energizes a seal, and squeeze on the seal cross section.*

4.5.2 Lubrication

Guidance: *Lubrication of mechanical components is a process subject to the requirements of NASA-STD-6016.*

4.5.2.1 [VDVR 48] All surfaces in contact for which friction under relative motion negatively affects performance of the valve **shall** be lubricated except surfaces for which material compatibility or contamination requirements prohibit lubrication.

[Rationale: Lubrication is one of the most important factors in successful mechanism design and operation. In vacuum or reducing environments, or under heavy wear, parts are more likely to permanently bond together due to the combination of wear and metal diffusion (cold-welding) tendencies once the protective oxide layer is worn away. Non-lubricated metal-on-metal contacts have high and unpredictable friction coefficients, and friction will increase with additional wear cycles. For reliable performance, all contacting surfaces that are expected to move with respect to one another should be lubricated.]

Guidance: *In some cases the operating medium may meet the definition of a lubricant. Use of dissimilar metallic materials for the contacting surfaces, though strongly encouraged, is not an equivalent to or substitute for lubrication and does not meet the intent of this requirement. However, in cases in which material compatibility or contamination requirements prohibit lubrication, use of such approaches should be pursued (see section 4.4.2). If dissimilar metallic materials are used, consideration should be given to the potential for galvanic corrosion.*

Lubricants in wetted portions of the valve may present a contamination risk downstream due to the lubricant being washed out. Any potential contamination or compatibility issues should be addressed by the valve design. Typically, valves with lubricant compatibility concerns have a wetted portion with limited lubricant quantities and a non-wetted portion with fewer restrictions on lubricants and quantities. Compatibility of operating media that permeate into the non-wetted portions of the valve needs to be assessed as specified by section 4.4.1.

Refer to NASA-STD-5017B, Appendix A, section A.2.2, for a discussion of lubricant selection and factors that should be considered. If a wet-lubricated mechanism in a valve contains interfaces in which friction is desirable (e.g., brakes, clutches, friction drives, friction joints, etc.), then barrier films should be used to keep wet lubricants from migrating to those interfaces. See NASA-STD-5017B, Appendix A, section A.2.2.1, for more information on barrier films.

4.5.2.2 [VDVR 49] The selection of lubricants for valve mechanisms **shall** include the following considerations:

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- a. The effect of the service environments (e.g., ground storage conditions, pressure, temperature, radiation, dust, humidity, salt spray, etc.) on lubricants and their properties.
- b. Migration properties of wet lubricants.
- c. Viscosity index (variation of viscosity with temperature) of wet lubricants.
- d. Elastohydrodynamic (EHD) film thickness if operating in the EHD lubrication regime.
- e. Protection against galling and friction welding in the boundary lubrication regime.
- f. Outgassing and breakdown products from wet lubricants that could contaminate sensitive surfaces.
- g. Polymerization of wet lubricants, particularly due to high contact pressures.
- h. Lubricant purity and filtration level.
- i. Lubricant depletion for wet lubricants. (This is typically handled through a “lubrication loss analysis,” which considers evaporation, migration, consumption, fling, and washout.)
- j. Lubricant wear-out for dry lubricants.
- k. Generation and management of dry lubricant wear debris.
- l. Compatibility of each lubricant with other lubricants and other materials (e.g., substrates, platings, coatings, flow media, downstream components, catalyst beds, and preservative or shipping oils).
- m. Exposure to propellant or propellant vapor.
- n. Interaction with pyrotechnic materials and their reaction products (blow-by).
- o. Temperature limits of the lubricants.
- p. Corrosion protection of the mechanism.
- q. Contact stress.
- r. Friction coefficient needed.
- s. The effect of wear debris on wet lubricant properties and valve performance.

[Rationale: Each of these factors can influence which lubricants are appropriate for a given application.]

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Guidance: *Not all of these considerations will apply to every case. Verification that these factors have been considered is expected to include a discussion of each factor or the rationale for inapplicability of each factor in the compliance assessment for this Standard.*

4.5.2.3 [VDVR 50] An evaporative loss analysis **shall** be performed to show that 90 percent of the initial liquid lubricant quantity remains at end of service life, not including lubricant degradation.

[Rationale: Because life testing evaluates cycle life and not necessarily calendar life, evaporative effects on lubricant availability typically cannot be evaluated with a life test alone. Equations for mass loss due to evaporation are based on mass loss of lubricant in vacuum tests and analytical idealizations of labyrinth geometry and, as such, may underpredict mass loss for complex labyrinth designs.]

4.5.2.4 [VDVR 51] The lubricant application process for every lubricant used, including lubricant quantity, application method, and verification of quantity, **shall** be specified in the engineering documentation.

[Rationale: Valve mechanism performance can be sensitive to the lubrication process parameters (e.g., lubricant selected, quantity, location, application method, etc.). The wrong lubrication process parameters can negatively affect mechanism performance by increasing drag and heating while decreasing torque or force margin and efficiency. Additionally, too much lubricant can create contamination problems, while too little lubricant can reduce mechanism life.

Guidance: *Application of lubricants to valve mechanisms is a process subject to the requirements of NASA-STD-6016.*

4.5.3 Bearings and Linear Guides

Guidance: *Rolling element bearings in valve applications are assumed to not require high precision or low torque ripple performance. If high precision or low torque ripple performance is required, refer to NASA-STD-5017B, sections 4.9.1 through 4.9.6 for additional requirements that should be applied.*

4.5.3.1 [VDVR 52] The mean Hertzian contact stress on the most highly loaded element in a rolling element bearing **shall** remain less than or equal to the appropriate values in Table 3, Allowable Contact Stress for Bearing Materials Under Non-Operational Yield Design Loads, when subjected to the non-operational yield design load.

4.5.3.2 [VDVR 53] For materials other than those listed in Table 3, an allowable contact stress **shall** be determined.

Table 3—Allowable Contact Stress for Bearing Materials Under Non-operational Yield Design Loads

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Bearing Material	Hardness Range (in Rockwell C Hardness [HRC])	Mean Hertzian Contact Stress
		Non-Quiet Running Applications*
440C Steel	58-62 HRC	2760 MPa (400 ksi)
52100 Steel	60-63 HRC	2960 MPa (430 ksi)
M50 Steel	62-64 HRC	2960 MPa (430 ksi)
M62 Steel	66-69 HRC	4070 MPa (590 ksi)

NOTE: For hybrid bearings using silicon nitride rolling elements with steel rings, the allowable contact stress will be that of the steel used.

* Rolling element bearings in valve applications are assumed not to be quiet running applications (i.e., are assumed not to require high precision or low torque ripple performance). If high-precision or low-torque ripple performance is required, refer to NASA-STD-5017B, section 4.9.6.

[Rationale: Stressing the bearing raceway material beyond its elastic limit creates a permanent indentation known as a brinell, which can be detected on the torque trace of the bearing and is unsuitable for quiet running applications. The values in the table for 440C and 52100 steel in high precision, low torque ripple (quiet running) applications were established by experiment and correspond to a brinell depth of 0.00003 times the ball diameter for 440C steel and 0.00005 times the ball diameter for 52100 steel (Leveille & Murphy, 1973). The values for M62 steel were established experimentally using ball-on-plate indentation tests with a brinell depth threshold of 0.00005 times the ball diameter based on the previous work on 440C steel and 52100 steel (Park, et al., 1998). Values for M50 are conservative limits based on hardness comparisons with 52100 steel. It is recommended that the above references be consulted to understand the configurations and bearing hardnesses tested before utilizing these limits.]

The values in Table 3 for non-quiet running applications are based on the load that produces brinell depths of 0.0001 times the ball diameter, as found in American Bearing Manufacturers Association (ABMA) standards and elsewhere. Experience shows that this brinell depth can be tolerated in most bearing applications without affecting the bearing's rolling contact fatigue life.]

Guidance: *It should be emphasized that the allowables in Table 3 are for the loading of non-rotating bearings only (e.g., random vibration loads during launch or loads on a bearing intended to release a degree of freedom). The allowables in Table 3 may not be appropriate for operating stresses (i.e., stresses experienced during intentional rotation of the bearing that would be suitable for inclusion in a life calculation), which will generally be lower and depend on a number of factors. See NASA-STD-5017B, Appendix A, section A.2.3.1.2, for guidelines.*

The yield design load is specified in this requirement to allow the use of a yield factor of safety to account for uncertainty in determining the loading conditions on bearings. Because the result of exceeding these allowables is a self-limiting indentation leading to an increase in torque ripple and/or reduction in bearing operating life, a factor of safety such as what is typically applied to a structural design is not necessarily warranted. Each bearing application should be examined

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to determine the appropriate yield factor of safety given the nature of the loading conditions and the consequences of the resulting brinells.

4.5.3.3 [VDVR 54] Bearing fatigue life calculations **shall** be based on the L0.05 life when subjected to maximum time-varying loads consistent with the conditions under which the L0.05 life was determined.

[Rationale: Use of the L0.05 life has been shown through testing to effectively eliminate fatigue life failures during life testing and service for space applications.]

4.5.3.4 [VDVR 55] The upper and lower extremes of the ball bearing contact ellipses **shall** be contained by the raceways.

[Rationale: Understanding the contact geometry and stress in a bearing is important for obtaining required bearing performance and life. Truncation of the contact ellipse can cause significant increases in stress that are not accounted for in traditional bearing analyses and can have correspondingly large impacts on load-carrying capacity and life.]

Guidance: See NASA-STD-5017B, Appendix A, section A.2.3.1.2, for more on contact ellipse truncation.

4.5.3.5 [VDVR 56] All ball bearings **shall** be preloaded with the following exceptions:

- a. Four-point (gothic arch) bearings.
- b. Deep groove ball bearings for which it can be shown that the absence of preload on the deep groove ball bearing is not detrimental to the performance of the mechanism.
- c. Wave generator bearings in strain wave gearing.

[Rationale: Preloading a ball bearing eliminates free play, reduces runout of the rotating member, increases axial and radial stiffness, prevents fretting damage, eliminates impact loading when exposed to a vibration environment, increases the load sharing among balls, and prevents skidding of balls.]

Guidance: It is recognized that there are situations in which preload is not advisable, and there are many bearing preload strategies and considerations when analyzing the effects of preload levels and unloading of balls. See NASA-STD-5017B, Appendix A, section A.2.3.1.3, for guidance.

4.5.3.6 [VDVR 57] If axial sliding of a bearing ring is needed to maintain preload and/or prevent axial overload, then the sliding interface **shall** be designed to operate as a linear sliding bearing over the range of qualification environmental limits, including lubrication to reduce wear and sliding friction forces to acceptable levels throughout the service life.

[Rationale: To maintain bearing preload and/or prevent axial overload, some bearing mounting schemes depend on one bearing ring or set of rings being free to translate axially in a valve body

or on a shaft. When bearing mounts that allow bearing rings to slide axially do not follow standard design practices for linear sliding bearings, vibration testing often damages the sliding interfaces and reduces their performance.]

Guidance: *Mounting the bearing ring(s) on or between compliant diaphragms or structures is a preferred method of allowing axial translation because it does not involve loaded interfaces sliding over each other. Standard design practices for linear sliding bearings include selecting dimensions, tolerances, and clearances to prevent tilting and jamming, and selecting bearing stress level, materials, finishes, and lubricants to prevent galling and seizing. In bearing mounting schemes that depend on one bearing ring of a non-separable angular contact bearing being free to translate axially in a valve body or on a shaft, it is important to include snubbers that prevent reverse thrust loading the bearing.*

4.5.3.7 [VDVR 58] Ball bearing preload **shall** be measured once all assembly steps that establish or affect bearing preload have been completed.

[Rationale: Measurement of preload needs to be verified after operations affecting bearing preload have been completed to ensure that the assembly operations did not adversely affect the preload and that the bearings function as desired in the fully assembled configuration.]

Guidance: *It is highly recommended that the preload be measured at intermediate levels of assembly as well. Direct measurement is preferred; but if bearing preload cannot be directly measured, then indirect methods of assessing preload (e.g., measurement of stiffness or of friction torque) may be used.*

4.5.3.8 [VDVR 59] Mechanisms utilizing guides or linear bearings to constrain a carriage to move in its length direction **shall** use a length-to-width ratio of 2:1 or greater, unless it can be shown by analysis that a length-to-width ratio of less than 2:1 will not cause the mechanism to bind or undergo stick-slip motion, accounting for the following:

- a. Possible friction coefficients.
- b. Contact forces.
- c. Actuating forces.
- d. Dynamically induced forces.
- e. Misalignments.
- f. Eccentric loading.

[Rationale: The performance of mechanisms utilizing guides or linear bearings is geometry sensitive. Length-to-width ratios greater than 2:1 rarely have problems unless friction coefficients are abnormally high. Ratios less than 2:1 can be used successfully but need careful analysis and characterization of parameters to ensure the system does not bind or become

susceptible to stick-slip motion. Ratios less than 2:1 are suitable only for high-precision, low-friction applications such as recirculating-ball linear bearing systems.]

Guidance: *For mechanisms utilizing a set of guides or linear bearings, the effective length is defined as the distance between guide points or linear bearing centers along the direction of motion, and the width is the distance between the rails or centerlines of the bearings perpendicular to the direction of motion, as depicted in Figure 1, Illustration of Length and Width for Various Examples of Mechanisms Using a Set of Guides. For mechanisms utilizing a single rail, the effective length is the effective length of the linear bearing or guide and the width is the distance from the load application point to the centerline of the rail as depicted in Figure 2, Illustration of Moment Arm, Effective Length, and Width for a Single Linear Bearing Application.*

A length-to-width ratio greater than 2:1 requires no analysis. However, care should be taken when using large length-to-width ratios within a mechanism because rail deflections over the length of the linear bearing can also cause binding problems.

The effective bearing length of an individual linear bearing is often not the overall length of the linear bearing but is the length of the portion of the linear bearing carrying the load, often called a “load zone.” Few manufacturers publish information about their linear bearings’ load zones, so it is often necessary to contact the manufacturer or make a conservative estimate of the load zone dimensions. The same uncertainty factors used in the force margin analysis (e.g., on friction) should be applied to any analysis performed to examine susceptibility to stick-slip motion. Further information on length-to-width ratios can be found in Schroeder (2010).

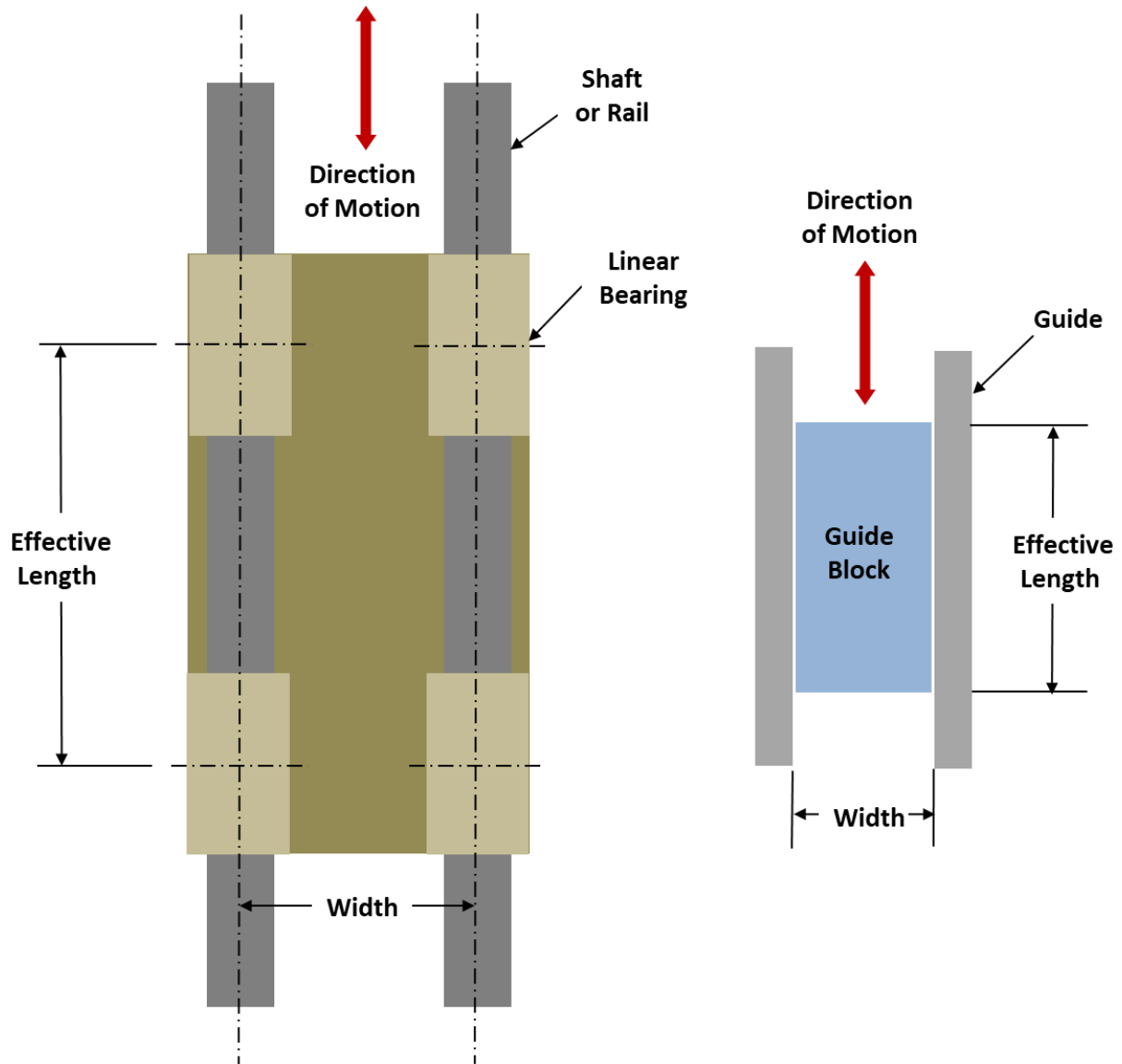


Figure 1—Illustration of Length and Width for Various Examples of Mechanisms Using a Set of Guides

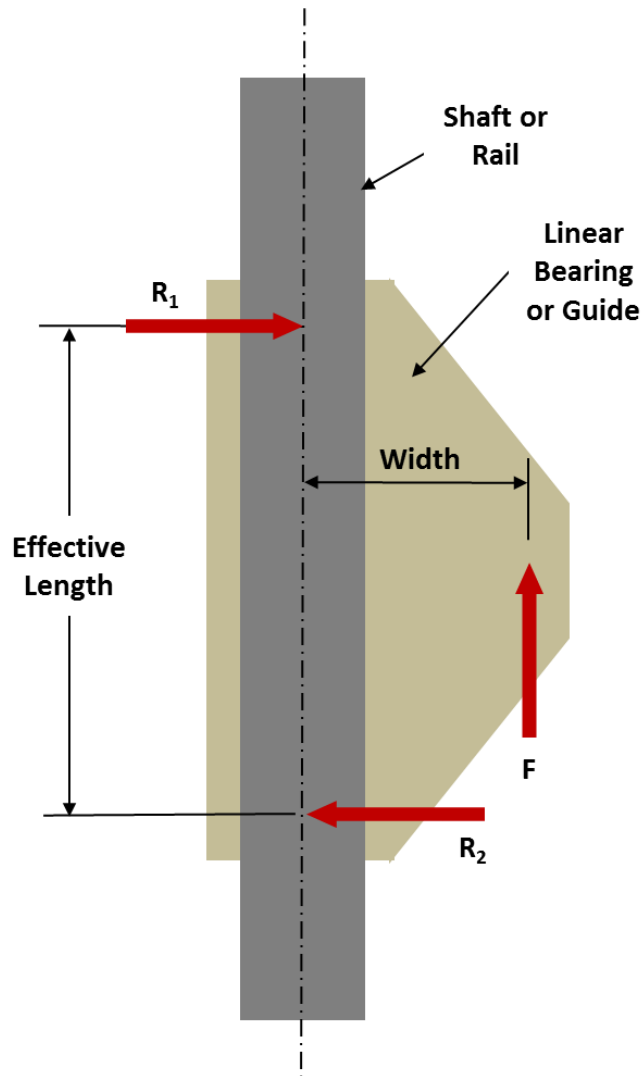


Figure 2—Illustration of Moment Arm, Effective Length, and Width for a Single Linear Bearing Application

4.5.4 Actuators

4.5.4.1 Brushless Direct Current (BLDC) Motors

4.5.4.1.1 [VDVR 60] Each BLDC motor **shall** have the following characteristics measured (or calculated from measured values):

- Torque constant (K_t).
- Motor constant (K_m).
- Torque versus speed curve using flight-representative drive electronics.
- Phase resistances.

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- e. Phase inductances.
- f. End-to-end commutated torque performance.

[Rationale: These motor characteristic measurements are important for understanding how the motor will perform in a mechanical system. Torque versus speed testing verifies the combined performance of the motor, rotor position transducer/sensors, and drive electronics. This testing should use flight-like drive electronics and rotor position transducer/sensors to determine how they perform as a system. BLDC motor performance is heavily influenced by the motor drive electronics and by the alignment of the rotor position sensors to the stator.]

4.5.4.1.2 [VDVR 61] The minimum measured torque output from each BLDC motor **shall** be verified using flight-representative drive electronics.

[Rationale: This testing is necessary because a typical dynamometer test run will not reveal “torque holes,” which are low torque angular positions where the commutation electronics switch motor current from winding to winding. A motor whose initial angular position lies in one of these torque holes may not start under load.]

Guidance: The output torque parameters of a BLDC motor are characterized with a torque profile test. See NASA-STD-5017B, Appendix A, section A.2.4.3, for guidance on torque profile testing techniques. Flight-representative drive electronics are electronics that produce the flight drive waveform when connected to the motor. These electronics typically share the same schematic design as the flight electronics but may use off-the-shelf components. However, caution is needed to ensure that off-the-shelf electronic components perform the same as the flight electronic components. For example, the gate capacitance of a radiation-hardened field effect transistor can be up to an order of magnitude different from an off-the-shelf field effect transistor, which would change the switching time and the response of the mechanism. Care also should be taken to consider the configuration and lengths of harnessing as they may affect performance.

4.5.4.2 Stepper Motors

4.5.4.2.1 [VDVR 62] Each stepper motor **shall** have the following performance characteristics measured:

- a. Powered breakaway torque.
- b. Unpowered (detent) torque versus angle for a full rotation.
- c. Pull-in torque with representative inertia, friction loads, and step rates.
- d. Pull-out torque with representative inertia, friction loads, and step rates.
- e. Step accuracy.
- f. Detent to powered torque null alignment.

- g. Phase resistances.
- h. Phase inductances.

[Rationale: Stepper motors operate differently from BLDC motors, so they need to have different characteristics measured. Measuring these motor characteristics for stepper motors allows one to understand how the motor will perform in a mechanical system.]

Guidance: *All operational tests for stepper motors are sensitive to the inertia and stiffness of loads coupled to the motor shaft, including measurement sensor load parameters. Reaction torque sensors are often employed to minimize frictional and inertial torques or forces from the sensor; however, the compliance of the load sensor can also impact test results. Detent to powered torque null alignment is the difference between the angular position the rotor takes with respect to the stator when unpowered to the matching cardinal step when powered.*

4.5.4.2.2 [VDVR 63] Stepper motor testing **shall** use flight or flight-representative drive electronics.

[Rationale: For reasons similar to those given for using flight-representative drive electronics when verifying brushless motor torque output, stepper motor drive electronics that are as flight-like as possible should be used when performing pull-in and pull-out torque tests. The drive electronics should produce the flight drive waveform when connected to the stepper motor (electrical input pulse shape, duration, frequency and peak voltage) and have similar characteristics for shunting diodes, output impedance, voltage drop, and current limiting.]

Guidance: *Flight-representative drive electronics are electronics that produce the flight drive waveform when connected to the motor. These electronics typically share the same schematic design as the flight electronics but may use off-the-shelf components. However, caution is needed to ensure that off-the-shelf electronic components perform the same as the flight electronic components. For example, the gate capacitance of a radiation-hardened field effect transistor can be up to an order of magnitude different from an off-the-shelf field effect transistor, which would change the switching time and the response of the mechanism. Consider the harness configuration and length as they may affect performance. Any differences in the drive electronics between the test configuration and the flight configuration should be documented in the test report.*

4.5.4.3 Electrically Powered Actuators

4.5.4.3.1 [VDVR 64] The maximum allowable temperature limits of the windings and other materials in the assembly of electrically powered valve actuators as well as the times to reach those temperature limits **shall** be established.

4.5.4.3.2 [VDVR 65] Electrically powered valve actuator temperature limits **shall** not be exceeded for the worst operational cases in the worst-case qualification environments.

[Rationale: Electrically powered actuators can overheat, and brush motors and solenoids can overheat more easily than other types of actuators. The temperature difference between the windings and the case of the actuator, where temperature can be measured, can be quite large.]

***Guidance:** Temperature margin to the maximum allowable actuator temperature limits should be incorporated to encompass uncertainty in the test and/or analyses. The testing and analysis should consider the margined torque or force output of the actuator. For motors, locked-rotor stall should be considered in the determination of maximum temperature rise in the motor.*

4.5.5 Springs

[VDVR 66] Springs **shall** be failure tolerant unless spring failure can be shown to be non-credible.

[Rationale: Springs are common valve components as well as common sources of problems. Failure tolerant springs can greatly improve valve reliability.]

***Guidance:** This requirement is not applicable to valve components that must provide a specific torque or force value within a narrow tolerance range to perform their basic function, such as a spring controlling the set point of a regulator or pressure relief valve.*

There are two ways to achieve failure tolerance in a spring: (1) use a second spring, and (2) use a spring that retains functionality after one coil or element of the spring (e.g., a single conical spring in a stack) is fractured or otherwise compromised. This second option generally demands use of a compression spring, and in the case of coil springs, the wire diameter and coil pitch cannot be such that the two spring halves can thread into each other after a fracture.

Determining that a spring failure is not credible involves demonstrating that adequate life and stress margins exist on the part. This could be accomplished with a combination of stress analysis, fatigue analysis, fracture control methods, and testing. However, given the size of many springs used in mechanisms, fracture approaches are often not feasible.

More information on spring use and design is available in NASA-STD-5017B, Appendix A, section A.2.5.

4.5.6 Gears

[VDVR 67] Gear trains **shall** meet performance requirements, accounting for the worst-case combinations of each of the following conditions, throughout the service life of the mechanism:

- a. Tooth pitting, brinelling, bending fatigue, and bending strength under nominal and peak operating loads.
- b. Impact tooth loads from maximum combined axial, radial, and moment loads sustained during the full life cycle of the mechanism.
- c. Backlash.

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- d. Effects of temperature and temperature gradients on quality of lubrication and gear contact pattern.
- e. Effects of tooth geometry.
- f. Undercutting and tooth profile modifications.
- g. Gear mounting, misalignment, and face load distribution.
- h. Variation in operating center distance.

[Rationale: These parameters, which are often overlooked in design and analysis, can influence gear train strength and wear.]

***Guidance:** Verification that these factors have been accounted for is expected to include line items for each factor in the gear train stress and wear analysis. If a particular factor does not apply in a given situation, rationale for this inapplicability is to be provided in the analysis documentation.*

4.5.7 Switches

4.5.7.1 [VDVR 68] Switch mounting, orientation, and actuation **shall** be such that the switch cannot physically impede mechanism travel.

[Rationale: It is possible to arrange microswitches or their actuation devices such that they can unintentionally interfere with mechanism motion. An improper setup or adjustment of a switch toward the end of the switch's allowable range can also impede mechanism motion. To ensure this does not happen, the arrangement of the switch is to be examined over the switch's entire possible range of adjustment (not just the procedural limits specified).]

4.5.7.2 [VDVR 69] The worst-case maximum travel of switch actuating features **shall** not damage the switch.

[Rationale: Microswitch plungers typically have very small ranges of motion and can be damaged when forced beyond these ranges. To avoid such damage, actuate the microswitch in ways that do not exceed these ranges.]

***Guidance:** Cam profiles can be added to the moving mechanism parts. A variety of "auxiliary actuator" levers available from microswitch manufacturers can be added to the microswitches. The microswitches can then be mounted offset from the moving mechanism parts (so as not to impede mechanism travel) and with their plungers normal to the direction of mechanism motion, with the lever tips acting as cam followers to safely operate the microswitch.*

4.5.8 Fasteners and Connections

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Guidance: Requirements for threaded fastening systems are documented in NASA-STD-5020, *Requirements for Threaded Fastening Systems in Spaceflight Hardware*. Such systems include not only threaded fasteners but also threaded joints such as two halves of a threaded shaft being joined together.

4.5.8.1 Set Screws

[VDVR 70] Set screws **shall** not be used to transmit torque between a shaft and a component mounted on the shaft.

[Rationale: Set screws need to be highly preloaded and dig into a shaft to work in this manner, creating surface imperfections and generating stresses that are difficult to quantify and often cannot be tolerated in low-margin aerospace applications. In addition, repeated loading invariably leads to a loosening of the fit as material around the set screws is deformed, regardless of whether the set screw backs out or retains its original position.]

4.5.8.2 Retaining Rings

[VDVR 71] All retaining rings used **shall** be multiple-turn spiral-wound retaining rings.

[Rationale: Retaining rings that are not multiple-turn spiral-wound rings, especially smaller ones, can be easily opened beyond their elastic limit when installed and can subsequently become dislodged from their groove. Spiral retaining rings, due to their 360-degree design, are much more robust against failures of this nature. All retaining ring types, including spiral retaining rings, are intended for use in applications where retained parts have no relative rotation with respect to the retaining ring, and react with no eccentric loads or cross-axis moments against the retaining rings. Retaining rings used in applications involving relative rotation, eccentric loads, or cross-axis moments exhibit a reduced axial load capacity and are at risk of liberation from the assembly. In such applications, the retaining ring should be decoupled from the rotating parts through a design feature such as a keyed washer, or from the eccentric loads or cross-axis moments by appropriate design.

Guidance: Improper installation techniques can still yield spiral retaining rings, so care is still necessary with their installation. See:

- a. <https://www.smalley.com/videos/installation-removal>
- b. <https://www.smalley.com/retaining-rings/installation-manual>
- c. <https://www.smalley.com/retaining-rings/installation-production-assembly>
- d. <https://www.smalley.com/retaining-rings/removal>

4.5.9 Filters

Guidance: NESC-RP-19-01498, *Filtration of Spaceflight Propulsion and Pressurant Systems*, contains an excellent discussion of filtration terminology, requirements, design, and verification.

NESC-RP-19-01498 recommends protecting sensitive system components such as valves with filters and/or Foreign Object Debris (FOD) screens. These filters and FOD screens may be part of the valve and/or a separate system component, depending on the system design. With the exceptions of bidirectional valves and hydrazine thruster valves, the use of filters or FOD screens at both valve inlet and outlet is discouraged as this may trap self-generated contamination within the valve and may not provide an accurate cleanliness measurement during acceptance testing. Fines from catalyst beds have a history of migrating upstream into hydrazine thruster valves, warranting consideration of outlet filters.

In general, the micron rating of any valve filters and FOD screens should be at least twice the micron rating of the system filter to ensure valve filters or FOD screens will not unexpectedly become the system's primary location for collecting contaminants. NESC-RP-19-01498 recommends that the system filter be sized based on the sensitivity of the system components to contamination.

4.5.9.1 Verification of Filter Holding Capacity

[VDVR 72] The holding capacity of all filters used in a valve **shall** be test verified with dust per ISO 12103.

[Rationale: Using ISO 12103 ensures that a consistent method of evaluating filter capacity is applied. By definition, FOD screens do not have a holding capacity and are not subject to this requirement.]

4.5.9.2 Verification of Filter Performance

[VDVR 73] Valve qualification and acceptance testing **shall** be performed with any valve filters and/or FOD screens present.

[Rationale: Verifying valve performance during qualification testing with filters and FOD screens present ensures that the filter or FOD screen does not adversely affect valve performance under margined conditions, and verifying valve performance during acceptance testing ensures that the filter or FOD screen does not adversely affect valve performance under expected flight conditions.]

Guidance: *Filters or FOD screens may be removed only if a test or process involves flowing media through the valve in reverse.*

4.5.9.3 Documentation of Generated Contaminants

[VDVR 74] The size, quantity, and characteristics of particulate matter generated by the valve during life cycle testing **shall** be recorded as part of qualification activities.

[Rationale: Understanding and documenting the particulate matter generated by the valve over its service life can help identify unexpected or premature wear, validate system filter sizing,

understand potential fluid system impacts, and provide baseline understanding of particulate generation rates against which anomalous rates may be evaluated.]

Guidance: *One method of acquiring this data is to place a filter downstream of the valve during life cycle testing and examine the particulate matter in the filter after the test. Another method is to periodically acquire samples of the operating medium during life cycle testing. The size, material and morphology of the particulate matter in the filter or in the samples should be documented so that wear particle analysis can determine its origin so as to gain an understanding of valve wear and impacts to the fluid system performance.*

4.5.10 Marking of Flow Direction

[VDVR 75] The primary direction of flow intended for the valve **shall** be indicated by visibly labeling the inlet and outlet ports on the exterior of the valve.

[Rationale: This helps ensure that the proper valve orientation is used during testing and system integration.]

Guidance: *For unidirectional valves, arrows can also be a helpful marking.*

4.5.11 Thin Wall Pressure Boundaries (TWPB)

Guidance: *JSC 67035, Best Practices and Guidelines (BP&G) for Thin Wall Pressure Boundaries (TWPB) for Human Spaceflight Applications, addresses types of TWPB commonly found in valves such as bellows, diaphragms, and torque motor flexure sleeves. Valve specifications for human spaceflight applications may choose to levy specific requirements on TWPB based on these BP&G.*

4.6 Test and Verification Requirements

Guidance: *Environmental test requirements are contained in SMC-S-016, Test Requirements for Launch, Upper-Stage and Space Vehicles, or its tailored equivalent. For the purposes of determining what tests are required by SMC-S-016, a valve is both a moving mechanical assembly and a pressure component. Requirements for leak tests are documented in NASA-STD-7012, Leak Test Requirements. Requirements for testing of valves exposed to dust in planetary environments are documented in NASA-STD-1008, Classifications and Requirements for Testing Systems and Hardware to Be Exposed to Dust in Planetary Environments.*

The test campaign requirements for moving mechanical assemblies are typically outlined in a dedicated test specification (e.g., SMC-S-016). Detailed valve mechanism testing activities within the overall test campaign should follow section 8 of AIAA S-114A-2020, Moving Mechanical Assemblies for Space and Launch Vehicles. The requirements below reflect certain aspects of testing that are important to capture for valve mechanisms.

Ordnance-actuated valves are also considered to be “pyrotechnic devices” and are therefore subject to the qualification requirements in applicable pyrotechnic standards or requirements documents.

4.6.1 Qualification Testing

4.6.1.1 General Qualification Testing Requirements

4.6.1.1.1 [VDVR 76] Each valve design **shall** be subjected to qualification testing that exposes the valve to all environments and operating media that it will experience during its service life.

***Rationale:** Qualification testing ensures that the design is sufficient to meet the requirements of the valve, with margin, in the operating environments it is expected to experience. Behavior under environmental conditions and operating media can be very difficult to predict, and omission of qualification testing can significantly increase the risk of in-service failure.*

***Guidance:** The operating media are required to be present in qualification performance, life, and exposure testing, as specified in sections 4.6.1.1.7 and 4.6.1.3 of this Standard. An evaluation should be performed to determine when operating media should be present during environmental qualification tests.*

The types of environmental qualification testing required for valve mechanisms are typically established by the program. A recommended set of mechanism tests is included in NASA-STD-5017B, Appendix A, section A.2.11. The program also typically specifies required margin, test order, tolerances, and general methods to be used. Note that the intent of the qualification program is to expose a common qualification unit to all environments and operating media (versus spreading the environments across multiple qualification units) to ensure that effects of cumulative exposure are accounted for. This testing includes bounding system-induced dynamic flow and pressure conditions to ensure these transient conditions do not cause any valve performance degradation, i.e., priming/repriming, surge pressure, and water hammer.

4.6.1.1.2 [VDVR 77] Each valve **shall** be subjected to environmental qualification testing in the valve’s appropriate configuration (e.g., open or closed) and operating or non-operating state.

*[**Rationale:** The hardware configuration (e.g., launch, on-orbit, landing) can affect many aspects of the valve (e.g., load path, stiffness, clearances, and slop in joints). It is important that the qualification testing be performed on the valve while the valve is in the configuration in which it will experience the environments and perform its functions; otherwise, differences such as those stated may cause the valve to behave differently in test than it would in service, leading to false confidence in the hardware or unrealistic test failures.]*

4.6.1.1.3 [VDVR 78] Valve qualification testing **shall** be conducted with mounting interface boundary conditions that replicate the flight boundary conditions, including the following:

- a. Stiffness.

- b. Mounting alignment and tolerances.
- c. Thermal distortions.
- d. Distortions induced by installation or externally applied loads, including from lines connected to the valve.

[Rationale: Testing with improper representation of boundary conditions can give misleading results due to factors such as different load-induced distortions, different frequency response, or different flow characteristics.]

Guidance: *Appropriate boundary conditions can sometimes be difficult to implement in test, and compromises often need to be made between interface fidelity and the level of assembly needed to achieve good fidelity. Verification that these influences have been accounted for is expected to include explicit description of how these boundary conditions are addressed in the test plan or, if the condition does not apply in a given situation, the rationale for this inapplicability.*

4.6.1.1.4 [VDVR 79] Inspections of the valve **shall** be conducted prior to the start of qualification testing and after valve disassembly at the conclusion of qualification testing.

[Rationale: Comparing inspection results before and after qualification testing allows the effect of the testing to be determined.]

Guidance: *Inspections prior to the start of qualification do not require disassembly and may be performed as part inspections prior to or during assembly, post-assembly inspections, post-acceptance test inspections, or dedicated pre-qualification inspections. All wear surfaces should be inspected and measured. If life testing is performed on the qualification unit, inspections should be performed at the conclusion of the life test. If the life test is conducted on a separate life test unit, then inspections should be performed on both the qualification test unit and the life test unit.*

4.6.1.1.5 [VDVR 80] Performance tests **shall** be conducted at both the start and the conclusion of qualification testing, prior to the performance of testing with known destructive potential (e.g., a static test to ultimate loads).

[Rationale: Pretest performance tests and inspections establish baseline condition and performance. Post-qualification performance tests and inspections allow the residual effect of the environmental test to be determined when compared with the pretest baseline.]

Guidance: *At a minimum, one post-test performance test and inspection should be performed at the end of the suite of qualification tests, but additional tests or inspections inserted into the test flow (e.g., between random vibration testing and thermal-vacuum testing, or even between axes of random vibration tests) allow for easier identification of a problematic environment when anomalies occur. Depending on the nature of the valve mechanism and the failure modes of interest, disassembly of the valve may be needed for effective post-qualification inspection.*

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Note that it is not necessary to verify function after exposure to tests of a potentially destructive nature (e.g., a static load test to ultimate load). A functional test would be expected after a test to the yield load, but generally an ultimate load test would only need to show that rupture or unstable failure did not occur.

Performance testing of an ordnance-actuated valve device via initiation of its energetic charge may be destructive. In that case, the performance test should only be conducted at the conclusion of a valve's qualification sequence, and any applied pyrotechnic standards should be consulted for applicable pyrotechnic testing requirements (e.g., lot testing).

4.6.1.1.6 [VDVR 81] Pass-fail criteria and the rationale for those pass-fail criteria **shall** be established for all qualification tests prior to the start of qualification testing.

[Rationale: Pass-fail criteria are established prior to testing to avoid rationalization of anomalous behavior detected during testing. This also helps streamline the decision making and documentation process when anomalies are encountered during the test.]

4.6.1.1.7 [VDVR 82] Qualification performance tests **shall** be performed with the operating medium used in service.

[Rationale: Using the operating medium used in service shows the effects of the operating medium on the materials of the valve. Material testing alone has been shown to be insufficient to capture effects on valve performance.]

4.6.1.2 Life Testing

Guidance: *Life testing is intended to evaluate cycle life and may or may not be representative of calendar life. The definition of what constitutes a cycle is application-dependent and determined on a case-by-case basis. Life testing may not be meaningful for ordnance-actuated valves or other valve mechanisms that are consumed or refurbished after every actuation. Such devices typically use lot testing approaches. Pyrotechnic devices are subject to the testing requirements levied in applicable pyrotechnic standards or requirements documents.*

4.6.1.2.1 [VDVR 83] Life testing **shall** be performed on all valve functions to verify that each valve function meets its life requirement.

[Rationale: Sometimes there is a desire to test only certain functions or nominal operations, but all functions of the valve mechanism need to be life tested to verify life of the valve, including backup or redundant provisions. Typical life concerns include fatigue limits, lubricant deterioration, excessive wear, and deterioration during extended quiescent periods. See NASA-STD-5017B, Appendix A, section A.2.11.1, for more guidance on life testing.]

4.6.1.2.2 [VDVR 84] Valves whose failure could result in a loss of human life **shall** be life tested to a number of cycles determined by multiplying the total of all cycles in the valve's required service life by a minimum life test factor of 4.0.

4.6.1.2.3 [VDVR 85] All other valves **shall** be life tested to a number of cycles determined by multiplying the total of all cycles in the valve's required service life by a minimum life test factor of 2.0.

[Rationale: It is difficult to assess reliability with a single life test. The uncertainty provided by unit-to-unit scatter, which remains unquantified with a single test, is mitigated by use of a life test factor. Higher factors create more confidence that subsequent builds will possess the required service life. A factor of 2.0 is consistent with the factor used on past successful robotic spaceflight missions, and a factor of 4.0 is consistent with previous human spaceflight implementations typically requiring higher reliability.]

Guidance: *The minimum life test factors specified above are intended to address mechanical life and wear concerns, not vibration and fatigue life concerns, although in certain cases the mechanical motion and life are driven by vibration and the cycle count and magnitudes are derived from the vibration environment. It is highly recommended that spare cycles be added to the total cycles required to allow troubleshooting or execution of extra cycles without exceeding the valve mechanism's certified life.*

4.6.1.2.4 [VDVR 86] Life testing **shall** include a number of cycles under the expected operating environmental extremes, exposure to operating media, loads, pressures, ranges of motion, and speeds that is representative of the number of cycles at those conditions expected in the service life of the valve.

[Rationale: All of these conditions can affect the life of the valve. Wetted valves and dry valves have different lives, torque and force margins, etc. Small or dithering motions can be more severe because they can wipe away wet lubricant and create debris dams at the ends of the range of motion that prevent the flow of oil back into the contact zone. A life test that exercised only the full range of motion for such parts could give a false impression of life.]

Guidance: *NASA-STD-5017B, Appendix A, section A.2.11.1, contains recommendations on how to allocate cycles of the life test to different environments.*

4.6.1.2.5 [VDVR 87] The life test **shall** include the operation of bearings under the maximum predicted operational contact stress for the number of cycles predicted to experience maximum operational contact stress in flight multiplied by the life test factor specified by section 4.6.1.2.2 or section 4.6.1.2.3 of this Standard.

[Rationale: Bearing life and lubricant life are highly dependent on contact stress; it is necessary to ensure that flight-like contact stresses are present in the life test to avoid misleading test results.]

4.6.1.2.6 [VDVR 88] Life testing **shall** include intentionally running into any mechanical stops present in the valve during each test cycle.

[Rationale: Mechanical stops perform a function of the valve and are therefore to be life tested. Often, mechanical stops are not contacted under nominal testing conditions, so the ability of the mechanical stops to function over the life of the valve may not be evaluated in ground testing. Mechanical stop contact loads may be a driving load case not only for the mechanical stop but for other parts of the valve. In service, conditions may be such that the mechanical stops are contacted consistently regardless of whether the mechanism reached its mechanical stops during ground testing. For this reason, the mechanical stops need to be intentionally tested during a life test.]

Guidance: Mechanical stops are often called "hard stops" but may be made compliant using components such as springs or preloaded spring plungers to limit the magnitude of contact loads.

When stops are not normally contacted due to the use of software stops or other means, it may be impractical to run the valve mechanisms into the mechanical stops during an assembly-level life test. In these situations, life testing of the mechanical stops may be conducted separately at a subassembly level in place of assembly-level testing. When subassembly-level life tests are used, it is recommended that the assembly-level life test run the mechanism into the mechanical stops for at least the first cycle before continuing the test using the nominal range of motion. This serves as a preconditioning step to help avoid false life test results should a mechanical stop contact occur.

4.6.1.2.7 [VDVR 89] When a protoflight approach is used, a life test **shall** be performed on a dedicated valve that has been exposed to all environments and levels encountered by the flight valve during its service life.

[Rationale: Performing the life test on a valve that has been exposed to environments helps ensure that environmental effects on valve life are taken into account.]

Guidance: Per SMC-S-016, life testing is to be performed on a qualification unit when available. When a protoflight approach is used, the environmental test levels should, at a minimum, envelope the ground and operational environments seen by the flight unit during its service life.

4.6.1.2.8 [VDVR 90] A performance test **shall** be conducted before the first and after the last cycle of the life test.

[Rationale: Beginning-of-life performance tests establish baseline condition and performance. End-of-life performance tests allow the residual effect of the life test to be determined when compared with the beginning-of-life baseline.]

Guidance: If the performance test cycles the valve in the same way as the life test, the performance test cycles can be counted as life test cycles.

4.6.1.3 Exposure Testing

[VDVR 91] As part of their qualification test program, all assembled valves shall:

- a. undergo an initial performance test,
- b. be exposed—at the expected temperature, pressure, and cumulative duration—to any operating medium to which the valve will be exposed during its service life, and
- c. undergo a second performance test following exposure.

[Rationale: Inadequate valve-level exposure testing has been the root or contributing cause of several high-profile spacecraft valve failures. All operating media can have adverse impacts on different valve components over long durations, even inert gases, and coupon-level testing cannot provide an understanding of how the effects of exposure on different valve components will work together to influence overall valve performance. Performance testing before and after exposure to the operating media allows determination of whether the exposure to the operating media had deleterious effects on valve performance.]

Guidance: *If substitute operating media are to be used during portions of the test campaign for a given valve unit, it is necessary to understand the effects of the substitute operating medium and ensure the valve is qualified like it will be flown. For example, if water is used for portions of qualification testing of a nitrogen tetroxide valve prior to an exposure test with nitrogen tetroxide, then the absorption of water by the non-metallics and the effects of potential release of that water into the nitrogen tetroxide during the exposure test need to be considered, or steps need to be taken to ensure that all residual moisture in the fluid system containing the valve is removed before using nitrogen tetroxide. Similarly, if water will be used for portions of acceptance testing prior to introducing nitrogen tetroxide, then the qualification testing should ensure that the water exposure, or lack thereof, is addressed in the same way it will be on the flight unit. If the second performance test is not performed with the operating medium, then it should be conducted as soon as possible after the operating medium is drained from the valve, while non-metallics are still saturated with the operating medium; e.g., while seals in a high pressure helium valve that have been exposed to nitrogen tetroxide vapor remain swollen, potentially causing excess helium leakage or reduced helium flow rate.*

4.6.2 Acceptance Testing

Guidance: *The requirements in this section are intended to be applied to flight valves. The best practice is to also perform acceptance testing on qualification units before beginning the qualification test program.*

The best practice is to use the flight operating medium for acceptance testing where feasible. Some applications (e.g., valves that meter gas flow) may be sensitive to the fluid dynamic properties of the operating medium. If substitute media are used in these applications, then care should be taken to either ensure that the substitute media are able to accurately represent the

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fluid dynamic properties of the flight fluid media or ensure that the proper corrections are used when assessing performance using the substitute media.

The performance data from acceptance testing should be reviewed across all tested valves to identify any whose performance is out-of-family (i.e., differs significantly from the performance of other valves).

Acceptance testing may not be meaningful for ordnance-actuated valves or other valve mechanisms that are consumed or refurbished after every actuation. Such devices typically use lot testing approaches. Pyrotechnic devices are subject to the testing requirements levied in applicable pyrotechnic standards or requirements documents.

4.6.2.1 [VDVR 92] Each valve **shall** be subjected to environmental acceptance testing that exposes the valve to all environments that it will experience in service.

[Rationale: Acceptance testing ensures that the individual hardware build is sound and capable of meeting its performance requirements in the operating environment it is expected to experience.]

Guidance: *The types of environmental acceptance testing required for moving mechanical assemblies are typically established by the program. The program also typically specifies required margin, test order, tolerances, and general methods to be used. Omission of acceptance testing can significantly increase the risk of in-service failure.*

4.6.2.2 [VDVR 93] Each valve **shall** be subjected to environmental acceptance testing in the valve's appropriate configuration (e.g., open or closed) and operating or non-operating state.

[Rationale: The hardware configuration can affect load path, stiffness, clearances, slop in joints, and many other aspects of the valve. It is important that the acceptance testing be performed on the valve while the valve is in the configuration in which it will experience the environments and perform its functions; otherwise, differences such as those stated may cause the valve to behave differently in test than it would in service, leading to false confidence in the hardware or unrealistic test failures.]

4.6.2.3 [VDVR 94] A run-in test **shall** be performed on each valve prior to undergoing any other acceptance testing.

[Rationale: Run-in testing (also known as wear-in testing) serves two purposes: (1) it acts as a screen to detect material and workmanship defects that manifest early in the valve's life (i.e., "infant mortality"), and (2) it allows the valve to work through initial transient behavior and reach steady-state performance. This allows for a better understanding of valve performance and easier observation of trends and detection of anomalies.]

Guidance: *If performance metrics do not appear to be leveling off, trends are not as expected, or performance levels are not as anticipated, this may be an indication of failure. Sufficient data need to be obtained during the run-in test to allow determination of these important performance characteristics and their trends. Without sufficient data (e.g., high enough sample frequency),*

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actual trends may be masked. In addition, measurements of important parameters should be made as directly as possible to help avoid ambiguous results.

4.6.2.4 [VDVR 95] The run-in test **shall** be conducted for at least 15 cycles or five (5) percent of the total expected service life, whichever is greater.

[Rationale: These run-in durations have been shown through experience to be adequate for achieving the workmanship screening goals of run-in testing in most cases; however, it may not be sufficient to achieve smooth, consistent performance in all situations.]

Guidance: *If performance metrics do not appear to be leveling off or friction levels have not been reduced to a desired level at the conclusion of the run-in test, then continued run-in may be warranted. For this reason, among others, it is recommended to include margin in the number of run-in cycles used in calculating the service life for the mechanism. The definition of what constitutes a cycle is application-dependent and determined on a case-by-case basis.*

4.6.2.5 [VDVR 96] The run-in test conditions **shall** be representative of the operational loads, speed, and environment.

[Rationale: Running-in using conditions other than those expected in service can produce data during the test that are not indicative of true performance or can even damage hardware. For example, running-in at a different speed than anticipated in service can change the lubrication regime in a wet-lubricated bearing, and running-in a molybdenum disulfide dry film lubricant in ambient (humid) air can result in excessive wear of the lubricant and inaccurate friction values, and can shorten the lubricant life in vacuum service.]

Guidance: *If a variety of environments are expected in service, a split similar to that recommended for life testing in NASA-STD-5017B, Appendix A, section A.2.11.1, should be used. This requirement is not intended to require application of all environments simultaneously.*

4.6.2.6 [VDVR 97] Inspection of the valve and valve performance tests **shall** be conducted after run-in testing prior to further acceptance testing, and at the conclusion of acceptance testing.

[Rationale: Performance tests and inspections after run-in establish baseline condition and performance. Comparing performance and inspection results before and after acceptance testing allows the effect of the testing to be determined.]

Guidance: *Unlike inspections after qualification testing, the post-acceptance inspections are made without disassembly or other breaking of configuration. At a minimum, one performance test and inspection should be performed at the conclusion of the acceptance test program but additional tests or inspections inserted into the test flow (e.g., between random vibration testing and thermal-vacuum testing or even between axes of random vibration tests) allow for easier identification of a problematic environment when anomalies occur. These performance tests need to be accounted for when calculating the required service life of the valve.*

4.6.2.7 [VDVR 98] Pass-fail criteria for all acceptance tests and the rationale for those criteria **shall** be established prior to the start of acceptance testing.

[Rationale: Establishing pass-fail criteria prior to testing avoids normalization of anomalous behavior detected during testing. This also helps identify what successful performance means and helps streamline the decision making and documentation process when anomalies are encountered during the test.]

4.6.3 Performance Test and Leak Test Parameters

4.6.3.1 [VDVR 99] Performance and leak tests **shall** be performed in all operating environments under the worst-case conditions for each environment.

[Rationale: The operating environments can influence valve performance and leak rates.]

***Guidance:** As an example, a valve required to cycle during vibration at cryogenic temperatures would undergo performance testing and leak testing under vibration and while at its minimum temperature. Where practical, these environments should be applied simultaneously. If this is not practical, then the combined effects of the environments should be analytically assessed.*

Leak tests should be performed with the test article pressurized at the minimum differential pressure if seal performance is dependent upon pressure for proper sealing.

4.6.3.2 [VDVR 100] All valve mechanism functions **shall** be exercised during performance testing.

[Rationale: Sometimes there is a desire to test only essential functions or nominal operations, but all functions of the valve mechanisms need to be tested to verify performance of the valve, including backup or redundant provisions. This applies regardless of whether the performance testing is conducted during qualification, life, or acceptance testing.]

***Guidance:** Performance testing includes the measuring of torque and force margins.*

4.6.4 Demonstration of Margin Against Chatter

[VDVR 101] Passively actuated valves **shall** undergo testing as part of qualification or development to demonstrate flow rate margin against chatter under operating conditions.

[Rationale: The goal of this testing is to demonstrate that the valve has flow rate margin against abnormal valve behavior, ensuring that it can operate smoothly without damaging the valve or generating debris that can harm surrounding components.]

***Guidance:** Testing for chatter can differ from valve to valve but typically involves gradually adjusting inlet flow rates, starting from values below those expected during operation and increasing to higher levels. The process should also be repeated with flow rate being swept from*

high to low. Flow rate margin should be verified under operating conditions at both low and high flow rates with the amount of margin being agreed to by the specifying program technical authority. If chatter occurs, it can be detected using accelerometers or by analyzing pressure traces. It is often audible as well.

Pressure relief valves will typically only need to show positive flow rate margin against chattering. Check valves will usually need to show more than simply positive flow rate margin against chattering. Regulators will typically only need to show positive flow rate margin against chattering, but the nature of regulator performance testing will often inherently demonstrate additional flow rate margin. It is important to ensure that any ground purge and flush conditions are included in the specification flow conditions and that chatter susceptibility testing includes ground purge and flush conditions.

If chatter is discovered within the operating range of flow rates, the risk of chattering should be assessed by the program. Testing that intentionally incites chatter for four times the total time duration of exposure, followed by performance testing, component inspection, and contamination generation quantification is recommended to help quantify the risk of a chattering valve.

Though intended for facility valves, ASME PTC 25 may contain useful information for testing spacecraft pressure relief valves.

4.6.5 Test Electronics

[VDVR 102] Valve testing **shall** use flight or flight-representative drive electronics.

[Rationale: Testing valves connected to flight-representative electronics helps ensure that valve performance includes all integrated effects. Testing valves connected to different electronics than those that will be used in flight can result in non-flight-like valve performance. For this reason, the qualification test units, including the life test unit, need to use flight-representative electronics that produce the flight waveform when connected to the valve.]

Guidance: *Flight-representative electronics are electronics that produce the flight drive waveform when connected to the valve. These electronics typically share the same schematic design as the flight electronics but may use off-the-shelf components. However, caution is needed to ensure that off-the-shelf electronic components perform the same as the flight electronics components. Some examples where the use of flight-like electronic performance in test are essential include:*

- a. Zener diodes, typically wired in parallel with solenoid valves, prevent damage to the sensitive upstream drive electronics from the voltage spikes/back electromotive force generated by the solenoid as it de-energizes. The breakdown voltages of these diodes have a great effect on the valve response.*
- b. Gate capacitance of a radiation-hardened field effect transistor can be up to an order of magnitude different from an off-the-shelf field effect transistor, which would change its switching time and, consequently, the response of the valve.*

Consider the harness configuration and lengths, and the software used, as they may affect performance. Any differences in the valve electronics between the test configuration and flight configuration should be documented in the test report.

4.7 Positive Isolation Valves

Guidance: *A positive isolation valve (PIV) is a type of single-use valve that is only actuated once, either to open and establish flow (a “normally closed” [NC] configuration), or to close and isolate one section of a fluid system from another (a “normally open” [NO] configuration). NC PIVs are quite common and provide a high-reliability isolation function that allows safe long-term storage of a propulsion system without concern for undesired commodity leakage, propellant vapor migration, or flow of the operating medium (e.g., propellant vapor, pressurant gas, pneumatic gas, purge gas, etc.) into other parts of the system. NO PIVs enable nominal or contingency isolation of one or more sections of a fluid system during spacecraft operations. The most widely used PIVs are pyrotechnically actuated valves (pyrovalves), but valves with non-pyrotechnically operated actuators are available. The requirements in this section address the design, testing, integration, and usage of NC and NO PIVs, maximizing the likelihood of functional success. For pyrovalves specifically, these requirements also mitigate the potentially catastrophic hazards associated with the pyrotechnic nature of the valves.*

Given that individual flight units cannot be tested due to the single-use nature of PIVs, lot qualification and acceptance testing are performed on multiple units to provide statistical significance, with the number of units to be tested approved by the delegated NASA Technical Authority. Lot testing requirements for pyrovalves will be found in applicable pyrotechnic specifications, but the approach will be similar for non-pyrotechnically operated PIVs. In addition, additional units are usually needed for testing at the fluid system and/or integrated vehicle level.

Additional requirements for NC PIVs are located in NASA-SPEC-5022, NASA Manufacturing and Test Requirements for Normally Closed Pyrovalves for Hazardous Flight Systems Applications, which is primarily applicable to launch vehicle payloads subject to NASA payload safety and United States Air Force range safety requirements, where a consistently high level of reliability and safety is required. Despite the title, NASA-SPEC-5022 is also applicable to normally open PIVs as well as non-pyrotechnically operated PIVs.

4.7.1 Positive Isolation Valve (PIV) Requirements

4.7.1.1 [VDVR 103] NC PIVs **shall** incorporate an all-metal permanent valving element (i.e., internal flow barrier) without mechanical joints that is impermeable to the internal leakage of the operating medium across the element and exhibits pre-operation leak rates less than 1×10^{-6} standard cubic centimeters per second of gaseous helium across the ranges of operating pressures for which the valve is intended to operate.

[Rationale: All-metal permanent valving elements are needed to ensure the specified leak rates are achieved with high reliability.]

Guidance: *The term ‘parent metal’ is often used to describe this type of all-metal construction, particularly when the barrier is an integral part of the inlet/outlet tube stubs with no fusion joints or other forms of mechanical connection.*

4.7.1.2 [VDVR 104] PIV qualification testing **shall** include actuation of the PIV after exposure to all relevant environments and operating conditions, with the test setup and test campaign possessing the following key attributes:

- a. Use of flight-representative drive electronics, commanding software/controller avionics, and power source elements at worst-case voltages.
- b. Testing at worst-case thermal conditions.
- c. Use of a flight-representative mounting configuration for the PIV onto a flight-representative structure and interfacing tubing with flight-representative upstream and downstream volumes.
- d. Use of ground test instrumentation to characterize the PIV mechanical environment produced by actuating the valve and transmitted to the interfacing tubing, mounting structure, and adjacent fluid system components.
- e. Exposure to flight-representative environmental conditions and operating media, including liquid- and/or vapor-phase media as applicable, during PIV actuation.
- f. Evaluation of worst-case pressure transients resulting from the actuation of all PIVs contained within the fluid system.
- g. For pyrovalves, evaluation of worst-case command timing for the firing of redundant initiators contained within the pyrovalve and evaluation of worst-case command timing for the actuation of redundant pyrovalves contained within the fluid system.

[Rationale: *The actuation of PIVs in flight is a highly energetic and dynamic event that has led to multiple catastrophic failures in past spacecraft, with NO pyrovalves being the largest culprit. The performance of PIVs is highly dependent on location and configuration, and their actuation can induce significant mechanical shock, potentially resulting in functional or structural failure of exposed hardware.*

Quantifying shock in a flight-representative configuration is essential to determining whether attenuation or design modifications are needed. Testing PIVs in a flight-like configuration is essential for capturing these high-shock events and mitigating potential catastrophic consequences.

Firing of pyrotechnic initiators is always conducted in a worst-case, flight-like manner. High pressures generated within the valve body due to simultaneous firing of redundant pyrotechnic devices have been known to exceed the MDP, causing structural failure or rupture. Partial or misfiring events have also been observed.]

Guidance: Any deviation from the flight-like configuration (e.g., changes in physical layout, mounting provisions, or firing circuits) should be evaluated during the design review and test planning process. The technical rationale for each deviation should be documented in a Test Like You Fly exception report and approved by the project or program.

To characterize the loads, deflections, stresses, and excitation modes associated with these rapid, high-energy events, instrumentation such as strain gauges, accelerometers, laser vibrometers, and high-speed video cameras should be used.

If multiple PIVs are actuated simultaneously or in close succession during fluid system operation, then this sequence is to be tested during qualification to quantify pressure surges and shock loads. The combined effects of these actuations could exceed MDP limits, result in hardware failure or rupture, or even trigger a destructive adiabatic compression detonation (ACD) event within the fluid system. See NESC Technical Bulletins No. 09-01 and No. 10-02.

4.7.2 Pyrovalve Requirements

Guidance: The pyrotechnic nature of pyrovalves generates some unique factors for consideration. General requirements for pyrotechnic systems in human-rated spacecraft are found in JSC 62809, Human Rated Spacecraft Pyrotechnic Specification. NASA-HDBK-5013, Pyrovalve Application and Performance Handbook, contains useful information and guidelines for pyrovalves. Firing pyrovalve initiators in a simultaneous manner has resulted in misfiring of the primary charge and partial/failed actuation, as well as exceedance of MDP and structural failure of the valve body. For this reason, it is recommended that initiators on pyrovalves should be fired using consecutive command timing during valve actuation with a minimum of two (2) milliseconds between firings (see NESC Technical Bulletins No. 09-01 and No. 10-02).

MDP will be different for the pyrotechnic portion of the valve than for the wetted portion.

After operation, new external leak paths are exposed through the pyrotechnic portion, and external leakage requirements after operation may be different than external leakage requirements before operation.

4.7.2.1 [VDVR 105] Pyrovalves **shall** not use titanium or its alloys as materials of construction in pyrovalve bodies, or aluminum or its alloys as materials of construction in pyrovalve primer chamber assemblies (PCAs).

[Rationale: Titanium and its alloys in a pyrovalve body and aluminum and its alloys in a pyrovalve PCA can ignite/burn and fail structurally when subjected to the high temperatures and high frictional energy dissipation associated with firing of a pyrotechnic device, rapid relative motion of the internal parts, shearing of the parent metal flow barrier (for NC pyrovalves), and seating of the ram at the end of valve actuation.]

Guidance: Non-pyrotechnically operated PIVs are not subject to this prohibition.

APPENDIX A: BEST PRACTICES FOR VALVES

A.1 PURPOSE

This Appendix presents best practices for the design, development, and testing of aerospace valves that past experience has shown to create the maximum potential for successful operation in service, pitfalls to recognize and avoid, and background information to enhance understanding of the requirements in section 4 of this Standard. This Appendix contains no requirements that must be followed to adhere to this Standard.

A.2 BEST PRACTICES

A.2.1 Reserved for future updates

APPENDIX B: REFERENCES

B.1 PURPOSE

This Appendix provides information of a general or explanatory nature but does not contain requirements. The latest issuances of reference documents apply unless specific versions are designated. Access reference documents at <https://standards.nasa.gov> or obtain documents directly from the Standards Developing Body, other document distributors, information provided or linked, or by contacting the office of primary responsibility designee for this Standard.

B.2 REFERENCE DOCUMENTS

B.2.1 Government Documents

Department of Defense

SMC-S-016, Test Requirements for Launch, Upper-Stage and Space Vehicles

NASA

JSC-62809, Human Rated Spacecraft Pyrotechnic Specification

JSC-67035, Best Practices and Guidelines (BP&G) for Thin Wall Pressure Boundaries (TWPB) for Human Spaceflight Applications

MSFC-SPEC-445, Requirements for Adhesive Bonding Process and Inspection

MSFC-STD-3012, Electrical, Electronic, and Electromechanical (EEE) Parts Management and Control Requirements for MSFC Space Flight Hardware

NASA-HDBK-5013A, Pyrovalve Application and Performance Handbook

NASA-SPEC-5022, NASA Manufacturing and Test Requirements For Normally Closed Pyrovalves for Hazardous Flight Systems Applications

NASA-STD-1008, Classifications and Requirements for Testing Systems and Hardware to Be Exposed to Dust in Planetary Environments

NASA-STD-3001, NASA Spaceflight Human-System Standard

NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment

NASA-STD-5001, Structural Design and Test Factors of Safety for Spaceflight Hardware

NASA-STD-5012, Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines

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NASA-STD-5017B, Design and Development Requirements for Mechanisms

NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware

NASA-STD-5020, Requirements for Threaded Fastening Systems in Spaceflight Hardware

NASA-STD-6001, Flammability, Offgassing, and Compatibility Requirements and Test Procedures

NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft

NASA-STD-7012, Leak Test Requirements

NASA-STD-8739.10, Electrical, Electronic, and Electromechanical (EEE) Parts Assurance Standard

NESC-RP-19-01498, Filtration of Spaceflight Propulsion and Pressurant Systems

NESC Technical Bulletin No. 09-01, Failure of Pyrotechnic Operated Valves with Dual Initiators

NESC Technical Bulletin No. 10-02, Potential Failure of Dual Simultaneously Initiated Pyrotechnic Operated Valves

B.2.2 Non-Government Documents

American Institute of Aeronautics and Astronautics (AIAA)

AIAA S-080, Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components

AIAA S-114A-2020, Moving Mechanical Assemblies for Space and Launch Vehicles

American Society of Mechanical Engineers (ASME)

ASME PTC 25, Pressure Relief Devices

ASTM International

ASTM D 395 – Standard Test Methods for Rubber Property—Compression Set

International Organization for Standards (ISO)

ISO 3601-3, Fluid power systems - O-rings - Part 3: Quality Acceptance Criteria

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IPC International

IPC J-STD-001, Requirements for Soldered Electrical and Electronic Assemblies

IPC J-STD-001 Addendum, Space and Military: Space and Military Applications Electronic Hardware Addendum to IPC J-STD-001H Requirements for Soldered Electrical and Electronic Assemblies

SAE International

SAE AS5752, Visual Inspection Standard for Elastomeric Sealing Elements Other than O-Rings

Other Documents

Leveille, A.; Murphy, J. (1973). *Determination of the Influence of Static Loads on the Output Torque of Instrument Ball Bearings*. Paper presented at the International Ball Bearing Symposium. The Charles Stark Draper Laboratory, Inc.: Cambridge, MA.

Park, W., et al. (1998). *Rolling Contact Fatigue and Load Capacity Tests of M62 Bearing Steel*. Proceedings of the 32nd Aerospace Mechanisms Symposium (NASA/CP-1998-207191). Mechanisms Education Association: Cocoa Beach, FL, 237-251.

Schroeder, J.R. (2010). *Demystifying the 2:1 Ratio and the Stick-Slip Phenomenon: A Technical Whitepaper Explaining the Theory Behind the Binding Ratio and How It Relates to Stick-Slip*. PBC Linear, a division of Pacific Bearing Company: Rockford, IL.

APPENDIX C: REQUIREMENTS IDENTIFICATION MATRIX

C.1 PURPOSE

Due to the complexity and uniqueness of space flight, it is unlikely that all the requirements in a Standard will apply. The Requirements Identification Matrix below contains this Standard's technical authority requirements and may be used by programs and projects to indicate requirements that are applicable or not applicable. Enter "Yes" in the "Applicable" column if the requirement is applicable to the program or project or "No" if the requirement is not applicable to the program or project. The "Comments" column may be used to provide specific instructions on how to apply the requirement, specify proposed tailoring, or provide an explanation/justification when not applicable.

Table 4—Requirements Identification Matrix

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.1.1.1	Dimensional Analysis	[VDVR 1] A dimensional analysis of all moving parts and intentional interference-fit parts shall be performed and documented to ensure that specified functional performance is maintained under worst-case environmental conditions and configurations.		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.1.1.2	Dimensional Analysis	[VDVR 2] The dimensional analysis shall account for the following: a. Manufacturing, assembly, and alignment tolerances. b. Temperature- and temperature-gradient-induced deformations or structural instabilities. c. Pressure- and pressure-gradient-induced deformations. d. Deflections due to vibration. e. Deformations or structural instabilities due to external loads, including gravity effects. f. Deflections due to operational loads. g. Deflections due to changes in pressurization. h. The full range of adjustability of the valve parts. i. Dimensional changes of non-metallic parts due to exposure to operating media. j. Dimensional changes due to corrosion and wear.		
4.1.2.1	Clearances	[VDVR 3] The valve dimensional envelope shall be specified in the valve's engineering documentation.		
4.1.2.2	Clearances	[VDVR 4] Valve internal allowable clearance ranges shall be established, documented, and maintained throughout the service life of the flight unit and throughout the life test.		
4.1.2.3	Clearances	[VDVR 5] The established clearances shall account for the following: a. The results of dimensional analysis per section 4.1.1. b. Environments arising from transportation. c. Allowable particulate contamination.		
4.1.3.1.1	General Torque and Force Margin Requirements	[VDVR 6] All torque and force margin requirements shall be applied under worst-case conditions throughout the valve's life, including throughout life testing.		
4.1.3.1.2	General Torque and Force Margin Requirements	[VDVR 7] Torque and force margins shall be calculated at both the input and output of devices multiplying or reducing torques or forces (e.g., gearboxes, strain wave gear drives, lever arms).		
4.1.3.1.3	General Torque and Force Margin Requirements	[VDVR 8] All torque and force margins shall be verified during an acceptance test at the highest possible level of assembly.		

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4.1.3.2	Static Torque and Force Margin	[VDVR 9] For all actively actuated valve functions, static torque and force margin per Equations 4-1, 4-2, and Table 1 shall be greater than zero within the valve mechanism’s full range of motion. $torque\ margin = \frac{T_{avail}}{\sum FS_f T_f + \sum FS_v T_v + \sum FS_a T_a} - 1$ (Equation 4-1) $force\ margin = \frac{F_{avail}}{\sum FS_f F_f + \sum FS_v F_v + \sum FS_a F_a} - 1$ (Equation 4-2) Table 1 – Minimum Safety Factors for Torque Margin Equation 4-1 and Force Margin Equation 4-2 <table><tr><th>Source of Torque Data</th><th>FS_v</th><th>FS_f</th><th>FS_a</th></tr><tr><td>Theory or analysis</td><td>3.00</td><td>1.50</td><td>1.25</td></tr><tr><td>Qualification test at environmental extremes</td><td colspan="3">See Note 1</td></tr><tr><td>Acceptance test at expected environmental extremes</td><td>2.00</td><td>1.25</td><td>1.10</td></tr><tr><td>Test evaluation of one-spring-out case²</td><td>1.00</td><td>1.00</td><td>1.00</td></tr></table> ¹ If the qualification unit undergoes acceptance testing before the qualification test campaign and meets the required torque or force margin with the acceptance test factors applied, then factors of safety of 1.0 applied to all resistive torques and forces are sufficient during operation under qualification environments. When qualification is performed without the qualification article first undergoing acceptance testing, a factor of safety is applied during the qualification testing. However, the margined environments under which qualification testing is performed will often add resistive torques or forces beyond that which will be encountered during acceptance testing or flight, and in some cases these additional resistive torque and forces can be large. In such cases, factors of safety less than the values listed for acceptance test may be appropriate. Analysis should be performed to determine the factors of safety to apply during qualification testing to ensure that the torque and force margins demonstrated during qualification testing match or exceed the torque and force margins demonstrated during acceptance testing. In the absence of such analysis, use the factors of safety for acceptance test at expected environmental extremes. ² When the torque or force margin of spring-driven mechanisms that use multiple springs in parallel to provide torque or force is evaluated by test for cases in which one of the multiple springs fails (the “one-spring-out case”), a minimum FS_f, FS_v, and FS_a of 1.0 may be used. Prior to a spring failure, the factors in the first three rows of Table 1 apply. Note that because using multiple springs in parallel for redundancy is distinct from designing a system to tolerate a failure of some portion of a single spring, the torque margin or force margin for a failure-tolerant single spring is evaluated with the same factor after failure as prior to failure. The one-spring-out factors do not apply to any case other than the use of redundant springs in parallel.	Source of Torque Data	FS_v	FS_f	FS_a	Theory or analysis	3.00	1.50	1.25	Qualification test at environmental extremes	See Note 1			Acceptance test at expected environmental extremes	2.00	1.25	1.10	Test evaluation of one-spring-out case ²	1.00	1.00	1.00		
Source of Torque Data	FS_v	FS_f	FS_a																					
Theory or analysis	3.00	1.50	1.25																					
Qualification test at environmental extremes	See Note 1																							
Acceptance test at expected environmental extremes	2.00	1.25	1.10																					
Test evaluation of one-spring-out case ²	1.00	1.00	1.00																					
4.1.3.3	Dynamic Torque and Force Margin	[VDVR 10] For all actively actuated valve functions, dynamic torque and force margin per Equations 4-1, 4-2, and Table 1 shall be greater than zero within the valve mechanism’s full range of motion.																						

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments						
4.1.3.4	Holding Torque and Force Margin	[VDVR 11] For all actively actuated valve functions, holding torque and force margins per Equations 4-1, 4-2, and Table 1 shall be greater than zero at the specified positions within the valve mechanism’s full range of motion.								
4.1.3.5.1	Stepper Motor Margin	[VDVR 12] Stepper motor torque margin shall be greater than zero within the valve mechanism’s full range of motion, using the appropriate allowable margin calculation method per Table 2, Stepper Motor Margin Calculation Methods. Table 2 – Stepper Motor Margin Calculation Methods <table> <tr> <th>Case</th> <th>Allowable Margin Calculation Methods</th> </tr> <tr> <td> When all of the following conditions are met: - The resistive torque due to friction is much greater than the torque needed to drive the inertia - The natural frequency of the spring-mass-damper system comprised of everything in the closed torque path is at least ten times greater than the stepping frequency - The driven inertia is not driven into a hard stop or spring stop - The stepper motor winding current flows for the full period of the step - A pull-in torque test is performed in the operating environments - The stepping frequency is not under closed-loop control </td> <td> - Pull-in torque margin analysis per Equations 4-1, 4-2, and Table 1 or - Torque margin analysis per Equations 4-1, 4-2, and Table 1 with T_{avail} derived from a stepper motor step response analysis </td> </tr> <tr> <td>All other cases</td> <td> - Torque margin analysis per Equations 4-1, 4-2, and Table 1 with T_{avail} derived from a stepper motor step response analysis </td> </tr> </table>	Case	Allowable Margin Calculation Methods	When all of the following conditions are met: - The resistive torque due to friction is much greater than the torque needed to drive the inertia - The natural frequency of the spring-mass-damper system comprised of everything in the closed torque path is at least ten times greater than the stepping frequency - The driven inertia is not driven into a hard stop or spring stop - The stepper motor winding current flows for the full period of the step - A pull-in torque test is performed in the operating environments - The stepping frequency is not under closed-loop control	- Pull-in torque margin analysis per Equations 4-1, 4-2, and Table 1 or - Torque margin analysis per Equations 4-1, 4-2, and Table 1 with T_{avail} derived from a stepper motor step response analysis	All other cases	Torque margin analysis per Equations 4-1, 4-2, and Table 1 with T_{avail} derived from a stepper motor step response analysis		
Case	Allowable Margin Calculation Methods									
When all of the following conditions are met: - The resistive torque due to friction is much greater than the torque needed to drive the inertia - The natural frequency of the spring-mass-damper system comprised of everything in the closed torque path is at least ten times greater than the stepping frequency - The driven inertia is not driven into a hard stop or spring stop - The stepper motor winding current flows for the full period of the step - A pull-in torque test is performed in the operating environments - The stepping frequency is not under closed-loop control	- Pull-in torque margin analysis per Equations 4-1, 4-2, and Table 1 or - Torque margin analysis per Equations 4-1, 4-2, and Table 1 with T_{avail} derived from a stepper motor step response analysis									
All other cases	Torque margin analysis per Equations 4-1, 4-2, and Table 1 with T_{avail} derived from a stepper motor step response analysis									
4.1.3.5.2	Stepper Motor Margin	[VDVR 13] When stepper motor detent torque is used to maintain rotor position in the presence of vibratory disturbances, detent stiffness and motor damping shall be considered when determining the holding torque margin.								

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.1.3.6	Servomechanism Margins	[VDVR 14] For servomechanism applications, control system performance margins shall be calculated in addition to meeting the applicable static torque and force margin, dynamic torque and force margin, holding torque and force margin, and stroke margin requirements.		
4.1.4.1	Stroke Margin	[VDVR 15] Stroke margins per Equation 4-3 shall be greater than zero for all valve mechanisms. $\text{stroke margin} = \frac{\text{output stroke of the actuator}}{\text{stroke required to achieve desired function}} - 1$ (Equation 4-3)		
4.1.4.2	Stroke Margin	[VDVR 16] Stroke margin shall account for worst-case credible combinations of the following: a. Environmental effects. b. Misalignments. c. Load-induced distortions. d. Trapped fluids. e. Pressure effects. f. Dimensional changes of non-metallic parts due to exposure to operating media. g. Dimensional changes due to corrosion and wear.		
4.1.5	Indication of Status	[VDVR 17] A direct indication of the critical states of each actively actuated valve shall be provided over the full range of valve operating and environmental conditions.		
4.1.6	Chatter	[VDVR 18] Valves shall not chatter within the range of operational conditions, including primary mission conditions as well as those encountered during component acceptance testing and processing conditions, such as purges.		
4.1.7	Mechanical Stop Incorporation	[VDVR 19] Non-jamming mechanical stops shall be incorporated into all valves where excess motion will result in detrimental effects to the valve or the overall fluid system.		
4.1.8	Ground Operations and Environments	[VDVR 20] Ground operations and ground environments shall be accounted for by one of the following: a. incorporating ground operations and ground environments into the valve specification, b. creating a ground operations constraints document, or c. a combination of a and b.		
4.1.9	Valve Contamination and Debris Tolerance	[VDVR 21] The valve shall meet all performance requirements after being exposed to the following: a. the materials, quantities, and size distributions of the contaminants entering the valve with the operating media as defined in the valve specification or provided by the program's technical authority, and b. the materials, quantities, and size distributions of the debris generated internally within the valve.		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.2.1	Valve Boundary Conditions	[VDVR 22] Valve engineering design and analyses shall account for the boundary conditions imposed by the installation of the valve, including: a. Stiffness. b. Mounting alignment tolerances. c. Temperature-induced distortions. d. Distortions induced by installation or externally applied loads, including from lines connected to the valve. e. Load-induced distortions. f. Pressure-induced distortions. g. Interface friction.		
4.2.2	Stall Conditions	[VDVR 23] Valves shall remain functional after exposure to actuator stall conditions at any point in their travel.		
4.2.3	Mechanical Stop Analysis	[VDVR 24] Valve components shall maintain positive structural margins of safety with the full design factors of safety applied when subjected to worst-case loads from contacting a mechanical stop, including structural dynamic effects.		
4.2.4	Creep and Stress Relaxation of Non-Metallic Parts	[VDVR 25] The effects of creep and stress relaxation of non-metallic parts on valve performance shall be analyzed or tested and accounted for in the valve design.		
4.2.5	Specification of Valve MEOP and MDP	[VDVR 26] The Valve Maximum Expected Operating Pressure (Valve MEOP) and Valve Maximum Design Pressure (Valve MDP), as defined by this document, shall be identified in the valve specification.		
4.3.1.1	Wire Color	[VDVR 27] All lead wires and insulated conductors in an electrical cable shall have different color insulation specified on the engineering drawings.		
4.3.1.2	Electrical Connectors	[VDVR 28] Valves utilizing multiple electrical connectors shall : a. use connectors configured to prevent incorrect mating (e.g., keyed connectors, different size connectors, etc.), and b. have each connector permanently marked with the identifier of the correct mating connector.		
4.3.2.1	Electrical Bonding	[VDVR 29] Gears shall not be used to carry electrical current.		
4.3.2.2	Electrical Bonding	[VDVR 30] Bearings shall not be used to carry electrical current.		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.4.1	Permeation Through Seals	[VDVR 31] Materials in regions of the valve that may be exposed to permeates shall be included in the material compatibility assessment of the valve.		
4.4.2	Galling Resistance	[VDVR 32] Sliding contacts in which material compatibility or contamination requirements prohibit lubrication shall use materials selected to minimize the potential for galling and cold welding.		
4.4.3	Interference Fits	[VDVR 33] Interference fitted joints shall employ the following process controls: a. Either (1) Dimensional verification that: A. the actual dimensions of every part being assembled meet drawing requirements, and B. the assembled parts are in the correct position and orientation. or (2) Logging of force versus distance during force fits, followed by comparison with acceptable force vs. distance envelopes. and b. Proof load testing, when a proof load can be applied in the direction of disassembly.		
4.4.4	Adhesive Bonding	[VDVR 34] Adhesive bond verification shall include a proof load test on witness specimens that use the same materials and processes and are processed at the same time as the hardware being verified.		
4.4.5	Verification of Cleanliness	[VDVR 35] A valve cleanliness plan that describes how the valve cleanliness requirements will be achieved and verified, and how clean valve hardware will be maintained clean shall be developed and maintained by the valve provider and approved by the program technical authority.		
4.4.6	Platings and Coatings	[VDVR 36] The use of platings and coatings to meet operating medium material compatibility requirements shall be approved by the specifying program technical authority.		
4.4.7	Radiation Susceptibility	[VDVR 37] Valves that will experience a high radiation environment shall be evaluated for potential performance degradation with a radiation susceptibility assessment that includes: a. A detailed analysis to determine the location-specific radiation exposure levels of critical valve components given the expected mission-specific radiation environment, intrinsic radiation shielding by the spacecraft, and valve body itself, b. Materials testing before and after radiation exposure if the calculated total ionizing dose is greater than the allowable material limit, and c. Valve-level radiation testing to determine in-situ performance degradation if the valve function is needed for safety or mission success.		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.5.1.1	Seals	[VDVR 38] Dynamic sealing surfaces for primary seals shall be axially separated from dynamic sealing surfaces for any backup seals and/or surfaces supporting loads by a distance larger than the stroke of the linear motion.		
4.5.1.2	Seals	[VDVR 39] All seal counterfaces shall be inspected to verify drawing requirements for dimensions, flatness, and surface texture (roughness, waviness, and lay).		
4.5.1.3	Seals	[VDVR 40] All seals shall be inspected prior to installation.		
4.5.1.4	Seals	[VDVR 41] The installation process of each seal in a valve shall be witnessed to ensure that it conforms to the procedure established for its insulation.		
4.5.1.5	Seals	[VDVR 42] Valves with redundant seal systems shall demonstrate required performance and margins in the cases where the primary seal is functioning properly, where the primary seal has failed, and the case where operating medium is trapped between the seals.		
4.5.1.6	Seals	[VDVR 43] Qualification and acceptance test plans that include a description of how redundant seal system performance will be qualification and acceptance tested shall be developed and maintained by the valve provider and approved by the program technical authority.		
4.5.1.7	Seals	[VDVR 44] When leakage of seals in a redundant seal system is independently verified during acceptance testing, a leak check port between seals shall be used.		
4.5.1.8	Seals	[VDVR 45] When leakage of seals in a redundant seal system is independently verified only during qualification testing without independent verification during acceptance testing, the following shall be performed for each seal used in the redundant seal system: a. Vibration qualification testing and subsequent leak testing that qualify the seal for the predicted ground and flight vibration level and duration. b. Thermal cycle qualification testing and subsequent leak testing that qualify the seal for the predicted thermal cycle magnitudes and life, including thermal transients. c. Pressure cycle qualification testing and subsequent leak testing that qualify the seal for the predicted pressure cycles from normal operation and surge. d. Operational life testing that qualifies dynamic seals for the predicted cycle life in applicable environments and with the flight operating medium, including the appropriate life test factor per section 4.6.1.2.		
4.5.1.9	Seals	[VDVR 46] An analysis of the gland design of each seal used in the valve shall be provided as part of verification documentation.		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.5.1.10	Seals	[VDVR 47] Moving parts shall be supported by bearings or guides designed to carry all operational loads, including vibration-induced loads, pressure-induced forces, and thermally-induced loads.		
4.5.2.1	Lubrication	[VDVR 48] All surfaces in contact for which friction under relative motion negatively affects performance of the valve shall be lubricated except surfaces for which material compatibility or contamination requirements prohibit lubrication.		
4.5.2.2	Lubrication	[VDVR 49] The selection of lubricants for valve mechanisms shall include the following considerations: a. The effect of the service environments (ground storage conditions, pressure, temperature, radiation, dust, humidity, salt spray, etc.) on lubricants and their properties. b. Migration properties of wet lubricants. c. Viscosity index (variation of viscosity with temperature) of wet lubricants. d. Elastohydrodynamic (EHD) film thickness if operating in the EHD lubrication regime. e. Protection against galling and friction welding in the boundary lubrication regime. f. Outgassing and breakdown products from wet lubricants that could contaminate sensitive surfaces. g. Polymerization of wet lubricants, particularly due to high contact pressures. h. Lubricant purity and filtration level. i. Lubricant depletion for wet lubricants. (This is typically handled through a “lubrication loss analysis” which considers evaporation, migration, consumption, fling, and wash-out.) j. Lubricant wear-out for dry lubricants. k. Generation and management of dry lubricant wear debris. l. Compatibility of each lubricant with other lubricants and other materials (substrates, platings, coatings, flow media, downstream components, catalyst beds, and preservative or shipping oils). m. Exposure to propellant or propellant vapor. n. Interaction with pyrotechnic materials and their reaction products (blowby). o. Temperature limits of the lubricants. p. Corrosion protection of the mechanism. q. Contact stress. r. Friction coefficient needed. s. The effect of wear debris on wet lubricant properties and valve performance.		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments																
4.5.2.3	Lubrication	[VDVR 50] An evaporative loss analysis shall be performed to show that 90 percent of the initial liquid lubricant quantity remains at end of service life, not including lubricant degradation.																		
4.5.2.4	Lubrication	[VDVR 51] The lubricant application process for every lubricant used, including lubricant quantity, application method, and verification of quantity, shall be specified in the engineering documentation.																		
4.5.3.1	Bearings and Linear Guides	[VDVR 52] The mean Hertzian contact stress on the most highly loaded element in a rolling element bearing shall remain less than or equal to the appropriate values in Table 3, Allowable Contact Stress for Bearing Materials Under Non-Operational Yield Design Loads, when subjected to the non-operational yield design load. Table 3—Allowable Contact Stress for Bearing Materials Under Non-Operational Yield Design Loads <table><tr><th rowspan="2">Bearing Material</th><th rowspan="2">Hardness Range (in Rockwell C [HRC])</th><th>Mean Hertzian Contact Stress</th></tr><tr><th>Non-Quiet Running Applications*</th></tr><tr><td>440C Steel</td><td>58-62 HRC</td><td>2760 MPa (400 ksi)</td></tr><tr><td>52100 Steel</td><td>60-63 HRC</td><td>2960 MPa (430 ksi)</td></tr><tr><td>M50 Steel</td><td>62-64 HRC</td><td>2960 MPa (430 ksi)</td></tr><tr><td>M62 Steel</td><td>66-69 HRC</td><td>4070 MPa (590 ksi)</td></tr></table> NOTE: For hybrid bearings using silicon nitride rolling elements with steel rings, the allowable contact stress will be that of the steel used. * Rolling element bearings in valve applications are assumed not to be quiet running applications, i.e. are assumed not to require high precision or low torque ripple performance. If high precision or low torque ripple performance is required, refer to NASA-STD-5017B, Section 4.9.6.	Bearing Material	Hardness Range (in Rockwell C [HRC])	Mean Hertzian Contact Stress	Non-Quiet Running Applications*	440C Steel	58-62 HRC	2760 MPa (400 ksi)	52100 Steel	60-63 HRC	2960 MPa (430 ksi)	M50 Steel	62-64 HRC	2960 MPa (430 ksi)	M62 Steel	66-69 HRC	4070 MPa (590 ksi)		
Bearing Material	Hardness Range (in Rockwell C [HRC])	Mean Hertzian Contact Stress																		
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4.5.3.2	Bearings and Linear Guides	[VDVR 53] For materials other than those listed in Table 3, an allowable contact stress shall be determined.																		
4.5.3.3	Bearings and Linear Guides	[VDVR 54] Bearing fatigue life calculations shall be based on the L0.05 life when subjected to maximum time-varying loads consistent with the conditions under which the L0.05 life was determined.																		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.5.3.4	Bearings and Linear Guides	[VDVR 55] The upper and lower extremes of the ball bearing contact ellipses shall be contained by the raceways.		
4.5.3.5	Bearings and Linear Guides	[VDVR 56] All ball bearings shall be preloaded with the following exceptions: a. Four-point (gothic arch) bearings. b. Deep groove ball bearings for which it can be shown that the absence of preload on the deep groove ball bearing is not detrimental to the performance of the mechanism. c. Wave generator bearings in strain wave gearing.		
4.5.3.6	Bearings and Linear Guides	[VDVR 57] If axial sliding of a bearing ring is needed to maintain preload and/or prevent axial overload, the sliding interface shall be designed to operate as a linear sliding bearing over the range of qualification environmental limits, including lubrication to reduce wear and sliding friction forces to acceptable levels throughout the service life.		
4.5.3.7	Bearings and Linear Guides	[VDVR 58] Ball bearing preload shall be measured once all the assembly steps that establish or affect bearing preload have been completed.		
4.5.3.8	Bearings and Linear Guides	[VDVR 59] Mechanisms utilizing guides or linear bearings to constrain a carriage to move in its length direction shall use a length-to-width ratio of 2:1 or greater, unless it can be shown by analysis that a length-to-width ratio of less than 2:1 will not cause the mechanism to bind or undergo stick-slip motion taking into account the following: a. Possible friction coefficients. b. Contact forces. c. Actuating forces. d. Dynamically induced forces. e. Misalignments. f. Eccentric loading.		
4.5.4.1.1	Brushless Direct Current (BLDC) Motors	[VDVR 60] Each BLDC motor shall have the following characteristics measured (or calculated from measured values): a. Torque constant (K_t). b. Motor constant (K_m). c. Torque versus speed curve using flight-representative drive electronics. d. Phase resistances. e. Phase inductances. f. End-to-end commutated torque performance.		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.5.4.1.2	Electronically Commutated (EC) Brushless Motors	[VDVR 61] The minimum measured torque output from each BLDC motor shall be verified using flight-representative drive electronics.		
4.5.4.2.1	Stepper Motors	[VDVR 62] Each stepper motor shall have the following performance characteristics measured: a. Powered breakaway torque. b. Unpowered (detent) torque versus angle for a full rotation. c. Pull-in torque with representative inertia, friction loads, and step rates. d. Pull-out torque with representative inertia, friction loads, and step rates. e. Step accuracy. f. Detent to powered torque null alignment. g. Phase resistances. h. Phase inductances.		
4.5.4.2.2	Stepper Motors	[VDVR 63] Stepper motor testing shall use flight or flight-representative drive electronics.		
4.5.4.3.1	Electrically Powered Actuators	[VDVR 64] The maximum allowable temperature limits of the windings and other materials in the assembly of electrically powered valve actuators as well as the times to reach those temperature limits shall be established.		
4.5.4.3.2	Electrically Powered Actuators	[VDVR 65] Electrically powered valve actuator temperature limits shall not be exceeded for the worst operational cases in the worst-case qualification environments.		
4.5.5	Springs	[VDVR 66] Springs shall be failure tolerant unless spring failure can be shown to be non-credible.		
4.5.6	Gears	[VDVR 67] Gear trains shall demonstrate that they meet performance requirements, accounting for the worst-case combinations of each of the following conditions, throughout the service life of the mechanism: a. Tooth pitting, brinelling, bending fatigue, and bending strength under nominal and peak operating loads. b. Impact tooth loads from maximum combined axial, radial, and moment loads sustained during the full life cycle of the mechanism. c. Backlash. d. Effects of temperature and temperature gradients on quality of lubrication and gear contact pattern. e. Effects of tooth geometry. f. Undercutting and tooth profile modifications. g. Gear mounting, misalignment, and face load distribution. h. Variation in operating center distance.		

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4.5.7.1	Switches	[VDVR 68] Switch mounting, orientation, and actuation shall be such that the switch cannot physically impede mechanism travel.		
4.5.7.2	Switches	[VDVR 69] The worst-case maximum travel of switch actuating features shall not damage the switch.		
4.5.8.1	Set Screws	[VDVR 70] Set screws shall not be used to transmit torque between a shaft and a component mounted on the shaft.		
4.5.8.2	Retaining Rings	[VDVR 71] All retaining rings used shall be multiple-turn spiral-wound retaining rings.		
4.5.9.1	Verification of Filter Holding Capacity	[VDVR 72] The holding capacity of all filters used in a valve shall be test verified with dust per ISO 12103.		
4.5.9.2	Verification of Filter Performance	[VDVR 73] Valve qualification and acceptance testing shall be performed with any valve filters and/or FOD screens present.		
4.5.9.3	Documentation of Generated Contaminants	[VDVR 74] The size, quantity, and characteristics of particulate matter generated by the valve during life cycle testing shall be recorded as part of qualification activities.		
4.5.10	Marking of Flow Direction	[VDVR 75] The primary direction of flow intended for the valve shall be indicated by visibly labeling the inlet and outlet ports on the exterior of the valve.		
4.6.1.1.1	General Qualification Testing Requirements	[VDVR 76] Each valve design shall be subjected to qualification testing that exposes the valve to all environments and operating media that it will experience during its service life.		
4.6.1.1.2	General Qualification Testing Requirements	[VDVR 77] Each valve shall be subjected to environmental qualification testing in the valve's appropriate configuration (e.g., open or closed) and operating or non-operating state.		

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4.6.1.1.3	General Qualification Testing Requirements	[VDVR 78] Valve qualification testing shall be conducted with mounting interface boundary conditions that replicate the flight boundary conditions, including the following: a. Stiffness. b. Mounting alignment and tolerances. c. Thermal distortions. d. Distortions induced by installation or externally applied loads, including from lines connected to the valve.		
4.6.1.1.4	General Qualification Testing Requirements	[VDVR 79] Inspections of the valve shall be conducted prior to the start of qualification testing and after valve disassembly at the conclusion of qualification testing.		
4.6.1.1.5	General Qualification Testing Requirements	[VDVR 80] Performance tests shall be conducted both at the start of qualification testing and at the conclusion of qualification testing, prior to the performance of testing with known destructive potential (e.g., a static test to ultimate loads).		
4.6.1.1.6	General Qualification Testing Requirements	[VDVR 81] Pass-fail criteria and the rationale for those pass-fail criteria shall be established for all qualification tests prior to the start of qualification testing.		
4.6.1.1.7	General Qualification Testing Requirements	[VDVR 82] Qualification performance tests shall be performed with the operating medium used in service.		
4.6.1.2.1	Life Testing	[VDVR 83] Life testing shall be performed on all valve functions to verify that each valve function meets its life requirement.		
4.6.1.2.2	Life Testing	[VDVR 84] Valves whose failure could result in a loss of human life shall be life tested to a number of cycles determined by multiplying the total of all cycles in the valve's required service life by a minimum life test factor of 4.0.		
4.6.1.2.3	Life Testing	[VDVR 85] All other valves shall be life tested to a number of cycles determined by multiplying the total of all cycles in the valve's required service life by a minimum life test factor of 2.0.		

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4.6.1.2.4	Life Testing	[VDVR 86] Life testing shall include a number of cycles under the expected operating environmental extremes, exposure to operating media, loads, pressures, ranges of motion, and speeds that is representative of the number of cycles at those conditions expected in the service life of the valve.		
4.6.1.2.5	Life Testing	[VDVR 87] The life test shall include the operation of bearings under the maximum predicted operational contact stress for the number of cycles predicted to experience maximum operational contact stress in flight multiplied by the life test factor specified by section 4.6.1.2.2 or section 4.6.1.2.3 of this Standard.		
4.6.1.2.6	Life Testing	[VDVR 88] Life testing shall include intentionally running into any mechanical stops present in the valve during each test cycle.		
4.6.1.2.7	Life Testing	[VDVR 89] When a protoflight approach is used, the life test shall be performed on a dedicated valve unit that has been exposed to all environments and levels encountered by the flight valve unit during its service life.		
4.6.1.2.8	Life Testing	[VDVR 90] A performance test shall be conducted before the first and after the last cycle of the life test.		
4.6.1.3	Exposure Testing	[VDVR 91] As part of their qualification test program, all assembled valves shall: a. undergo an initial performance test, b. be exposed—at the expected temperature, pressure, and cumulative duration—to any operating medium to which the valve will be exposed during its service life, and c. undergo a second performance test following exposure.		
4.6.2.1	Acceptance Testing	[VDVR 92] Each valve shall be subjected to environmental acceptance testing that exposes the valve to all environments that it will experience in service.		
4.6.2.2	Acceptance Testing	[VDVR 93] Each valve shall be subjected to environmental acceptance testing in the valve's appropriate configuration (e.g., open or closed) and operating or non-operating state.		
4.6.2.3	Acceptance Testing	[VDVR 94] A run-in test shall be performed on each valve prior to undergoing any other acceptance testing.		
4.6.2.4	Acceptance Testing	[VDVR 95] The run-in test shall be conducted for at least 15 cycles or five (5) percent of the total expected service life, whichever is greater.		
4.6.2.5	Acceptance Testing	[VDVR 96] The run-in test conditions shall be representative of the operational loads, speed, and environment.		
4.6.2.6	Acceptance Testing	[VDVR 97] Inspection of the valve and valve performance tests shall be conducted after run-in testing prior to further acceptance testing, and at the conclusion of acceptance testing.		

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4.6.2.7	Acceptance Testing	[VDVR 98] Pass-fail criteria for all acceptance tests and the rationale for those criteria shall be established prior to the start of acceptance testing.		
4.6.3.1	Performance Test and Leak Test Parameters	[VDVR 99] Performance and leak tests shall be performed in all operating environments under the worst-case conditions for each environment.		
4.6.3.2	Performance Test and Leak Test Parameters	[VDVR 100] All valve mechanism functions shall be exercised during performance testing.		
4.6.4	Demonstration of Margin Against Chatter	[VDVR 101] Passively actuated valves shall undergo testing as part of qualification or development to demonstrate flow rate margin against chatter under operating conditions.		
4.6.5	Test Electronics	[VDVR 102] Valve testing shall use flight or flight-representative drive electronics.		
4.7.1.1	PIV Requirements	[VDVR 103] NC PIVs shall incorporate an all-metal permanent valving element (i.e. internal flow barrier) without mechanical joints that is impermeable to the internal leakage of the operating medium across the element and exhibits pre-operation leak rates less than 1×10^{-6} standard cubic centimeters per second of gaseous helium across the ranges of operating pressures for which the valve is intended to operate.		

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4.7.1.2	PIV Requirements	[VDVR 104] PIV qualification testing shall include actuation of the PIV after exposure to all relevant environments and operating conditions, with the test setup and test campaign possessing the following key attributes: a. Use of flight-representative drive electronics, commanding software/controller avionics, and power source elements at worst-case voltages. b. Testing at worst-case thermal conditions. c. Use of a flight-representative mounting configuration for the PIV onto a flight-representative structure and interfacing tubing with flight-representative upstream and downstream volumes. d. Use of ground test instrumentation to characterize the PIV mechanical environment produced by actuating the valve and transmitted to the interfacing tubing, mounting structure, and adjacent fluid system components. e. Exposure to flight-representative environmental conditions and operating media, including liquid- and/or vapor-phase media as applicable, during PIV actuation. f. Evaluation of worst-case pressure transients resulting from the actuation of all PIVs contained within the fluid system. g. For pyrovalves, evaluation of worst-case command timing for the firing of redundant initiators contained within the pyrovalve and evaluation of worst-case command timing for the actuation of redundant pyrovalves contained within the fluid system.		
4.7.2.1	Pyrovalve Requirements	[VDVR 105] Pyrovalves shall not use titanium or its alloys as materials of construction in pyrovalve bodies, or aluminum or its alloys as materials of construction in pyrovalve primer chamber assemblies (PCAs).		