PREFERRED RELIABILITY PRACTICES

MARMAN CLAMP SYSTEM DESIGN GUIDELINES

Guideline:

Reliable payload and component separation systems are fundamental to any space vehicle program. Marman clamp systems are one of the most popular systems in use today and very little more is known about them now than when they were first introduced. The best tool when designing and using these systems is the understanding of the analysis and test data of proven designs and the case histories of what has or has not worked in the past. Although these systems are forgiving, there have been enough marman clamp system failures, unfortunately poorly documented in the public domain, that extreme care should be exercised in any design. New marman clamp separation system designs should be supported with an extensive development test program.

Benefit:

Incorporating information contained in this guideline will increase the reliability of marman clamp separation systems.

Center to Contact for More Information:

Goddard Space Flight Center (GSFC)

IMPLEMENTATION METHOD:

The marman clamp separation system, shown in Figure 1, consists of a tension strap, which creates inward radial forces on V-segments, which in turn wedge together the flanges of the cylindrical structures in the axial direction. Figure 1 depicts the typical components of a marman clamp separation system and defines the nomenclature that is used in this Guideline. In order to design a reliable marman clamp system the following items should be implemented:

1.Release Devices

To increase the reliability of a separation system use more than one actuation device in a truly redundant arrangement. Selection of a release device should be based on its minimum available energy to precipitate separation, with ample margin. The system components however, should be designed for the maximum possible release energy, with appropriate factors of safety such as for load distribution and material properties.

MARMAN CLAMP SYSTEM DESIGN GUIDELINES

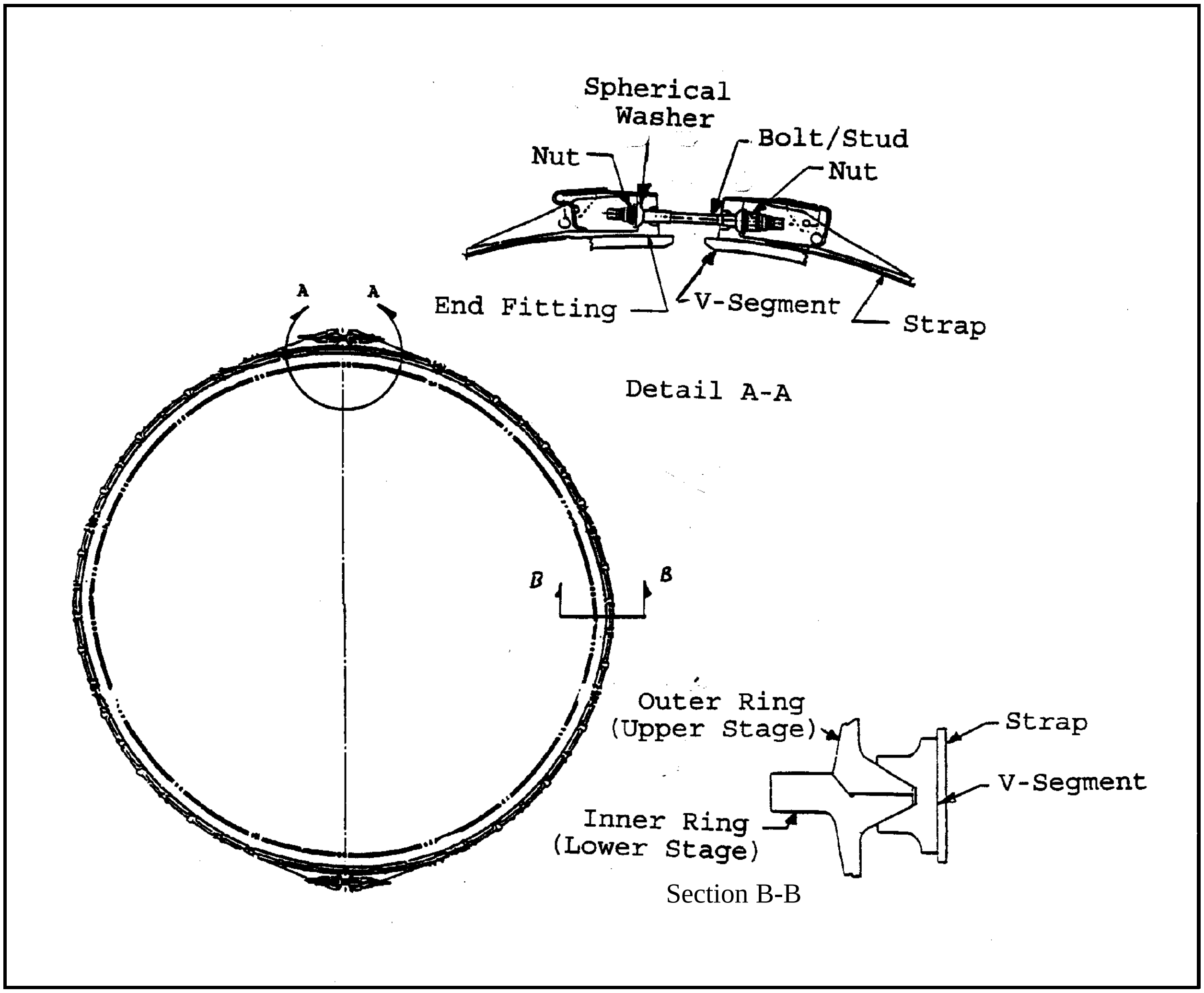

Figure 1. Typical Marman Clamp System

2.Friction Control

For marman clamps low friction is desirable; however, of more relevance is friction <u>control</u>, which results in repeatability and predictability. Friction at the V-segment-to-ring interface reduces the required clamping strap preload, so it is most conservative to neglect it in preload calculations. High friction also results in lower reliability. Testing may increase confidence in an assumed friction coefficient but cannot guarantee it. Virtually all separation systems utilize solid-film lubricants such as MoS_2 to control friction.

MARMAN CLAMP SYSTEM DESIGN GUIDELINES

For all contact and sliding surfaces materials that gall or cold weld are to be avoided. Similar materials should not be in contact with each other. The use of proven lubrication substances is strongly recommended, and care must be taken as some sliding surfaces are under high contact stress. Contact and faying surfaces should have a surface finish of 1.6μm RMS or less.

The friction between the strap and the V-segment must be minimized to achieve a uniform hoop loading in the strap. Teflon, due to its cold-flow tendency, is not recommended. Solid-film lubricants, such as Dicronite DL-5 [Rotary Components, INC.; MIL. STD. DOD-L-85645], have been used with success.

Strap-end mechanisms should be allowed to rotate freely as the strap is preloaded in order to minimize local bending effects. End fittings should incorporate spherical washers to reduce bolt bending and bolt stresses. These components should be lubricated to reduce torsional shear, bending and axial stress. Aerospace greases, such as Apiezon N, Krytox 283-AC, and MoS_2 are recommended. Special surface finishes, such as silver-plating on A-286 steel, can be beneficial. All friction values used should be justified and shown to be repeatable.

It is not recommended to use high friction to transmit the primary spacecraft transverse shear and torsion forces across the clamped joint interface. It is preferable to utilize lips, pins or splines to transmit the shear across the separation plane. Interface torsion can be reacted by keying V-segments to the ring, midway between tensioning devices. This will prevent overloading the key during strap installation.

3.Separation Dynamics

Angular tip-off rates should be minimized, both for orbital accuracy considerations and to prevent re-contact with the separated stage. All separation forces, either primary (kick-off springs), or secondary (switches, electrical connectors), should be as symmetrical as possible. Redundant components and springs, including dummy ones if used, should be placed symmetrically. Springs should be used in matched sets. They should be bench-tested, matched and bagged together. The nearest equal-force springs should be placed oppositely in the separation plane.

Special care should be taken to protect adjacent components from contamination. Release devices should be limited to those that have integral chambers to preclude release of gasses or fragments. Any intentionally released or fractured parts(severed bolts, frangible nuts) should be suitably restrained.

A tethering system can preclude re-contact of the separated clamp with the upper stage. Use lanyards whose straps cannot rotate upwards, springs (to pull the released clamp away from the upper stage), energy dissipators (to cushion any impact), and caging devices (to prevent rebound of the flailing straps). Care must be taken to assure that the tethering system does not interfere with separation itself.

Marman clamps smaller than about ½m in diameter should have two release devices, 1½m in diameter three release devices, 2⅓m in diameter four devices. Straps larger than 2⅓m have seldom been used. A single strap is <u>not</u> recommended. It is recommended that the active strap separation devices be symmetric, even though it is unlikely they will fire at exactly the same instant.

4.System Strength and Stiffness

Unlike most structural parts, marman clamp system components are subject to near design loads during the installation process. The detailed strength evaluation of all structural components of a marman clamp system should be completed following the stress analysis procedures given in Related Practice 1.

One of the areas of significant concern is the in-plane loads on the clamp rings, which include the radial distributed load plus the loads imposed by the tensioning/release mechanisms (see Figure 2). Tensioning the strap is done by torquing two or more bolts equally spaced around the strap circumference. Since the diametrical location of the strap centroid and loading device are not the same, there will be local radial forces adjacent to the tensioning device to transition the bolt force to the strap centerline. Figure 3 shows free-body diagrams of a typical design. There are two distinct design problems:(1) the non-uniform ring loading, and (2) the higher stresses in the rings under the tensioning/release mechanisms. Side and bending loads may be minimized by maintaining perpendicularity of tensioning and joining bolts to strap end details, e.g. bathtub fittings. Bolt heads and nuts must seat flush to prevent bending in the bolts and fittings. Figure 1, Detail A-A, shows a typical design of strap ends to minimize undesirable stresses. An extremely important aspect of this design is the relationship between the strap attachments, the tensioning bolt and the bath-tub fitting. To preclude tension on the <shear> fasteners the fastener shear load line should intersect the tensioning bolt centerline in the middle of the fitting end pad, which should put it in line with the radial force vector line, I. e., all three forces vectors are concurrent.

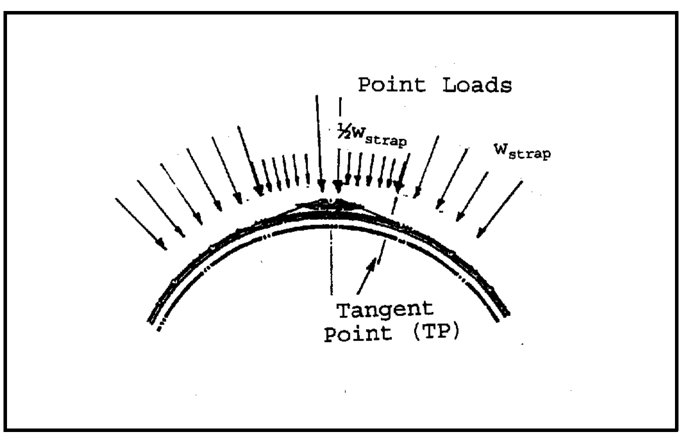

Figure 2. Ring Radial Loading

MARMAN CLAMP SYSTEM DESIGN GUIDELINES

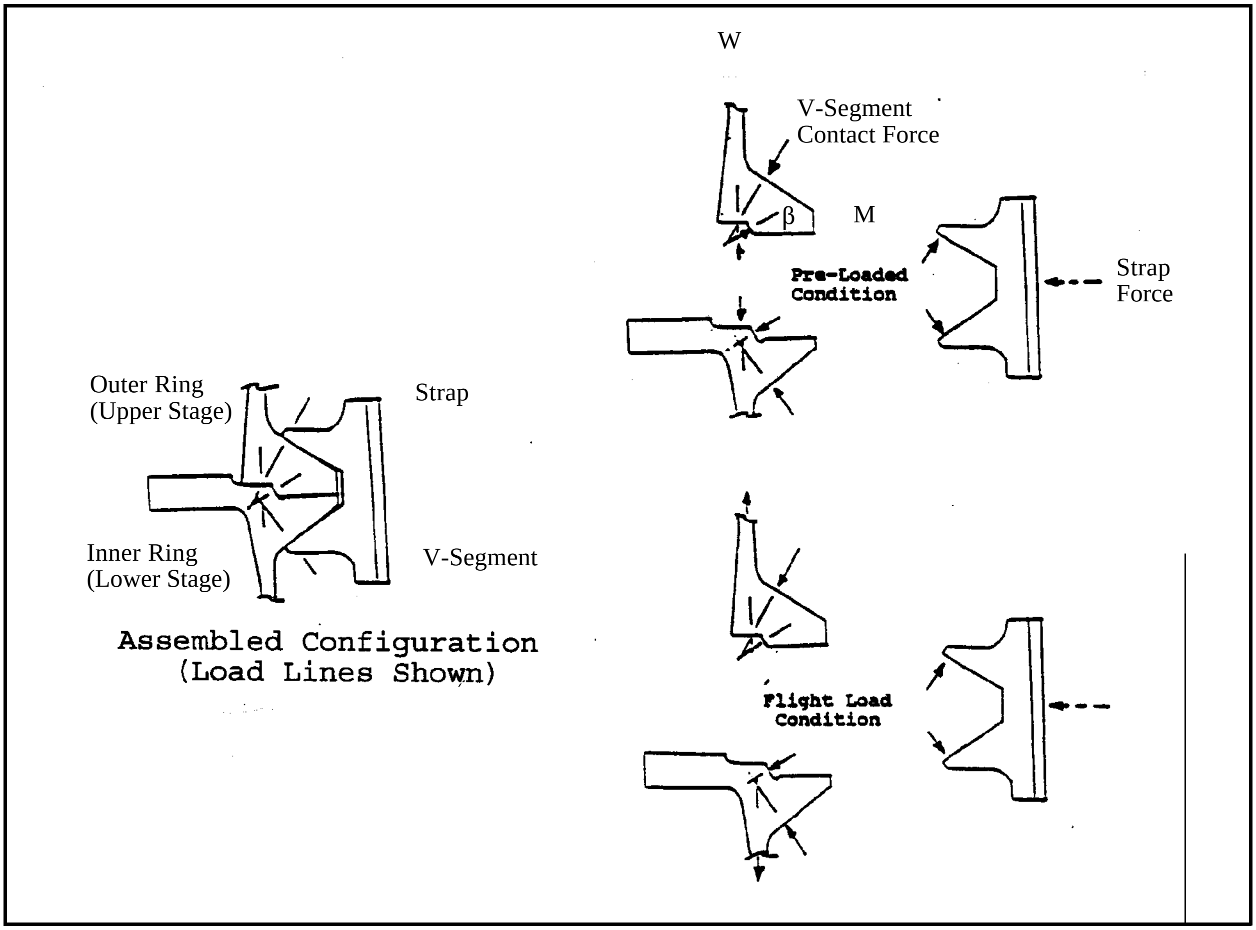

Figure 3. Clamp System Load Lines

It is recommended that the two rings be within 70% of each other in radial and torsional (roll) stiffness, Reference 2.

The following equation, based on a simple summation of the static longitudinal forces, has been commonly used to determine the strap load:

$$\text{Strap Load} = wD(\tan\beta - \mu)/(1 + \mu\tan\beta)$$

where w = line load (force/unit circum. length)= $w_{axial} + w_{moment}$, $w_{axial} = F_{axial}/\pi D$, $w_{moment} = 4M/\pi D^2$, F_{axial} = longitudinal force at sep. plane, M = moment at sep. plane, D = characteristic ring dia.,ß= angle of ring flange, and μ = Coefficient of friction. For no friction the equation would be

$$\text{Strap Load} = wD\tan\beta$$

MARMAN CLAMP SYSTEM DESIGN GUIDELINES

The criterion for designing strap preloads is that no gapping occurs when the maximum expected load is applied.

5.Installation Procedures

Nearly uniform strap tensioning can be achieved by alternate and incremental loading of the tensioning devices. After each increment the strap assemblies are tapped successively around the periphery starting at the tensioned end to equalize the strap load. Much of the tensioning load will be reacted by friction between the strap and V-segment and in turn the V-segment and ring. The tool used to tap the strap should be firm, yet resilient enough to prevent physical damage to the metal.

It is recommended that the strap be instrumented with strain gaging on the outer surface and monitored during installation to verify that the strap load is nearly uniform. This will also allow periodic monitoring for load relaxation.

Conventional bolt torque methods is not sufficiently accurate for marman clamp installation. Satisfactory methods include load-indicating washers under the bolt heads or nuts, strain-gaged bolts (with multiple strain gages to minimize false readings) or Strainserts (bolts internally instrumented by the manufacturer). If force washers are used care must be taken to eliminate bolt bending to preclude false readings.

For safety of personnel, protective apparatus should be provided during the installation procedure. The stored energy in the straps is usually high enough to cause serious injury should failure occur.

6. Integrated Design Considerations

There should be no significant loads introduced in the joint other than those directly associated with the strap tension and primary carry-through flight loads. Avoid non-cylindrical mating structures, other significant local forces and non-uniform circumferential stiffnesses.

7. Materials and Procedures

Typical system designs consist of aluminum rings; aluminum, annealed titanium or CRES steel V-segments; a CRES steel strap; and CRES steel for fasteners and other details. Flight history has shown these materials to be structurally forgiving.

MARMAN CLAMP SYSTEM DESIGN GUIDELINES

It is recommended that high stress-corrosion-resistant materials be used throughout the design of the separation system. Materials from Reference 3, Table I, and Reference 4, A-rated, that have high elongation are recommended for the strap.

Hydrogen embrittlement must be avoided by not using cadmium plating or other electroplating finishes on sensitive alloys or if used, adequate bake-out procedures should be followed.

It is recommended that the strap joints be made with mechanical attachments rather than welding. If a trunnion configuration is used, all attachments should be beyond the tangent point of the outer strap section (see Figure 2) to preclude significant tension loads on the joint. Recognition should be given to the non-equal forces in the mechanical attachments.

8. Design Details

The entire flight/ground environment should be considered in the design of the system components, including (1) the STS return ground soak condition which affects the strap load and (2) thermal soak during flight, e. g. delayed staging. Thermal excursions alter the strap loads since the strap and rings are usually dissimilar materials.

The angle between the interface plane and the clamped flange sloped edge is usually in the 15° to 20° range. Flange angle less than 15° requires extremely good friction control. Larger angles, although not as serious a risk, require substantial increases in preload.

Short V-segments will minimize load peaking between the V-segment and ring although at greater weight and cost.

Design the connection between the V-segment and strap so that adequate relative motion is allowed, otherwise the attachment may fail during installation (with no obvious warning), resulting in a loose part upon separation.

For personnel safety it is recommended that the strap be manufactured from a highly ductile material and the assembly be designed to be strain-limited[1]. The "weak link" in the system should be the typical strap section rather than a low strain-energy item such as the tensioning bolt or a local strap detail. The local stresses around the fittings and strap joints are <u>significantly</u> less critical than the strap typical section.

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[1]The component with most of the strain energy, the strap, is the critical component and will exceed its proportional limit prior to any other component in the system. Obviously, this is contingent on the strap having a high elongation.

MARMAN CLAMP SYSTEM DESIGN GUIDELINES

Technical Rationale:

Since we still do not know all that happens with marman clamp systems we need to rely on experience. Confidence levels may be high if no major deviations from previous successful designs have been employed and if the design parameters fall within the range of current experience.

Impact of Nonpractice:

Not considering the wide range of technical and safety issues for a marman clamp separation system may lead to failures of the flight systems during installation, testing or flight. Failures of the marman clamp system include a non-release, a partial separation resulting in an unstable payload, a premature release, or a late release. Any of these conditions could lead to mission failure and could also jeopardize personnel safety.

Related Guidelines & Practices:

1. "Structural Stress Analysis," NASA Preferred Reliability Practices, Practice No. PD-AP-1318.

References:

1. GSFC Engineering Directorate paper "Spacecraft Deployable Appendages," May, 1992.
2. GOES-IJK Separation System Study, Astrotech Space Operations, Inc., for Ford Aerospace & Communications Corporation, February 12, 1987.
3. Design Criteria for Controlling Stress Corrosion Cracking, NASA/MSFC, MSFC-SPEC-522B.
4. Material Selection List for Space Hardware Systems, JSC 09604/MSFC-HDBK-527.