THERMAL DISTORTION TESTING OF A 90-DEGREE DEPLOYMENT HINGE

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ABSTRACT

Virtually all modern spacecraft have at least one (if not many) deployable items, some of which require a high degree of positional accuracy and repeatability. There are many variables that affect the deployment performance, and often the most critical and difficult variable to quantify is the affect of the thermal environment on the deployment mechanisms. Temperature changes before and after deployment can greatly affect the final deployment position and the subsequent thermal distortion of the mechanism, and it is critical to properly quantify these factors. Historically the affects of temperature change on deployment mechanisms have been evaluated via analysis due to the relative cost and difficulty in performing a test. However, during the design process of a recent Lockheed Martin deployment hinge, the engineers wanted to provide their customer with a more reliable empirical assessment. Thus, it was decided to conduct a thermal distortion and repeatability test on the hinge during the qualification phase. Testing of this nature is very rare for relatively inexpensive deployment hinges and is usually reserved for high precision, actively–latched optical hinges. Results of this testing are presented, along with lessons learned when performing the test.

1. INTRODUCTION

The Lockheed Martin HA-90 (High Accuracy 90 degree) hinge is a commercially available deployment mechanism designed for the deployment of antenna systems and instruments that require a relatively high degree of deployment accuracy and repeatability (±3 arc-minutes). The mechanism is constructed from typical aerospace materials (aluminum 7075, titanium 6AL-4V, 300 series steels), and has a cam-type latch (see Figure 1). The repeatability and accuracy of the hinge is primarily achieved via 2 pairs of precision angular contact bearings. Damping is provided by a viscous fluid damper (DEB model 1025).

A thermal distortion requirement is usually added to the specification for any new deployment hinge design. Due to the expense and difficulty in performing a thermal distortion test, analysis is typically used to verify the requirement (via finite element structural/thermal modeling). Although thermal distortion modeling is usually accurate for static structural applications, the analysis is highly questionable when applied to a mechanism. Moving components in mechanisms (shafts, bearings, latches, linkages) complicate the distortion analysis significantly and to truly accept the results of the analysis would require test data to verify the results. During the design phase of the HA-90 hinge, the analysis verification method for the distortion requirement was questioned and subsequently an HA-90 hinge thermal distortion test was planned.

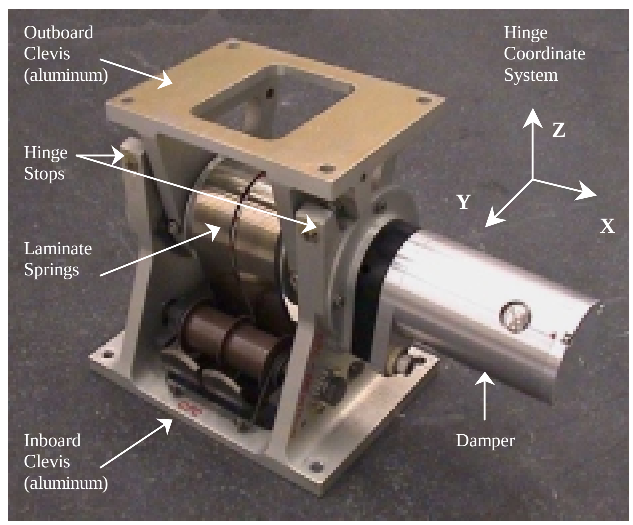


FIGURE 1: HA-90 Hinge

2. TEST DESCRIPTION

The overall goal of the hinge thermal distortion testing was to quantify the hinge positional repeatability and thermal distortion through multiple deployments with varying lock-up loads and temperatures (between -86 and +100 deg C). The hinge coordinate system is shown in Figure 1. The testing was designed to quantify the thermal distortion and deployment repeatability about all three hinge axes. The test was conducted by placing the hinge inside a foam thermal box (no vacuum). Heating was achieved via a set of high wattage radiative heat lamps, and cooling was achieved by flowing liquid nitrogen into the base of the box. Internal fans were used to circulate air in the box, allowing for a uniform temperature. Optical cubes and theodolites were used to measure the hinge distortion (see Figure 2).

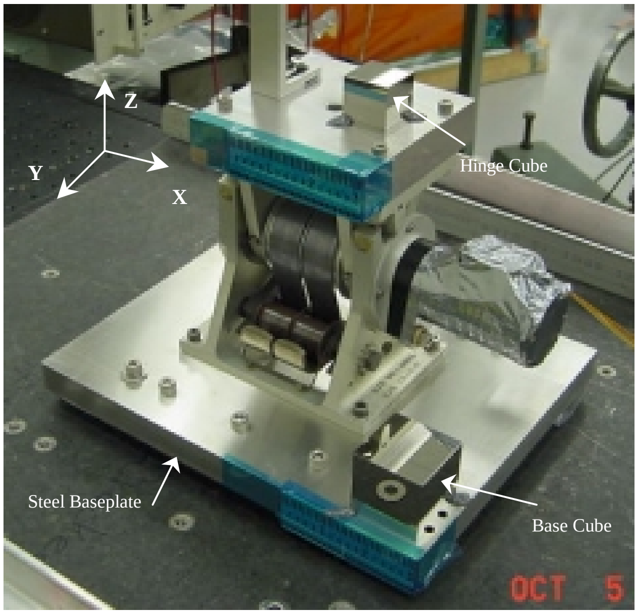


FIGURE 2: HA-90 OPTICAL CUBES

Four theodolites were required to obtain the hinge distortion about all three axes (see Figure 3). Small windows were cut in the box to allow the theodolites to see the hinge optical cubes. Precision optical glass (zero distortion) was placed over the windows to isolate the internal box environment from the laboratory.

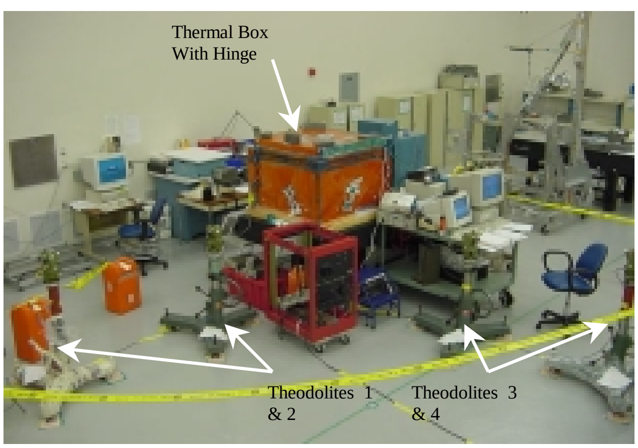


FIGURE 3: THEODOLITE SETUP

Another goal of the testing was to quantify the affect of deployment lock-up loads on the hinge at various temperatures (lock-up load directly influences the initial deployment position). A simulated lock-up load was applied to the hinge by cutting another window into the box to allow for the insertion of a loading bar. The load bar force was applied with a vise and measured with a load cell.

Mounting the hinge inside the box presented some difficulties. A majority of the test results were obtained by mounting the inboard and outboard hinge clevises to steel plates and then mounting optical cubes to those steel plates (Figure 2). This configuration kept the hinge rigid during load applications and also served as a deployment base. This method provided accurate results of the hinge distortion about the X and Y axes of the hinge, but the Z axis measurements were found to be invalid due to the CTE mismatch between the aluminum hinge and steel plates. The steel plates were “slipping and sticking” at the hinge interfaces. To obtain an accurate Z distortion measurement, the hinge was supported on a tripod kinematic mount and the optical cubes were bonded directly to the aluminum hinge clevises (See Figure 4).

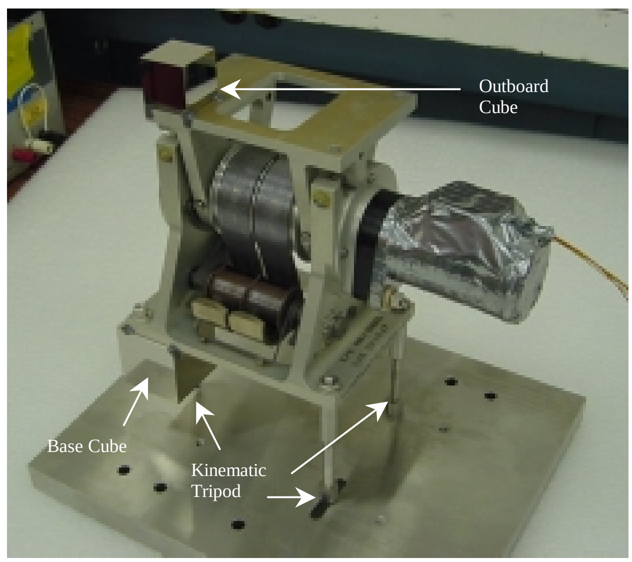


FIGURE 4: HA-90 KINEMATIC MOUNT

3. TEST RESULTS

Although this type of hinge is relatively common, the thermal distortion and deployment repeatability testing uncovered some new characteristics. To understand the results and to predict the hinge final deployment position, the hinge deployment must be broken down into three distinct stages:

STAGE 1) Initial deployment position: This is the first position the hinge achieves immediately after deployment when the latches engage. This position is a function of two factors: first is the deployment lockup load and second is the hinge temperature at deployment. The lockup load is driven by the inertia of the deployable appendage, the hinge spring torque, and the damping rate. With a higher lockup load, the hinge stops are compressed more, allowing the hinge latches to fall in farther than with a lower lockup load. The hinge position is primarily driven by the position of the latches (see Figure 5). The hinge temperature at deployment is the second contributor to this factor. The latches for this hinge are steel (required for stiffness) and the clevis parts are aluminum (required for low weight). Due to CTE mismatch between the aluminum hinge clevis and the steel latch, the latch falls into a different position depending on the temperature of the hinge. This further affects the initial deployment position.

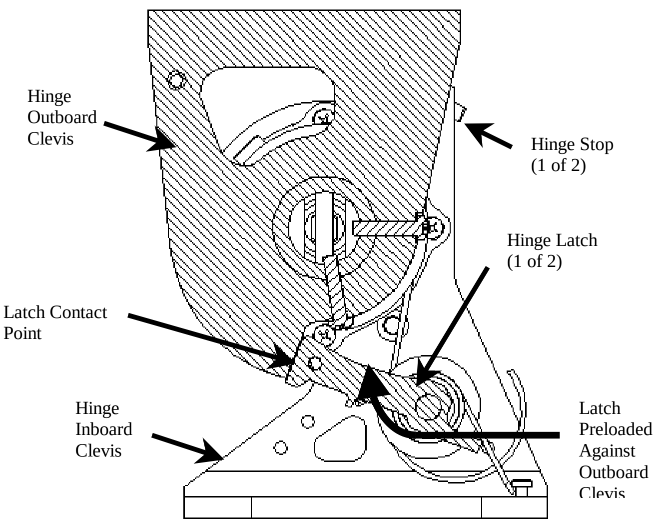


FIGURE 5: HA-90 CROSS SECTION

STAGE 2) Hinge latch stabilization: This factor had not previously been considered, but it was the most significant contributor to the final hinge deployment position. After initial deployment and as the hinge temperature changes (normal orbital thermal cycling), the CTE difference between the latch and clevis caused the latches to work-in even more thus further changing the hinge position. As the hinge temperature increases, the aluminum clevis would expand more than the steel latch, allowing the latch contact point to travel farther up the clevis contact surface. This phenomenon was named "latch creep". The magnitude of latch creep was also found to be a function of the initial lockup load and deployment temperature. The latch creep was less pronounced with higher lockup loads (due to the more advanced initial latch position). Less latch creep is also noted with a higher deployment temperature. If the hinge is deployed at a high temperature, the latch immediately stops at the same location it would normally "creep" to if deployed at ambient.

STAGE 3) Thermal Distortion: After initial deployment, and after the latch position has fully stabilized (usually after 3-4 thermal cycles), the hinge is then subject to pure thermal distortion. The thermal distortion is purely a function of the hinge temperature and is also primarily caused by CTE mismatch between the latch and hinge. The distortion magnitude is directly proportional to the range of hinge exposure temperatures and was correlated with a thermal distortion analysis of the hinge completed after the testing.

Figure 7 is hinge position data about the rotation axis of the hinge (X axis) demonstrating the three stages of the hinge deployment.

4. ON-ORBIT CORRELATION

Two Lockheed Martin communications satellites launched in 2001 and 2002 each used four HA-90 hinges to deploy antenna reflectors, see Figure 6. Each hinge experiences a large range of deployment temperatures and exposure temperatures due to the fact they are located on different corners of the spacecraft. At any point in time, at least one hinge is fully shaded from the sun, and thermal distortions are subsequently produced. Pointing telemetry received from both satellites indicates a maximum distortion of ±1.5 arcmin, which correlates with the qualification testing.

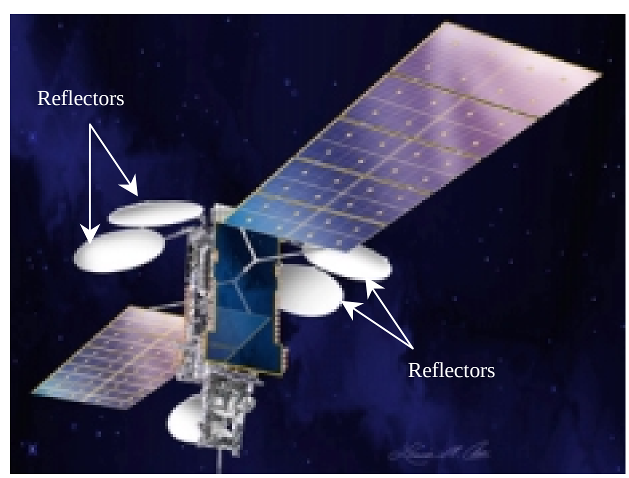


FIGURE 6: LOCKHEED MARTIN COMMUNICATIONS SATELLITE

5. LESSONS LEARNED

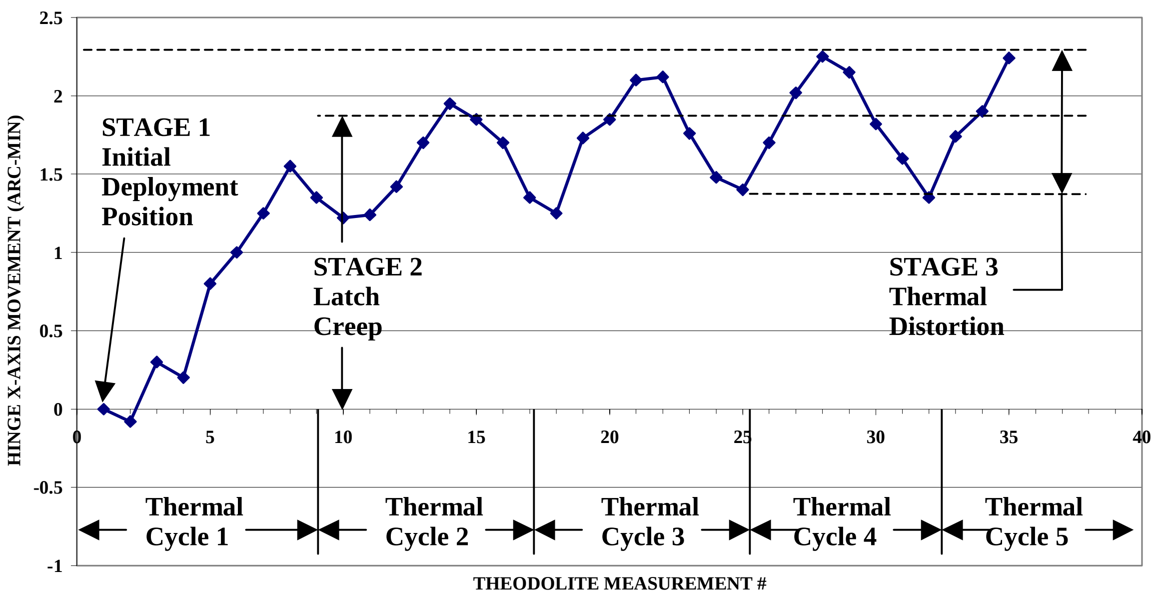
Lessons learned from the testing:

- For minimum distortion, hinge materials should have similar coefficients of thermal expansion. Although a steel latch was required in this hinge for stiffness reasons, the CTE difference from the aluminum hinge clevis added significant thermal position errors. This of course is fairly obvious, but many times designers are restricted by requirements (weight for example) that limit other performance features.
- The most significant contributor to thermal deployment error was due to “latch creep” or the movement of internal parts post deployment.
- When using optical equipment for measuring small angles, minimize the number of joints between the reference optical cubes. Mounting the optical cubes directly to the mechanism itself (no interface plates) provided the best results. Extra joints are extra sources of movement.
- Distortion measurements were most accurate when the mechanism was kinematically mounted. This minimized cross-axis parasitic errors.

6. CONCLUSION

Deployment repeatability and thermal distortion tests of the HA-90 hinge showed that repeatability and thermal distortion is dependent on multiple factors including lockup loads, deployment temperatures, and exposure temperatures. Multiple satellite programs (both inside and outside Lockheed Martin) are using this hinge and the qualification data has been correlated with on-orbit telemetry. This type of empirical assurance is rare for a relatively inexpensive deployment hinge, and the test has given the using programs the insight they require during the spacecraft design phase to confidently quantify the contribution of thermal affects for the hinge in their deployment application.

FIGURE 7: HA-90 X AXIS DISTORTION



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