Development of a Deployment and Latching Mechanism for a Pointing System on the Neutron Star Interior Composition Explorer (NICER) for Goddard Space Flight Center

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Abstract

Many space applications require high stiffness and stable latching systems. The Deployment and Latching Mechanism design for the Neutron Star Interior Composition Explorer (NICER), provides a stable, high-stiffness structure (> 1,500,000 in-lb/rad (169 MN-m/rad)) in the deployed and stowed positions. The Deployment and Latching Mechanism consists of a rotary deployment actuator, rotary latching actuator and an over-center slider crank mechanism latch. This design allows the NICER system to be repetitively latched in both stowed and deployed positions, providing locking (high stiffness) in both rotational directions. This paper describes the development, design, incorporation of lessons learned and testing of the Deployment and Latching Mechanism.

Figure 1. Neutron Star Interior Composition Explorer (NICER) (shown in Deployed and Latched Position)

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Introduction

The deployment and latching mechanism is part of the Deployment and Positioning System (DAPS). The DAPS is an articulating mechanism for the NICER program consisting of a deployment and latching mechanism, a pointing mechanism, and an interconnecting boom structure. The DAPS provides a stable, high-stiffness structure in the deployed and latched positions for a star-tracker system that “enables (together with NICER’s GPS-based absolute timing) high-precision pulsar light-curve measurements through ultra-deep exposures spanning the 18-month mission lifetime.”¹ It has a deployment articulating arm that needs to be deployed 84° from the vertically stowed position and latched prior to pointing mechanism activation. The arm and the full instrument is required to be stowed and latched multiple times on board the International Space Station (ISS). A final stow and latch cycle is required for safe removal from the Space Station. DAPS has specially designed interfaces at the ISS interface and at the payload. The latch can provide locking for the ride to the ISS, multiple latched stow and deploy cycles on the ISS, and if required, it will perform a final stow and latch for removal from the ISS if necessary.

Deployment and Latching Mechanism Development

The deployment and latching mechanism is a subassembly of the NICER DAPS located between the Space Station Flight Releasable Attachment Mechanism (FRAM) interface and the boom arm with a dual axis pointing gimbal attached at the boom end that is the x-ray instrument attach point. The deployment and latch mechanism enables positioning and latching of the NICER instrument in both stowed and deployed positions. It consists of a bracket that is mounted onto the FRAM and employs a Moog deployment actuator, a Moog latching actuator, and the latching mechanism. The deployment mechanism is operated by these two electro-mechanical actuators, each having a stepper motor coupled to a zero-backlash gear transmission. The boom is attached to the deployment actuator. This type of actuator configuration is a very common approach for many space-related deployment applications, thus, there is extensive heritage justifying the use of these actuation mechanisms.

The deployment actuator travel from stop to stop is 84°. At both the deployment actuator’s stowed and deployed positions, the latching actuator engages the latch to hold the deployment actuator position. Prior to deployment actuator operation, the latch actuator releases the latch to allow the deployment actuator to stow or deploy. This is accomplished using an over-center slider crank mechanism that prevents the

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¹ Note: The citation number is not provided in the text.
deployment actuator from rotating in the stowed and deployed positions. In one direction, the deployment actuator hardstop prevents movement and in the other direction, movement is prevented by the over-center slider crank latch mechanism contacting the latching actuator hardstop.

The initial idea was to develop a latch that utilized physical hardstops for stowed and deployed positions without using motor power to hold position. The NICER program required two position high stiffness latch locations capable of reacting to loads in both CW and CCW directions. Heritage designs utilized either motor holding capabilities, additional latch actuators for each position, or an over-center device that held one position but was not a high-stiffness mechanism. Based on program requirements, a new latch mechanism would be needed to do the job.

Moog quickly ascertained that the demanding stiffness requirements of this application would not be achieved with a simple dual-sided wedge design, and instead focused our design concept around an efficient single-sided wedge that could take advantage of the integrated hardstop. The latching concept was completed with an over-center crank, resulting in a two-direction latch with physical stops in both directions. The latching actuator provides the crank portion of the slider crank mechanism, positioning the plunger wedge in the latched or released position, while a bolt with integral wedge works as the slider. An integral travel stop was added to the bolt assembly to limit deployment actuator travel when non-operation loads are applied. Mechanism design locks latch in place by establishing a ridged structure between the deployment actuator and the latching actuator hardstop. Under high torque loading, the latch design will not open, which prevents gapping or unlatching of the mechanism.

Though Moog heritage designs included Extra-Vehicular Activity (EVA) bolts, a unique addition to the NICER DAPS actuator mechanisms is the integration of the Extra Vehicular Activity (EVA) with the Extra–Vehicular Robot (EVR) attachment that is designed to provide the manual override of the actuator in case of loss of power. This EVA/EVR interface is designed to be operated by the astronauts or by the ISS robotic manipulator arm in a zero-gravity environment using a standard electrical powered driver. A magnetic clutch is provided to protect the zero-backlash gear transmission from being over-stressed. Also, the operating nomenclature on the actuator provides clear instruction and ease of viewing to reduce the potential for misuse. Each actuator’s output position is indicated by a non-redundant potentiometer. NASA was planning to use cameras located on the robotic arm and possibly an astronaut’s eyes to indicate revolutions of the
EVA/EVR bolt from hardstops or home positions to “ease” into the hardstops by counting revolutions and starting and stopping when hardstops were about to be engaged.

The latch design must prevent movement of the deployment actuator during NICER operation. Knowing this, a detailed free body diagram was created and used to create a mathematical model of the latch mechanism. The model optimizes the latch mechanism, by balancing input load with latch component loads and latching actuator performance. It also calculates all loads within the latch mechanism, torsional loading of the deployment actuator, latch component loads, friction, etc. The model can resize the latch mechanism for alternate load environments.

Figure 4. Latch System Free Body Diagram

Stiffness of the overall deployment system when latched was a critical design criteria. Each component was designed to maximize its individual stiffness to assure the latching mechanisms combined stiffness is as high as possible. A detailed tolerance stack was used to assure no misalignments or binding were possible.

Once the design was complete, a high-fidelity proof of concept tool was fabricated. The proof of concept tool was used to develop the assembly process and verify performance. Math model calculations were confirmed with the proof of concept tool, which correctly calculates the latch force and latch actuator torque.

To address life for the deployment and latching mechanism, the possibility of galling, seizing, friction and wear was reduced or eliminated. Life of the deployment and latching mechanism is accomplished with a four-fold approach.

1. All sliding surfaces, including shims, bolt components, slider block, link and link pins are made from non-galling stainless steel or a super alloy that is not galling coupled with the non-galling steel.
2. All sliding surfaces in the latching mechanism are diffusion layer hardened. Internally these parts retain the toughness of the original material and hardens only a thin outer layer. This hardening further protects the sliding surfaces from galling.
3. To help minimize friction of the sliding surfaces, protect these surfaces from galling and seizing, and reduce wear, a dry film lubricant is applied. This low temperature impingement-applied lubricant also is enhanced with the application of other lubricants (co-lubrication).
4. To further minimize the effects of friction, chance of galling and seizing, and wearing, a secondary grease lubrication was applied to all sliding surfaces of the deployment and latching mechanism.
The proof of concept tool utilized flight latching mechanism parts but used representative output flanges for both actuators and a plate instead of the flight mounting bracket. Duplex pair bearings were also mounted under each of the output flanges to simulate the flight configuration. The goal was to check the mechanism’s tolerances, required torques and the torsional stiffness of the mechanism’s deployment actuator at the stowed and deployed positions. The proof of concept tool also enabled assembly, shimming, and load setting operations to be finalized prior to the flight unit build.

Proof of concept testing was very successful, the latching mechanism exceeded all program requirements. Flight latch assembly began after completion of latch tool proof of concept testing. In-process stiffness testing reconfirmed math model results and verified flight latch stiffness.
The Flight unit successfully completed in-process stiffness testing, with only a slight reduction of overall stiffness. Deployment and latch assembly was then completed with no issues. The deployment and latch mechanism successfully completed protoqual testing with no issues. Latch performance did not change after exposure to vibration and thermal vacuum.

**Figure 7. Stiffness results**

- **Proof-Of-Concept Model Stiffness**
  - Stiffness: 1910000 in-lbs/rad
  - 215,800 N-m/rad

- **NICER Deployment and Latching Mechanism Stiffness**
  - Stiffness: 1728000 in-lbs/rad
  - 195,237 N-m/rad
Life testing was completed using the proof of concept tooling. All non-flight latch components were replaced with flight versions and the latch was cycled 3000 cycles (latch then unlatch), 3000 in both deployed and stowed position. No wear or damage was observed, and latch performance was unchanged. Life testing demonstrated the effectiveness of the design and processes to greater than 2X the NICER life requirement. Extended life testing is currently in process.
Lessons

During development of the deployment and latch mechanism, many key challenges were solved. The following is a list of useful lessons.

Don’t forget about spring hysteresis
Spring hysteresis is always a concern. Spring manufacturers typically only provide maximum force and spring rate. They are unable to provide accurate hysteresis values, since hysteresis is highly dependent on design and resultant friction. Development testing confirmed spring force dropped 10% - 20% after cycling. Moog planned for spring force hysteresis losses and performed cyclic spring force testing. Moog’s new latch system compensates for all environmental conditions providing repeatable performance.

Initial design development needs to include spring force hysteresis losses in the design. All springs have hysteresis, so quantification of the hysteresis should be completed before finalization of fabrication of parts. Early development testing should be performed in flight configuration to determine actual force at final position.

Iterate until optimal design is reached
Complex systems like the deployment and latch mechanism need to balance all the requirements. It would be easy to design a latch with 4 times the force required. There would be no concern of the latch moving when loaded, but torque margin requirements could not be met without increasing all other components. Problems arise from increased loads, friction (requires higher motor torque), and weight. Since this is a space mechanism, the latch is required to have a safety factor greater than three. To address this problem, the most critical requirement was determined to be the resultant force on the latch. The latch force was sized to be only slightly higher than the worst case resultant force on the latch. This established the baseline concept that was then optimized with the mathematical model. Through the optimization process, we balanced the latch capabilities to the motor capabilities, creating a more robust design while still maintaining a safety factor in excess of three. Moog’s optimization of the deployment and latching system resulted in a system that exceeded program requirements.

Determine key requirements and balance the design around these requirements. Iterate until an optimal design solution is found.

Design improvements could change operating scenarios
The NICER mechanism requires each actuator to have provisions to be overridden by a robot or astronaut’s tool to return it to a stowed position in case of loss of power, motor failure, etc. Additional requirements were flowed down after completion of initial design requiring incorporation of range limiting features to prevent impact with space station structures. A limit bar and guardrail were incorporated into the design, this caused an issue with the EVA/EVR implementation. Moog designed a completely new compact clutch designed to slip before the actuator limits were reached, utilizing Moog extensive space heritage technology. This also protected the deployment and latch mechanism if the latching actuator was mistakenly left in the latched position and the deployment actuator EVA/EVR was engaged or the latch actuator was attempting to latch without the deployment actuator in either the stowed or latched position.

Laying out of all possible scenarios beyond the typical operating envelope can directly influence the design requirements. These can include the addition of safety features not only to limit unanticipated problems but also add to the robustness of the design.

Manage your requirements
Torque margin is always the basis of design for electromechanical space mechanisms. Inertias, harness losses, internal losses of the mechanisms, etc. as well as the temperature extremes that these mechanisms must perform in, all have an effect on torque margins. In the case of the NICER program, factors of safety requirements were higher at the beginning of the program and dropped at different milestones as the design moved to finalization. During the Preliminary Design Review, the factors were greater than used during the
Critical Design Review and were further reduced for Acceptance/Qualification Testing. This progression almost insures acceptable margins for the mechanism if all loads and frictions are accurately determined or are conservatively estimated at the beginning of the design phase. At delivery, because the initial design will be driven by these higher factors of safety, the unit will assuredly have a higher torque margin than required. The proof of concept tool provided the design team friction and load values.

Torque margin requirements can be managed effectively if unknown variables like friction and losses can be anticipated or tested in a proof of concept model early during the program progression.

Proof of concept testing is invaluable
The bolt design utilizes a shoulder bolt to limit the travel of the bolt. Standard military part number shoulder bolts are made of 300 series stainless steel. 300 series stainless steel bolts have relatively low strength, low hardness, and are prone to gall. A shoulder bolt was manufactured from high-strength stainless steel to prevent galling. Initial development testing was performed using a 300 series shoulder bolt, before a high-strength shoulder bolt could be manufactured. The 300 series shoulder bolt galled as predicted and drag increased over time.

Proof of concept testing is invaluable to confirm design assumptions and identify possible issues. Testing should be performed as early as possible to limit schedule impacts.

Systematic analysis reduces system risks
High latch stiffness is critical to the NICER system. Stiffness of a system is a combination of its components and joints. Slippage between mating surfaces reduces overall stiffness. The deployment and latch mechanism uses many different methods to assure high latch stiffness. The latch design has no play between parts when latched, and all joints are sufficiently loaded to prevent slippage. The deployment latching system exceeded program expectations as analyzed.

When high stiffness is required, all play should be eliminated. A systematic tolerance analysis should be performed to minimize joint mismatch and slippage.

Summary and Discussion

The Deployment and Latching Mechanism for NICER, utilizes an innovative new latching system. Providing a stable, high-stiffness structure in the two positions. The mechanism consists of two rotary actuators and an over-center slider crank mechanism latch. The system has successfully completed development, protoqual and life testing. Moog delivered the Deployment and Positioning System containing the deployment and latching mechanism on July 2015.

The deployment and latching mechanism solves many space systems problems:

High stiffness deployable platform
The design utilizes Moog’s high reliable space heritage actuators providing robust repeatable positioning. The new latching system locks the platform firmly in place with very high stiffness, with no power applied.

High stiffness in multiple positions with repetitive latching
Design enables repetitive latching in multiple positions without any loss of stiffness in both rotational directions.

NASA robotic interfaces
Design incorporates NASA’s new Standard Dexterous Grapple Fixtures, enabling robotic manipulation of all actuators by NASA’s Dextre, also known as the Special Purpose Dexterous Manipulator.

High stiffness to weight ratio
In comparison, an extremely large actuator would be required to be powered on to meet equivalent stiffness.
The following is a quick summary of the system capabilities:

- Torque: 56.5 – 113 N-m (500 – 1000 in-lb)
- Unlatched Unpowered Holding Torque: 9 – 33.9 N-m (80 – 300 in-lb)
- Latch Unpowered Holding torque: 171.2 N-m (1515 in-lb) [no movement]
- Latch Unpowered Holding torque: >384.1 N-m (>3400 in-lb) [slight movement, no damage]
- Stiffness: 169,477 N-m/rad min (1,500,000 in-lb/rad min) [at 384.1 N-m (1515 in-lb)]

The Deployment and Positioning System containing the Deployment and Latching Mechanism has completed protoqual testing and is in final integration, scheduled for launch in fall 2016.

Although the deployment and latching mechanism used a deployment actuator and a latching actuator, the mechanism is scalable. The NICER requirements dictated the sizes of the actuators used. Depending on the stiffness required and the torque required at the deployment actuator, the deployment actuator can be scaled up or down. The latching actuator is sized based on the load required in the bolt, the over-center load that is reacted by the actuator and the load the slider crank has to react to. The NICER deployment and latching mechanism is arranged in a vertical configuration with the latching actuator on the bottom. Depending on the available envelope, the latching actuator can be positioned anywhere radially around the deployment actuator. If envelope is available, a horizontal configuration would allow for a lower vertical profile and increased stiffness.

**Future Work / Optional Designs**

Add intermediate latching positions with some loss of stiffness

Intermediate positions can be added. Hysteresis caused by change in torque direction would result in a loss of stiffness between the initial torque direction and the second torque direction.

Develop a two-slider design for intermediate positions with no loss of stiffness

The addition of a second slider independent of the first, contained in the same slider block, can be used to latch the deployment actuator at intermediate positions. The second independent slider will resist loading in the opposite direction. Clearance on the back side of each slider and shimming on the deployment actuator, will ensure loading in both directions. The loading in both directions will result in the elimination of system hysteresis and result in similar torsional stiffness in both directions.

Develop a two-slider design to enable ≥360° output rotation (no hardstops needed)

The addition of the second slider, as described above, can also allow the deployment actuator to rotate more than 360° or if continuous rotation is required and to be latched in multiple predetermined positions.

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**References**

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