PRECISION SELECT MECHANISMS FOR THE GLAS & SOLSE2 INSTRUMENTS

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Abstract

The Geoscience Laser Altimeter System (GLAS) instrument had requirements for a 2-position mechanism to rotate mirrors into and out of the optical path of the altimetry detectors and the lasers. The Solar Ozone Limb Sounding Experiment II (SOLSE2) instrument had a similar requirement of rotating a visible (VIS) or ultra-violet (UV) filter into the instrument optical path. Both GLAS and SOLSE2 had similar operational and survival environments and lifetime requirements.

A novel, precision rotational latching mechanism was designed to fulfill the needs of both missions. The GLAS instrument had driving stability and repeatability requirements, such that if the mechanism met these stringent requirements, it would more than surpass the required performance for the SOLSE2 mechanism.

The resulting mechanism, referred to as a "select mechanism" since it allows selection between 2 positions, was successfully designed and implemented for both missions.

Introduction

The laser transmit path of the Geoscience Laser Altimeter System (GLAS) uses 3 Nd:YAG 4 Watt lasers with beams of ~25 mm square cross-section. Each of the three lasers must fire down a common optical path. In order to select which laser is used, a mechanism has been designed to rotate a Zerodur flat mirror 45 degrees into the common beam path. The GLAS instrument uses 2 of these "Laser Select Mechanisms" (LSM) to rotate mirrors in front of 2 of the 3 lasers. The LSM was required to have a mechanical repeatability and thermal stability of <4 arc seconds over a –40C to +40C temperature range. The duty cycle is very low, with less than 5 stow or deploy actuations on orbit over a period of up to 5 years.

The receiver path of the GLAS instrument has 2 redundant detectors used for altimetry. If the primary detector should fail, a mechanism will rotate a ~30 mm x 20 mm aluminum mirror 45 degrees into the receiver optical path and direct the incoming beam to the redundant detector. The "Altimeter Detector Select Mechanism" (ADSM) requirements were much looser than the LSM. Repeatability and stability were specified as <30 arc seconds. Duty cycle would be 1 operation on orbit if required.

It was recognized that a single mechanism design could accomplish both GLAS tasks. During the GLAS–funded development of the LSM and ADSM, SOLSE2 mechanism requirements were found to be similar to the ADSM.

SOLSE2 was a Czerny-Turner visible/UV imaging spectrometer that flew on STS-107. It had a requirement to select between a visible or UV 50mm filter, up to 30 times on orbit. Volume limitations required a rotation of 24.5 degrees, with stability and repeatability requirements similar to the ADSM in a more benign thermal environment. SOLSE2 took advantage of the GLAS mechanism development and adopted a slightly modified LSM/ADSM design for use as a Filter Select Mechanism (FSM).

The LSM, ADSM, and FSM utilize a common drive assembly, referred to as a select mechanism. The 3 mechanisms only differ in the driven payload, some materials (Invar 36 was used extensively in the LSM due to the thermal stability requirement) and rotational stroke (45 degrees for GLAS, 24.5 degrees for SOLSE2). See figure 1.

Select Mechanism Description

The select mechanism uses a single high-output paraffin (HOP) linear actuator to drive a novel, 2-position (stowed and deployed), rotational latch. The HOP-actuator provides motion in only 1 direction, from the initial stowed position to deployed. Compression springs provide restoring force at each end position, and the energy to backdrive the mechanism from deployed to stowed position. Redundant LED/photodiode pairs are used as limit switches. Depending on start temperature and bus voltage, actuation time is approximately 45 seconds from power-on to deployed position, ~80 seconds from deployed to stowed position. Bray 601 grease is used on all interior sliding surfaces.

The select mechanism is mechanically loaded against a hardstop in each position and can therefore be powered off when not in use. No launch lock is required.

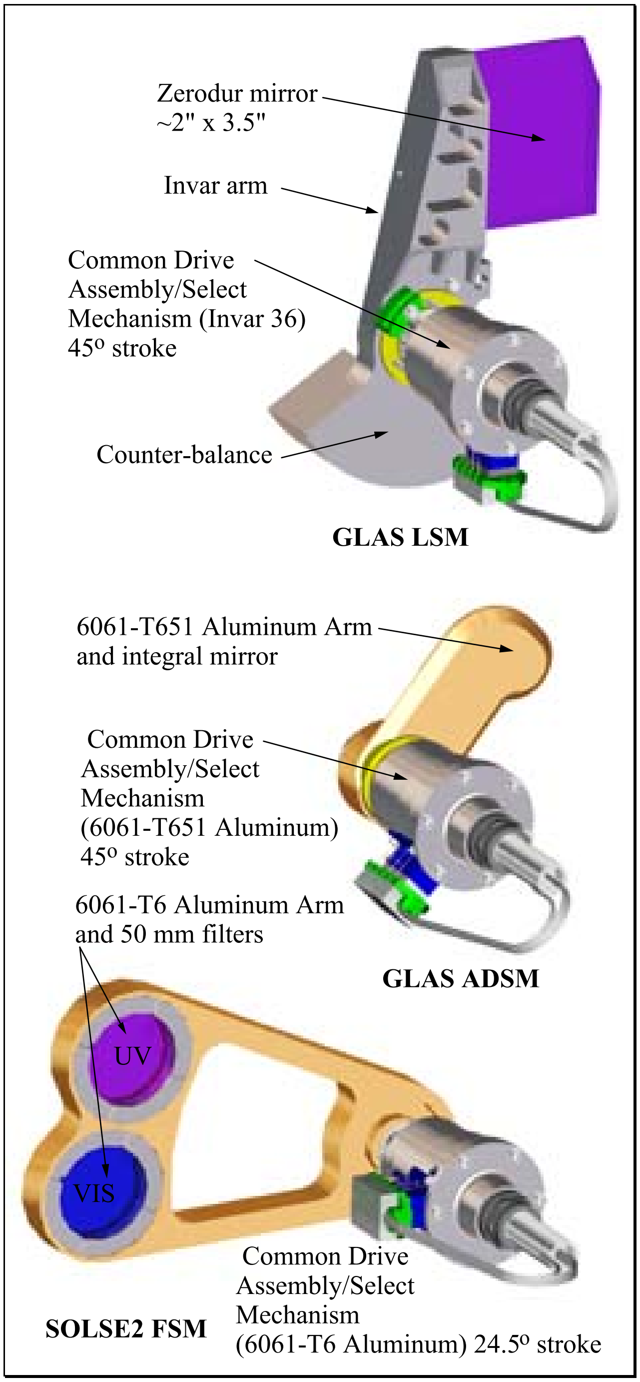

Figure 1. LSM, ADSM, and FSM

HOP Actuator

A Starsys Research IH-5055 HOP linear actuator was chosen for it's compact size, high reliability and high force output (50 lbf). The HOP actuator has a maximum stroke of 0.5 inches, but only ~0.382 inch of stroke is required for the select mechanism. A "hard stop" condition occurs when the mechanism bottoms out at an actuator stroke of ~0.45 inches. The HOP actuator is only capable of output force in 1 direction and requires a preload of ~5 lbf to reset the output shaft.

Precautions must be taken when using HOP actuators. If a HOP actuator is left in the powered-on state for a prolonged period, it may fail (burst), potentially damaging the select mechanism and releasing paraffin. The select mechanisms had 3 levels of HOP precautions: (1) LED switches are used to power off the HOP after it reaches a stroke of approximately 0.237 inch and 0.382 inches, (2) an automatic power-off timeout based on a voltage/temperature lookup table, and (3) command power-off, used only in ground testing.

Select Mechanism Mechanical Operation

The select mechanism rotational latch is analogous to the ubiquitous "ball-point pen" push-deploy, push-retract mechanism. In the case of the pen mechanism, the user provides the push action; the restoring force is provided by a spring. With the select mechanisms, the HOP actuator provides the push force, and a series of springs provides the restoring force. A drive pin that slides in a helical slot transforms the HOP linear motion into rotary motion.

In its initial (launch) state, the select mechanisms position is referred to as "stowed". In the stowed position, the latch is spring-loaded against an internal hardstop surface on the base of the actuator housing. This restoring force is provided by the load spring. Any displacements induced during the launch vibration environment are reacted against by the load spring.

In order to rotate the select mechanism into the "deployed" position, the HOP actuator is powered on. A constant power of 10W@28V is applied. The output shaft of the HOP actuator begins to slowly extend as the interior wax changes phase and expands. The HOP output shaft pushes the lockhousing and detent retainer down, compressing the 3 return springs.

Within the lockhousing, the 3 lock pins, aligned radially outward and equally spaced 120 degrees apart, are spring-loaded against the inner wall of the main housing by the initiator spring via the initiator pin. As the lockhousing and detent retainer progress downwards, they pass an undercut in the main housing. As the lock pins pass the edge of the undercut, they are no longer reacted against by the main housing inner wall, and they snap outwards by the action of the initiator pin/initiator spring unloading. The lock pins are restrained from leaving the lockhousing by the lock pin detent. The lock pin detent has 3 forks which slide perpendicularly into relief cuts in the shanks of the lock pins. The lock pin detent floats, but is held captive by the lockhousing and the detent retainer.

A slot in the detent retainer contains the drive pin. The drive pin is loaded into the bottom of the slot by the load spring via the drive pin ring. The drive shaft slides inside the detent retainer. The upper half of the driveshaft has a helical slot cut through it. The angle expressed in the helical slot defines the angular stroke. The drive pin goes completely through the helical slot. The lower half of the drive shaft is pressed into the inner race of a back-to-back, angular contact bearing pair (Barden C100HDH, 10 lb preload, dry). The outer races of the bearing pair are fixed to ground. The arm and whatever optics mounted to it are bolted directly to the end of the driveshaft. Driveshaft-arm sliding is prevented through the use of a keyed washer.

With the select mechanism in the stowed state, the drive pin rests in the upper portion of the helical slot. As the lockhousing and detent retainer are forced downward, the drive pin is forced downward though the helical slot in the axially fixed (via the bearing pair, but free to rotate, also via the bearing pair) drive shaft. This causes the drive shaft, and the arm, to rotate.

Just prior to the drive pin bottoming out in the helical slot of the drive shaft, an exterior hardstop stops rotation of the arm and drive shaft. This stops the drive pin from moving any further downward. However, the lockhousing and detent retainer continue to be forced downwards. Since the drive pin rides in a slot through the detent retainer, as opposed to a hole, this continued downwards motion compresses the load spring via the drive pin ring. The select mechanism is now in over-travel, as the arm has rotated into its end position stop but the lockhousing and detent retainer are still moving.

Shortly after the lock pins are deployed and the full angular stroke is reached, as the lockhousing and detent retainer continue downwards, a flag on the lockhousing trips a LED/photodiode limit switch at ~0.237 inch of HOP stroke, and power is cutoff to the HOP actuator. This causes all downward motion to cease.

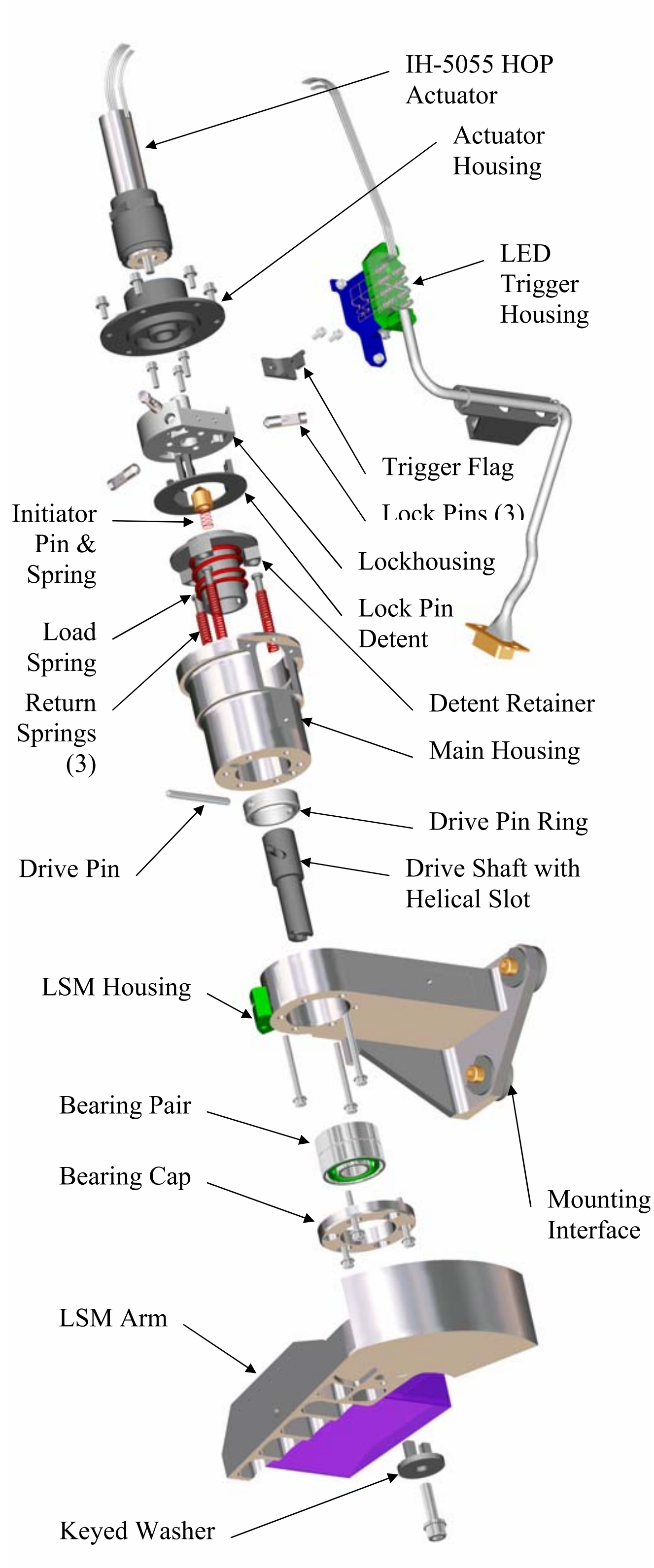

Figure 2. Exploded LSM

The return springs and load springs now partially unload and reverse the direction of the lockhousing and detent retainer motion. This motion causes the now-deployed lock pins to catch on the lip of the main housing undercut. This effectively binds the mechanism components. It also partially resets the HOP output shaft.

The mechanism is now in the "deployed" state. The arm has rotated through is full angular stroke and is spring-loaded into an exterior hardstop. Any rotational displacement off of the hardstop back-drives the drive pin along the slot in the detent retainer, which further compresses the load spring and produces increased restoring force. This acts to keep the arm loaded into the hardstop.

In order to rotate the arm back to the stowed position, the lock pins have to be retracted, allowing the lockhousing to move upwards past the undercut. Since the HOP actuator can only provide forced displacement in one direction, this is accomplished by further over-driving the lockhousing and detent retainer downwards. This is where the floating lock pin detent comes into play.

The HOP actuator is powered on and pushes the lockhousing and detent retainer further downwards. The drive pin, constrained from any further downward motion, causes additional compression of the load spring. The lock pin detent, constrained by the detent retainer, moves downwards until it catches on a lip on the inner wall of the main housing, which stops its downwards travel. The lockhousing & detent retainer continue moving downwards. The lock pins, carried by the lockhousing, begin to slide down the fork slots of the now-constrained lock pin detent.

The forks of the lock pin detent have an over-center cam profile. As the lock pins are forced down along this profile, they retract back into the lockhousing, which compresses the initiator spring via the initiator pin. As they continue to slide downwards, the lock pins are forced over a small, over-center "hump" in the fork profile, which provides sufficient friction to prevent the initiator spring from unloading. This locks the lock pins within the lockhousing.

As the lockhousing and detent retainer continue downwards, they trip a second LED/photodiode limit switch at ~0.382 inch of HOP stroke, and power is cutoff to the HOP actuator. All further downward motion ceases. The load spring and 3 return springs are now at maximum compression. With no further push force coming from the HOP actuator, the lockhousing and detent retainer reverse direction and are pushed back towards the HOP actuator by the unloading of all the springs. The wax within the recently powered-off HOP actuator acts as a damper and the motion is slow.

As the lockhousing and detent retainer are pushed back, the drive pin is un-constrained and pulled upwards with the detent retainer. This causes the drive shaft (via the pin sliding in the helical slot) to rotate off of the external hardstop and back towards the initial stowed position. The retraction of the lock pins allows the lockhousing to travel past the undercut in the main housing and back towards the stowed position.

At this point, the forks of the lock pin detent protrude above the top surface of the lockhousing. The lock pin detent, via the frictional force of the initiator spring through the initiator pin and 3 lock pins, is being carried upwards with the lockhousing. The tops of the lock pin detent forks come into contact with the hardstop surface on the base of the actuator housing, which stops it from any further upwards travel. The lockhousing (and lock pins) and detent retainer continue their upward motion. The sudden constraint from any further travel allows the remaining force of the return springs to backdrive the lock pins slightly further inwards and back over the over-center cam profile on the lock pin detent forks. This releases the lock pins, allowing them to travel outward under the force of the initiator spring until they contact the inner wall of the main housing.

The lockhousing and detent retainer continue upward until the top surface of the lockhousing contacts the hardstop surface. The arm rotational motion stops, having traveled its full stroke. The select mechanism is now in its original stowed configuration. Any rotation of the arm away from this orientation compresses the return springs, which act to rotate the arm back to the stowed position.

Performance Summary

In nearly 1000 total cycles during all phases of development, the GLAS select mechanisms never failed to operate. The GLAS select mechanisms met all repeatability requirements, and the LSM came to within a few arc seconds of the stability requirement after several material changes and opto-mechanical redesigns of the arm and mirror.

The GLAS Instrument (with the ADSM and 2 LSM’s) was launched in January of 2003 on the ICESat mission. On-orbit telemetry indicates that they are in excellent condition. As of this writing they have not been actuated.

SOLSE2 was launched onboard STS-107 as part of the Fast Reaction Experiments Enabling Science, Technology, Applications and Research (FREESTAR) payload bridge in January of 2003 and successfully accomplished 10 stow/deploy (visible/UV filter changes) cycles on orbit.

Conclusions

A novel, HOP-actuated, 2-position rotary latch mechanism has been designed to meet the requirements of several applications in 2 different space instruments. The design has proven robust and reliable. The design lends itself to multiple materials, as both 6061 aluminum (ADSM and FSM) and Invar 36 (LSM) versions have been developed and flight qualified.

Future development could include additional "steps" added to the lock pin detent forks and additional limit switches to increase the number of positions from 2. Also, the helical slot angle and HOP-actuator linear travel can be varied to provide almost any stroke angle. The use of a self-limiting HOP actuator, with actuator-internal power shut-off features, would simplify the operation of future select mechanisms by eliminating temperature/voltage look-up tables.

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