A NOVEL SUN TRACKING MECHANISM

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ABSTRACT

An opportunity payload was proposed on GSAT-2, an experimental geo-stationary communication satellite. The payload required Sun pointing within ± 1^0, when the communication satellite is pointing to earth. This requirement necessitated two drives, i.e. one for continuous tracking in pitch axis at one rotation per orbit and another to correct sun declination in roll axis. These rotations about two orthogonal axes generally call for two orthogonal mounted motor drives. However, after detailed study, a novel concept was proposed to achieve these two motions using only one motor drive, also a separate launch hold down was not required in the configuration proposed. In addition to mass saving, with the achieved compact size, it became feasible to accommodate the payload within the envelope allowed on the spacecraft.

1. SUN TRACKING MECHANISM PRINCIPLE

Sun was visible for approximate half orbit only, so the mechanism was to track the sun for 11 hrs and 20 minutes in a 24 hours orbit. This required about 170 degrees rotation about satellite pitch axis. Pitch axis sun tracking was accomplished by harmonic geared stepper motor drive. For the other perpendicular axis declination correction, the pitch axis drive was designed to move/Over-drive about 10 degrees beyond 170 degrees of tracking angle on both ends "Fig.1". A special "declination drive" mechanism, gets activated in the over-drive zone and drives the payload package about declination axis proportional to over-drive angle.

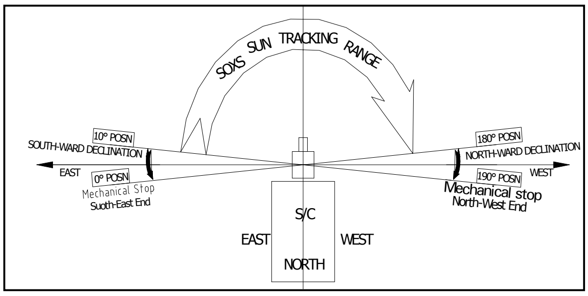

Fig. 1. Mechanism operation

The zone in which the "over-drive" (East end or west end) is done will decide the direction of tilt. Every day at the end of the days sun tracking, the required declination angle for the next day is set by over-driving the mechanism before fly back, at west end or after fly back at east end(depending on the direction of correction). Then the mechanism is positioned and kept ready for next day's sun tracking in clock mode.

2. MECHANISM SPECIFICATIONS:

Mechanism specifications are given in Table-1 below:

Table –1 Mechanisms specification

East-west (pitch axis) rotation	10 to 180 degrees (continuous tracking in earth rate)
North south rotation (declination axis)	± 23.5 degrees (daily correction)
Pointing accuracy	± 0.2^0 (mechanism)
Drive step angle	0.00637^0
Output drive torque	40 NM
Holding torque	25 NM (without power)
Operating temperature	0 to 70 deg.c
Declination. Drive step angle	0.03 deg
Ratio of main drive to declination. axis drive	5:1
Detent torque at friction disc mechanism	0.4 NM
Total mechanism mass	4.5 Kg

3. MECHANISM DESCRIPTION

The mechanism consists of:
1) Main drive module,
2) Payload support platform and
3) Declination Drive Mechanism.

3.1 <u>Main drive module</u>

A stepper motor driven high torque "drive module" is used for 'East-West' sun tracking in 'Earth rotation rate'. This is done by driving the stepper motor in clock mode to match the 24-hour orbit, using motor drive electronics. The stepper motor step angle is 1^0 and the output step angle with 1:157 Harmonic gear reducer, is 0.0064^0. The drive module is mounted on to the bottom of Anti Earth View (AEV) deck of the spacecraft. This high torque motor drive module, "Fig.2," was designed and developed for earlier satellite GSAT-1 antenna pointing mechanism [1].

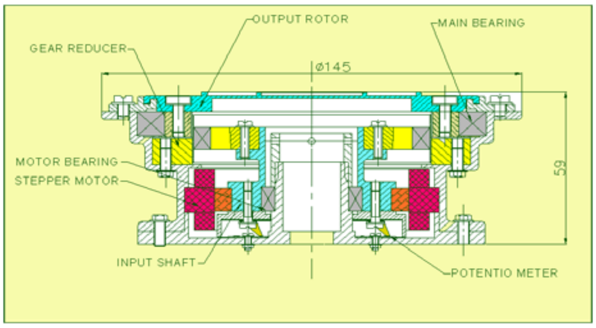

Fig. 2 Main Drive Module

The drive module consists of SAGEM hybrid stepper motor and a pancake type harmonic drive reducer. The motor is mounted with duplex pair angular contact ball bearings and the rotor is fixed on to the input shaft. The motor drives the input shafts of harmonic drive in steps of 1^o. Fixed gear is fixed to the outer housing and the dynamic gear is supported on a four-point contact main bearing and carries the output flange. The gear reduction is 157:1. The output flange interfaces with the Payload platform. The stepper motor has redundant windings. The harmonic gears and bearings are lubricated with Braycote 601 grease and the drive housing is provided with labyrinth seal to minimize lubricant loss. One thick film resister potentiometer is built on to motor shaft to indicate motor rotation.

3.2 Payload support platform

The payload detector package was mounted on a built-up frame called "Payload Platform", "Fig. 3". It is like gimbals' frame and is connected to the output flange of "Drive module". Outer end of the Payload platform is again supported on an end-bracket fixed to spacecraft through an axially floated spherical bearing. The "Payload detector package" is mounted on to Payload platform through two "trunions" interfacing perpendicular drive module axis allowing the package to tilt about trunion axis. This axis is called "declination axis". Drive Module Main bearing and end-bracket spherical bearing support the payload package and platform for launch loads.

3.3 Declination Drive Mechanism

Two "Drive rods" are mounted on either ends of payload platform, "Fig.3 & Fig.4". One "stopper bracket" each are mounted on the spacecraft deck for each drive rod, exactly in the rod's path. When the payload platform is moved to east end or west end "over drive" zones, the stopper bracket obstructs and stops the movement of that side drive rod but the platform is not stopped from moving. Therefore, the drive rod is pushed back relative to payload platform. This relative back ward push of the rod is used to turn the pulley and the connected payload package for declination correction.

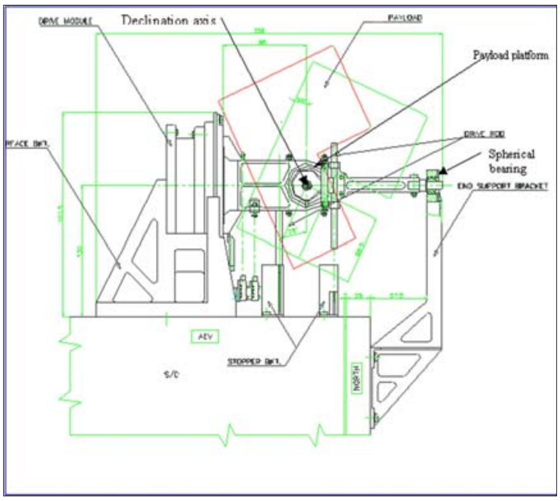

Fig-3 Sun Tracking Mechanism

The linear movement of the drive rod is converted to the rotary movement by using traditional "***Indian curd churning mechanism"***. When the "drive rod" is pushed along its axis it pulls the wire rope wound on the pulley helical groove and makes the pulley to turn "Fig.5". Both ends of the wire rope are rigidly attached on either side of the drive rod after passing over the pulley.

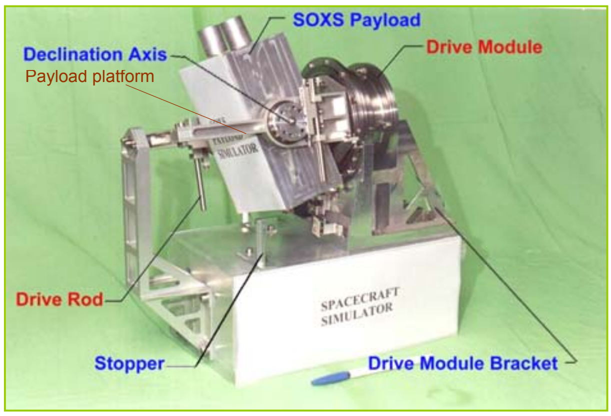

Fig.4 Sun tracking Mechanism assembly

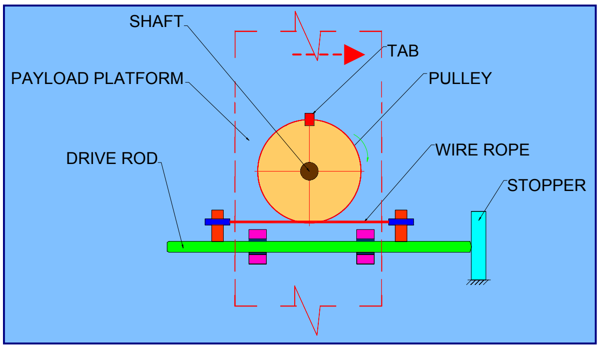

Fig. 5 Declination Drive Principle

When one side drive rod is pushed-in, the other side drive rode is pushed out automatically due to the interconnection of the two, through the payload package, pulley and wire rope. The pre-tension in the wire rope and the swaged tab on the rope makes the drive slip free and backlash free. The drive ratio between main pitch-drive and declination-drive is kept at approximately 1:5 and hence "over-drive" of 10^{o} in pitch axis causes a rotation of 50^{0} in declination (-25^{o} to $+25^{o}$).

To keep/hold, the payload in the driven declination position a friction hold is provided in the declination drive by two Delrin pads, and stainless steel pressure pads loaded with a compression spring. This friction Hold is provided only on west side declination trunion. This trunion is floated axially to accommodate thermal expansion contraction of payload package with respect payload platform. East side declination trunion is axially arrested to support the payload for launch loads along its axial direction.

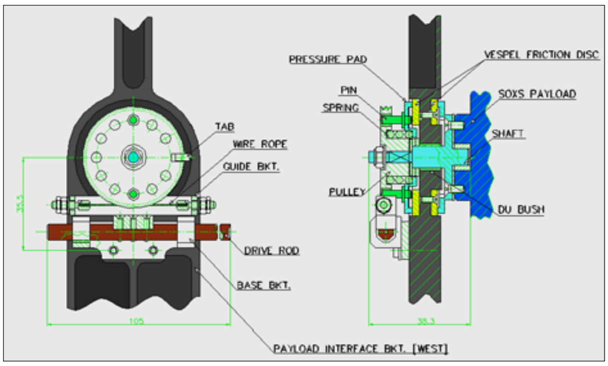

Fig. 6 Friction hold on declination trunion

During launch, the mechanism is moved to East end "mechanical stop". The high detent torque available in the drive module holds the payload in position without an additional launch hold down. With the same detent, declination axis is also arrested by drive rod and stopper bracket in the extreme over-drive position.

4. POINTING ANGLE MONITORING

The mechanism is designed to operate in open loop. The payload-pointing angle is obtained by counting the number of motor pulses from the micro-switches reference positions. Two simple single axis sun sensors "Fig.7," mounted on the payload package and aligned one each to the two pointing axes, indicate Sun pointing error if any, in two axes in a range of $\pm5^{0}$. The detail of pointing angle monitoring is given below.

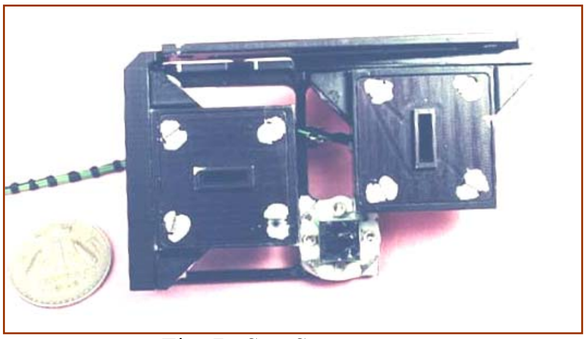

Fig. 7. Sun Sensors

One Limit Switch/micro-switch each on either side is mounted to provide 'Northeast-end' and 'Southwest-end' angle reference. Third micro-switch is mounted in the middle to have near center point angle reference "Fig.8". The switches actuation points were calibrated using optical theodolites for their actuation angles. These switches serve as reference indicators to obtain the payload-pointing angle when the platform is driven to actuate the switch. From that point, a predetermined set of pulses to stepper motor drives the mechanism to the required point and by keeping count of the moved motor steps the pointing orientation is obtained on ground. In case the reference position or the number of steps is lost, the mechanism can be driven to any one micro-switch point to reestablish pointing angle.

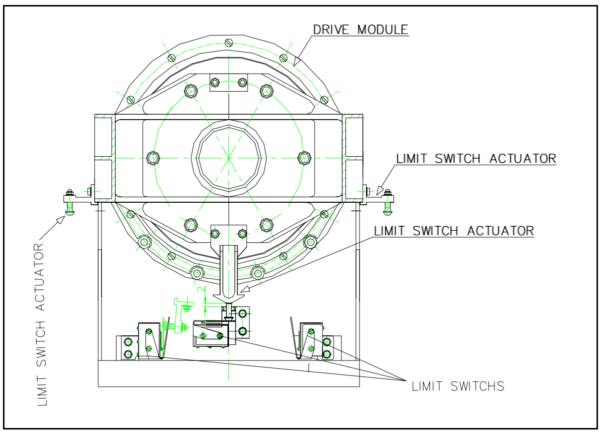

Fig. 8. Limit-Switches Mounting Detail

In addition to the above, a thin film potentiometer built on to the motor shaft to indicate the motor rotation. For every rotation of the motor shaft the output, goes through one saw tooth curve. The number of full turns plus the indicated angle of potentiometer gives the total angle of movement.

5. HARNESS LOOP

Large harness bundle with most of the wires with double-shielded cables was to be routed from payload package to the spacecraft "Fig.9". Two loops, first loop for allowing the tilt of $\pm 23.5^0$ about declination axis and second loop to allow tracking axis movement of 190^0 were configured. To reduce the harness torque and loop length, harness shielding was removed for the portion of declination loop. Extensive life cycle test and harness torque characterization tests were done on the simulated harness.

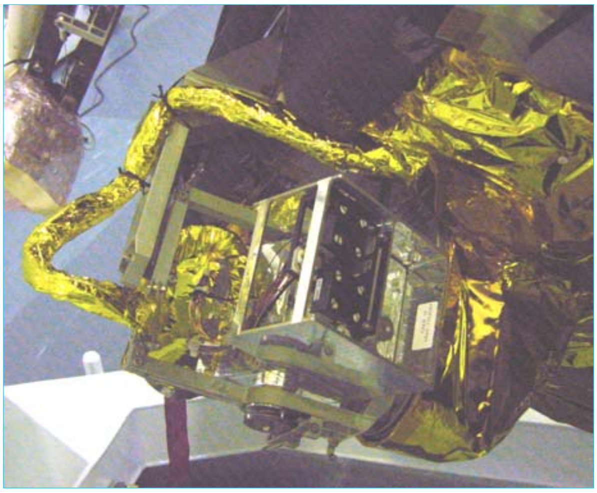

Fig. 9 Mechanism on Spacecraft with Payload Package and harness loop

Two models, one Qualification model and one Flight model were made. The Qualification model went through the qualification testing successfully. The flight model after its testing at subsystem level was integrated with Solar X-ray Spectrometer (SOXS) payload package and then to spacecraft. The assembly was subjected to detailed alignment and testing.

6. ON-ORBIT PERFORMANCE

GSAT-2 spacecraft was launched on 9th May 2003 on-board second developmental flight of Indian Geo synchronous Launch Vehicle (GSLV). The SSTM (SOXS Sun Tracking Mechanism) was successfully driven and tested on 13th, May 2003. The micro-switch reference position verification was also done on the same day and found to be matching with the ground data. The mechanism was holding the launch orientation of payload confirming the adequacy of the detent hold. Sun tracking of the payload was initiated and the tracking performance was normal. The plot of sun sensor error at the start, during and end of tracking is shown in "Fig.10". The plot of potentiometer output and motor step counter are given "Fig.11". Presently SOXS Sun Tracking Mechanism (SSTM) is being operated on regular basis based on payload operation requirements.

7. NOVELTY AND LESSONS LEARNT

The novelty of this paper and the lessons learnt from this study include:

- With the proposed novel concept of using only one motor drive for the required pointing of two axes, it became feasible to accommodate the payload within the spacecraft bus constraints.

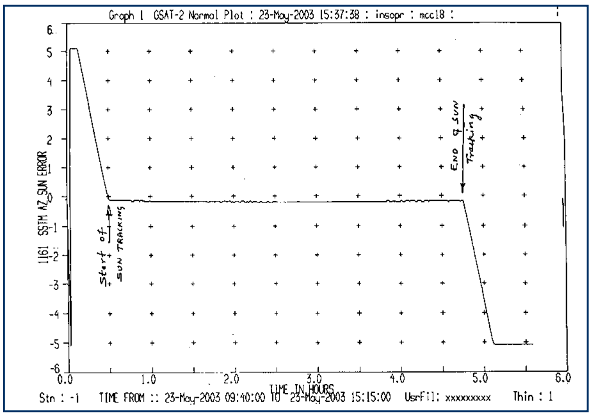

Fig. 10 Sun Sensor Angle during tracking

- High detent torque available in the motor drive was effectively used in avoiding a separate launch hold down for the payload.

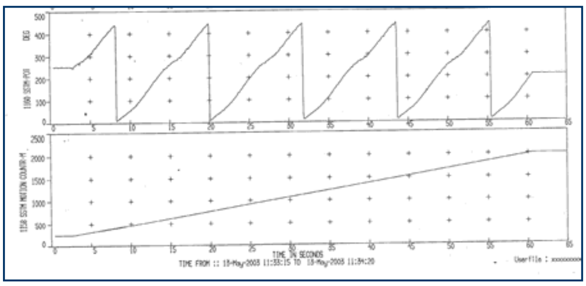

Fig. 11 Potentiometer and Motor step counter data

- Very simple but novel backlash free declination drive was achieved with minimum mass.

- Micro switches provide good position switching accuracy and repeatability.
- It is better to incorporate extra sensors to confirm and demonstrate intended mechanism function/working in-orbit.
- The sun sensors, gave very valuable data for assessing mechanism on-orbit tracking performance.
- It is very essential to design the mechanism considering the electrical harness, its routing, and the expected torques.
- Potentiometer life could be enhanced by many times by wet lubricating the contacts.

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9. REFERENCES

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