INCLINATION CONTROL USING A PULSE MODE AXIAL THRUSTER

M. SUZUKI K. YONEYAMA

Tsukuba Space Center
National Space Development Agency
Ibaraki, Japan

ABSTRACT

A spin stabilized satellite which has a thruster system functioned only in a pulse mode is not capable of changing the orbital inclination in an ordinary way. However, the inclination of ETS-II (Japanese Engineering Test Satellite-II) crossed over the limit of one degree in April 1979. We executed the inclination control maneuvers for experimental purpose by an anomalous method using a pulse mode axial thruster, by which the attitude is generally controlled.

This attempt was performed successfully. It has become clear that the operation requires longer time and careful operation, but does not particularly need additional fuel than a continuous mode thrusting.

Keywords: Geostationary Orbit, Inclination Control, Spin Stabilized Satellite, Pulse Mode Axial Thrusting

1. INTRODUCTION

ETS-II (KIKU-2) was launched on February 23, 1977, from Tanegashima Space Center (NASDA) by an N-1 launch vehicle into a geostationary orbit over the equator at 130 degree east longitude. This satellite is a spin stabilized satellite and has two axial and two radial thruster systems which are only functional in the pulse mode thrusting.

Because it has no continuous mode, ETS-II does not have a capability to change the orbital inclination in an ordinary way. However, the inclination crossed over the limit of the planned boundary, one degree, in April 1979, after the designed life time ended. Then, we made a plan to reduce the inclination for the purpose of an experiment, taking the following conditions into consideration.

1) The primary experiments of ETS-II have already been finished.
2) The inclination gets to 1.3 deg. on August 1, 1979.
3) ETS-II functions well enough and a few additional experiments are going to be continued.
4) The residual fuel of the secondary propulsion system is much enough for executing the inclination control.

2. INCLINATION CONTROL METHODS

Two methods are considered for the operation of the inclination change of the satellite which has no continuous thrusting mode like ETS-II. One of them is to use an axial thruster and the other is to use a radial thruster.

2.1 Inclination Control Using an Axial Thruster

In general, the attitude control is carried out in pulse mode, while the orbital inclination control is executed in continuous mode, using an axial thruster. However, most of the energy generated during attitude control turns into small acceleration along the spin axis. If the spin axis is not far from the normal to the orbital plane, we can control the inclination, utilizing this acceleration. Namely, repeated attitude controls near the nodal point (descending node in Figure 1) cause the inclination to decrease.

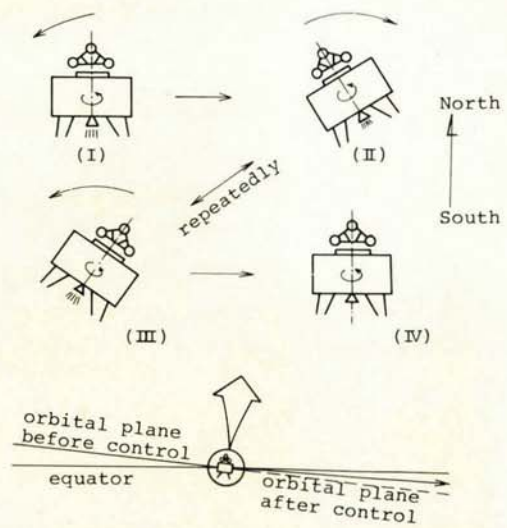


Figure 1. Inclination Control Using an Axial Thruster

2.2 Inclination Control Using a Radial Thruster

After a satellite has been laid down in an orbital plane by an axial thruster, acceleration along the normal to the plane is added by a radial thruster around the descending and ascending node (Figure 2), by which the inclination can be reduced. The satellite shall be returned to the normal attitude later.

2.3 Comparison Between the Two Methods

The summarized result of our trade off study is shown on Table 1. We obtained technical prospects of success from both methods, and adopted the former one, because of its reliability.

3. SIMULATION OF INCLINATION CONTROL

We estimated the inclination change by a computer program in the condition that the satellite attitude is controlled along the plane where the normal attitude exists.

The results are shown on Figure 3, where the curves 1 to 5 correspond to the positions in orbit. Namely, the case in which the satellite is controlled in attitude at about an hour before crossing over the descending node, is indicated with curve 2. The efficiency in this case is reduced by about 3% comparing with one which is executed at descending node (curve 3) and it is reduced by about 10% in the case of 1 and 5. Consequently, we planned to execute the operation within one hour around descending node.

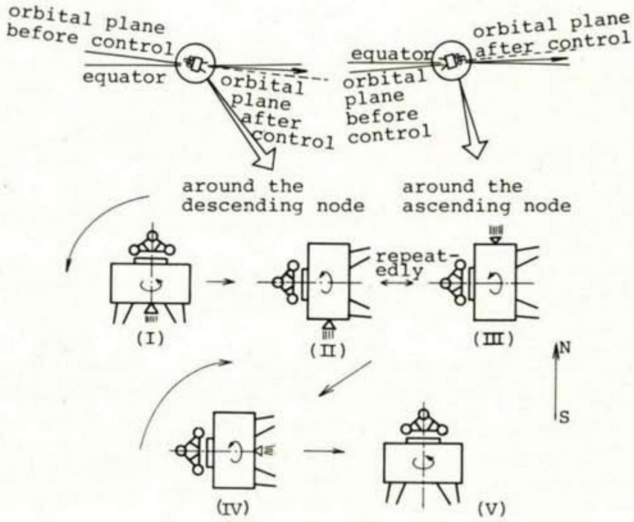


Figure 2. Inclination Control Using a Radial Thruster

We can also realize in Figure 3 that the inclination is changed by 0.0022 degrees when the attitude is inclined from 90 degrees to 70 degrees in declination. 1.3 degrees change is achieved by thirty times of attitude controls between plus and minus 20 degrees from the normal attitude.

Table 1. Comparison Between The Two Methods

Item	Case by an Axial Thruster	Case by a Radial Thruster
Operational Interruption	Discontinuous or partitioned operation is possible, utilizing the opportunity that the satellite returns in a normal attitude during the operation.	Interruption is difficult by reason of the problem being concerned with heat and electric power, because of the attitude lying.
Executing Time	As the operation can be executed only around the descending node owing to a configuration of thrusters, it takes longer time.	It takes shorter time, as the operation can be executed around both nodes. However reorientation maneuvers are required twice.
Thrusting Efficiency	The efficiency is reduced in proportion to the spin axis being far from the normal to the orbital plane.	The efficiency is reduced by the reorientation maneuvers and in proportion to the spin angle during thrustings.
House keeping of the Satellite	It is anticipated that the condition of the satellite will not change on a large scale in relation to the maneuvers.	Simulation by computer is required about housekeeping data, because of the large-scale attitude changing.
Maintenance of Communication Links	The links are maintained by an omni-antenna.	The contrivance requires that the spin axis should be kept off the direction of the earth.

4. STATE OF THE EXECUTION

4.1 Outline of the Execution

We planned to divide the maneuver into two parts with the apprehension that the sun sensors or earth sensors might lose their objects during a long operation. The first experiment was executed in about an hour around the descending node on August 20, 1979. The attitude controls which changed the attitude by ±20 degrees off the orbital normal were carried out thirteen times, and the inclination was decreased from 1.32 to 0.76 degrees.

The second one was held on October 8, 1979, and the controls which changed the attitude by ±15 degrees were executed twenty-five times extending over one and a half hours. As a result, the inclination was decreased from 0.81 to -0.06 degrees.

The progress of the controls is shown on Figure 4. These controls were followed by additional maneuvers for re-aquision of normal attitude.

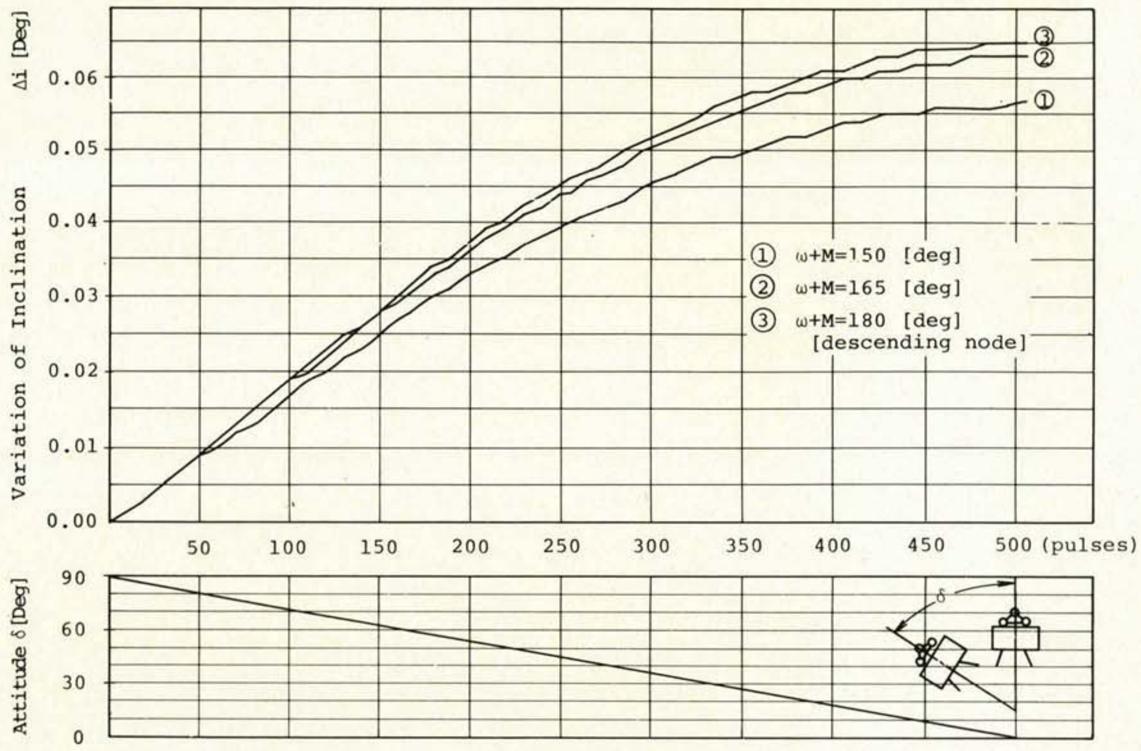


Figure 3a. Fluctuation of the Inclination Accompanied with an Attitude Control (in the case of ETS-II)
[ω:argument of perigee M:mean anomaly]

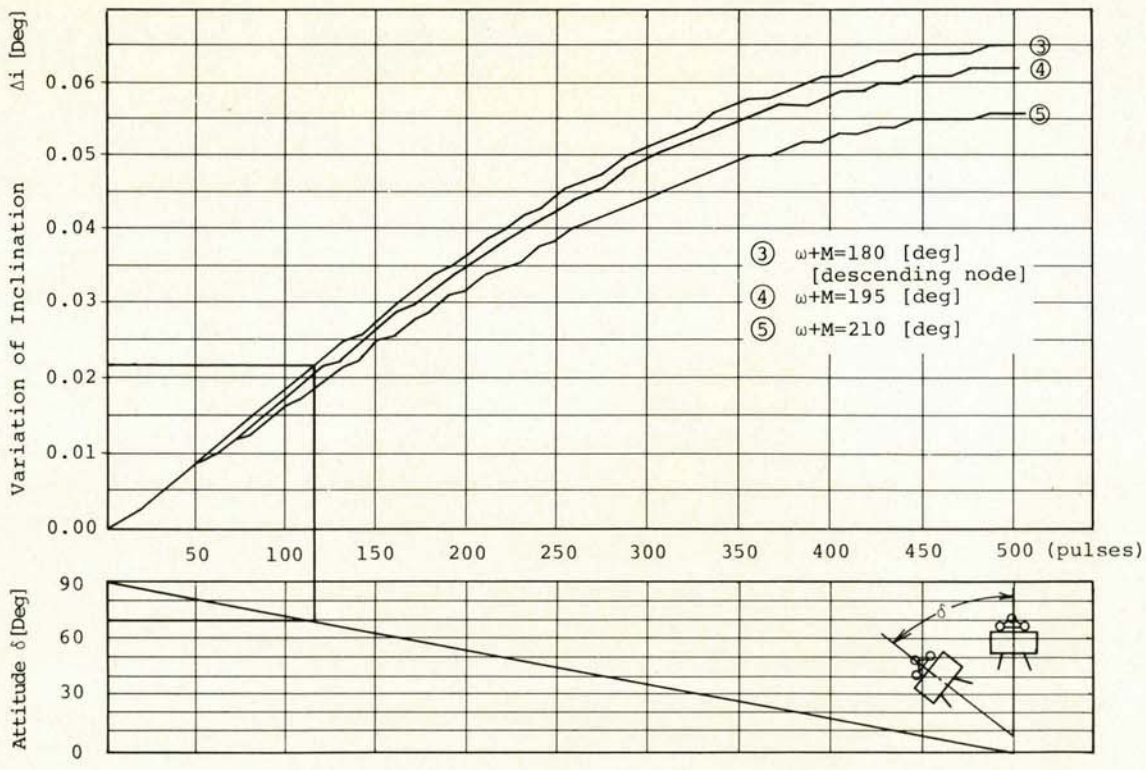


Figure 3b. Fluctuation of the Inclination Accompanied with an Attitude Control (in the case of ETS-II)
[ω:argument of perigee M:mean anomaly]

4.2 Monitoring the Execution

HK data are generally monitored during controls and the sun angle was especially watched at these executions for the purpose of securing the attitude alterations. Consequently, the attitude was changed in the plane where the sun angle would alter in a large scale. Figure 5 and 6 indicate the fluctuation of the sun angle corresponding to attitude controls.

In the first experiment the monitored sun angle slipped off the estimated one and the earth sensor lost the object. We supposed that the gap was caused by a spin rate increase from 90.55 to 91.70 rpm depending on the thruster alignment. As a result of re-calculation considering the spin rate increment, the gap was filled up as indicated in Figure 5.

We executed the second experiment after due consideration of the said spin rate problem. (Figure 6)

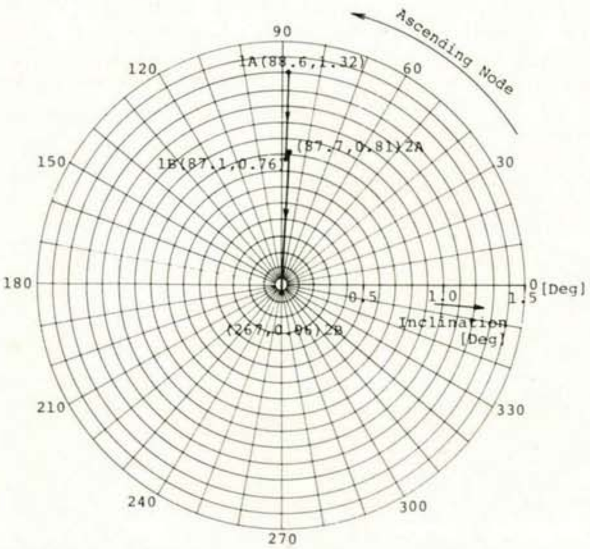
4.3 The Efficiency

These maneuvers needed fuel as much as 1.72 and 2.69 kg and changed the inclination 0.56 and 0.88 degrees respectively. Namely, it was necessary about 3.1 kg per 1 degree. On the other hand, CS (Japanese Medium-Capacity Communications Satellite for Experimental Purposes) which is a spin stabilized satellite with continuous thrusting mode, needs about 7.0 kg per 1 degree.

Considering these conditions and the weights of two satellites which are about 130 (ETS-II) and 310 kg (CS) respectively, the ratios of weight to fuel quantity are nearly equal to each other as follows.

$$\frac{130}{3.1} \fallingdotseq 42 \text{ (ETS-II)} \qquad \frac{310}{7.0} \fallingdotseq 44 \text{ (CS)}$$

This result shows that this anomalous inclination control is not very different from the normal method as to efficiency.



1A	Before the 1st Exp.	'79.08.20; 11.35.00
1B	After the 1st Exp.	'79.08.21; 11.20.00
2A	Before the 2nd Exp.	'79.10.08; 08.04.30
2B	After the 2nd Exp.	'79.10.11; 13.00.00

Figure 4. Progress of the Inclination Controls

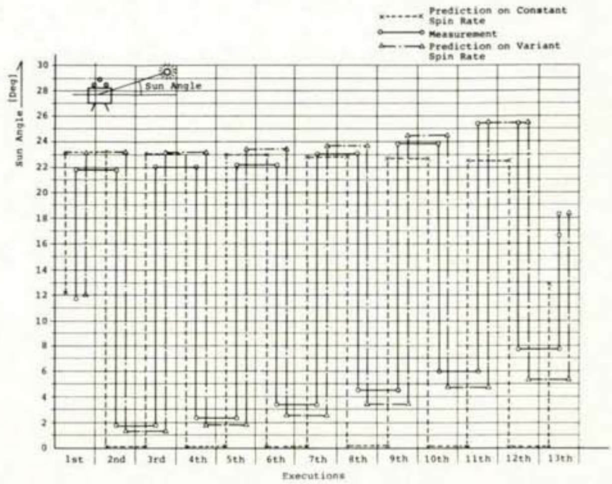


Figure 5. Fluctuation of Sun Angle (1st Exp.)

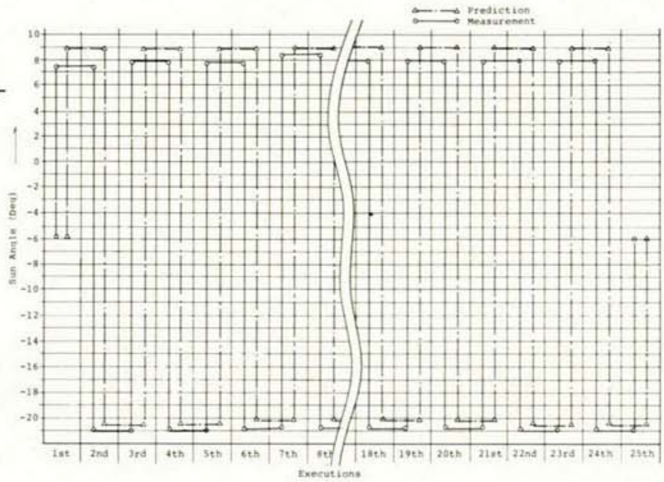


Figure 6. Fluctuation of Sun Angle (2nd Exp.)

5. CONCLUSION

This attempt to use a pulse mode axial thruster for the inclination control of a spin stabilized satellite was performed successfully. It requires longer time and more careful operation, but does not particularly need additional fuel than a continuous mode thrusting.

We consider that this method is also able to be applied to some other satellites.

6. ACKNOWLEDGEMENT

We would like to express our gratitude to people who co-operated with us in this experiment.