Despin Antenna Control System for Planet-A

Masayoshi KAWAGUCHI*, Yoshinari MASUMOTO*,
Harumitsu YAMAMOTO*, Hironori HARA* and Tomonao HAYASHI**

Abstract

Japan's planetary exploration spacecraft "PLANET-A" is to employ a mechanical despin antenna control system which operates at 0.2 rpm and 5 rpm spin rates. This will be the first time that a mechanical despin antenna control system is used in space at an ultra-low spin rate of about 0.2 rpm. A breadboard model (BBM) of a despin antenna control system operating at 0.2 rpm and 5 rpm spin rates and incorporating several new techniques was assembled and its performance confirmed through BBM tests and computer simulation. This paper describes the functions of the despin antenna control system developed for PLANET-A and its test results.

1. Introduction

PLANET-A is being developed by the Institute of Space and Astronautical Science (ISAS) as an interplanetary probe which will flyby Halley's comet.
The missions of PLANET-A are imaging of Halley's comet in the ultraviolet region and analyzing energy spectrum for solar wind particles near the comet.
A high gain parabolic antenna will be employed to transmit data from the spacecraft to an earth station.
PLANET-A will be spin stabilised at 5 rpm (nominal rate) as well as at 0.2 rpm for imaging of Halley's comet by a charge coupled device (CCD) camera. Thus, the reflector fot the antenna will be despun with respect to the spacecraft at 0.2 rpm and 5 rpm spin rate. An overall view of the spacecraft is shown in Fig. 1.
The pointing angle of the reflector will be controlled to be equal to angle α (sun-S/C-earth angle), and angle α is changed by timer logic or ground command.
The relation between the pointing angle β and angle α is shown in Fig. 2.
The pointing angle jitter requirement is ±0.3 deg and is difficult to maintain at 0.2 rpm and 5 rpm spin rates, because of the motor cogging torque. The despin antenna control system developed for PLANET-A employs several new techniques to meet this requirement.

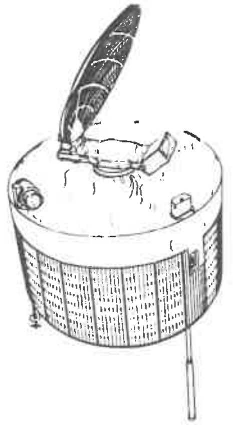


Fig. 1. Overall view of the PLANET-A spacecraft.

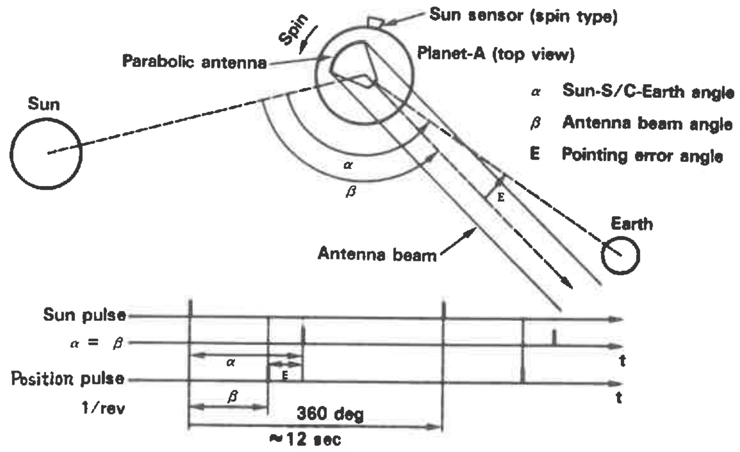


Fig. 2. Concept of pointing.

---

* Nippon Electric Co.,Ltd.; 4035,Ikebe-cho, Midori-ku Yokohama 226, Japan
** Institute of Space and Astronautical Science ; 4-6-1, Komaba,Meguro-ku Tokyo 153, Japan

2. System Configuration

The PLANET-A despin control system consists of the following major components.

(1) Despin Drive Assembly

The Despin Drive Assembly (DDA) of PLANET-A is composed of a 16-pole brushless DC torque motor, resolver and optical encoder. The optical encoder, generating the rate and position pick-up pulses of DDA is provided with redundancy. Rate pick-up pulses of 4096 pulses/rev are employed for raising the response speed in the 0.2 rpm spin rate mode.
Cogging torque was actually measured to be less than 0.5 oz-in at the BBM. Dry lubrication is employed for the bearings to allow operation at -50°C.

(2) Despin Control Electronics

A block diagram of the PLANET-A Despin Control Electronics (DCE) is shown in Fig. 3. The PLANET-A DCE features the use of a spin synchronized pulse generator (SSPG) developed for use at ultra-low spin rates, and a method of selecting optimum network depending on the spin rate mode (0.2 rpm or 5 rpm). An edge trigger type phase comparator is employed for the motor servo loop to minimize phase error.
The SSPG output provides the rate reference pulses to the motor servo loop. The pointing angle is changed by modifying the phase of the rate reference pulses. The angle α which determines the pointing angle of the reflector can be set with 0.7 deg resolution by ground command and can also be changed automatically by means of an up-date system.

(3) High Gain Parabolic Despin Antenna

The diameter and weight of the reflector of the PLANET-A despin antenna are approximately 80 cm and 3.5 kg respectively. The moment of inertia of the reflector is 0.16 kgm². The maximum gain of despin antenna is 22.3 dBi and to keep the gain decrease within 0.2 dB down, the requirement of pointing accuracy is ±1.0 deg. Because the pointing angle resolution is 0.7 deg, it is necessary that pointing jitter be less than ±0.3 deg.

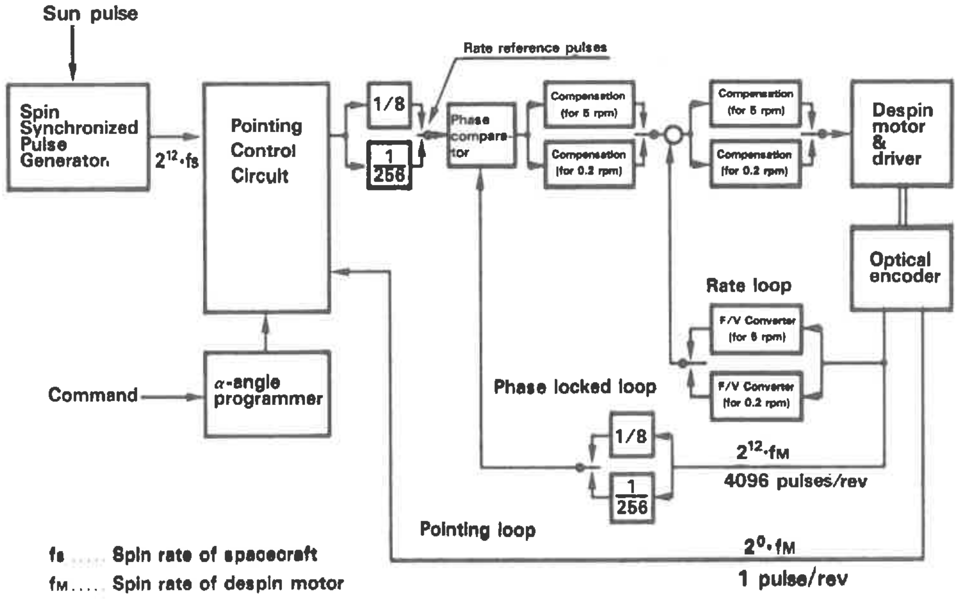


Fig. 3. Block diagram of DCE.

3. Functions of Despin Control Electronics

(1) Spin Synchronized Pulse Generator

The conventional despin antenna control system employs an analog or digital phase locked loop (PLL) for generating spin synchronized pulses which are used as the rate reference. However, PLL is not employed in the case of PLANET-A, as the sun pulse input would be applied only once in 5 minutes for 0.2 rpm spin mode. This would not be satisfactory since it would take more than 50 minutes before the PLL is locked, assuming that at least 10 sun pulses are necessary. Accordingly, PLANET-A employs a circuit which digitally produces spin synchronized pulses by counting the spin period of the spacecraft by a counter. The circuit operates on the principle that the frequency of the pulses whose period equals 1/N of the spacecraft spin period becomes N times (N=4096 in the case of PLANET-A) as large as the spin rate. The spacecraft spin period is obtained from the sun pulse period.
Fig. 4 shows a block diagram of the spin synchronized pulse generator (SSPG). Using the above principle, the SSPG output pulses are correctly spin synchronized when at least two sun pulses are applied. The disadvantage of this method is that as the spin rate becomes high, the spin period measuring error becomes large and the frequency error of the spin synchronized pulses becomes large. Fig. 5 shows the relationship between the spin rate and SSPG error. However, when the SSPG is used in combination with the pointing control loop, the error will be corrected by pointing control and will not be accumulated. This has been confirmed by BBM tests.

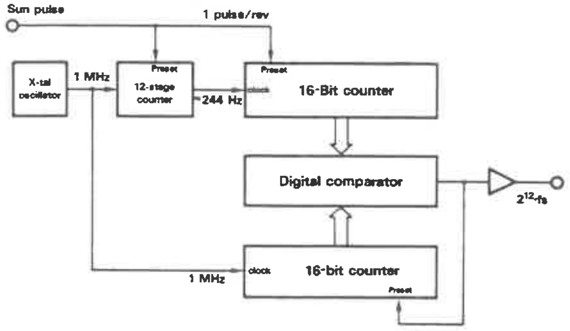


Fig. 4. Block diagram of SSPG.

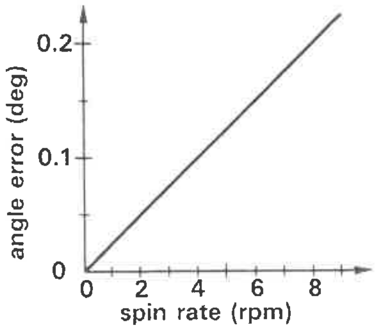


Fig. 5. Relation between spin rate and SSPG error.

(2) Pointing Control Circuit

Fig. 6 shows a block diagram of the pointing control circuit. The pointing error angle is given by the difference between the angle α and angle β as shown in Fig. 2. The pointing control circuit controls the pointing angle to make the error angle E zero.
This control operation is performed by leading or lagging the phase of the SSPG output pulses. When, for example, the antenna is offset 45 deg clockwise from angle α, the DDA is lagged by taking the pulses which correspond to the error angle (e.g., 512 pulses for an error angle of 45 deg), at a rate of one pulse out of 8 pulses from the pulse train of the SSPG output. Similarly, when the antenna is offset counterclockwise, the DDA is led by applying pulses at a rate of one pulse out of 8 pulses to the pulse train of the SSPG output.
A control direction detector is provided so that pointing control operation will not be performed if the path exceeds 180 deg in the wrong direction.

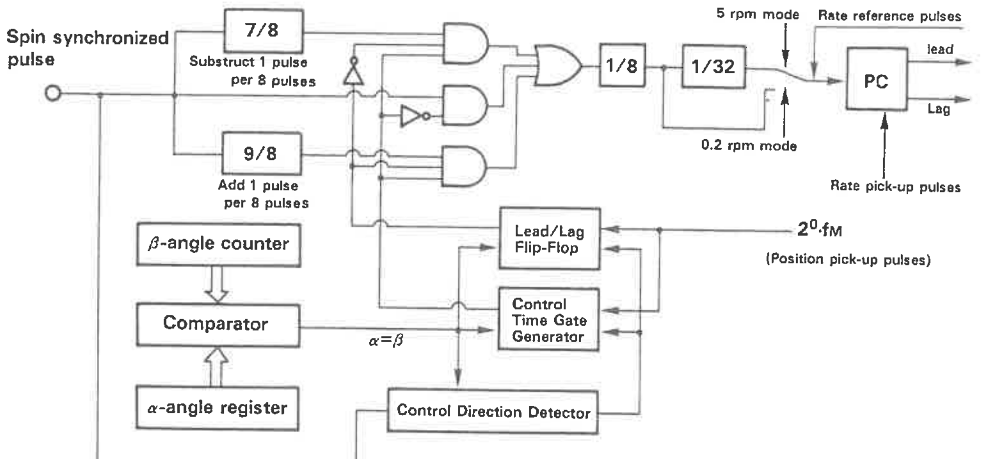


Fig. 6. Block diagram of pointing control circuit.

(3) Servo Control Loop

The servo control loop of PLANET-A consists of a rate feedback loop for rate damping and a phase locked loop (PLL) for synchronizing the DDA with the rate reference pulses as shown in Fig. 3. In the ultra-low DDA operation mode of 0.2 rpm, the cogging torque caused by the magnetic pole gap of the DDA may act as an external disturbance to greatly vary the despin rate.
In order to suppress the disturbance due to the cogging torque, the gain of the rate feedback loop is maximized and as many as 512 comparing times per revolution are introduced. As the operation is required in both spin rates of 0.2 rpm and 5 rpm, it is necessary to select two different constants for the loop filters. C-MOS analog switches are applied to switchover the elements of the loop filters. The gain of the rate feedback loop is made as large as possible, approximately 60 dB. The decrease in the phase margin of the rate feedback loop caused by this, is compensated for by transferring the cutoff frequency to a higher frequency range through the use of a 4th-order low-pass filter in the frequency/voltage converter and by phase compensation through a lead-lag filter.

3. Simulation of DCE with Digital Computer

A computer simulation model was employed to confirm the performance of the DCE shown in Fig. 3. Using the computer simulation model shown in Fig. 7, the response to the step input of the servo control loop was simulated by a digital computer. The results of simulation are shown in Fig. 8. Stability analysis of the servo control loop was also performed by digital computer. Bode plots of total open loop are shown in Fig. 9. In this analysis, phase margin is kept at more than 30 deg.

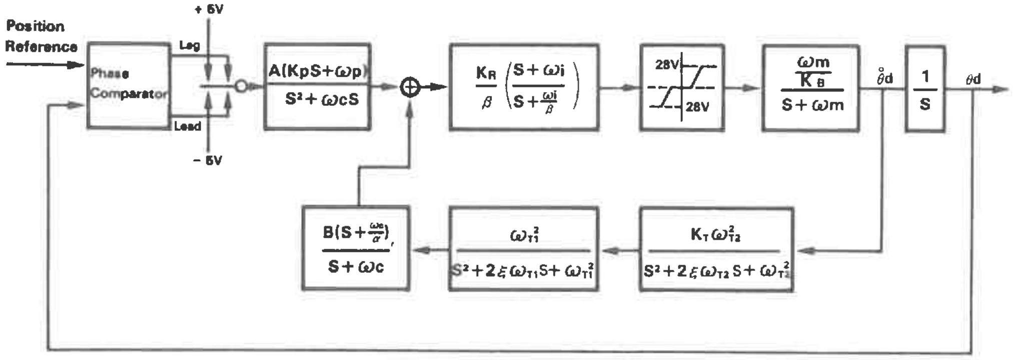
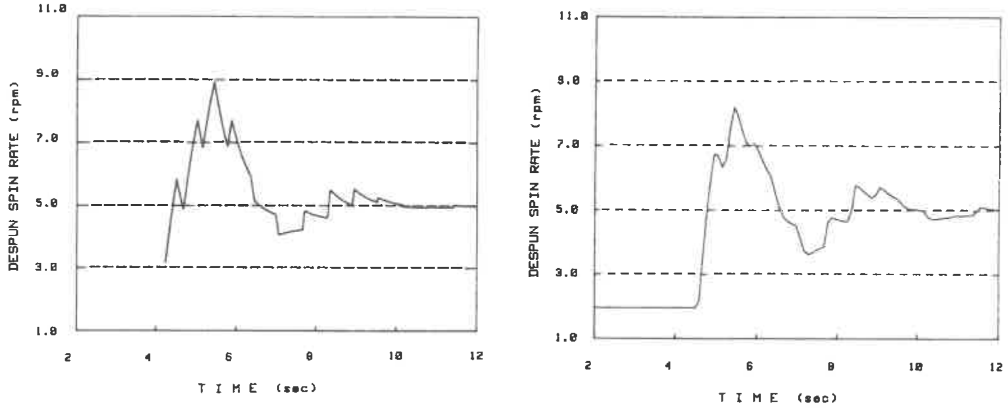
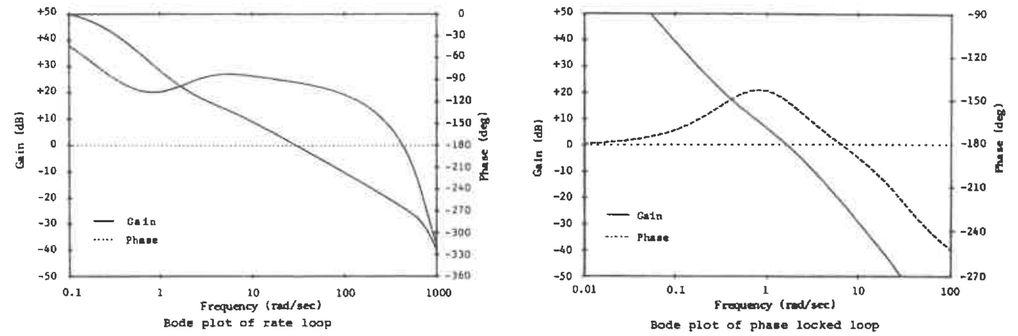


Fig. 7. Computer simulation model of DCE.



(a) Result of computer simulation. (b) BBM test result.

Fig. 8. Result of computer simulation of servo control loop start-up response.



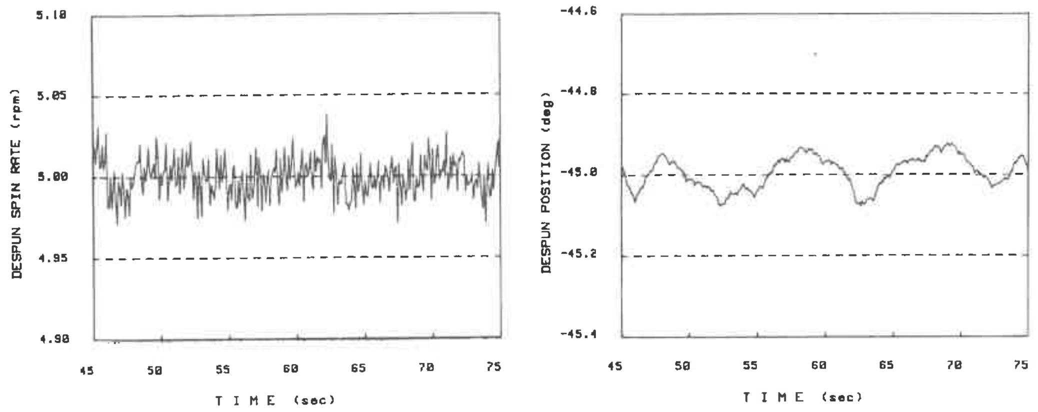
(a) rate loop. (b) phase locked loop.

Fig. 9. Bode plots of servo control loop.

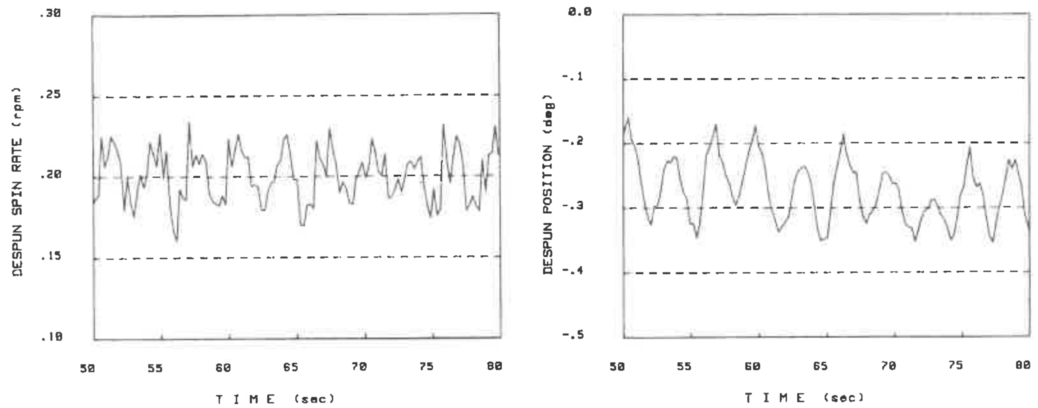
4. Results of BBM Tests

In order to check the DCE hardware design, a BBM was manufactured and tested. The position and rate variations obtained by these tests are shown in Fig. 10. The performance characteristics obtained by the BBM tests are as follows.

(1)	Pointing jitter.	±0.1 deg (5 rpm mode) ±0.2 deg (0.2 rpm mode)
(2)	Lock range.	3.5~9.5 rpm (5 rpm mode) 0.1~0.5 rpm (0.2 rpm mode)
(3)	Time required for changing antenna by 45 deg.	approx. 12 seconds (5 rpm mode) approx. 5 minutes (0.2 rpm mode)
(4)	Power consumption.	2.5 W (max)



9a) Rate jitter at 5 rpm. (b) Pointing jitter at 5 rpm.



(c) Rate jitter at 0.2 rpm. (d) Pointing jitter at 0.2 rpm.

Fig. 10. BBM test results of pointing and rate jitter.

5. Conclusion

It is concluded that PLANET-A despin control system can be operated at ultra-low spin rates satisfactorily through extensive computer simulation and BBM tests. The influence of cogging torque which has a deleterious effect on the despin rate is suppressed. The pointing jitter design requirement of ±0.3 deg for the communication system is completely met.

References

1. ISAS: PLANET-A Status Report (SES-TD-82-006), dated June 1982.
2. H. C. Benohr, W. Kleinau, R. Alexander: Pointing Control of the HELIOS Pencil Beam Antenna, IFAC symp Autom Control Space, Vol.7, NO.2, 1976, pp.227-240
3. W. H. Follet, T. M. Spencer: Description and In-Orbit Performance of the Orbiting Solar Observatory Control System, AIAA Guidance and Control conference, AIAA Paper No. 72-852

Attitude Control System of the Sounding Rocket S-520-5

Ichiro NAKATANI*, Jun-ichiro KAWAGUCHI*, Toshiya NAKAJIMA*
and Ritsuo HASEGAWA**

Abstract

This paper represents the three-axis attitude control system of the sounding rocket S-520-5 with two flexible antennas.

The attitude control system is basically ON-OFF control type with PI feedback, and main consideration is the performance of the attitude control system under the influence of the antennas' vibration.

1. Introduction

The Institute of Space and Astronautical Science (ISAS) plans to launch the S-520-5 sounding rocket in September 1982. The mission includes spectroscopic observation of the sun in the extreme UV region with small onboard telescope, and electric field measurement with two expansible antennas.

To achieve the sun observation, three-axis attitude control system is installed as a payload. the attitude control system consists of rate gyros, sun sensors, onboard computer, and N_2 cold sidejet tank/ thruster assembly.

The rocket is not entirely rigid body because of the two antennas which can be considered as flexible appendages. Therefore it is necessary to assess the influence of the flexibility to the attitude control system.

The following sections are for: performance of S-520 type rocket, missions related to attitude control, control system hardware, simulation model and equations, and results of the simulation. Finally, conclusions.

2. Performance of S-520 rocket

Fig. 2-1 shows the specification of S-520. Total length is 7.94m, 524mm in diameter, and 2165kg in total weight. Payload section is separated after burn-out.

Payload capability is indicated in Fig. 2-2. A 200kg payload for 300km altitude is typical.

The sidejet attitude control system with electronics of S-520-5 is installed in the payload section.

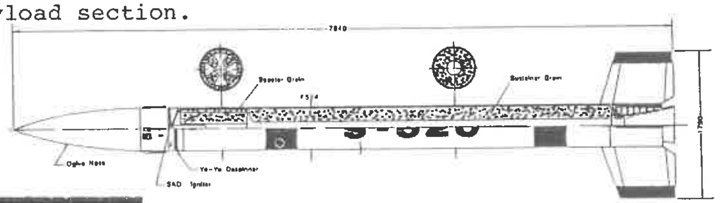


Fig.2-1 S-520 rocket

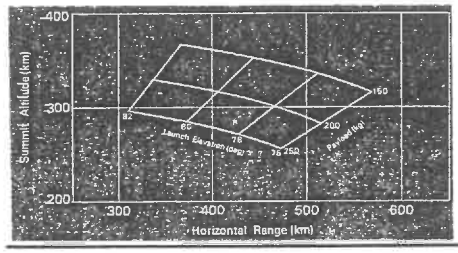


Fig.2-2 Payload capability

---

*ISAS, 4-6-1, Komaba, Meguro-ku, Tokyo, 153, Japan
**Mitsubishi Precision Co., Ltd., 345 Kamimachiya, Kamakura-city, 247, Japan