N91-24609

AN ANTENNA-POINTING MECHANISM FOR THE ETS-VI K-BAND SINGLE ACCESS (KSA) ANTENNA

Noboru TAKADA*
Takahiro AMANO**, Toshiro OHHASHI** and Shigeo WACHI**

Abstract

This paper describes both the design philosophy for the Antenna Pointing Mechanism (APM) to be used for the K-band Single Access (KSA) antenna system and experimental results of the APM's Engineering Model (EM) tests. The KSA antenna system will be flown on the Engineering Test Satellite VI (ETS-VI).

I. Introduction

Recently, the requirements of data-relay satellite systems have been increasing. The Data Relay Tracking Satellite (DRTS) and some user satellites will be launched in the 1990s in Japan. The DRTS system will provide data-relay services between low-earth-orbit satellites and ground stations. A high bit-rate communications link is required to transmit the enormous amount of data (including image data), so pointing requirements for an antenna are becoming more stringent. The technology of acquiring and tracking low-earth-orbit satellites is also becoming more important. The KSA antenna system of ETS-VI is currently under development to establish the essential technology of DRTS for acquiring and tracking satellites. The mechanism to position the antenna in a desired direction forms one of the essential components of this technology. The engineering model of the APM for the ETS-VI KSA antenna has been designed, developed, integrated and tested.

The configuration of ETS-VI is shown in Figure 1. The KSA antenna is attached to the earth panel of the main body. The APM of the KSA positions the antenna about 2 axes to acquire the user satellite and the ground terminal, while providing the antenna position signal and physical support for the antenna.

The results of design trade-offs are shown in Table 1. For the APM, speed can be controlled by pulse rates; the antenna position can be determined by counting input pulses without the need for a fine angular displacement sensor; the antenna position can be held by the holding torque of a stepping motor without the need for a brake; and

---

* Tsukuba Space Center, National Space Development Agency of Japan, 2-1-1, Sengen Tsukuba-shi, Ibaraki, 305 Japan

** Toshiba Corporation, Komukai Works, 1, Toshiba-cho, Komukai, Saiwai-ku, Kawasaki-shi, Kanagawa, 210 Japan

the driving electronic circuit can be simple. So an APM using a stepping motor, a harmonic drive, and a position indicator was selected.

The APM consists of a two-axis gimbal. Only one axis of the Engineering Model of the APM (APM-EM) was planned to be manufactured to evaluate functionality. The mechanical configuration of the APM EM is shown in Figure 2.

The APM EM consists of

- A stepping motor, whose function is to rotate the antenna according to input pulses.
- A harmonic drive, whose function is to reduce the rotation angle and to increase the rotation torque of the stepping motor.
- A position indicator, whose function is to provide a position signal for the antenna.
- Bearings, which support the structure assembly.
- An electrical limit switch, whose function is to provide a stop signal in the case of exceeding the permitted limit for the rotation.
- Mechanical stoppers, whose function is to stop the rotation.
- A structure assembly, which supports the antenna and the above elements.

2. System Requirements for the APM

The system requirements for the APM are shown in Table 2. The maximum slew rate is the one required to acquire the low-orbit user satellite. The pointing range is determined by the need to cover the orbit of the user satellites. The step size is driven by the range of the Radio Frequency (RF) sensor and by other factors. The holding torque is necessary to prevent rotation of the KSA antenna at the time of the deployment and the firing of thrusters for the main body during attitude or orbit control. Maximum mass and electric power are also determined as a part of identifying system requirements.

3. Design of the APM

3.1 Design philosophy

The system requirements for a small step size is one of the most important specifications allowing the APM to achieve high pointing accuracy. To accomplish high pointing accuracy, the need to prevent alignment errors becomes very strict. Two sources of alignment errors are mentioned. One is static error and the other is dynamic error. The static error is almost negligible in rotating the APM about 2 axes. However, dynamic errors cannot be neglected. So the dynamic errors are considered in the design.

The alignment is influenced by the thermal environment. The clearance between the outer race of the bearing and the housing causes the alignment error. It is a result of the temperature range and the difference between the thermal expansion coefficient of the material of the bearing outer race and that of the housing material. The relation between temperature range and alignment error is shown in Figure 3. By using a titanium alloy housing, the alignment error is lessened even if the temperature range is wide. Also, the weight of the APM is reduced.

The torsional stiffness of the APM also influences the dynamic error. The stiffness of the APM was dominated by the stiffness of the harmonic drive. Therefore, the torsional stiffness of the harmonic drive was measured during performance testing.

3.2 Design of elements

The design of each element of the APM is described in the following section.

Harmonic drive

The harmonic drive is well known as a lightweight gear with a high reduction ratio. The configuration of the harmonic drive is shown in Figure 4. A good characteristic is that it has no backlash. This characteristic is suitable for the APM-required high pointing accuracy.

The design of the harmonic drive starts from a determination of required size. After considering the output torque of the APM, a CS-32-SP-type harmonic drive was selected. Though a high reduction ratio decreases the motor torque required, it also increases the pulse rate of the motor. A high reduction ratio also requires that the teeth of the gears be smaller, so manufacturing becomes difficult. The reduction ratio of the harmonic drive is 1/157. The lubricants used for the harmonic drive are shown in Table 3.

Stepping motor

In determining the specifications of the stepping motor, one must take into consideration the electrical power, the step angle, the output torque, the pulse rate, and the size. The specification for the motor is shown in Table 4. The electrical power is determined by the requirements of the APM. Both the step angle of the motor and the reduction ratio of the harmonic drive meet the pointing accuracy requirement. The output torque has two aspects. The first is the torque needed to rotate the moment of inertia of both the harmonic drive and the KSA antenna at the maximum slew rate. The second is the torque needed to bend the cable between the KSA RF platform and the ETS-VI main body by rotating the APM. The step angle of the motor is 0.45 degree, and the motor can respond to a pulse rate of 110 pulses per second (pps) to perform the maximum slew rate of the APM. Generally, the torque of a stepping motor is proportional both to the square of the diameter and to the axial length. Therefore, the weight of the motor is mainly determined by the output torque. The diameter of the motor is equal to that of the harmonic drive.

Position indicator

During signal acquisition, the KSA antenna direction is positioned by closed-loop control using the output of the position indicator. So the position indicator is required to provide the correct position of the antenna. The potentiometer was chosen because of its heritage in space, simplicity of the electric circuit, and light weight. The specifications of the potentiometer are shown in Table 5.

Bearings

Radial and axial load capacity are the most important requirements for the bearings. Light weight and protection from the harmonic drive's wear debris are also required for the bearings. Therefore, the shielding-type, single deep-groove ball bearings (6008ZZZ) were selected. The solid lubricant and the material of a retainer for the bearings are described in Table 6.

4. Results of design

The results of the design are shown in Table 7. The APM EM satisfies every requirement. The developed APM EM is shown in Figure 5.

5. Test of the APM

5.1 Sequence of the test

The APM EM was subjected to a functional test, a thermal-vacuum test and a vibration test. After these tests, the requirement of a 3-year orbital life was shown to be met by performing the life test in a thermal-vacuum environment. The sequence of these tests is shown in Figure 6.

5.2 Method of test

The test configuration for the functional test is shown in Figure 7. A dummy inertial mass simulating the moment of inertia of the KSA antenna and RF compartment was connected to the APM through couplings and a vacuum feed-through element. The dummy inertial mass, consisting of four masses, was rotated in a horizontal plane so imbalance of the masses gave no torque to the APM. Therefore, this configuration was suitable for measuring a small step angle with heavy inertia. An accurate rotary encoder was set at the top of the functional-test apparatus. The small step size of the APM was measured by the rotary encoder. The environment around the APM was gaseous nitrogen at the time of operation.

For the thermal-vacuum test, the functional-test apparatus was used again. The APM and the hardware below the flange were in a vacuum chamber. The configuration for the thermal-vacuum test is shown in Figure 8. The temperature of the APM was controlled by the base plate temperature. The vacuum level was less than 10^{-5} torr. The life-test configuration was the same as the one for the thermal-vacuum test, except that the torque for the APM to bend the cable between the KSA RF platform and the ETS-VI main body is simulated.

For the functional test and the thermal-vacuum test, the following functions and performance parameters of the APM were measured:

- electric power
- maximum slew rate
- step size
- holding torque

The temperature conditions of the thermal-vacuum test are shown in Figure 9. The functions and the performances of the APM were measured at −15°C and +55°C in the thermal-vacuum test. The vibration test was performed to confirm that the APM would survive the launch environment.

To demonstrate the capability of a 3-year orbital life, the life test was performed in the thermal-vacuum environment for about 5 months. For the life test, the APM rotated the dummy inertial mass against the torque required to bend the RF cables for over a ±10-degree range. The driving pattern was determined for the assumed case of a user satellite for 3 years. Functions and performance were measured about every 2 weeks.

6. Test results

Performance data from the functional test, thermal-vacuum test and the life test are shown in Table 8. The APM EM accomplished the required functions and performance both at atmospheric pressure and in thermal-vacuum conditions. Its performance did degrade after the vibration test. Also, after the life test, the APM satisfied all of its requirements.

7. Conclusion

The design of the APM for the KSA antenna of ETS-VI satellite was completed, and capability of the design to meet all performance requirements was established by test.

C-2

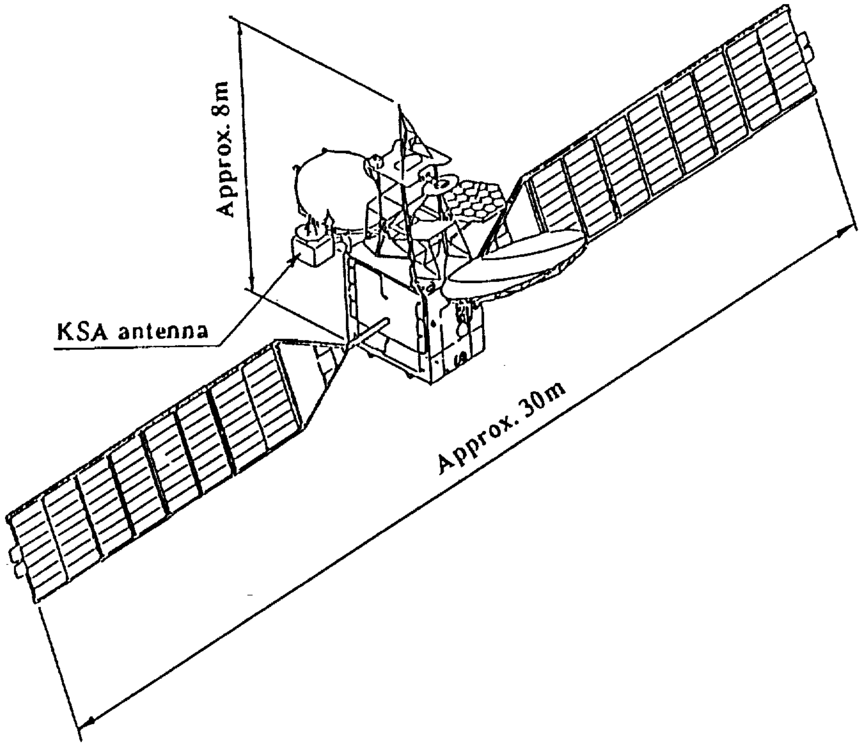

Figure 1. Configuration of the ETS-VI

Table 1. Trade-offs in Designing the Antenna-Pointing Mechanism

	Stepping Motor +Reduction Gear	DC Servo Motor +Reduction Gear	Direct Drive
Control Law	Open Loop	Closed Loop	Closed Loop
Positioning Sensor	Fine Null-Position Sensor	Fine Angular Displacement Sensor	Fine Angular Displacement Sensor
Angular Velocity Sensor	None	Necessary	Necessary
Speed	Low	Necessary	High
Holding Torque	High	Low (used with Brake)	Low (used with Brake)
Output Torque	High	High	Low
Volume, Mass	Small	Small	Large
Drive Electronics	Simple	Complex	Complex
Past Development	PDM (Paddle Drive Mechanism) developed	JEMRMS (JEM's Remote Manipulator System ongoing	None

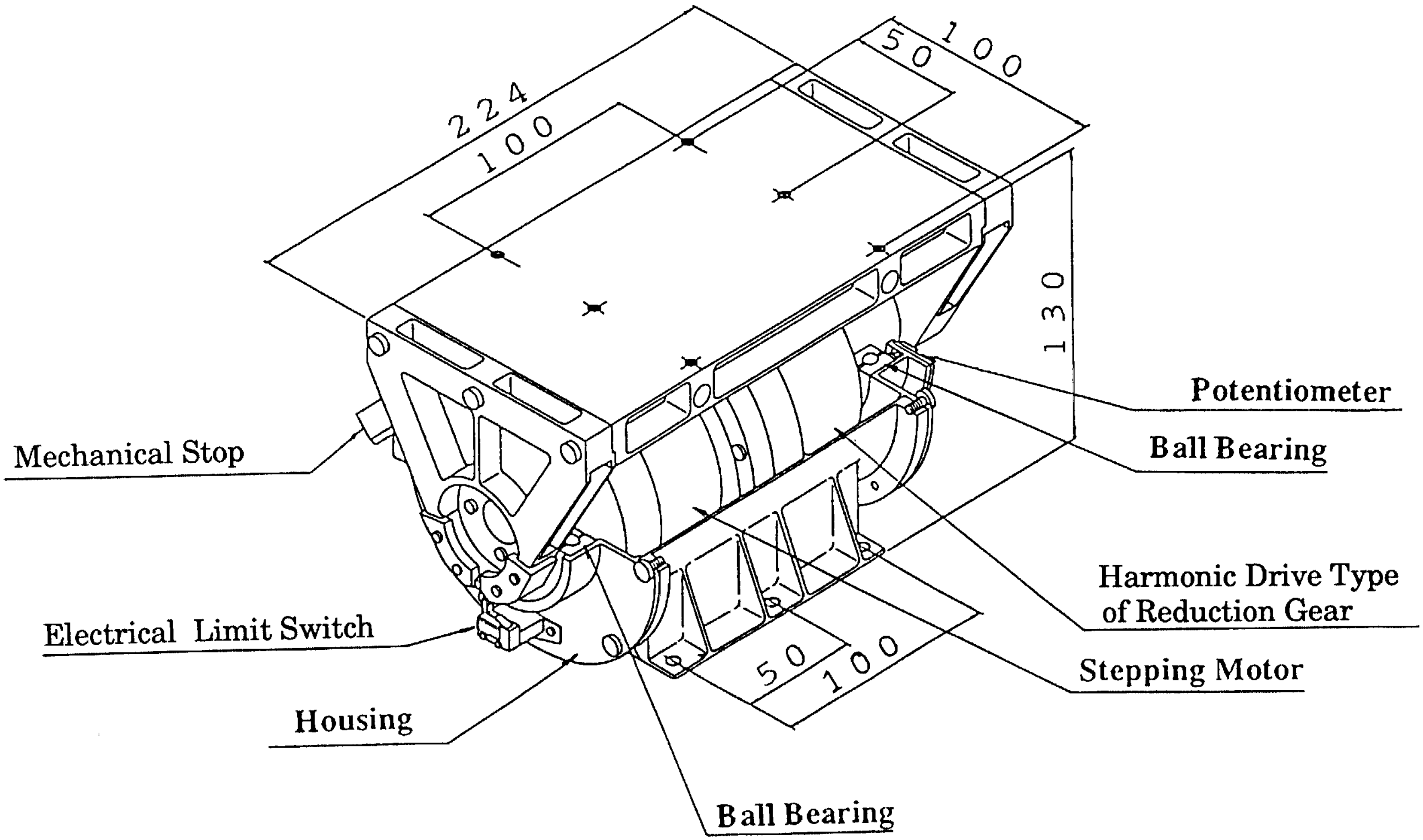

Figure 2. Configuration of the APM EM

Table 2. Requirements for the APM

ITEM	REQUIREMENT
MASS	10 kg (max)
ELECTRIC POWER	39 W (max) SLEWING MODE 4.5 W (max) TRACKING MODE
POINTING RANGE	0.3 deg/sec
MAXIMUM SLEW RATE	± 10 deg
STEP SIZE	0.005 deg (max)
HOLDING TORQUE	10.3 Nm (min)
PAYLOAD INERTIA	13 kgm^2 (max)
REQUIRED LIFE	3 YEARS

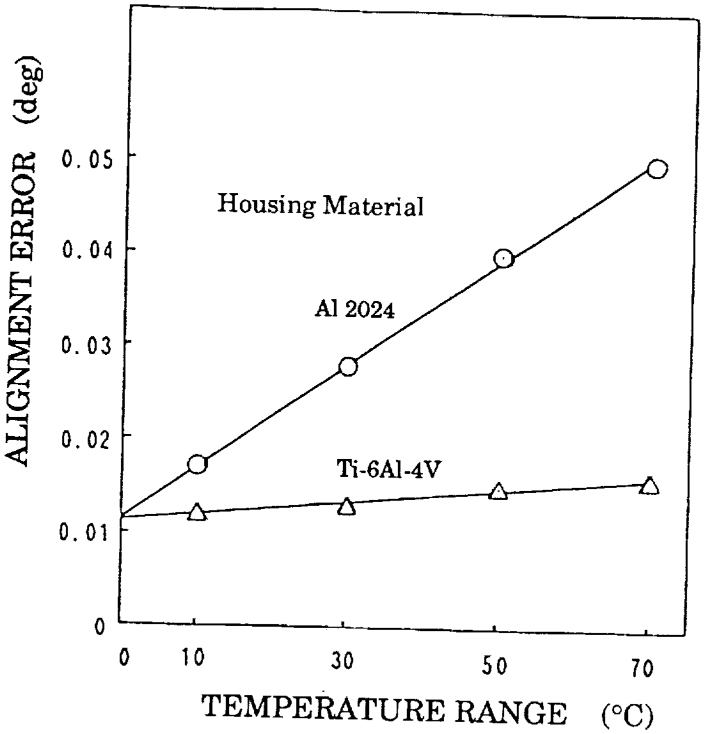

Figure 3. Temperature Range and Alignment Error

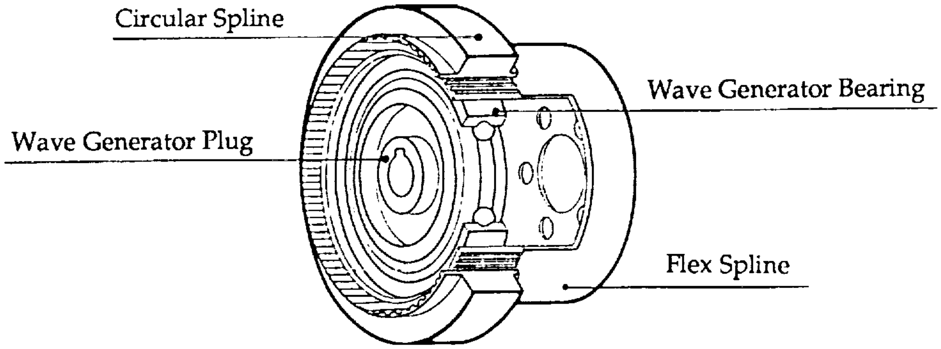

Figure 4. Configuration of Harmonic Drive®

Table 3. Lubricant of the Harmonic Drive®

PARTS		LUBRICANT
BEARING	OUTER RACE INNER RACE BALL	SILVER ION PLATING
	RETAINER	GOLD PLATING
FLEX SPLINE		GOLD PLATING

Table 4. Specifications of the Stepping Motor

ITEM	SPECIFICATION
ELECTRIC POWER	15 W
VOLTAGE	26 ± 2V
STEP ANGLE	0.45 deg
OUTPUT TORQUE	0.45 Nm
PULSE RATE	0 ~ 110 pps
MASS	1760 g

Table 5. Specifications of the Potentiometer

ITEM	SPECIFICATION
TEMPERATURE	-30 ~ +70 ℃ (Operation) -60 ~ +100 ℃ (Non-Operation)
RANGE OF MOVEMENT	360 deg
EFFECTIVE ANGLE	± 18 deg
LINEARITY	±0.08 deg ±0.016 deg (null point)
INPUT VOLTAGE	± 15 V (max)

Table 6. Lubrication of Bearings

PARTS	LUBRICANT
OUTER RACE	MoS_2 Sputtering
INNER RACE	
BALL	
RETAINER	PTFE + glass fiber + Mo

Table 7. Results of Design*

ITEM	REQUIREMENT	DESIGN*
MASS	5 kg (max)	4.9 kg (max)
ELECTRIC POWER	19.5 W (max) Slewing Mode 2.25 W (max) Tracking Mode	19.5 W (max) Slewing Mode 2.25 W (max) Tracking Mode
MAXIMUM SLEW RATE	0.3 deg/sec	0.31 deg/sec
POINTING RANGE	±10 deg	±13.0 deg ± 0.5 deg (Mechanical Stopper) ±11.5 deg ± 0.5 deg (Electrical Limit)
STEP SIZE	0.005 deg (max)	0.00287 deg (Nominal)
HOLDING TORQUE	10.3 Nm (min)	10.3 Nm (min)
PAYLOAD INERTIA	13 kgm^2(max)	13 kgm^2 (max)
REQUIRED LIFE	3 YEARS	3 YEARS (15624 cycles)

*(For One Axis)

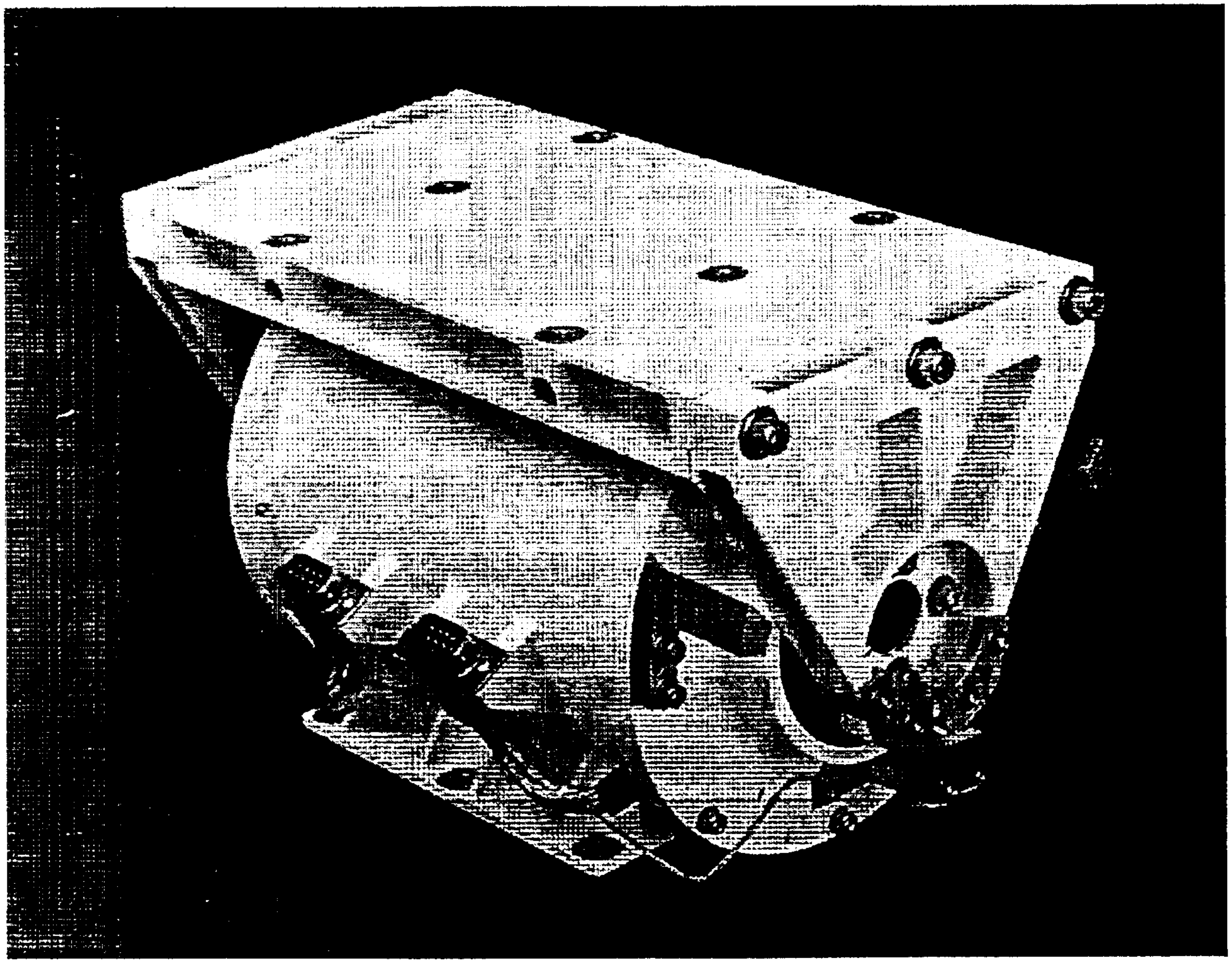

Figure 5. The APM EM

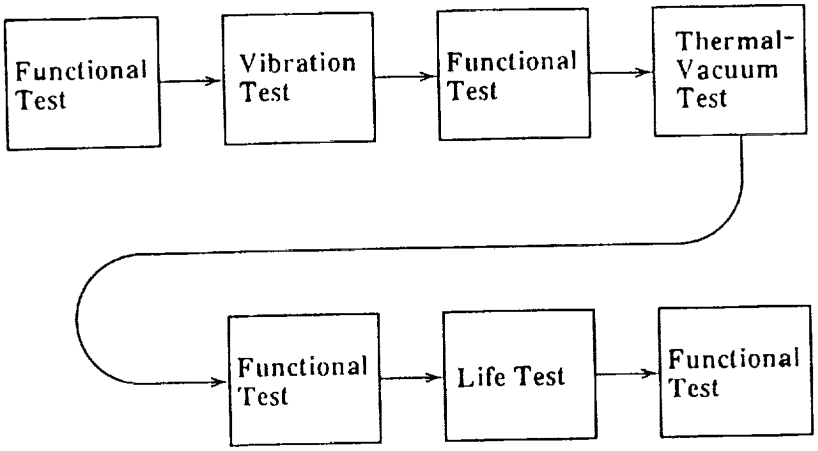

Figure 6. The Sequence of the Tests

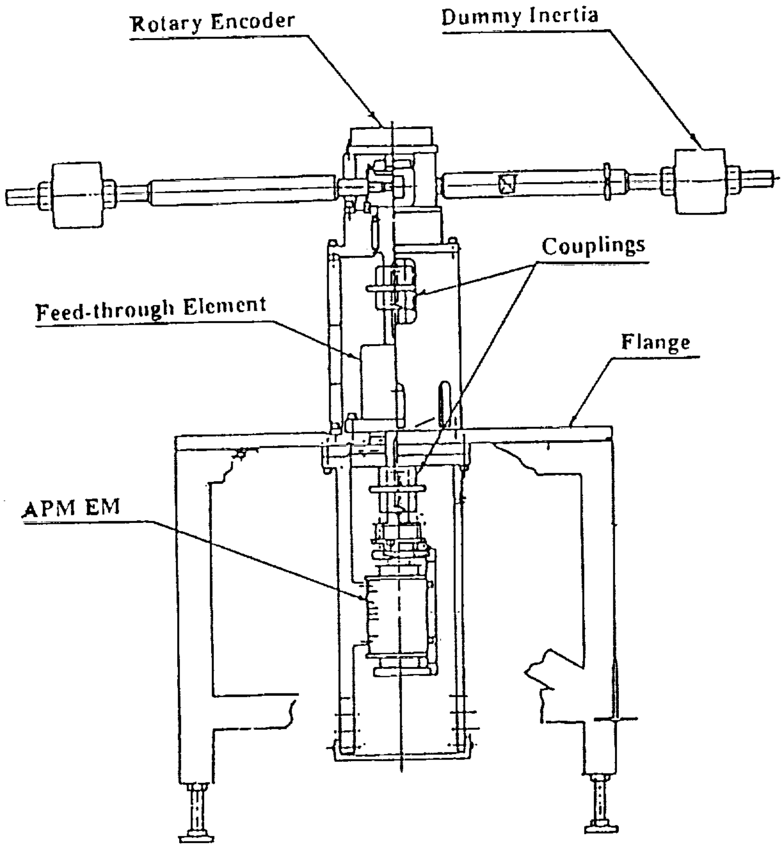

Figure 7. Configuration of the Functional Test

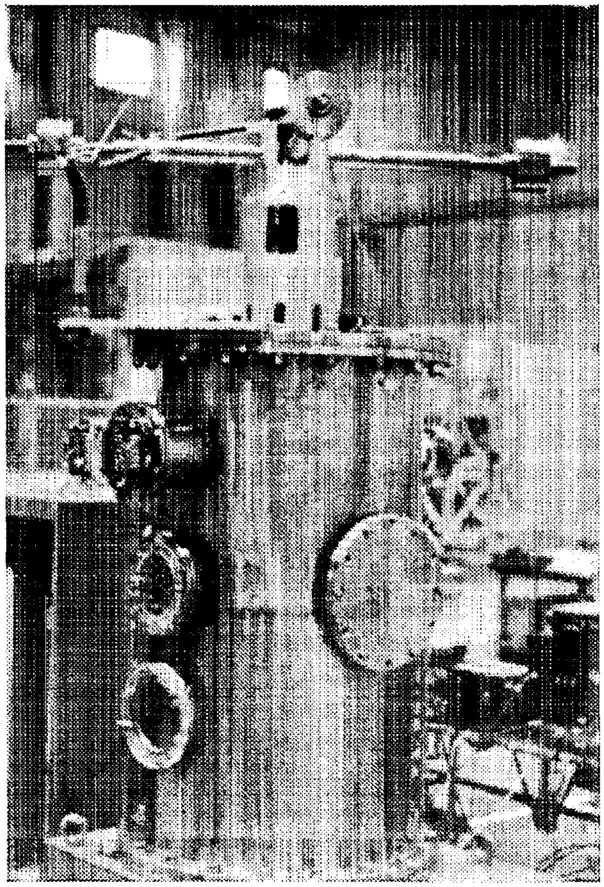

Figure 8. Configuration of the Thermal-Vacuum Test

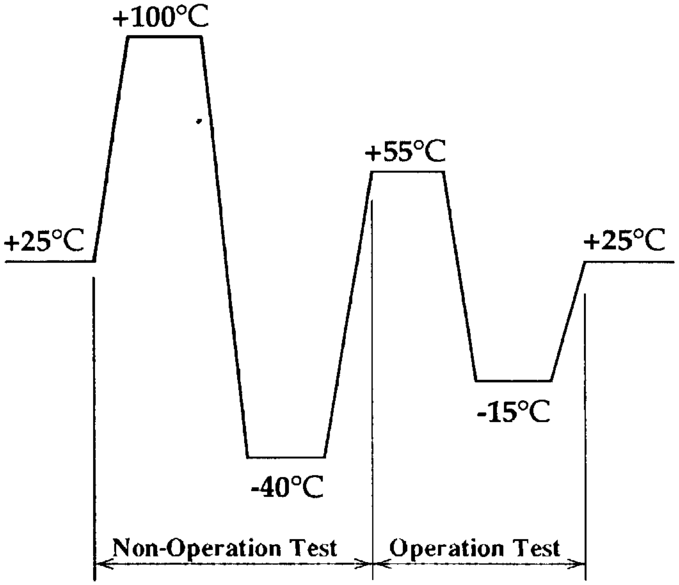

Figure 9. Temperature Conditions

Table 8. Test Results of the APM

ITEM	REQUIREMENT	FUNCTION TEST	FUNCTION TEST (after vibration test)	THERMAL-VACUUM TEST		FUNCTION TEST (after thermal vacuum test)	LIFE TEST		FUNCTION TEST (after life test)
				+55℃	-15℃		+55℃	-15℃	
ELECTRIC POWER	19.5 W (max)	8.9 W	8.6 W	8.9 W	10.3 W	9.2 W	8.6 ~ 8.9 W	9.8 ~ 10.5 W	9.8 W
MAXIMUM SLEW RATE	0.3 deg/see	0.57 deg/sec	0.41 deg/sec	0.57 deg/sec	0.48 deg/sec	0.48 deg/sec	0.57 deg/sec	0.57 deg/sec	0.57 deg/sec
POINTING RANGE	±11.5 ± 0.5 deg (Electrical Limit)	+11.215 ~ +11.259 deg -11.711 ~ -11.816 deg	——	——	——	——	——	——	——
STEP SIZE	0.00287 deg cw (Nominal)	0.00287 deg	0.00291 deg	0.00285 deg	0.00294 deg	0.00274 deg	0.00253 deg ~0.00273 deg	0.00284 deg ~0.00287 deg	0.00276 deg
	ccw	0.00268 deg	0.00285 deg	0.00285 deg	0.00252 deg	0.00264 deg	0.00253 deg ~0.00273 deg	0.00283 ~0.00289 deg	0.00277 deg
HOLDING TORQUE	10.3 Nm (min)	10.3 Nm (min)	10.3 Nm (min)	10.3 Nm (min)	10.3 Nm (min)	10.3 Nm (min)	10.3 Nm (min)	10.3 Nm (min)	10.3 Nm (min)