A Precise Attitude Determination and Control Strategy for Small Astrometry Satellite "Nano-JASMINE"

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Abstract: Intelligent Space Systems Laboratory (ISSL) University of Tokyo has developed a 35 kg astrometry satellite, "Nano-JASMINE" (Nano JAPAN Astrometry Satellite Mission for INfrared Exploration) in cooperation with National Astronomical Observatory of Japan (NAOJ). In the Nano-JASMINE mission, the satellite attitude spin rate should be controlled to an accuracy of 4×10^{-7} rad/s during the observation. To accomplish such severe attitude stabilization, we have developed two novel methods. The first method is a magnetic disturbance estimation and compensation method. In conventional large satellites, a Magnetic torque is not the dominant attitude disturbance. However, in small satellites, the magnetic torque is the dominant attitude disturbance. This is because the moments of inertia of small satellites are much smaller than those of the large satellites. Therefore, it is necessary to develop a novel magnetic disturbance estimation and compensation method. The second method is a high-accuracy spin rate estimation method. In small satellites, high-accuracy rate sensors which are widely used in large satellites are not available, since the power consumptions and the sizes of these sensors are too large for small satellites. Thus, we develop a new spin rate estimation method for Nano-JASMINE. This paper proposes these two methods, the magnetic compensation and estimation method and the high-accuracy spin rate estimation method for the precise attitude estimation and control in the Nano-JAMINE mission. The verification results with the simulations and the experiment show the effectiveness of these methods. The methods enable future small satellites to control its attitude more accurately.

Keywords; attitude control, attitude estimation, residual magnetic moment, magnetic attitude disturbance

1. Overview of Nano-JASMINE

Intelligent Space Systems Laboratory (ISSL) has developed a micro astrometry satellite "Nano-JASMINE" (Nano JAPAN Astrometry Satellite Mission for INfrared Exploration) in cooperation with National Astronomical Observatory of JAPAN (NAOJ) [1]. The size of Nano-JASMINE is about 50 cm cubic, and its weight is 35 kg. Table 1 shows the specification of Nano-JASMINE. Nano-JASMINE will be launched into a sun-synchronous orbit. The satellite will perform all-sky survey during an operational period of about two years. The objective of the Nano-JASMINE mission is to measure three dimensional positions of stars to an accuracy of three milli-arc-seconds (mas) by performing the stellar parallax measurements. Nano-JASMINE drives its CCD in a Time Delay and Integration (TDI) method to obtain the star images. Taking advantage of the TDI method, it is possible to truck and observe more numerous numbers of faint stars. To get star images by the TDI method, the spin rate of Nano-JASMINE should be synchronized to the TDI scanning rate to an accuracy of half the size of one CCD pixel (its view angle is about 740 mas) during the exposure time (about 8.8 sec).

Table 1. Specification of Nano-JASMINE [1]

Item	value
Size	508 × 508 × 512 mm^2
Mass	35 kg
Orbit	Sun-synchronous Orbit
Mission	Infrared astrometry
Focal length	1.67 m
Diameter	5 cm
Detector	CCD in TDI method
Attitude rate requirement	4×10^{-7} rad/s (TDI scanning direction)
	2×10^{-6} rad/s (The other direction)
Sensor	Sun sensor, Magnetometer, FOG, STT
Actuator	RW, MTQ, Magnetic Canceler

In the past years, no small satellite whose weight is less than 50 kg has accomplished such high accuracy attitude stabilization yet. Thus, new strategy for precise attitude control is needed as described in the next section.

2. Previous Studies and Problem Settings

Because of its small size, attitude control of small satellites has some specific problems. For example, because of their small moment of inertia, attitude stability of small satellites is easy to being disturbed by the environmental disturbances, especially by the magnetic disturbances of the satellites[2],[3]. Furthermore, productions of electricity in small satellites are much fewer than those of classical large satellites. Therefore, it is needed to develop novel attitude sensors and actuators which are suitable for small satellites, as well as the algorithms utilizing them for fine accuracy attitude determination and control.

In the past several years, many researches have been conducted on power-saving small components in parallel with on fine attitude determination and control algorithms utilizing these components for small satellites. As a result, attitude determination and control accuracy of recent small satellites have achieved remarkable development. For example, INDEX (REIMEI), which is a 70 kg micro-satellite developed by Institute of Space and Astronautical Science (ISAS), achieved pointing accuracy within 0.05 degrees [4]. In the INDEX mission, several techniques for small satellite attitude estimation and control were applied. For instance, the MTQs driven in the SR-inverse method, the FOGs and the STT for micro-satellite were utilized for estimation and control of the satellite attitude. Furthermore, the residual magnetic moment (RMM) of the satellite, which is the cause of the magnetic disturbance, was estimated with the Least Square method and compensated with the MTQs. Another small satellite PRISM, which is an 8.5 kg satellite developed by ISSL, achieved 0.7 degree/sec attitude stability utilizing the MEMS gyros and the MTQs with Cross-Product method [2]. In the PRISM mission, the RMM of the satellite is estimated with a Kalman Filter and compensated with the MTQs. In this way, many power-saving attitude sensors and attitude control techniques for small satellites have been established. By utilizing these techniques, attitude estimation and control accuracy of small satellites becomes more and more accurately.

However, to accomplish the milli-arc-second order control accuracy which is required in the Nano-JAMISNE mission, two additional technical problems must be solved: the first is more precise magnetic disturbance compensation and the second is accurate spin rate estimation without conventional high-accuracy sensors. As described before, magnetic disturbances are dominant attitude disturbances in small satellites, because of its small moment of inertia. Attitude disturbances in satellites are classified into magnetic disturbances, gravity gradient, air pressure and solar pressure. Table 2 shows the value of these disturbances in Nano-JASMINE. From this table, it is shown that magnetic disturbances are dominant attitude disturbances in the Nano-JASMINE mission. Hence, magnetic disturbance compensation system is essential to control the attitude of the satellite precisely. As mentioned before, several techniques for the magnetic disturbance compensation have been established already. In these techniques, the RMMs of the satellites are treated as constant. However, RMM of satellite are not constant: they also have time-varying components, which is caused by the changes of the electrical currents and the alignment changes of ferromagnetic components. Without compensating for these time-varying components of the RMM, as well as the constant components of the RMM, the attitude stabilization requirement in the Nano-JASMINE mission cannot be achieved. Therefore, we have to develop new magnetic disturbance compensation method which can handle with the time-varying components of the RMM. This method will be mentioned in chapter 3.

Table 2. Attitude disturbances in Nano-JASMINE

Disturbances	Magnitude (Nm)
Magnetic	$5.0 \times 10^{-6*}$
Gravity gradient	1.0×10^{-9}
Air pressure	1.6×10^{-9}
Solor pressure	1.0×10^{-9}

* Residual Magnetic Moment : 0.1 Am^2

Additionally, no angular rate sensor for small satellites is available which can handle with the accuracy required in the Nano-JASMINE mission. To cope with this problem, we have developed spin rate estimation system using the star images obtained from the mission telescope. This system will be mentioned in chapter 4.

In the following of this paper, the magnetic disturbance compensation system is introduced in chapter 3, and the spin rate estimation system is introduced in chapter 4. Other technical features of Nano-JASIMNE for precise attitude control are described in chapter 5. Finally, in chapter 6, the summary of this paper and the future works are mentioned as a conclusion.

3. Magnetic disturbance compensation

3.1. Strategy of Magnetic disturbance compensation

Magnetic disturbances are caused by the interaction between residual magnetic moment (RMM) of satellites and the geo-magnetic field. Therefore, to suppress the magnetic disturbances, the RMM of the satellite should be reduced. RMM has two kinds of components: time-varying components and constant components [3]. In conventional satellites, only constant components are cared and be compensated. However, in the Nano-JASMIE mission, not only constant components but also time-varying components should be cared and be compensated.

The causes of the RMM are current loops of electrical devices of satellites and components consist of magnetic materials. Steady current loops and existence of the magnetic materials cause constant components of RMM. Changes of these current loops and alignment changes of these magnetic materials cause time-varying components of RMM. These time-varying components of RMM have their frequencies depending on their causes.

The orbital environment changes cause low frequency components of RMM. For example, according to sunshine conditions, energy productions of the solar batteries and energy consumption of secondary batteries are changed. They change current loops on the solar panels and magnetic moment of the secondary batteries. Furthermore, according to sunshine conditions, temperatures of satellite change. This variation in the temperatures causes alignment changes of ferromagnetic materials, which shift directions of magnetic moments. In this way, RMM of satellites change with integral multiples of orbital frequencies. Current loop changes in onboard computers cause middle frequency components of RMM. According to the calculation cycles of the computers, the current loops on the circuit boards of the computers change. For example, AD/DA combaters cause changes in current loops depending on their sampling and calculation frequencies. Thus, RMM of satellites changes with integral multiples of calculation cycles of onboard computers. Some components of satellites induce time-varying RMM with the other frequencies. For example, because RWs use electronic motors, they cause changes in RMM with their evolution frequencies. Switching active components of a satellite induce stepped changes of RMM, since current loops of the satellite suddenly changes.

As just described, time-varying components of RMM have their own frequencies depending on their causes. In the Nano-JASMINE mission, these RMMs are classified into three kinds: High frequency, Middle frequency and Low frequency. These kinds of RMM are compensated by using different methods depending on their frequencies. High frequency components (10 Hz~) can be ignored, since they are canceled out by the effect of the inertia of the satellite. Low frequency (~0.1 Hz) or constant components can be estimated in orbit and compensated for by a feed-forward and a feed-back control. Sudden changes of the RMM caused by the switching of active components are also estimated in orbit and compensated by feed-forward technique. This method is mentioned in chapter 3.3. In the case of the middle frequency (0.1~10 Hz) components, it is difficult to estimate and cancel them out in orbit because of the period of the control cycle. Therefore, these middle frequency components as well as the constant components are suppressed by satellite design. This method will be mentioned in chapter 3.2. Table 3 shows a summary of these strategies for the RMM compensation in the Nano-JASMINE mission.

Table 3. Strategy of RMM compensation [3]

Frequencies of RMM	Compensation method
Low (~0.1 Hz)	estimate and cancel out in orbit
Middle (0.1~10 Hz)	suppress by design
High (10 Hz~)	ignore

3.2. Satellite design method for RMM suppression

Since the middle frequency components of the RMM are difficult to estimate and compensate in orbit, they must be reduced before the launch. To reduce these components of the RMM, several techniques are adopted in Nano-JASMINE [3].

For example, structure materials of Nano-JAMINE, such as bolts and connecters are chosen from those which not contains magnetic substances, if at all possible. Furthermore, layouts of components and current loops in Nano-JASMINE are designed as possible as not to cause the RMM. For example, the current circuit patterns on the printed-circuit-boards (PCBs) in Nano-JASMINE are designed form the standpoint of reducing the areas of current loops as much as possible, so as not to create large magnetic moment. For example, current lines on the surface of a PCB and those on the flip side of the PCB are designed to be same pattern as shown in Fig. 1. By adopting this design, the areas of current loops are reduced.

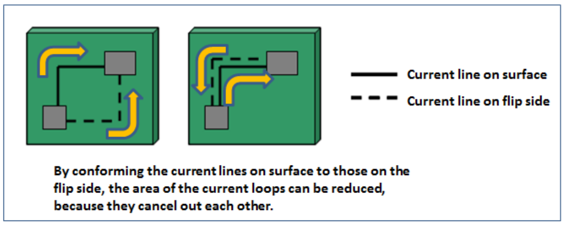

Fig. 1 Circuit pattern design for RMM suppression

This current loop design strategy is also adapted to the layout design of the solar cells. The solar cells are allocated so as to the current direction on them cancel out each other. In addition, not to cause reduce electrical current loops, many harnesses in Nano-JASMINE are twisted. If it is difficult to reduce the RMM by changing layout or design, frequency of the RMM is shifted to high frequency which is negligible for attitude stabilization. For example, although the RW causes time-varying RMM, it is impossible to suppress the amount of the RMM since the structure of the RW cannot be changed. In the Nano-JASMINE mission, evolution frequency of the RW is limited to higher than 10 Hz, in which frequency the RMM does not affect the attitude stabilization of the satellite.

3.3. RMM estimation and compensation in orbit

To cope with the low frequency and constant components of RMM, we have developed the RMM estimation and compensation system consisting of the RMM estimator and the magnetic canceler, which is the high-accuracy MTQ[6]. In this system, RMM estimation is conducted by combining the on-line estimation method on orbit and the off-line method on the ground.

The on-line RMM estimation is conducted for estimating the time-varying RMM in orbit within real time. The estimation is carried out with an Extended Kalman filter (EKF). The state vector of this EKF is a six-dimensional vector consisting of angular velocity and the RMM of the satellite. The measurement vector of this EKF is the angular velocity from the FOGs. In this filter, the noises of the FOGs and the magnetometers should be reduced before the estimation, since they are causes of large estimation error. In the Nano-JASMINE mission, the bias noises of the FOGs and the magnetometers are estimated with the other EKFs. Estimated RMM is compensated for with a feed-back technique.

The off-line RMM estimation is conducted for estimating the constant components of RMM at the ground station. The estimation is carried out also with an EKF by utilizing the telemetry data of the satellite. The estimated RMM is uplinked to the satellite and compensated for with a feed-forward technique. Sudden changes of the RMM caused by the switching of the active components are also estimated by the off-line estimation method at the ground station from the telemetry data.

The estimated RMM is canceled out by the magnetic canceler, which is a high-resolution MTQ for RMM compensation. The specification of the magnetic canceler is at table 4.

Table 4. Specification of the magnetic canceler

Item	value
Max output	0.6 Am^2
Accuracy	5.0×10^{-5} Am^2
Mass	686 g
Power consumption	1.2 W

3.4. SCLT results of the RMM compensation

To verify the effectiveness of the RMM estimation and compensation system, a static closed-loop test (SCLT) has been carried out with the hardware in the loop simulator (HILS) which has been developed for Nano-JASMINE.

In the SCLT, the dynamics of the satellite, the space environment and the sensor data are calculated in the HILS. Calculated sensor data are sent to the OBC of the satellite, which calculates commands to the actuators and sends them back to the HILS.

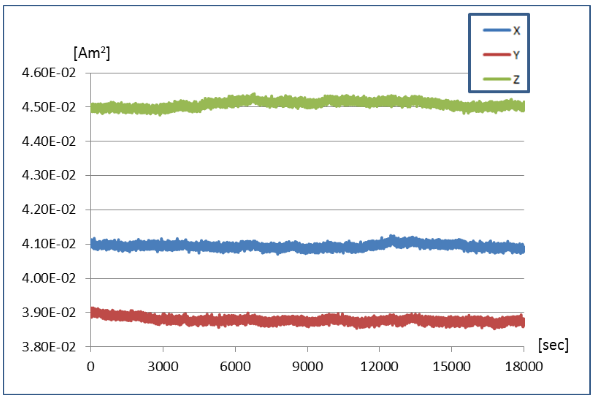

Fig. 2 RMM of the satellite

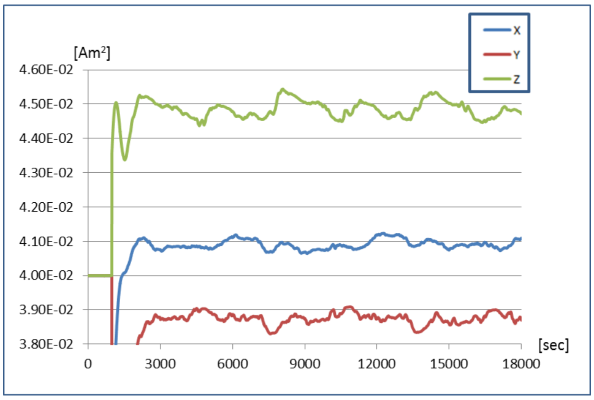

Fig. 3 RMM estimation result

Fig. 2~Fig. 5 shows the simulation results of the RMM compensation and estimation. Fig. 2 shows RMM of the satellite without the estimation and compensation. The RMM measurement experiments showed that the constant component of the RMM in Nano-JASMINE is about $4 \times 10^{-2} Am^2$. This value is realized with designing magnetic characteristics of the satellite. In the HILS, the time-varying components of the RMM are model as the combination of Gaussian noises, random walks, spike noises and bias noises. Fig. 3 shows estimation results of the RMM. In the first 1500 sec, constant component of the RMM is estimated as $4 \times 10^{-2} Am^2$ with the off-line estimation. After 1500 sec, time-varying components of the RMM are estimated with the on-line method. In Fig. 2, the accuracy of the RMM estimation is about $5.3 \times 10^{-4} Am^2$ (Root Mean Square).

Fig. 4 shows the residual components of the RMM after compensated with the magnetic canceler. From this figure, after the on-line estimation started, the RMM of the satellite is suppressed to less than 1/80 of the original value. Fig. 5 shows the magnetic disturbance caused by the RMM. After the on-line estimation and compensation is carried out, the amount of the magnetic disturbances are suppressed to about 5.6×10^{-9}Nm (Root Mean Square). As shown at Table 2, without any compensation, the magnetic disturbances are more than 100 times larger than the other disturbances. On the contrary, SCLT results show that with this magnetic compensation method, the magnetic disturbance is suppressed to the same order to the other disturbances.

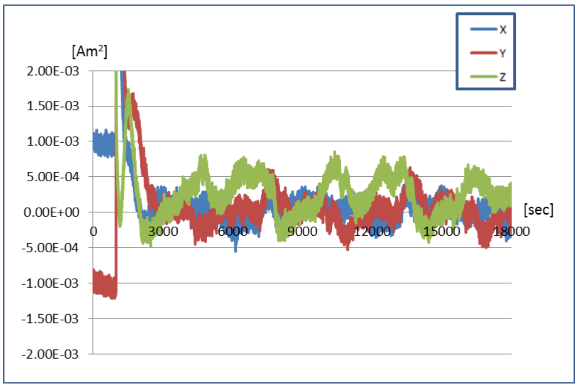

Fig. 4 Residuals of RMM after compensation

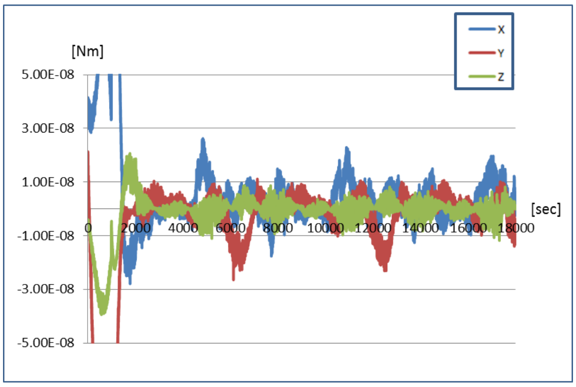

Fig. 5 Magnetic disturbance

4. Precise spin rate estimation

4.1. Spin rate estimation using mission telescope

During the observation phase, the angular rate of Nano-JASMINE should be synchronized to the TDI scanning rate to an accuracy of 4×10^{-7} rad/s. To achieve such high attitude stability, it is necessary to estimate the angular rate of the satellite within so high accuracy that any conventional sensor can detects within.

In the Nano-JASMINE mission, the angular rate of the satellite is estimated from the star images obtained from the mission telescope[1]. Fig. 6 shows the relationship between the motion of the satellite and the star images. If the satellite rotates with faster angular rate than the TDI scanning rate, the star images obtained from the telescope are blurred in the direction according to the axis of the rotation. Since the TDI scanning direction is designed to around the Z-axis of the satellite, the excess angular rate in the Z-axis blurs the star images in the TDI direction and the angular rate in X or Y-axis blurs them in the orthogonal to the TDI scanning direction. Therefore, the Line Spread Function (LSF) obtained from a star image can be utilized to spin rate estimation. How blur the star images are can be calculated from the LSFs obtained from the star images. Fig. 7 shows the relationship between the LSF and the star image.

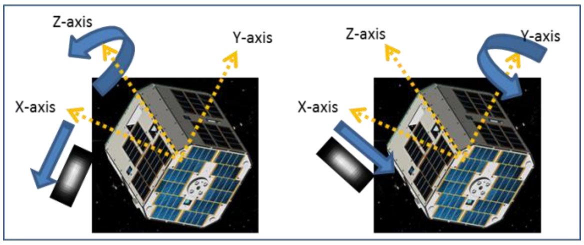

Fig. 6 Spin direction of the satellite and blur directions of star images

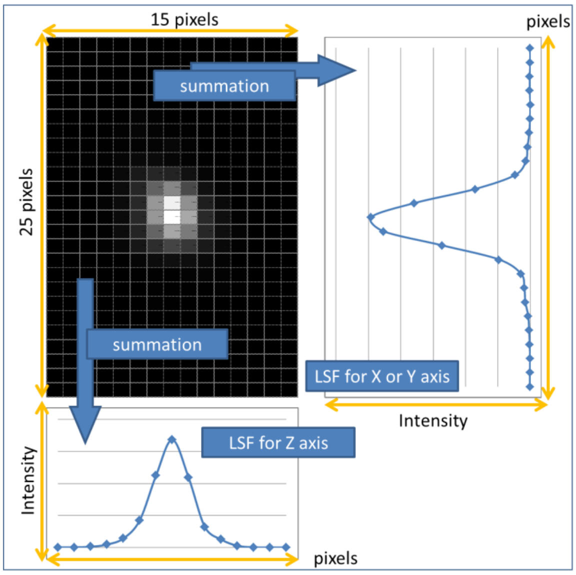

Fig. 7 LSF calculation from a star image

In Nano-JASMINE, each star image obtained from the mission telescope is extracted within a size of 15×25 pixels. The cross direction (TDI direction) of the image is composed of 15 pixels and lengthwise direction of the image is composed of 25 pixels. The cross direction in the image corresponds to the Z-axis of the satellite body system, and the lengthwise direction corresponds to the X or Y-axis of the satellite body system. Thus, summarizing every pixel value (ADU) along the cross direction and lengthwise direction, the LSF for the Z-axis and for the X or Y-axis can be obtained respectively. From these LSFs, variances of the star image can be obtained as follows,

$$\sigma = \left(\sum_{x=0}^{Max}\left(x^2 LSF(x)\right)\right) - \mu^2 \quad \cdots (1)$$

$$\mu = \sum_{x=0}^{Max}\left(x LSF(x)\right) \quad \cdots (2)$$

Where x is the pixel number, *LSF(x)* is the value of the LSF at pixel number x, *Max* is the maximum pixel number for each axis (for instance, as for Z-axis, *Max* is 15) respectively.
From the simulation results, the angular rate of the satellite and these variances has relationships as follows,

$$\sigma_X^2 = A\omega_X^2 + C_X \quad \cdots (3)$$

Where X corresponds to the axis in the image, A is a proportionality factor determined from the exposure time, C_X is a function of the exposure time and the wave length of the stars, and ω is the angular rate of the satellite exceeding the TDI rate. Thus, from the star images, satellite spin rate can be estimated.
A simulated experiment is conducted to research into the relationship between the satellite spin rate and the variance calculated from the star images. In the simulation, the effects of the wave lengths on the variances of the star images are also investigated by using 2 different wave lengths: 950 nm and 650 nm. Fig. 8 shows the simulation results. In this figure, the blue-data points and the red-data points are corresponding to the variances calculated from the star images of 950 nm wave length and of 650 nm wave length respectively.

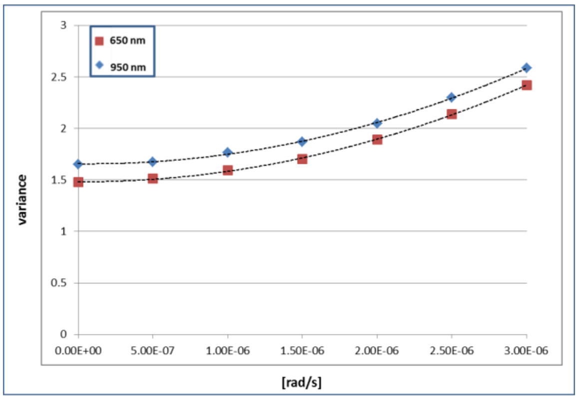

Fig. 8 Variances of the star images via the spin rate of the satellite

In this figure, the variances of the star images increase in parabolic with the exceeding angular rate of the satellite as according to the equation 3. This figure also shows that the colors of the stars do not affect the slopes of the parabolic curves, but affect the intercepts of the parabolic curves as shown in the equation 3. The difference of the image shapes at the same spin rate derives from the nature of the optical system. Therefore, the shapes of the star images at the same angular rate of the satellite are different by their colors. However, how spread the images with the spin rate increases are not different by their colors. The spreading rate of the star images is depending only on the exceeding angular rate of the satellite.

4.2. Results of the verification experiment

To verify the angular rate estimation method for Nano-JASMINE, an experiment for verification using the mission telescope for the flight-model has been carried out. In this experiment, 5 mm diameters LEDs are utilized for light sources, instead of the real stars. Furthermore, instead of the satellite motion, the TDI transfer motion is utilized for blurring the star images. Even though the light source does not move with respect to the satellite, if the exposure time of the LED is longer than the TDI clock interval, the images are extended to the TDI direction by the TDI transfer motion. How long the images are extended is depending on the differences between the exposure time of the LED and the TDI clock interval. Fig. 9 shows the relationship between the spin rate of the satellite and the variance of the star images obtained from the experiment. In this figure, the differences between the exposure time of the LED and the TDI clock are translated into the angular rate of the satellite. This figure shows that the variances of the star images increase in parabolic with the angular rate (the exposure time of the LED). From the result of this experiment, we have obtained the variance curve via the spin rate of the satellite which is approximately same to the one obtained from simulation result.

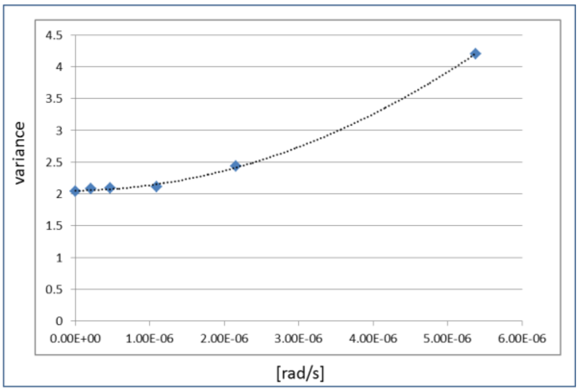

Fig. 9 Variance-spin rate curve obtained from the experiment

4.3. SCLT results of the spin rate estimation

To verify the spin rate estimation method, SCLT examination has also been conducted with the HILS. In the simulation, the simulator PC calculates the variances of the star images according to the spin rate of the satellite. The PC sends these variances to the onboard computer of the satellite. The satellite estimates its own angular rate from these variances. Fig. 10 ~ 12 shows the SCLT results. Fig. 8 shows the simulation results about the angular rate of the satellite. In the simulation, during the first 4000 sec, satellite spin rate is estimated with the EKF using the data from the STT and FOGs. After 4000 sec, the star image based estimation is conducted. In the figure, the spin rate of the satellite after 4000 sec is more stable than those of before 4000 sec. Thus, this result shows that by using the star image based estimation, the angular rate of the satellite can be more stable.

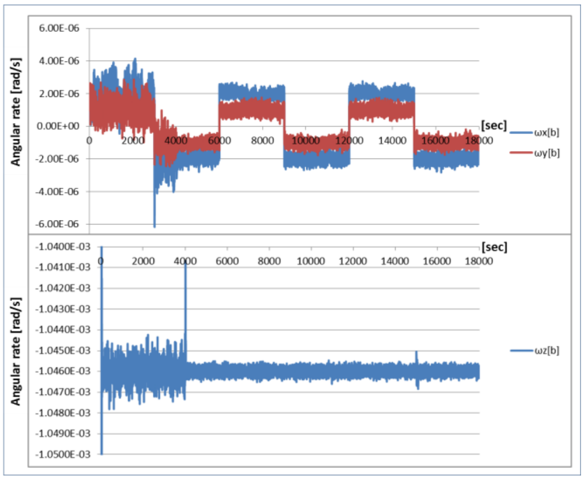

Fig. 10 Angular rate of the satellite

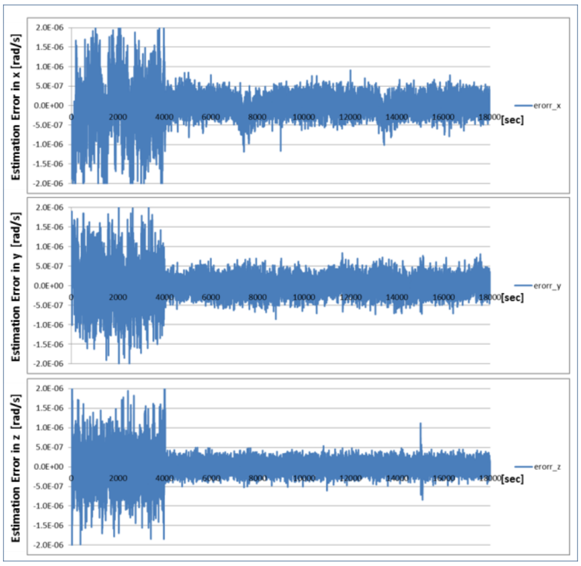

Fig. 11 Rate estimation error in each axis

Table 4. Angular rate estimation accuracy

Axis	Estimation Error (root-mean-square)
X axis	2.269×10^{-7} rad/s
Y axis	2.068×10^{-7} rad/s
Z aixs	1.914×10^{-7} rad/s

Fig. 11 shows the angular rate estimation error in each axis. In this figure, upper, middle, lower graph is corresponding to x, y, z axis respectively. In these graphs, the FOGs and the STT based estimation is conducted in the first 4000 sec, and the star image based estimation is conducted after 4000 sec. From this figure, the star image based estimation enables more precise angular rate estimation than conventional sensor based estimation. Table 4 shows the estimation errors of the star image based method. These errors are evaluated by the root-mean-square method from the same data in Fig. 11. From this table, it is shown that the method can estimate the angular rate to an accuracy of 2×10^{-7}rad/s.

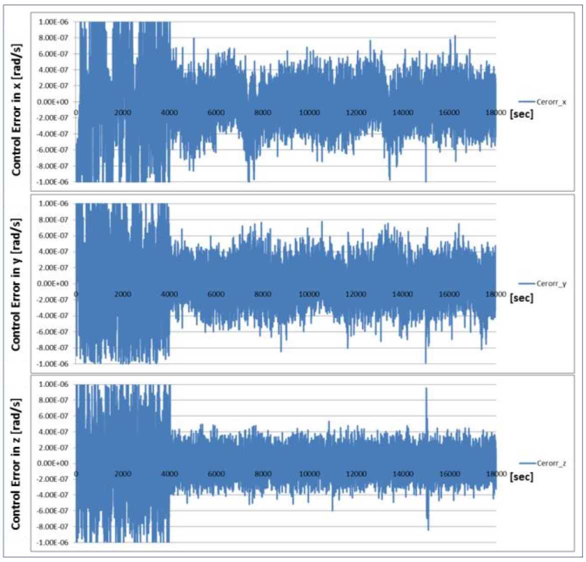

Fig. 12 Rate control error in each axis

Table 5. Angular rate control accuracy

Axis	Control Error (root-mean-square)
X axis	2.271×10^{-7} rad/s
Y axis	2.080×10^{-7} rad/s
Z aixs	1.979×10^{-7} rad/s

Fig. 12 shows the angular rate control error in each axis. The control error calculated as the difference between the target angular rate and the actual angular rate of the satellite. In this figure, upper, middle, lower graph is corresponding to x, y, z axis respectively. Table 5 shows the control errors of the star image based method. These errors are evaluated by the root-mean-square method from the same data in Fig. 12. From this table, it is shown that the spin rate of the satellite is stabilized with better than the accuracy of 4×10^{-7} rad/s by utilizing the star image based method.

5. Other technical features of Nano-JASMINE

There are other technical features in Nano-JASMINE for precise attitude control. For instance, the moment of inertia ratios of Nano-JASMINE are designed to be similar to those of a spherical rigid body. By adopting such design, the attitude disturbances caused by the gravity gradient and the air pressure can be reduced. Another example is adopting small reaction wheel as main actuator for satellite attitude control. By compensating RMM with the magnetic canceler, the satellite attitude can be stabilized with fewer momentum accumulation of the reaction wheel. Thus, small reaction wheel, whose inner disturbances are fewer than that of the large, can be adopted as a main actuator for attitude control.

6. Conclusion

ISSL has developed the attitude determination and control system for a 35kg satellite, "Nano-JASMINE". In the Nano-JASMINE mission, highly precise attitude stabilization accuracy, 740 mas/ 8.8 sec, is required. This paper focuses on two problems to be solved for accomplishing the required attitude stability and describes a solution for each of these problems.

The first problem is attitude disturbance estimation and compensation. Because of its small moments of inertia, the magnetic disturbance is the dominant disturbance for Nano-JASMINE. Since a magnetic disturbance is caused by a residual magnetic moment (RMM) of a satellite, the RMM should be estimated and reduced for precise attitude control. In the Nano-JASMINE mission, the time-varying RMM as well as the constant RMM should be compensated. In the previous satellite missions, some methods for compensating the constant RMMs have been studied. However, in the previous satellite missions, no methods for compensating the time-varying RMMs have been studied. In this paper, an estimation and compensation method for the time-varying RMM is described. A low frequency RMM is estimated and compensated in orbit by using an extended kalman filter. A middle frequency RMM, which is difficult to estimate in orbit, is reduced by designing the magnetic characteristics of the satellite. Estimated RMM is canceled by the Magnetic Cancelers, which are high-accuracy MTQs. To verify the effectiveness of this method, a SCLT has conducted. The verification result shows that by using this method, the RMM of the satellite is estimated and compensated with 5.3×10^{-4} Am^2 accuracy.

The second problem is precise spin rate estimation. Because of the limitations on power generations and payload capabilities, it is difficult to apply conventional high-accuracy sensors to a small satellite as Nano-JASMINE. Thus, novel techniques to estimate the satellite spin rate without conventional sensors are required. For this reason, a star image obtained from the mission telescope is utilized for estimating the angular rate of the satellite in the Nano-JASMINE mission. A simulation study shows that the LSF variance calculated from a star image is related to the angular rate of the satellite. Thus, the spin rate of the satellite is to be estimated from the star images. To verify the effectiveness of the method, an experiment using the telescope for the flight-model has been carried out. Result of the experiment supports the result of the simulation study. In addition, result of the SCLT shows that the spin rate of the satellite is stabilized with better than the accuracy of 4×10^{-7} rad/s by utilizing the star image based method.

These two methods described in this paper are applicable to other small satellites. The methods enable future small satellites to control its attitude more accurately.

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