

Mission and System Design of Microsatellite HIBARI for Demonstration of Variable Shape Attitude Control

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Abstract

We are developing a 40kg class microsatellite “HIBARI”. The main technical missions for HIBARI is demonstration a novel attitude control method called “Variable Shape Attitude Control (VSAC)” proposed by Matunaga Lab, Tokyo Institute of Technology. HIBARI controls the attitude to utilize a reaction torque generated by driving the solar array paddles. This satellite is planned to be launched in FY 2021 under “Innovative Satellite Technology Demonstration Program” led by Japan Aerospace Exploration Agency (JAXA). The on-board equipment was selected through radiation tests and is currently in the BBM development phase. In this paper, the mission, the outline of each subsystem and development schedule are reported.

可変形状姿勢制御実証衛星ひばりのミッションとシステム設計

摘要

東工大では 40kg 級可変形状姿勢制御 (VSAC : Variable Shape Attitude Control) 実証衛星ひばりの開発を行なっている。本衛星は、太陽電池パドルを回転駆動させ発生した内部トルクで衛星本体を迅速に姿勢制御する。ひばりは JAXA 主導の革新的衛星技術実証 2 号機に採択され、2021 年度内に打ち上げ予定である。放射線試験を通じた搭載機器の選定をし、現在は BBM 開発フェーズである。ここではひばりのミッション、各サブシステム概要および開発スケジュールを示した。

1. Introduction

In recent years, with the advancement of performance and miniaturization of devices, the micro/nano satellites and CubeSats have become higher specs, and their missions have diversified. However, there are limitations in performance due to size and power constraints. In particular, it is an attitude control system and an optical system. This is because of the difficulties to mount Control Moment Gyro (CMG), thrusters and large aperture lenses on micro/nano satellites and CubeSats. In addition, the attitude stability against disturbance is lower than that of large satellites in terms of moment of inertia. In this manner, there is a limit to the requirements that can be met by micro/nano satellites and CubeSats at present, and new systems for those are needed to achieve further advancement. Matsunaga, Tokyo Institute of Technology focused on changing the shape of the satellite, and proposed a novel method of attitude and orbit control.^{1,2,3} And we are currently developing a

technical mission satellite HIBARI that demonstrates this control method.^{4,5,6} This satellite is planned to be launched within a few years by the Epsilon Launch Vehicle under the "Innovative Satellite Technology Demonstration Program" led by Japan Aerospace Exploration Agency (JAXA).

The significance of changing the shape of the satellite can be roughly divided into two. The first is that attitude control is feasible using the counter torque associated with changing the shape of satellites, for example driving solar array paddles by actuators. This attitude control is called variable shape attitude control (VSAC). Fig. 1 shows this concept. Since this method changes the relative position of a part of the system, it has been shown that attitude maneuver can be made quickly and energy-efficiently compared to Reaction Wheel (RW) and CMG.

The second significance is that orbit and attitude control using external force and external torque such as solar radiation pressure and aerodynamic force can be performed by adjusting the projection area by shape

change. For example, the orbital velocity can be finely adjusted and the phase can be controlled by changing the aerodynamic force in a low earth orbit. In addition, external force torque can be generated in the desired direction by the satellite shape, and it can be used for angular momentum desaturation such as RW.

The driving object for variable shape of this satellite is a solar array paddle that efficiently applies the EPS system to attitude control. In this manner, the satellites enable to save space and power by realizing multiple functions with one actuator, leading to cost reduction and high specs of them. Although mission of this HIBARI is demonstration of this control method, in HIBARI project, we aim to conduct an astronomical observation for transient object of gravitational wave sources. This paper describes the mission outline, system, and development status of the HIBARI.

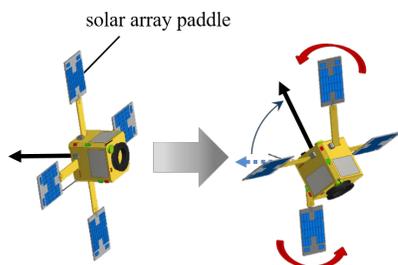


Fig. 1. Concept of VSAC

2. Mission

As mentioned above, the significance of changing the shape of the satellite is twofold. This time, we focused on VSAC and defined the success criteria as shown in Table 1. In the minimum success, the motor drives the paddle to actively change the shape of the satellite, thereby confirming that the attitude changes. Highly accurate STT and gyro sensor are used to confirm this attitude change.

In full success, we confirm the agility of VSAC. The performance target is 40deg / 20sec. This is equivalent to CMG used for agile maneuver, which is referred to the one mounted on 50kg class microsatellites.

For extra success, we will target 40deg/10sec, which doubles the agility of full success. We also demonstrate attitude control using non-holonomic properties. With non-holonomic properties, before and after attitude change, the angular momentum is preserved and the shape does not change, but the attitude can be changed. For example, by driving the paddle in order as shown in Fig. 2, the attitude can be changed without changing the satellite shape. Arbitrary three-axis maneuver is possible by using this method. In addition, as a control performance, we set the attitude stability as a target. This is for astronomical observation missions that require agility and high stability in the next project.

The numerical value is set to 300arcsec/10sec in consideration of the specifications of the attitude determination system. First, the stability is evaluated only with VSAC, and then it is evaluated combining with RW. Telephoto camera is also used to evaluate stability in addition to STT and gyro sensor. Stars are captured by this camera, and a minute attitude change is detected by the shake and extension of the stars image.

Furthermore, for extra success, we set orbit / attitude control demonstration by external force, which is the second of the significance of satellite shape variable. However, these are done after the VSAC experiment is over. GPS information is used to evaluate orbit changes.

Table 1. Success criteria

| Level | Mission |
|-------|--|
| Min. | <ul style="list-style-type: none"> Confirmation of attitude change by variable shape function |
| Full | <ul style="list-style-type: none"> performance evaluation of VSAC <ul style="list-style-type: none"> target agility: 40deg/20sec |
| Extra | <ul style="list-style-type: none"> performance evaluation of VSAC <ul style="list-style-type: none"> target agility: 40deg/10sec target stability: 300arcsec /10sec confirmation of attitude control using non-holonomicity confirmation of orbit / attitude change with controlled atmospheric resistance |

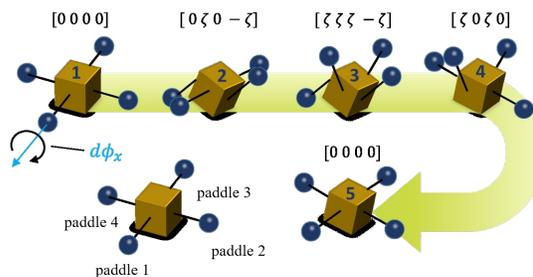


Fig. 2. Non-holonomic Attitude Control

Fig. 3 shows the mode transition of HIBARI. The satellite first enters critical mode after rocket release. Fig. 4 shows sequence of this mode. In this mode, MTQ is used to reduce the angular velocity at the time of rocket discharge, and then the satellite body is stable in the spin state to point the sun direction. The spin stable state is maintained until the power stabilizes, and each device such as communication and cameras is checked out followed by deploying the paddles. The paddles are deployed one by one, which is confirmed by each wide-angle camera on the side panel of the satellite. The spin stable solar pointing control by this

MTQ is assumed to be the nominal mode of HIBARI. However, the nominal mode after RW driving is 3-axis stable sun pointing by it.

In the mission mode, VSAC experiments are conducted. At first, we confirm the agility, stability and non-holonomicity of extra success with only VSAC. After that, we start driving RW and evaluate attitude control using VSAC and RW together. These experiments are performed in the shade to ensure the accuracy of STT.

When a power shortage or unexpected attitude is detected during the nominal or mission mode, the system enters the safe mode with no control to minimize power consumption. And the main CDH performs processing according to the error and copes with the problem by switching to the critical mode again.

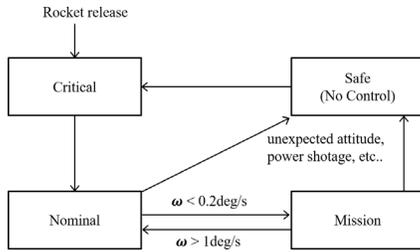


Fig. 3. Attitude Control Mode Transition

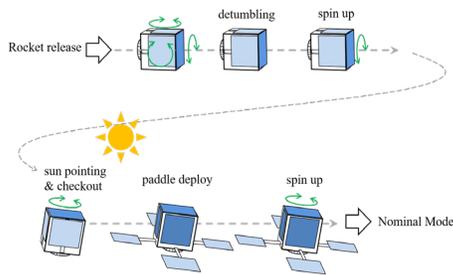
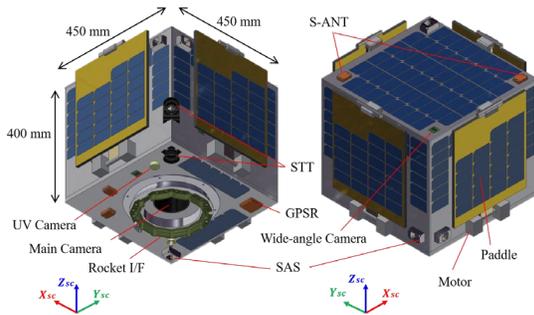


Fig. 4. Sequence of Critical Mode



3. System

In this section the system of HIBARI and each subsystem are described. The subsystems include CDH (Command & Data Handling), COMM (Communication), ADCS (Attitude Determination & Control System), EPS (Electric Power System), Camera system, and Structure & Thermal. The system diagram is shown in Fig. 5.

A microcontroller showing 'each subsystem CDH' in Fig. 5 is prepared in each subsystem to monitor the system, and the main CDH monitors the microcontrollers. This is to reduce the load on the main CDH and improve the reliability of each subsystem. For each CDH, microcontrollers are selected due to the high radiation tolerance.

Fig. 6 shows the overview of HIBARI. The satellite bus size is $450 \times 450 \times 500 \text{ mm}$, which can envelop in the Epsilon Launch Vehicle. The mass of the satellite bus unit is about 30 kg. The satellite has 4 paddle units and this is 2.5 kg per one.

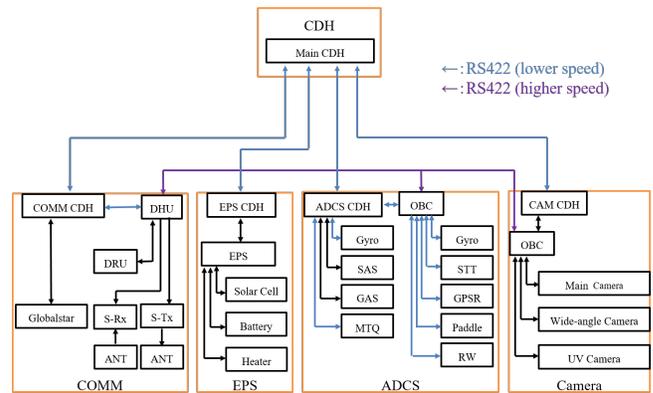


Fig. 5. System Diagram

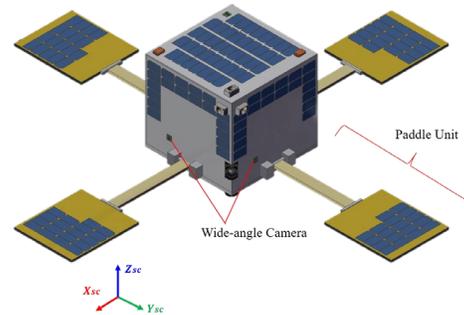


Fig. 6. HIBARI Overview

3.1. CDH & COMM

The main CDH performs monitoring of each subsystem, management of operation mode, and processing of command / telemetry. When the main CDH detects an error, it switches to the operation mode. It also manages time of satellite, and synchronizes periodically with the CDH of each subsystem.

There are two types of communication devices, S-band and Globalstar communication. The S band is used as a nominal communication system, receiving commands from the ground, and transmitting HK and experimental data to the ground. In order to establish communication with the ground even in any attitude, the satellite is arranged with an antenna that can cover the whole sky, considering the antenna pattern and their location. In addition, the receiver is always turned on so that commands can be received even when emergency. Globalstar is used for demonstration of real-time communication with the ground for next project astronomical observation.

3.2. ADCS

The ADCS consists of a coarse attitude system based on high reliability CDH and a fine attitude system based on OBC that can be operated at high speed. The coarse attitude system is used when the reliability is required in the critical mode or the safe mode, or used for backup of the fine attitude system. The fine attitude system is used during missions where accuracy is required. Even if the OBC in fine system freezes, the coarse attitude system functions as a backup, and it is designed to be able to reboot the OBC.

Also, although the data in ADCS is primarily processed as telemetry via CDH, a higher speed communication line is separately prepared (purple line in Fig. 5), which can flow directly to the COMM system in order to transmit a huge amount of data at the mission period.

3.3. EPS

EPS manages the power of the system. Table 3 shows the power consumption by each mode. The orbit is a sun synchronized orbit with altitude of 500 km and 60 minutes of sunshine. Based on this table, solar cells are arranged so that sufficient power can be generated when they are directed to the sun, and the power balance become positive regardless of the satellite attitude in the safe mode. In addition, a 160Wh battery is mounted so that power is not depleted during the initial critical mode until sun pointing and during missions. In addition, EPS detects the over current of CDH of each subsystem, and is responsible for power off and reboot.

Table 3. power consumption

| | power consumption [W] | | | | | |
|------------|------------------------|--------------|--------------|--------------|--------------|------|
| | Detumbling/ Spin up | Nominal ① | Nominal ② | mission ① | mission ② | safe |
| CDH & COMM | 5.3 | 5.3 | 5.3 | 5.3 | 5.3 | 5.3 |
| ADCS | 3.1 | 8.3 | 10.8 | 22.6 | 23.7 | 2.7 |
| EPS | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Camera | 0 | 4.2 | 4.2 | 8.2 | 8.2 | 0 |
| Total | 9.5 | 18.9 | 21.4 | 37.2 | 38.3 | 9.2 |

3.4. Camera

Camera System has three kinds of cameras, a Main Camera, Wide-angle Cameras, and a UV Camera. Table 4 summarizes each Field of View (FoV), number of mounted, and usage. The Main camera is used for observation of the earth and astronomical objects at nominal mode. Also, during the stable attitude control mission, this camera is used to capture stars and evaluate stability. The wide-angle camera is mounted on each of the six panels of the satellite and take images of paddle deployment and drive. this camera is also used as a 3-axis attitude determination earth sensor by taking the edge of the earth. We are developing and on-orbit demonstration of a 3-axis attitude determination earth sensor using this wide-angle camera and image identification technology.⁸⁻¹¹ The UV camera is demonstrated on-orbit for the future observation missions gravitational wave source.

Since the Camera system also has a large amount of data, a separate higher speed communication line is prepared.

Table 4. specifications of Camera System

| Cam | FoV[deg × deg] | Num. | Usage |
|------------|-------------------|------|--|
| Main | 8×5.5 | 1 | <ul style="list-style-type: none"> observation of the earth and astronomical objects evaluation of attitude stability |
| Wide-angle | 60×50 | 6 | <ul style="list-style-type: none"> capture paddle deployment and drive determination of 3-axis attitude by using as earth sensor |
| UV | 8×6 | 1 | <ul style="list-style-type: none"> Demonstration for future observation missions |

3.5. Structure & Thermal

The thermal structure system is designed to meet the arrangement requirement and heat requirement of each component and vibration requirement at the rocket launch. Also, the paddles should be designed to meet the agility requirements of VSAC experiments. For this purpose, it is necessary to increase the moment of inertia of the paddles, for example, by lengthening the paddles or increasing the mass of paddles. In HIBARI, the paddle length is increased by using a hinge and the weight of the tip is added to increase the inertia of the paddle. The paddle deploying sequence is shown in Fig. 7. The paddle is first deployed 180 degrees by spring hinges and fully deployed by motors. Also, the power line of the paddles is routed with a margin enough to drive the paddles.

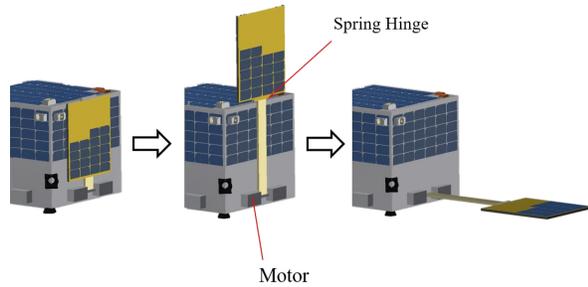


Fig. 7. Sequence of Paddle Deploying

4. Development Plan

The development schedule is shown in Fig. 8. We are currently developing and testing Breadboard model (BBM). As a next step, we solve problems in BBM except Structure & Thermal system, develop Engineering Model (EM), and conduct electrical tests and environmental tests with each component. In addition, the operation test of software model for the ADCS system is performed. Structure & Thermal system is planned to manufacture in the stage of Engineering Model (EM) and carries out a vibration test of the case and paddles. As a test of the paddle driving mechanism, a deployment test and a drive test using an air levitation device are performed.⁷ After while, we perform thermal vacuum tests by combining with the thermal model of each component. Finally, we plan to develop FM and conduct each environmental tests and long-term End to End test.

5. Conclusion

We are developing a 40kg microsatellite “HIBARI”, which demonstrate a novel attitude control method called VSAC. This paper described the mission and concept design of HIBARI. HIBARI is planned to be launched in FY2021. Currently in the BBM development phase.

| | FY2019 | FY2020 | FY2021 |
|------------------|-----------------|---|--------|
| Review | ◇MDR ◇PDR | ◇CDR | ◇PQR |
| Except Structure | BBM | EM | |
| | ◇Elec Integrate | ◇TVAC/Vib | |
| Structure | BBM | EM | |
| | ◇Paddle deploy | ◇TVAC/Vib | |
| | ◇Vib | ◇Mass balance ◇Paddle deploy | |
| Common | ◇SEE | | |
| | ◇TID | | |
| | | FM | |
| | | ◇EMC ◇Paddle deploy | |
| | | ◇Mass/Fit check ◇Alignment ◇Vib/Alignment | |

Fig. 8. Schedule

Acknowledgements

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