A Consideration of Antenna Developing Mechanism for Observation of Electric Wave from Jupiter using Cubesat

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Abstract

Now KOSEN space collaboration team is conducting the development of Cubesat (2U size) to observe the electric wave from Jupiter. In order to achieve the mission, it is necessary for the Cubesat to be equipped with a 7.2m long dipole antenna. However, in terms of outfitting problem, it is difficult to implement actuators inside a Cubesat. Hence, in this paper, the authors propose an antenna deployment mechanism by using biometal fiber. In order to verify the effectiveness of the proposed antenna deployment mechanism, an experiment is carried out and the results obtained is evaluated. Furthermore, for removing the attitude disturbance and vibration during the antenna deployment, the authors conduct an attitude control system which is by changing the position of the center of gravity of the satellite generating gravity gradient torque. Formulations and numerical calculations are also conducted in order to verify the effectiveness of the proposed attitude control system.

Key Words: antenna deployment mechanism, biometal fiber, attitude control system, Cubesat

Cubesatによる木星電波観測衛星のアンテナ展開機構の一考察

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概 要

現在，高専スペース連携では，2Uの超小型衛星による木星から飛来する電波の観測ミッションを提案している．この木星から飛来する電波を観測するために，長さ7mのダイポールアンテナを展開する必要がある．しかし，艤装の観点では，超小型衛星にアクチュエータを用いることは困難である。そこで，本稿では，アンテナ展開機構として，バイオメタル・ファイバーを用いた手法を提案している．アンテナ展開機構の有効性を検証するために，アンテナ展開実験を行い，得られた結果の解析を実施した．また，本稿では，アンテナ展開に伴う姿勢変動を補償するための姿勢制御系について提案し，定式化ならびに数値計算により解析を実施し，得られた結果について検証する．

1. Introduction

Recently, business market for small satellite has been developing significantly. In particular, the demand for ultra-small satellites called as “Cubesat” which has developed by organizations such as universities, technical colleges and private companies. Then development cost and term, launching cost and coordination for cubesat are lower comparing with normal large satellites. In future, it is considered that small satellite business shall be actively conducted. In this report, a preliminary study of observation of Jupiter’s decametric radio emission[1] by using a cubesat is conducted in collaboration with other technical colleges.

In this report, a cubesat for observing Jupiter’s Decametric Radio Emission is treated. Then it is known as Jupiter has the strongest magnetic field and high frequency radio emission of all planets. It is generally known that the huge energy generated by the Jupiter’s magnetosphere is converted into decametric radiation, which is considered as a highly complex interaction between Jupiter’s plasma and its magnetic field. Then elucidation of Jupiter’s emission might be solution for the Earth’s electric energy problem in the future. Then it is necessary that Jupiter’s emission is observed as a frequency of 20MHz corresponding to a 7.2m long dipole antenna. In this report, antenna deployment mechanism for 7.2m dipole antenna is conducted with Biometal Fiber(BMF) for cubesat, then attitude control system while the antenna deploying is treated as preliminary study. Moreover preliminary experiment for prototype antenna by using BMF is executed. In this report, the authors treat an attitude control system with gravity gradient torque to compensate attitude disturbance for deploying the antenna. And relationship between the gravity gradient torque and effectiveness for the attitude is formulated, an attitude control system by changing the position of center of gravity of the satellite is proposed. Finally, proposed attitude control system with eccentric for center of gravity by moving the part of mass is estimated and obtained results are concluded.

2. Antenna deployment system by using BMF

2.1. Outline of the antenna deployment system

In this section, the outline of the proposed antenna deployment mechanism is described. It is needed that the cubesat equips 7.2m dipole antenna inside before being launched into the outer space. Fig.1 shows the process of antenna deployment of the cubesat in outer space and image of holding condition for antenna. Then the 7.2m dipole antenna is consisted of multiple segments, each segment is coupled with hinge including BMF. When BMF is received current as control input, BMF is reduced then each antenna segment is developed by production of tension of BMF.

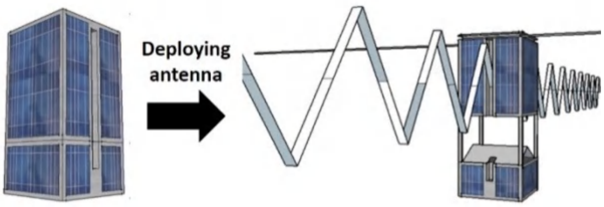

Fig.1 Antenna deployment process of cubesat

2.2. BMF property

In this section, BMF(Biometal fiber) property is described. BMF is a titanium-nickel based shape memory alloy as fiber type and extending with giving electric current. Then the authors treat the BMF as actuator to control antenna deployment mechanism. Further the BMF is lightweight, equipment space can be saved because of the volume is so small with flexibility and the electric power supply is so law. Therefore it is available that BMF is used to such cubesat. Moreover BMF has strong shrinkage force and it is considering that the behavior of BMF reduction can be control by current sequence. Then the speed of contraction of BMF is controllable, which is considered to be able to generate a stable antenna deployment while considering the occurrence of attitude variation in the process. Next, Table 1 shows the property values of BMF150 used in this report. And Fig.3 shows photo of BMF150.

Table 1 Property values of BMF150

Charactristics Variable	Value
Standard Diameter	0.15mm
Practical force produced (Load)	1.47N
Practical Kinetic Strain	4%
Service Life	1,000,000times
Standard Drive Current	0.34A
Standard Drive Voltage	20.7V/m
Standard Power	7.05W/m
Standard Resistance	61Ω/m
Tensile Strength	17.7N
Weight (mg/m)	112mg/m

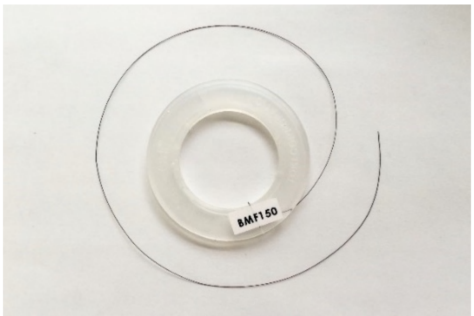

Fig.2 Photo of BMF150

2.3. Outline of the antenna deployment mechanism

In this section, the outline of the proposed antenna deployment mechanism is described. Next, flow of deployment of each antenna segment is introduced. Fig.3 shows aspect of each antenna segment and coupling with hinge including BMF. At first, initial condition for antenna deployment mechanism is expressed shown in Fig.3 represented as left hand. In this condition, BMF is kept for initial length without current. If BMF is received the current as control input, then BMF is reduced and fiber tension of reduction length is produced. Thus, the antenna is deployed by reduction of BMF. This action is repeated, antenna deployment is achieved. And it is possible to control the contraction speed of the BMF because the satellite would be able to deploy the antenna stably while taking the attitude variation occurred during the process into account.

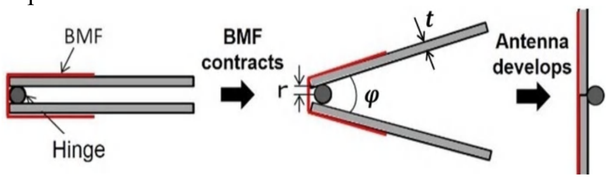

Fig.3 Antenna deployment mechanism

2.4. Formulation of antenna deployment mechanism

In this section, the formulation of the antenna deployment mechanism is described. To construct the antenna deployment system for the cubesat, it is necessary to determine the required length of BMF while considering its practical kinetic strain (4%) and the antenna structure. Then the contraction displacement of BMF required for the antenna deployment as $\Delta a[mm]$ is introduced by the radius of hinge r and the thickness of antenna plate t , as the following equation;

$$\Delta a = 2t + 2r \tag{1}$$

where $t[mm]$ is the thickness of the antenna plate and $r[mm]$ is the radius of the hinge. Thus, the required length of BMF for the antenna deployment can be determined by dividing Δa with practical kinetic strain of BMF (4%). And the angle of antenna deployment as $\varphi[deg]$ is introduced by considering the actual and required contraction length of BMF. Then the angle of antenna deployment as $\varphi[deg]$ is obtained as following;

$$\varphi = 2\cos^{-1}\left(1 - \frac{a}{\Delta a}\right) \tag{2}$$

where $a[mm]$ is the actual contraction length of BMF used for the antenna deployment. Then the speed of antenna deployment can be controlled through the time differentiation of Eq. (2) by input current sequence.

3. Preliminary Deployment Experiment by BMF

3.1. Preliminary Experimental Condition

In this section, the preliminary experiment of the antenna deployment mechanism is described. To verify the effectiveness of the proposed antenna deployment mechanism by using BMF, the rotation angle of antenna deployment is measured when a constant current inputs the BMF. Then Table 2 shows the experimental condition, and more Fig.4 shows the experimental set-up of the antenna deployment mechanism. In this report, aluminium plate is treated as antenna material because of conducting electricity and lightweight characteristic. Further the actual contraction length of BMF which is 4.8[mm] can be determined by considering the length of BMF used and its practical kinetic strain (4%).

Table 2 Experimental condition

Length of BMF used	120	[mm]
Thickness of antenna plates (t)	0.5	[mm]
Radius of hinge (r)	1.0	[mm]
Required contraction length of BMF (Δa)	3.0	[mm]
Voltage	3.5	[V]
Current	0.4	[A]

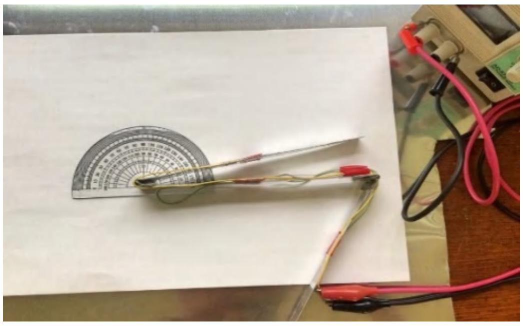

Fig.4 Experimental set-up of antenna deployment

3.2. Preliminary Experimental Result

Next, experimental result for antenna deployment is described in this section. Fig.5 shows the experimental result of time history of the antenna rotation angle when a current inputs constantly as 0.4A. Although a time delay for a few seconds is observed from the experimental result due to be heated up the BMF, finally the antenna rotation angle is achieved to 180 degrees. Hence, the effectiveness of antenna deployment mechanism by using BMF is verified.

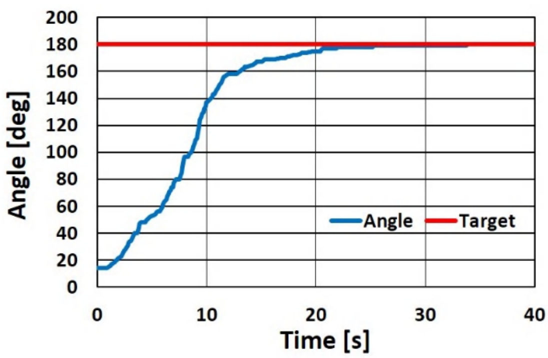

Fig.5 Experimental result of antenna rotation angle

4. Attitude control system

4.1. Outline of the attitude control system

In this section, the outline of the formulated attitude control system is described. It is considered that vibration and disturbance of attitude variation for the satellite would be occurred when the antenna would be deployed by using BMF. Then, in this report, an attitude control system by changing the position of center of gravity of body to compensate the occurrence of attitude fluctuations caused by the antenna deployment is proposed. Fig.6 shows outline of movement of body mass to compensate the attitude fluctuations by gravity gradient torque. To verify the effectiveness of the proposed attitude control system, the expanded satellite is modeled as shown in fig.6 for the calculation of gravity gradient torque and torque generated by the difference of orbital velocities.

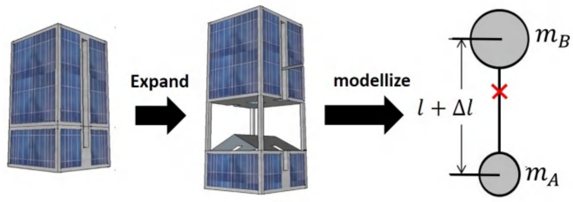

Fig.6 Modeling of satellite of body eccentric model

4.2. Formulation of gravity gradient torque

In this section, the formulation of the gravity gradient torque with eccentric object is described. Fig.7 shows aspect of Earth's gravitational force acted on the different parts of satellite. Here, the gravity gradient torque is generated as the difference force for each location of the satellite. Then the forces generated at A and B are introduced as $F_{A\perp}[N]$ and $F_{B\perp}[N]$,

$$F_{A\perp} = \frac{\mu m_A r_0 \sin\theta}{{r_A}^3} \tag{3a}$$

$$F_{B\perp} = \frac{\mu m_B r_0 \sin\theta}{{r_B}^3} \tag{3b}$$

where $r_0[m]$ is the distance between center of gravity of the satellite and center of the Earth, and $\theta[deg]$ is the attitude angle of satellite. And more, $\mu[m^4/s^2]$ is the gravitational constant, $m_A[kg]$, $m_B[kg]$ are the mass of A and B, and $r_A[m]$, $r_B[m]$ are the orbital radius of A and B. Next, formulation of gravity gradient torque is treated. The gravity gradient torque as $Tg[Nm]$ is introduced by considering the difference of $F_{A\perp}$ and $F_{B\perp}$ in Eq. (3a) and Eq. (3b).

$$T_g = -\frac{3\mu m_A m_B (l+\Delta l)\sin\theta\cos\theta}{r_0^3 (m_A+m_B)} \tag{4}$$

where $l[m]$ is the distance between center of A and B and $\Delta l[m]$ is the displacement of expansion length of the body.

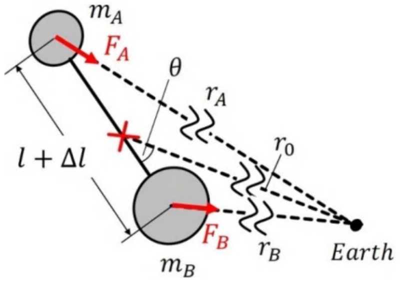

Fig.7 Forces acted on satellite due to the Earth's gravitational force

4.3. Formulation of torque generated the difference of orbital velocities

In this section, the formulation of torque due to the difference of orbital velocities is described. In the outer space, any mass will have its own orbital velocity because of the satellite in orbit keep a position where gravity force equilibrating to centrifugal force. Then the orbital velocity is decided as the altitude of the object. Fig.8 shows aspect of orbital velocities of satellite model. Here, the orbital velocity of its lower part will vary from the upper part due to the difference in altitudes. Next, the orbital velocities of the satellite for the attitude control system is formulated. Here, the orbital velocities of A and B are expressed as $v_A[m/s]$ and $v_B[m/s]$;

$$v_A = \sqrt{\frac{\mu}{r_A}} \tag{5a}$$

$$v_B = \sqrt{\frac{\mu}{r_B}} \tag{5b}$$

Next, momentum equation is obtained as the principle of momentum conservation by Eq. (5).

$$(m_A v_A n_A - m_B v_B n_B)(l+\Delta l)\cos\theta = I\omega \tag{6a}$$

where $I[kgm^2]$ is moment of inertia of the satellite, $\omega[rad/s]$ is the angular velocity of the satellite, then n_A, n_B are introduced as the following.

$$n_A = \frac{m_B}{m_A+m_B} \tag{6b}$$

$$n_B = \frac{m_A}{m_A+m_B} \tag{6c}$$

Then the torque for the difference of orbital velocities is introduced as following $T_v[Nm]$;

$$T_v = \frac{\mu m_A m_B}{2(m_A+m_B)}(l+\Delta l)\left(\frac{1}{{r_B}^2} - \frac{1}{{r_A}^2}\right)\cos\theta \tag{7a}$$

where r_A and r_B are introduced as the following;

$$r_A = \sqrt{{r_0}^2 + n_A(l+\Delta l) + 2n_A r_0 (l+\Delta l)\cos\theta} \tag{7b}$$

$$r_B = \sqrt{{r_0}^2 + n_B(l+\Delta l) - 2n_B r_0 (l+\Delta l)\cos\theta} \tag{7c}$$

4.4. Equilibrium point for satellite

In this section, the dynamical equilibrium of the satellite body is described. Equilibrium point of a satellite is solved as the point where the total sum for T_g and T_v is corresponding to zero. Hence, equilibrium state for the satellite is solved by consideration for Eq.(4) and Eq.(7), as following;

$$\frac{3\sin\theta}{{r_0}^3} - \frac{1}{2}\left(\frac{1}{{r_B}^2} - \frac{1}{{r_A}^2}\right) = 0 \tag{8}$$

where $\theta[deg]$ is the inclination angle when the satellite is in its equilibrium state. It is found that the relationship between the inclination attitude angle θ and expanded length of the satellite's body Δl is existing. Hence, expanded length of the satellite's body Δl can be adopted to attitude control system for the satellite body as control variable.

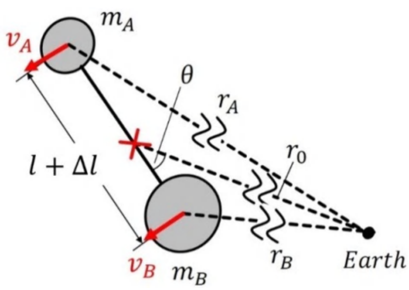

Fig.8 Orbital velocities of satellite

5. Conclusion

In this report, the antenna deployment mechanism by using BMF for observing Jupiter's decametric radio emission has been conducted. To verify effectiveness of the proposing antenna deployment mechanism by using BMF, the prototype antenna deployment device by using BMF is constructed and preliminary experiment for the antenna deployment is executed. Moreover, to compensate attitude disturbance with antenna deployment for the satellite, formulations for dynamics have been carried out. Then the authors proposed attitude control system which is by changing the position of center of gravity of the satellite to obtain gravity gradient torque. At the result, it is found from the formulation that the method of changing the position of center of gravity of the satellite is available to attitude control system.

Reference

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