A Numerical Investigation to Suppress Thermal Distortion of Large Deployable Reflector on ETS-VIII

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1. Introduction

Space structures are subjected to various environments in space. One of these environments is severe thermal condition where the difference of temperature during day-time and night-time is about 200 degrees Celsius, as shown in Fig. 1. A signal level of a radio wave from the LDR (Large Deployable Reflector) mounted on the ETS-VIII (Engineering Test Satellite -VIII, as shown in Fig. 2), which was launched in 2006, was observed to change during the Earth eclipse. This phenomenon was assumed to be caused by thermal distortion of the LDR. The distortion effect may become a considerable issue when maintaining the accuracy of communication beams reflected by a large space antenna in case of future artificial satellite.

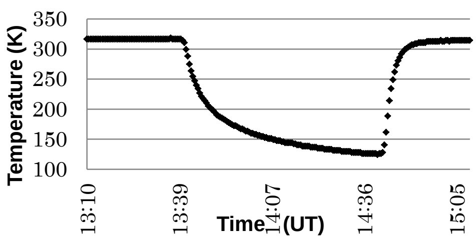


Fig. 1 Temperature of the LDR during Earth eclipse

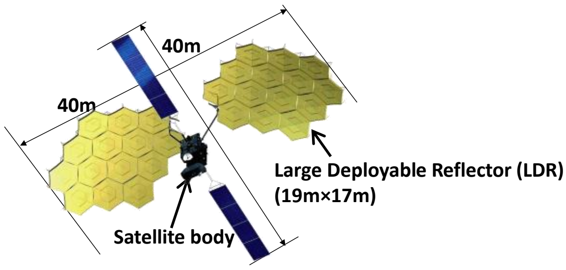


Fig. 2 Overview of the ETS-VIII

From this point of view, a thermal distortion analysis using FEM was carried out on the LDR. The thermal distortion was suppressed, in the previous work [1], by finding optimal combination of CFRP tubes and titanium alloy joints constituting the antenna that had different thermal expansion characteristics. However, this means may not be used once the satellite has launched into space. Therefore, a different means to suppress the thermal distortion is sought out, in this study, by focusing into the internal force generated at the spring used to deploy the antenna.

2. Numerical model

The LDR is consisted of CFRP-tubes and titanium alloy joints. Each member is named upper radial member, lower radial member, diagonal member, center axis member and longitudinal member, as shown in Fig. 3. For the beginning stage, a numerical model constituted of structural tubes and a spring is constructed. An automatic open umbrella mechanism, consisted of spring elements and stretcher elements, is introduced into this model. Consequently, internal force is transmitted through the diagonal member. In this study, a single module of the LDR is modeled for analysis.

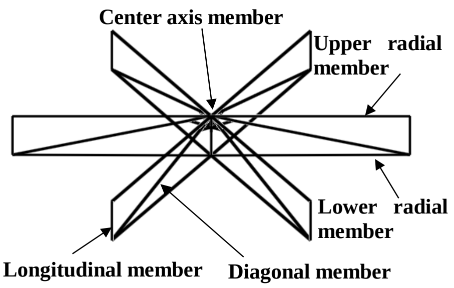


Fig. 3 One-module model for analysis

3. Numerical method

The thermal expansion is considered by using the equation which expresses the relation between the temperature of an object and the thermal strain:

$$\Delta\varepsilon_T = \alpha\Delta\mathrm{T} \quad (1)$$

where $\Delta\varepsilon_T$ is the thermal strain increments, α is the coefficient of thermal expansion, and ΔT is the temperature increment. The relation between the mechanical strain and the thermal strain can be expressed as the following equation.

$$\varepsilon_m = \varepsilon - \varepsilon_T \quad (2)$$

where ε_m is the mechanical strain, ε is the total strain and ε_T is the thermal strain. We implemented these relations in a finite element numerical code based upon Bernoulli-Euler beam elements and conducted several thermal distortion analyses.

4. Numerical results

The behaviors of one-module unit during several patterns of thermal transition as shown in Table 1 are analyzed.

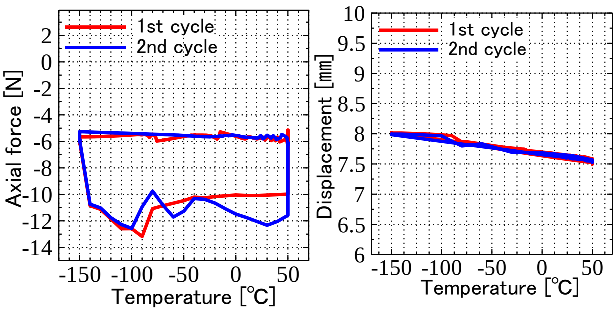
Table 1 Analytical patterns

	Thermal transition	Steady state
Case 1	Rapid	Long
Case 2	Rapid	Short
Case 3	Slow	Long
Case 4	Slow	Short

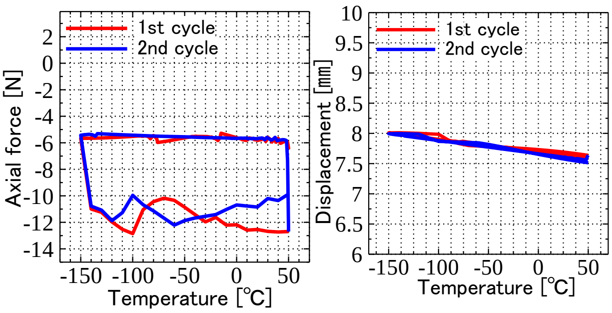
Figure 4 shows the relationship between axial forces, displacements and the transition patterns of temperature in the diagonal member. The displacements do not depend on the transition patterns of temperature, however, the increase speed of temperature does seem to affect the axial forces observed in the diagonal member. It indicates that the detailed information of the transition of temperature actually observed on the satellite should be used.

5. Conclusion

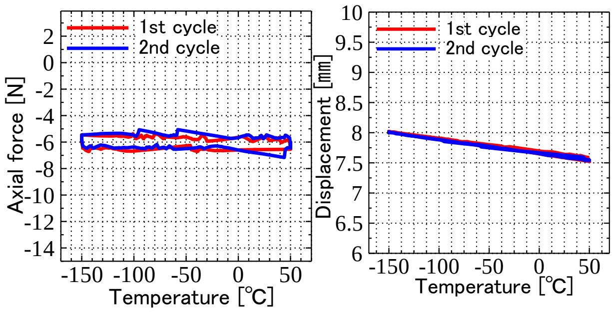
In this study, we carried out some thermal distortion analyses in one-module unit of the LDR, and conducted the relation between the transition patterns of temperature and axial force as well as between that of temperature and the displacements. For the next stage, we extend the numerical model to a full model of the LDR (14-module unit), and seek the means to suppress the distortion.



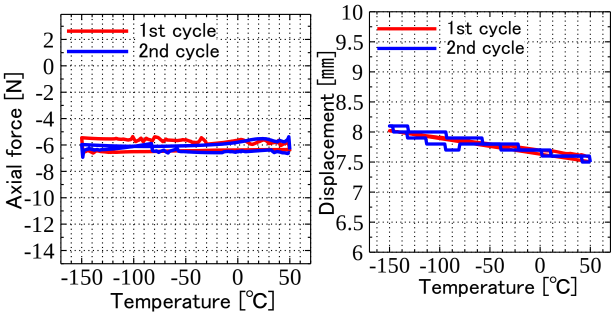
Numerical results (Case 1)



Numerical results (Case 2)



Numerical results (Case 3)



Numerical results (Case 4)

Fig. 4 Relationship between axial force, displacements and the transition patterns of temperature in the diagonal member

References

[1] M. Usui, K. Wakita, K. Kondo, L. T. T. Thanh, Y. Matsui and D. Isobe: Suppression of Thermal Deformation of the Large Deployable Reflector, *Transactions of the Japan Society of Mechanical Engineers, Series C*, Vol. 77, No. 777, pp.2107-2119, 2011, in Japanese.