K7-27

Vacuum Test and Thermal Analysis for Consideration of a Motor for the Space Climber

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Abstract: This paper's aim is to investigate the heat generated while the Climber moves, as well as the thermal shock from outside influences. Climber moves between two tethered satellites. An onboard stepper motor provides the driving force. Tether length is assumed to be over 100m, which means the stepper motor will be active for a long time. however, there are not many cases where a motor has been run continuously for an extended time in LEO. That is why this paper discusses the construction of a simplistic thermal analysis model for a stepper motor, based on vacuum chamber test results. By setting the emissivity of the stepper motor based on actual test results, a thermal analysis model accurate to within 1 degrees Celsius of the actual motor was realized.

１．Introduction

Currently, for the realization of the space elevator in the world a variety of experiments and analysis have been performed. Climber is done only on the ground experiment, it have never been a space experiment. Therefore, in order to obtain operating demonstration in space, we are planning the Space Climber mission to test a moving climber between the TSS. The purpose of the mission is to realize Climber motion and log data. It is predicted to have an impact on the satellites and tether. Furthermore, when dealing with mechatronics in space, vacuum chamber, thermal cycle resistance, radiation resistance, interface compatibility is all necessary. Therefore, in this paper as a basic research of the motor drive system, we focused on the vacuum characteristics.

2. Climber Design

Requirement for Climber is that autonomously move between the TSS, and the mass must be under 500 g. We made BBM with a BLDC. BBMver.3 was successful in horizontal movement along 0.6mm tether, but the weight becomes 1.2kg, so it could not become 1kg. Reviewing the design, weight increase due to the reduction gear was found to be a problem. Normally BLDC use in space, using the harmonic drive (gear ratio 100:1). Climber in relation to size limitations fit in a 1U, it could not be adopted. While the spur gear fits in available space to achieve a reduction in combination in multiple stages, it is considered that it has led to an increase weight. We thought using stepper, but very few space missions have incorporated stepper motors. Therefore, it has become necessary to perform the operation verification test of a system using a Stepper. Fig. 1 shows an image of BBM ver.3

Fig. 1. BBM ver.3 appearance

3. Experiment of vacuum

For the motor to operate in LEO, we selected high vacuum compatible D35.1. Vacuum chamber used is shown in Fig.2. The outer wall of the motor is insulated with PEEK, so a K-type thermocouple for internal temperature measurement was used. Fig.3. shows the layout of the temperature sensor.

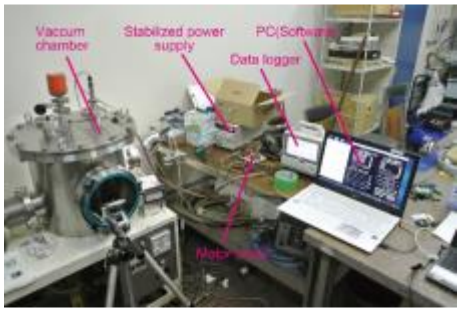

Fig. 2.　Vacuum experiment setup

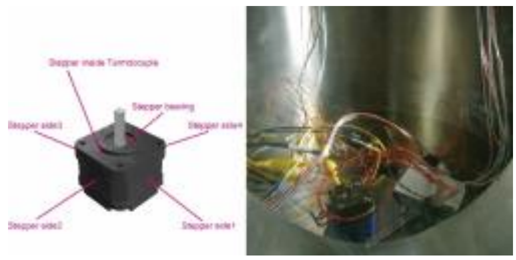

Fig. 3.　Temperature sensor layout

4. Experiment Vacuum Test Result

Vacuum experiment results shown in Fig.4. From the results, when the stepper is driven at 1 kHz, 1/8 micro step, the internal temperature in the first 20 minutes is seen that exceeded 60 ° C. Temperature increases with a shape close to Log function, entering an equilibrium state at around 70 ° C. In this case, the outside of the Stepper is around 40 ℃. Also, the bearing section showed an almost unchanged temperature similar to the walls of the stepper. As a result, the heat generated by the friction of the bearing was found to be very little.

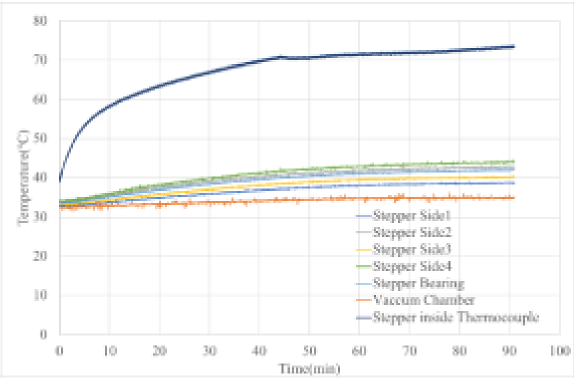

Fig.4.　measurement result at 0.3 A application

5. Making Motor Thermal Model and Analysis Results

In practice, hysteresis loss, eddy current loss, and Joule loss affect the most, although there is also a fourth loss: mechanical loss. However, mechanical loss can be neglected because the bearing part generates less heat. Fig.5 show thermal analysis model. It omitts the shaft, bearings and motor covers from the thermal analysis model, because it doesn’t cause heat generation.

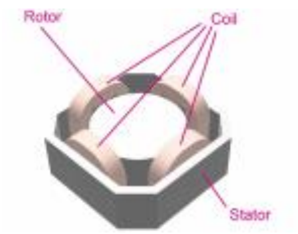

Fig. 5 Thermal analysis model of stepper

Table 1. Analysis condition summary

Part name	Material	Emissivity	Loss amount (W)
Coil	Cu(Copper)	0.8	0.7
Stator	Cobalt	0.65	0.2
Rotor	SUS440	0.35	0

The rotor portion only sees temperature increase due to radiation, so it was excluded from the results since it was around 40 ° C. The following shows the analysis results.

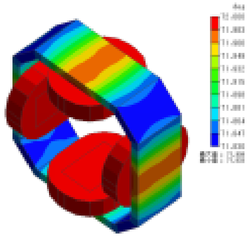

Fig.6. After 60 min

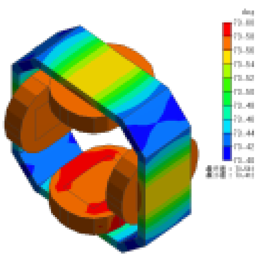

Fig.7. After 90 min

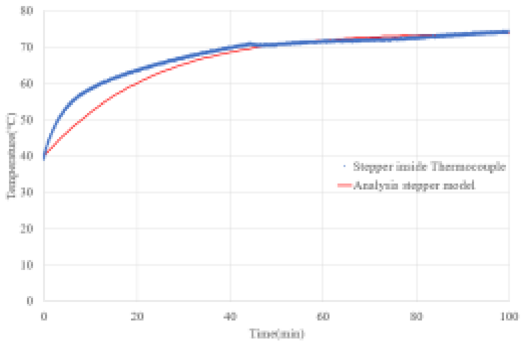

Fig.8. Comparison of experiment and analysis value

From Fig.8 we see that the rise in temperature of the actual measured stepper is faster than the analytical values. I think two reasons, the first reason is because this is a simple analysis model, radiant heat of the cover case and insulation effect of Poly Ether Ether Ketone are not included. The second reason is that accuracy and position of the thermocouple is not accurately known, because we could not disassemble the motor. After 40 minutes almost, the test values become equivalent to the analysis values.

6. Conclusions and Future Works

We succeeded in modeling the motor of the space climber through a thermal analysis model. Future works will involve the construction of the LEO thermal environment, to analyze the whole climber in orbit and to analyze the entire TSS model.

References

[1] Pamela Woo, Arun K. Misra, Energy Considerations in the Partial Space Elevator (2014)

[2] LI Van, HUANG Xiaoyan, Thermal an alysis of a brushless DC motor for aerospace application using thermal network models(2013)