On-Orbit Thermal Analysis of High Voltage Technology Demonstration Satellite, HORYU-II

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### Background/ Objectives

<table>
<thead>
<tr>
<th></th>
<th>Large satellite</th>
<th>Nano-satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maker</strong></td>
<td>Country, Company</td>
<td>Company, University etc</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>$&gt;100$kg</td>
<td>Less than 50kg</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Expensive</td>
<td>Cheap</td>
</tr>
<tr>
<td><strong>Due date</strong></td>
<td>long</td>
<td>short</td>
</tr>
</tbody>
</table>

- Affected easily by the external environment.
- It consists of COTS*.
- The acceptance temperature range of COTS* is narrow.
- The thermal control of the whole system is necessary.

**Examination of the thermal design of HORYU-II**

*COTS : Commercial Off The Shelf*
HORYU-II

<table>
<thead>
<tr>
<th>Size</th>
<th>350 × 310 × 315mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>7.1kg</td>
</tr>
<tr>
<td>Design Life Time</td>
<td>1 year</td>
</tr>
<tr>
<td>Orbit</td>
<td>Sun-synchronous polar orbit</td>
</tr>
<tr>
<td>Altitude</td>
<td>670km</td>
</tr>
</tbody>
</table>

Main mission: 300V photovoltaic power generation

→ Already succeeded in the mission.

The highest photovoltaic power generation in the world
Thermal design

- **HORYU-II** is fundamentally a passive thermal control.
  - ±Y surfaces: Z306 (Black paint) - $\alpha=0.96$, $\varepsilon=0.87$
    - Heat exchange
  - ±X, Z surfaces: Arojin treatment - $\alpha=0.1$, $\varepsilon=0.03$
    - Heat insulation

- The inside of the battery box is insulated by a glass epoxy
- Battery heater

<table>
<thead>
<tr>
<th>System</th>
<th>Permissive temperature range</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBC</td>
<td>-20 $\sim$ +70 °C</td>
</tr>
<tr>
<td>COM</td>
<td>-10 $\sim$ +60 °C</td>
</tr>
<tr>
<td>Battery</td>
<td>0 $\sim$ +45 °C</td>
</tr>
<tr>
<td>Mission</td>
<td>-15 $\sim$ +50 °C</td>
</tr>
</tbody>
</table>

Battery pack
Battery box
Glass epoxy
Attitude control

- HORYU-II is controlled only by magnetic field alignment
- A hysteresis damper attenuates libration motion

By analysis,

two full rotations per one orbit around the Earth.
Thermal Mathematical Model

Thermal Desktop (built in AutoCAD)
- Total Node: 127 Nodes
- Model is the same size as HORYU-II

The difference is within 5°C
We could make precise calculation model

Thermal balance test
Thermal Analysis Result

Uncertain factors

- Space environment
- Attitude (Rotation speed)

The worst case analysis

Worst Cold: the sunlight hardly enters ±Y surfaces.
Worst Hot: the sunlight mostly enters ±Y surfaces.

Analysis result

<table>
<thead>
<tr>
<th></th>
<th>Worst Cold (°C)</th>
<th>Worst Hot (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>External panel</td>
<td>-30</td>
<td>24</td>
</tr>
<tr>
<td>Internal pole</td>
<td>-4.5</td>
<td>5</td>
</tr>
<tr>
<td>COM</td>
<td>-3</td>
<td>5.5</td>
</tr>
<tr>
<td>Battery</td>
<td>1.9</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Telemetry Data

Data sampling period: 10min (600sec)

Orbital period of HORYU-II: 98min

We can get about 10 data per orbit.

This sampling rate was not enough to calculate the satellite attitude.

We tried to determine the attitude from the orbit data of temperature changes.

- External panels – unstable temperature change
- Inside – stable temperature change

We focused on the temperature of COM* and tried to match the model calculation temperature with the on-orbit temperature.

*COM: communications (RF radio)
Gyro Sensor

Immediately after the separation more than 10 deg/sec the hysteresis dumper and the long monopole antenna attenuated the rotations.

On July 25, 2012

A rotation of HORYU-II seems to be stable.

<table>
<thead>
<tr>
<th>Axis</th>
<th>Root Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>0.38 deg/sec</td>
</tr>
<tr>
<td>Y</td>
<td>1.36 deg/sec</td>
</tr>
<tr>
<td>Z</td>
<td>1.04 deg/sec</td>
</tr>
</tbody>
</table>
The variation of temperature change given by TD is narrower than the on-orbit data.

*TD : Thermal Desktop*
Parametric analysis

<table>
<thead>
<tr>
<th>Angular Velocity (deg/sec)</th>
<th>COM (°C)</th>
<th>+X surface (°C)</th>
<th>−X surface (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.38</td>
<td>1.36</td>
<td>1.04</td>
<td>6</td>
</tr>
<tr>
<td>0.38</td>
<td>2.36</td>
<td>1.04</td>
<td>6.2</td>
</tr>
<tr>
<td>0.38</td>
<td>1.36</td>
<td>2.04</td>
<td>5.5</td>
</tr>
<tr>
<td>0.38</td>
<td>2.36</td>
<td>2.04</td>
<td>6</td>
</tr>
<tr>
<td>0.38</td>
<td>1.36</td>
<td>2.5</td>
<td>6.3</td>
</tr>
<tr>
<td>0</td>
<td>1.36</td>
<td>1.04</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Too many possible combinations of rotating speed in 3 axes. Therefore, defining a unique combination of rotating speed is difficult from the information obtained at present.
On-orbit temperature data

**External panel**
- Temperature range: $-22^\circ\text{C} \sim +50^\circ\text{C}$

**Inside**
- Temperature range: $0^\circ\text{C} \sim +22^\circ\text{C}$

**Battery**
- Temperature range: $+10^\circ\text{C} \sim +12^\circ\text{C}$
Compared with On-orbit data

- The on-orbit temperature was within the temperature range we predicted in the thermal analysis. The thermal design of HORYU-II was appropriate.
Conclusions and Future tasks

• Conclusions

✓ We could conduct thermal analysis by Thermal Desktop.
✓ We could confirm a soundness of the thermal design of HORYU-II from the on-orbit temperature data.

• Future tasks

✓ Specifying the attitude of HORYU-II under the influence of magnetic field.
✓ Check the influence of the long monopole antenna on the rotation attenuation.
Thank you for your attention.
Appendix
Thermal environment

Sunlight

Space: $-270 ^\circ$C

Eclipse

Temperature of satellite

More than $+100 ^\circ$C

Less than $-100 ^\circ$C
Thermal design

Allowable temperature range for onboard equipments

Maximum expected temperature range

Expected temperature range for design

Design margin

Prediction error
HORYU-II

+X

Dipole antenna

Solar Cells for power supply

Electric circuit for Antenna expansion

SCAMP

Monopole antenna

Separation switch x3

Y

Z
HORYU-II

Solar Cells for Cell degradation (CD)

Electron collector
Debris sensor
Solar Cells for power supply
TREK

Illuminometer/External connector for 300V

Solar Cells for Cell degradation (CD)

ELF SCM

+Y

X

Z

-Y

X

Z
HOYRU-II

Solar Cells for 300V generation

Solar Cells for power supply

Solar Cells for 300V generation

SCM for 300V

Solar Cells for power supply
HORYU-II

Communication equipment
Magnet for control
Battery Box

Base board
OBC substrate
COM substrate
ELF substrate
Trek substrate 1
Trek substrate 2
300V substrate
Power substrate
Hysteresis damper
Gyro Sensor

- Model number: ADXRS614
- 1 axis angle velocity measurement
- Measurement range: Max ±30°/sec
- Measurement accuracy: ±1°/sec
- Built-in temperature sensor

Direction of the arrow = Positive rotation

X axis (ELF board)

Y axis (Gyro board)

Z axis (Base board)
Hysteresis dumper

The principle to attenuate librational motion

A principal axes of inertia
The direction of the geomagnetism vector
attenuate librational motion

Mechanical energy
Thermal energy

HORYU-II perform libration motion along the geomagnetism
Control of magnetic field alignment

Sunlight

- 50min
- 40min
- 30min
- 20min
- 10min
- 60min
- 70min
- 80min
- 90min
- 0min (100min)
Thermal Analysis Software

Thermal Desktop®
(Cullimore and Ring Technologies corporation)

- With AutoCAD making a Thermal Mathematical Model
- Making thermal networks
- Steady-state/Transient analysis
  (Parametric analysis)

As a thermal design and a thermal analysis tool, Thermal Desktop is used by NASA development projects and so reliable.
Worst Hot – Analysis result
Worst Hot – Analysis result
Worst Cold – Analysis result
Worst Cold – Analysis result

Temperature, °C

Time, min

Battery

COM

Node

Temperature [°C], Time = 50000 sec
Temperature relationship with COM and X panels

A temperature change of ±X panels transfers to the internal components by thermal conduction through center pillars.