Development of 100W-class Loop Heat Pipes for Space Use and On-orbit Experiment Test Plan

Atsushi Okamoto, Ryuta Hatakenaka, Takeshi Miyakita, Hiroyuki Sugita
JAXA Tsukuba Space Center

Presented by
Atsushi Okamoto
okamoto.atsushi@jaxa.jp
Outline

- Motivation and Objective
- Overview of the development of LHPs in JAXA
- Development of BBM
  - BBM specifications
  - Ground testing in ambient
    -- Start-up and step-wise power test
    -- Power cycle test
    -- Condenser sink temperature change test
- On-orbit experiment test plan
- Summary
Motivation and objective

Development of LHPs has been conducted:
- to meet the wide variety of requirements which cannot be met with only existing thermal control technology (e.g. temperature control with high accuracy, shut down operation)
- to realize the LHP-based deployable radiator for near future high heat generation spacecraft bus

Schematic of LHP

Spacecraft bus with deployable radiator

Heat dissipation of spacecraft vs required radiator area

Required radiator area $A_{rad} \text{ [m}^2\text{]}$

$$A_{rad} = \frac{Q/\epsilon}{\varepsilon_{fin} \times \varepsilon_{mount} \times \sigma \times (T_{rad} - T_{sink})}$$

- emissivity of radiator surface $\epsilon$ : 0.85
- radiator fin efficiency $\varepsilon_{fin}$ : 0.9
- coating mounting efficiency $\varepsilon_{mount}$ : 0.9
- stephan-boltzmann constant $\sigma$ : $5.67 \times 10^{-8}$
- radiation sink temperature $T_{sink}$ : 4K

Limit of body mount radiator

Deployable radiator required
Overview of the development of LHPs in JAXA

Research and development of two types of LHP has been conducting.

**Reservoir embedded LHP (RELHP)**
+ Reservoir is embedded in the evaporator core.
+ **This type of LHP is in the space demonstration phase.**
+ On orbit experiment of a deployable radiator using this type of LHP has been conducting.

**Normal LHP**
+ **This type of LHP is in BBM phase.**
+ BBM was designed and manufactured to acquire the design technique to acquire the manufacturing technology
+ Visualization of working fluid using neutron radiography was also conducted to understand the LHP operation to acquire the data for improvement of LHP modeling and design
+ **On-orbit experiment on ISS is planned in 2016.**
Overview of the development of LHPs in JAXA (Cont.)

- **RELHP and On-orbit experiment of RELHP based deployable radiator**
  RELHP based Deployable Radiator (DPR) was installed on Japanese satellite KIKU-8. KIKU-8 was launched by H-II rocket in 2006 and on-orbit experiment has been conducting.

![Diagram of Deployable Radiator (DPR)]

- **LHP showed good performance on orbit.**
- **No degradation of LHP was confirmed during three years after the launch.**
- **We are ready to apply this type of LHP to the practical mission.**
Overview of the development of LHPs in JAXA (Cont.)

Development of Normal LHP

Development of H/W and numerical simulation model has been conducting. As part of the study, visualization of working fluid using a neutron radiography was conducted. Based on these activity, BBM was designed, fabricated and tested.
Development of BBM

**BBM specifications**

100W-class ammonia LHP

Appearance of BBM

Close-up view around Evaporator/CC

<table>
<thead>
<tr>
<th>Major specifications of BBM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Evaporator</strong></td>
</tr>
<tr>
<td><strong>Primary Wick</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Vapor line</strong></td>
</tr>
<tr>
<td><strong>Condenser line</strong></td>
</tr>
<tr>
<td><strong>Liquid line</strong></td>
</tr>
<tr>
<td><strong>Working Fluid</strong></td>
</tr>
</tbody>
</table>
Tests performed in ambient

- Step-wise heating test
- Power cycle test
- Condenser sink temperature cycle test
- Start-up test at low heat load
- High heat load test
- Tilted orientation test
- Shut-down test
- Operating temperature test
- Forced start-up test
Development of BBM (Cont.)

◆ Ground testing of BBM in ambient
  -- Start-up and step-wise power test
  heat load: 5W → 10W → 15W → 20W → 30W → 40W → 50W → 60W →
  70W → 80W → 90W → 100W → 125W
  condenser sink temp. : 10degC

BBM successfully started up at heat load 5W and showed very stable behavior up to 125W.
Ground testing of BBM in ambient

Operating temperature vs heat load to evaporator saddle
(chiller set point temperature: 10degC)
Ground testing of BBM in ambient

![Graph showing LHP(BBM) Heat leak ratio (Q_{leak}/Q_{applied}) vs heat load to evaporator saddle (W). The graph indicates a relationship between the heat leak ratio and the heat load to the evaporator saddle, with a chiller set point temperature of 10degC. The graph shows data points that suggest a quadratic relationship between the variables.]

Heat leak ration (heat leak to reservoir / heat load to evaporator) vs heat load to evaporator saddle
Ground testing of BBM in ambient
-- Power cycle test
heat load: 100W → 5W → 100W → 5W → 100W
condenser sink temp. : 10degC

LHP showed stable behavior in sudden change in heat load to the evaporator.
Ground testing of BBM in ambient

-- Condenser sink temperature change test

heat load: 100W constant
condenser sink temp. : 10degC → 35degC

LHP showed stable behavior in sudden change in condenser sink condition.
Operating temperature increase 6degC when condenser sink temperature increased 25degC.
On-orbit experiment test plan

- On-orbit experiment of LHP radiator on ISS is planned.
- Experimental apparatus (LHP radiator) will be installed on the adaptor (MPEP, Multi-Purpose Experiment Platform) which is held by robot manipulator of JEM.

Exposed pallet of ISS/JEM

Robot manipulator

LHP radiator

MPEP

MPEP (Multi-Purpose Experiment Platform)
On-orbit experiment test plan (Cont.)

Launch scenario

① Launch in pressurized Cargo

② Attach MPEP onto Airlock

③ Close inner hatch

④ Open outer hatch

⑤ Grapple MPEP by JEMRMS

◆ Launch scenario

TFAWS 2015 – August 3-7, 2015 – Silver Spring, MD
LHP radiator for on-orbit experiment
Design and fabrication have been conducting based on the BBM development
- Working fluid: Propylene
- Maximum heat load: 50W
- Heat transport length: 1.5m
On-orbit experiment test plan (Cont.)

Technology demonstration in a mutual complement of following activities;
- On-orbit experiment on ISS/JEM
- Ground testing
- Numerical simulation

On-orbit experiment on ISS/JEM

Correlation using test data

Design analysis
Performance prediction

Ground testing

Correlation using test data

Design analysis
Performance prediction

Evaluation of the effect of the gravity on the performance and characteristics of LHP radiator

Technology demonstration plan of LHP radiator for application to space

Development of PFM has been conducting. It will be launched in winter of 2016.

Part of this study will be conducted in collaboration with Nagoya Univ.
Overview of the development of LHPs in JAXA was introduced.

- BBM was designed and fabricated based on the technology which was acquired through the fundamental studies.
- BBM showed good performance as a result of the ground testing in ambient.
- Preliminary test plan for on-orbit experiment of LHP radiator was introduced.

Evaluation test in vacuum chamber was carried out. As a result, BBM showed good performance also in vacuum condition. The development of PFM for on-orbit experiment is now underway. LHP will be launched in winter in 2016 by HTV, Dragon, or Cygnus spaceship.