Turbo-Brayton Refrigerator of Yokohama HTS Cable Project

Naoko Nakamura
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MAYEKAWA MFG. CO., LTD.

Established in: 1924
Capital: 1 billion yen
Sales: 130 billion yen (group)
Employees: 4,500
Manufacture: Gas compressor, Industrial freezer, Refrigerator
Market: Food, Meat and Seafood processing, Distribution and Energy

MAYEKAWA is doing business globally, having 60 domestic offices and 3 plants and 2 laboratories, and 102 overseas offices including 7 plants.
Operation Range of MAYEKAWA

-271°C He Compressors
-269°C Helium Refrigerator
-220°C Ne Turbo Brayton Cycle Refrigerator
[Brayton NeO]
-120°C NH3 / CO2 Cooling System [SIERRA]
-95°C Air Cycle [PascalAir]
-5°C CO2 Heat Pump [unimo]
-15°C Adsorption Chillers [AdRef-Noa]
-50°C NH3 / CO2 Cooling System [NewTon]
-30°C CO2 heat pump desiccant dehumidier [Chirs]
-30°C Refrigerators Cascades
-269°C Helium Refrigerator
-271°C He Compressors
130°C Steam Compressor
50°C Heat Pump
120°C Steam Expander
90°C Water
120°C Air
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Outlines of the Yokohama Project

Project Outlines

- Asahi S/S, Yokohama, TEPCO’s power system
- 66 kV – 2 kA – 200 MVA class HTS cable with 1G DI–BSCCO wire
- Compact 3–in–One cable designed for 150 mm conduit
- Approx. 250 meter cable with a joint and terminations
- Project Member : TEPCO, SEI, MAYEKAWA supported by NEDO, METI

HTS Cable Specifications

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Capacity</td>
<td>230 MVA(66 kV, 2 kA)</td>
</tr>
<tr>
<td>Maximum Current</td>
<td>2.75 kA</td>
</tr>
<tr>
<td>AC Loss</td>
<td>1 W/m/ph at 2 kA</td>
</tr>
<tr>
<td>Withstand Voltage</td>
<td>AC 90 kV for 3 hours Imp ±385 kV 3 repetitions</td>
</tr>
<tr>
<td>Fault Current</td>
<td>1. No degradation against the F.C. of 31.5 kA, 2 sec.</td>
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<tr>
<td></td>
<td>2. The rated capacity can be transmitted immediately after F.C. of 10 kA, 2 sec.</td>
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## Project Schedule

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<tbody>
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<td><strong>(1) 1st Phase Project</strong></td>
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<td>Field test in Asahi S/S</td>
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<td>• Verify reliability and durability of HTS cable system</td>
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<td>Design and manufacture CB/CU</td>
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<td>Performance test in Moriya factory</td>
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<td><strong>(2) 2nd Phase Project</strong></td>
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<td>• Verify reliability of new refrigerator system</td>
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<td>Move to Asahi S/S</td>
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<td>Installation Unit test</td>
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<td>Real grid operation</td>
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※REF: Refrigerator, COMP: Compressor, EXPND: Expander, CB: Cold Box, CU: Compressor Unit

- Demonstration test of 1st Phase in real grid has started on **October 29, 2012** and finished on **December 25, 2013**. More than 1 year continuous reliable operation has been verified with successful result.
- Demonstration test of 2nd Phase in real grid has started on **March 31, 2017**. Reliability of new refrigerator has been verified in the continuous operation.
Results of 1st Phase Operation Test

More than 1 year Continuous Reliable Operation has been verified with successful result.

Challenge at different operation temperature. System was continuously and constantly stable.

The flow rate and pressure of the liquid nitrogen remained stable during more than one year under unstable and changing electric load. High reliability of HTS cable system is verified.
Technical Issues of the Cooling System

Table 1. Specifications

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
<th>Unit(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerator (Stirling type)</td>
<td>1 kW @ 77 K</td>
<td>6 (Redundancy 1 unit)</td>
</tr>
<tr>
<td>Pump (Centrifugal type)</td>
<td>0.15 MPa 40 L/min</td>
<td>2 (Redundancy 1 unit)</td>
</tr>
<tr>
<td>Reservoir</td>
<td>1000 L</td>
<td>1</td>
</tr>
</tbody>
</table>

Technical Issues of the Refrigerator

- **Low Efficiency**
  Average COP of one year is 0.05 we measured. COP of a refrigerator is needed 0.1 for saving energy of HTS Cable.

- **Short Maintenance Interval**
  This refrigerator needed vacuuming every two weeks and replacing parts every 8,000 hours. Maintenance interval for the power system is required over tree years.

Table 2. Improvement of Cooling Capacity

<table>
<thead>
<tr>
<th>Items</th>
<th>Cooling capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuuming</td>
<td>30 ~ 100 W / 1 unit</td>
</tr>
<tr>
<td>Overhauling</td>
<td>200 W / 1 unit</td>
</tr>
<tr>
<td>Working gas charge</td>
<td>40 W / 1 unit</td>
</tr>
</tbody>
</table>
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5. Conclusion
Target performance of a new refrigerator

Requirements Performance of a Refrigerator for HTS Cable

(1) Large Capacity

Cooling systems of HTS cable are located every multiple km. The cooling capacity of one cooling station is needed 5 ~ 20 kW for reducing total cost.

First Target = 5 kW

(2) High Efficiency

HTS Cable has advantage of saving energy. If COP of cooling system is 0.1, a loss of HTS cable is reduced 50 % compare with conventional cable.

COP = 0.1

(3) High Reliability

OPEX is decreased long term maintenance interval and reducing troubles. A Target of maintenance interval is close to it of industrial refrigerator.

Maintenance Interval = 3000 ~ 4000 hours

Reverse Brayton Cycle

High performance turbo-machine, multistage compressor

Magnetic bearing
**Turbo-Brayton Refrigerator**

- **High Efficiency**: Adiabatic efficiency of turbo-machine = 0.8
- **High Reliability**: Perfect contactless by using magnetic bearing

### System Flow

- **Compressor Unit**
- **Cold Box**
- **Results of Cooling Capacity**
- **Results of COP**

#### Components:
- **1st - 2nd Compressor**
- **3rd Compressor - Expander**
- **After cooler**
- **Heat Exchanger**
- **Buffer**
- **Liquid nitrogen**
- **LN2**
- **Neon**

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*Impeller of Compressors, Expander*  
*1st - 2nd Compressor*  
*3rd Compressor - Expander*  
*Turbo-Brayton Refrigerator*
Cooling System of 2nd Project

10,000 hours has passed since starting operation of cooling system including the refrigerator.

Layout of the cooling system

<table>
<thead>
<tr>
<th>Turbo-Brayton Refrigerator</th>
<th>Pump Unit and Reservoir</th>
</tr>
</thead>
</table>

Sub-Cooler

Outlet Temperature of Refrigerator
Pressure in Reservoir
Flow Rate

Temperature [°C], Flow rate [l/min]

Cooling Capacity
COP

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5. Conclusion
The refrigerator is more compact and more easier operation.

**Characteristic**
- Compact (adapted marine container size)
- Easy operation
- Saving Energy by high efficiency
- Long in a maintenance interval
- Small burden on the environment (used Neon gas of Natural refrigerant)

**Table 2. Specifications**

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling capacity</td>
<td>5 kW @ 77 K</td>
</tr>
<tr>
<td>COP</td>
<td>0.1 @ 77 K</td>
</tr>
<tr>
<td>Dimensions (Outdoor)</td>
<td>2,200 × 3,600 × 2,200 mm</td>
</tr>
<tr>
<td>Weight (Outdoor)</td>
<td>5,500 kg</td>
</tr>
<tr>
<td>Power supply</td>
<td>AC380 ~ 480 V, 75 kVA</td>
</tr>
<tr>
<td>Cooling water</td>
<td>200 L/min (Inlet temperature 32 °C)</td>
</tr>
</tbody>
</table>
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5. Conclusion
Conclusion

1. Yokohama project of 1st phase, more than 1 year continuous reliable operation has been verified with successful result. For practical use of HTS Cable, a Turbo-Brayton refrigerator was developed in this project.

2. Turbo-Brayton refrigerator in Asahi S/S has been verified a reliability in the continuous HTS Cable system operation in a real grid.

3. Turbo-Brayton refrigerator commercial base was developed for practical use of HTS Cable. The refrigerator is more compact and more economical.

4. Practical use of HTS Cable will be soon realized by success of demonstration test and
Thank you very much.