

Superconducting and Cryogenics Technology of MAYEKAWA

October, 2017



CONTENTS

- 1. About MAYEKAWA**
- 2. Outline of the High Temperature Superconducting (HTS) Cable Project in Japan**
- 3. Turbo-Brayton Refrigerator of HTS Cable Project**
- 4. Turbo-Brayton Refrigerator Commercial Base**
- 5. Conclusion**

1. About MAYEKAWA

2. Outline of the High Temperature Superconducting (HTS) Cable Project in Japan

3. Turbo-Brayton Refrigerator of HTS Cable Project

4. Turbo-Brayton Refrigerator Commercial Base

5. Conclusion

Company Profile

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



Tokyo office



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

Plants

- Belgium
- India
- South Korea
- USA
- Mexico
- Brazil

Offices

- | | | | | |
|---------------|-------------|---------------|--------------|-------------|
| • England | • Turkey | • Indonesia | • Canada | • Chile |
| • France | • UAE | • Australia | • Venezuela | • Argentina |
| • Spain | • Thailand | • New Zealand | • Costa Rica | |
| • Switzerland | • Viet Nam | • Philippines | • Colombia | |
| • Germany | • Singapore | • China | • Ecuador | |
| • Russia | • Malaysia | • Taiwan | • Peru | |

Market



Food



Dairy



Beverages



Breweries



Oil, Gas & Chemical



Marine



Leisure



Environment



Cryogenics

Read more>> <http://www.mayekawa.com/market/>

Operation Range of MAYEKAWA



- 1. About MAYEKAWA**
- 2. Outline of the High Temperature Superconducting (HTS) Cable Project in Japan**
- 3. Turbo-Brayton Refrigerator of HTS Cable Project**
- 4. Turbo-Brayton Refrigerator Commercial Base**
- 5. Conclusion**

Outlines of the HTS Cable 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

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



HTS Cable

Role allotment



TOKYO ELECTRIC POWER COMPANY

- Consideration of Test Site**
- Operation of Power Transmission**



Sumitomo Electric Industries, Ltd.

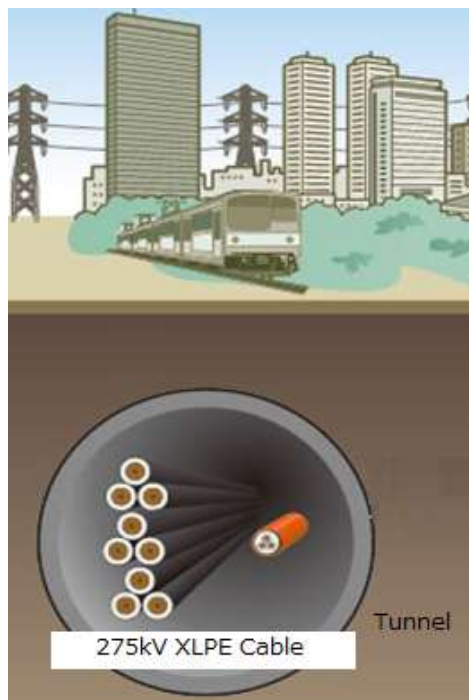
- Design & Manufacturing of HTS Cable**
- Operation of SC Power Cable**



- Design & Manufacturing of Cable Cooling System Including Liquide Nitrogen Circulation System)**
- Operation of Cable Cooling System**

Big Urban Issue; Saving Energy & Space

➤ Saving Space; Smaller Space & Lower installation cost



Compact HTS cable can be installed in existing tunnel and cable duct.



HTS cable has the advantage of larger amount of power transmission with more compact size and lower voltage.

- ✓ Reduce construction cost of tunnel
- ✓ Reduce number of substation

Reducing CAPEX

275 kV XLPE Cable



66 kV HTS Cable



- ✓ Same transmitted power
- ✓ Lower Voltage
- ✓ Smaller Space

※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.

Connecting Diagram at Asahi S/S

Established Connecting Diagram

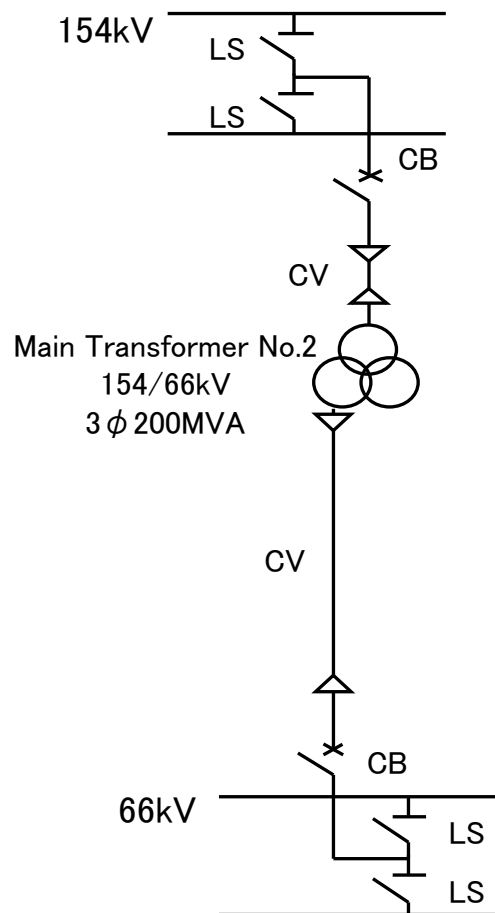
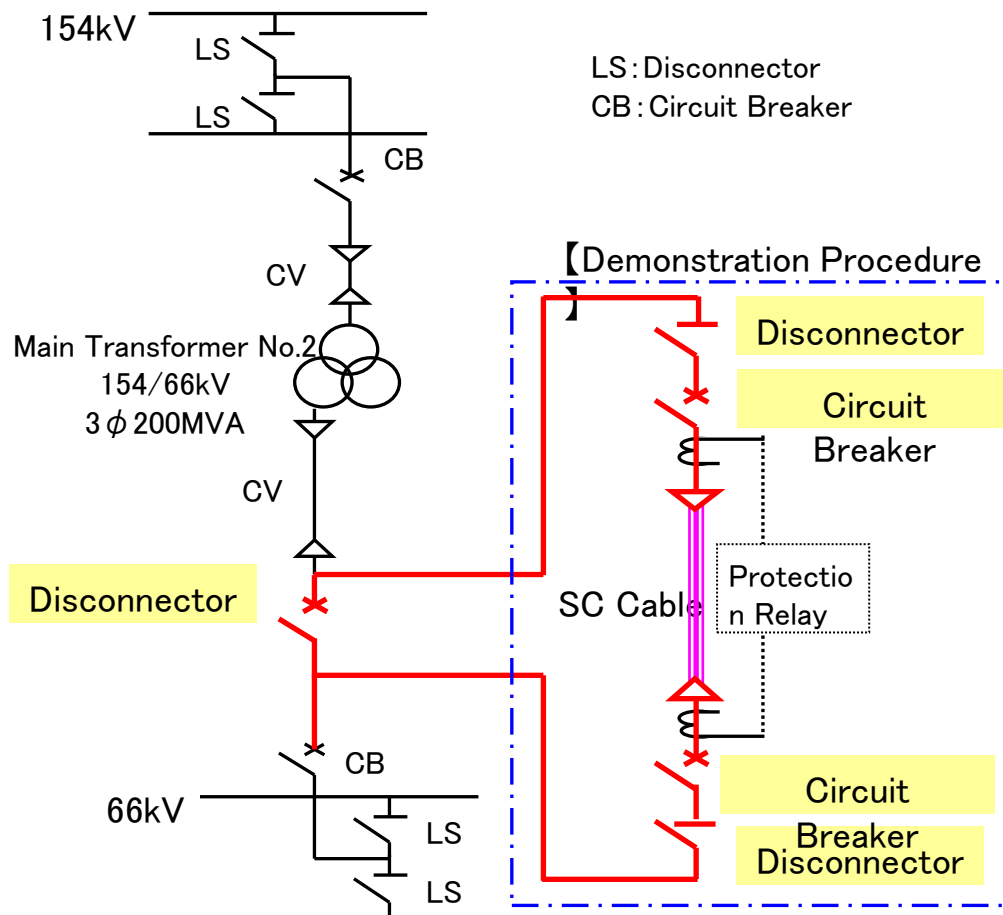
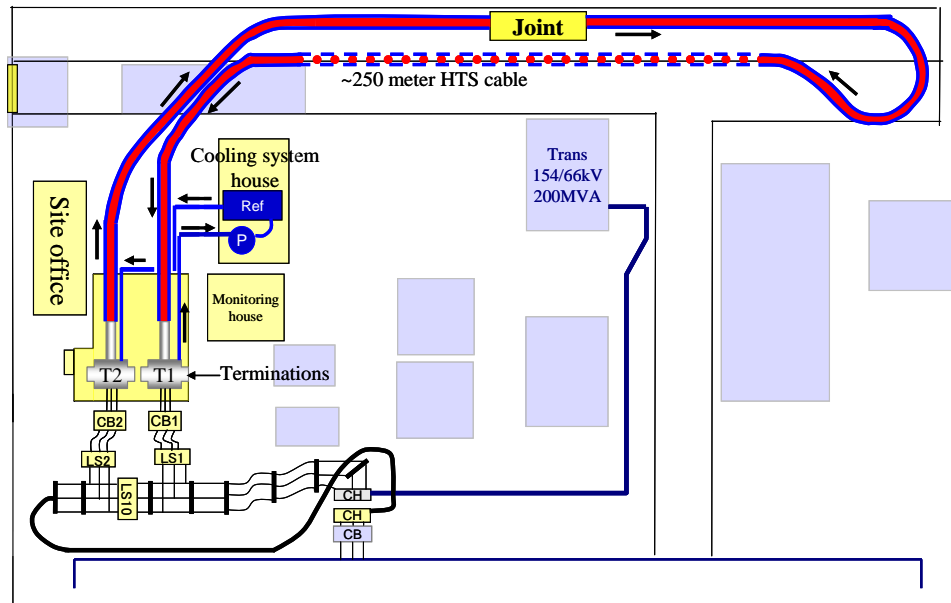


Diagram After Installing SC Cable



HTS Cable System of 1st Phase Project



Layout in Asahi S/S



HTS Cable



Stirling Refrigerators

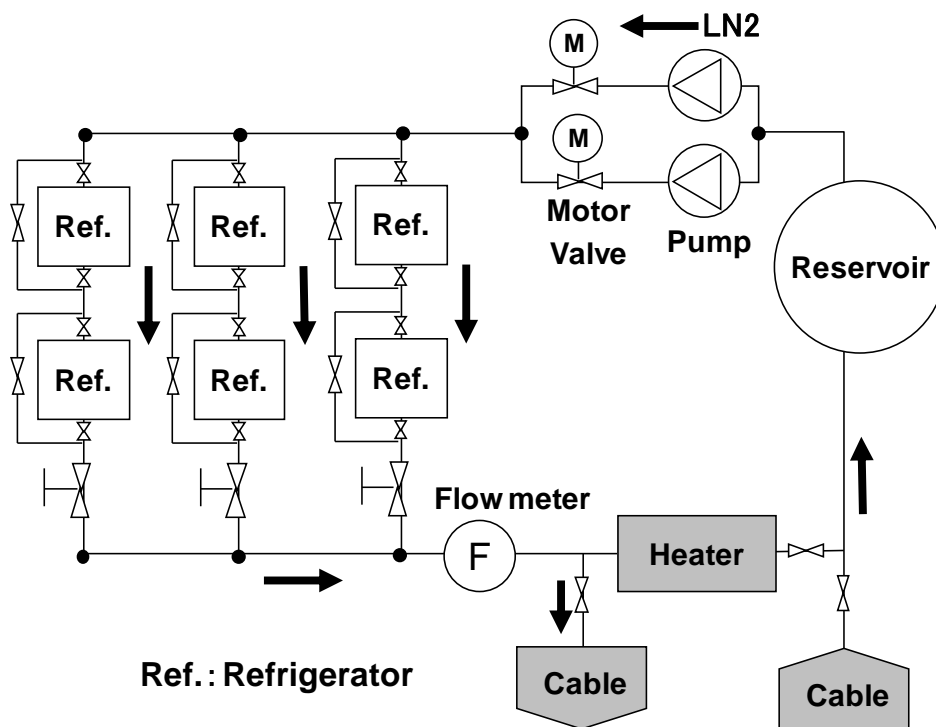


Pump Units



Reservoir

Cable Cooling System (1st Phase)



Cooling System Flow of 1st Phase Project

Table1. Specifications

Items	Specifications	Unit(s)
Refrigerator (Stirling type)	1 kW @ 77 K	6 (Redundancy 1 unit)
Pump (Centrifugal type)	0.15 MPa 40 L/min	2 (Redundancy 1 unit)
Reservoir	1000 L	1



Stirling Refrigerators

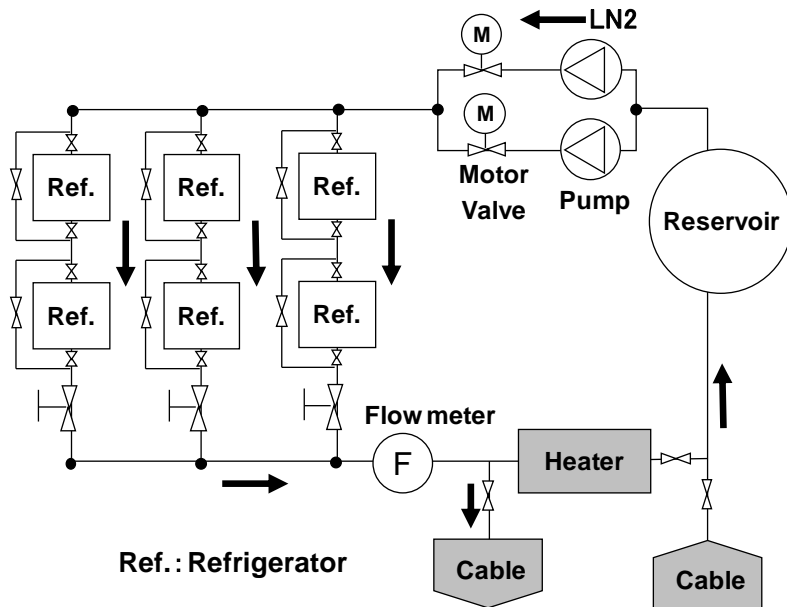


Pump Units



Reservoir

Technical Issues



Cooling System Flow of 1st Phase Project

Table 2. Improvement of Cooling Capacity

Items	Cooling capacity
Vacuuming	30 ~ 100 W / 1 unit
Overhauling	200 W / 1 unit
Working gas charge	40 W / 1 unit

Technical Issues of the Refrigerator

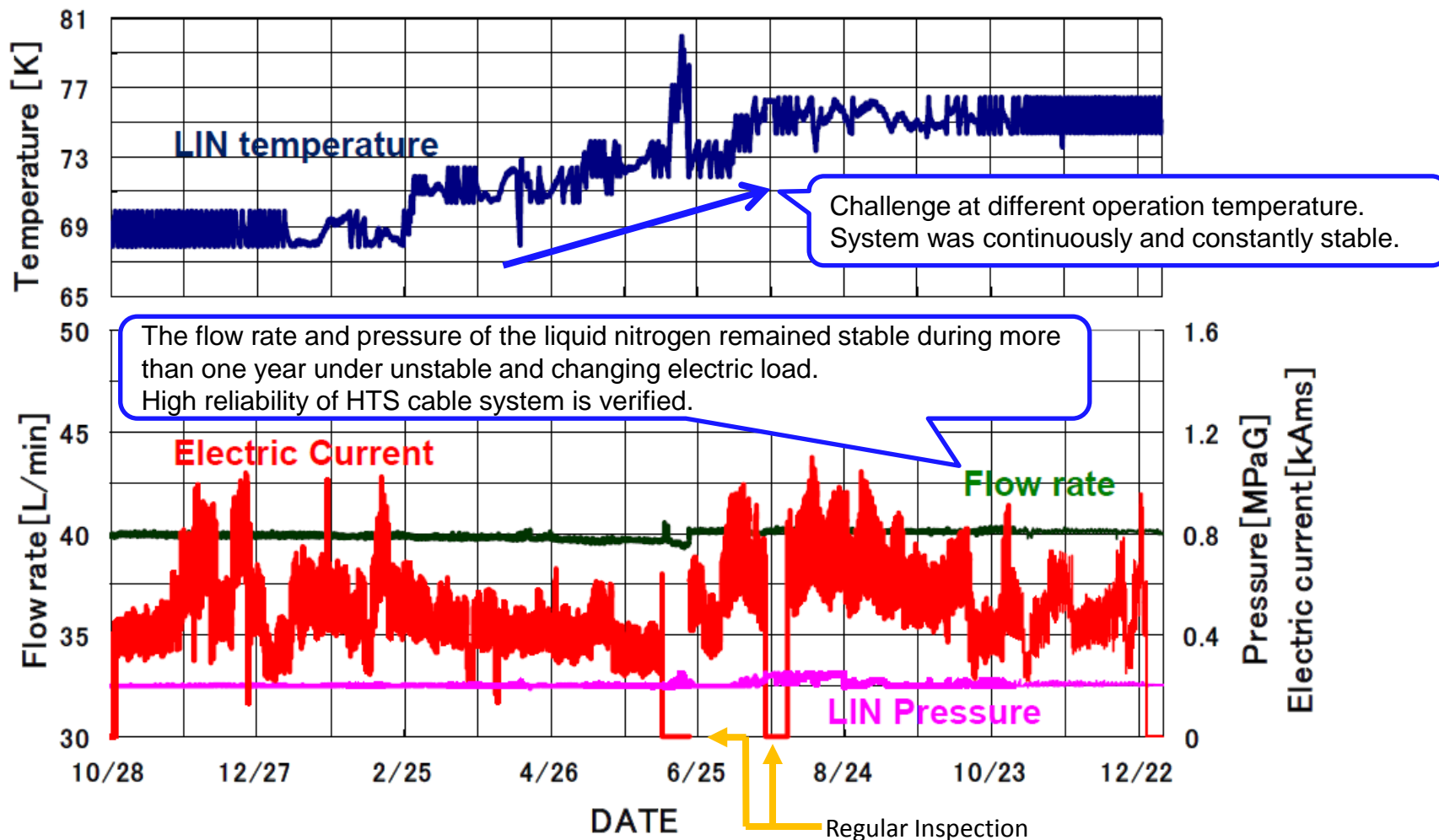
- Low Efficiency**
 Average COP of one year is 0.05 we measured. COP of a refrigerator is needed 0.1 for saving energy of HTS Cable System.
- Short Maintenance Interval**
 This refrigerator needed vacuuming every two weeks and replacing parts every 8,000 hours. Maintenance interval for the power grid system is required over tree years.



Stirling Refrigerators

Results of 1st Phase Operation Test

More than 1 year continuous reliable operation has been verified with successful result.



- 1. About MAYEKAWA**
- 2. Outline of the High Temperature Superconducting (HTS) Cable Project in Japan**
- 3. Turbo-Brayton Refrigerator of HTS Cable Project**
- 4. Turbo-Brayton Refrigerator Commercial Base**
- 5. Conclusion**

Target Values of a Refrigerator

Requirements Performance of a Refrigerator

(1) Large Capacity

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

First Target = 5 kW



Reverse Brayton Cycle

(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. OPEX is reduced.

COP = 0.1



**Adiabatic efficiency = 0.8,
Three stage compressor**

(3) High Reliability

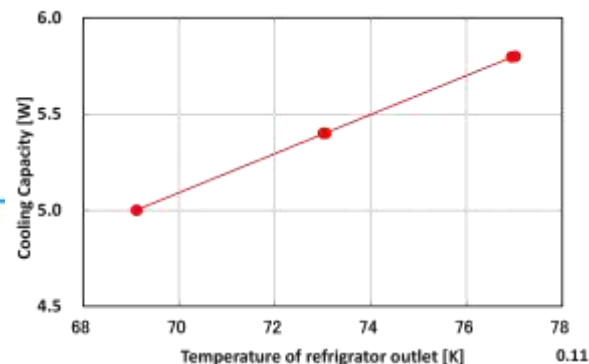
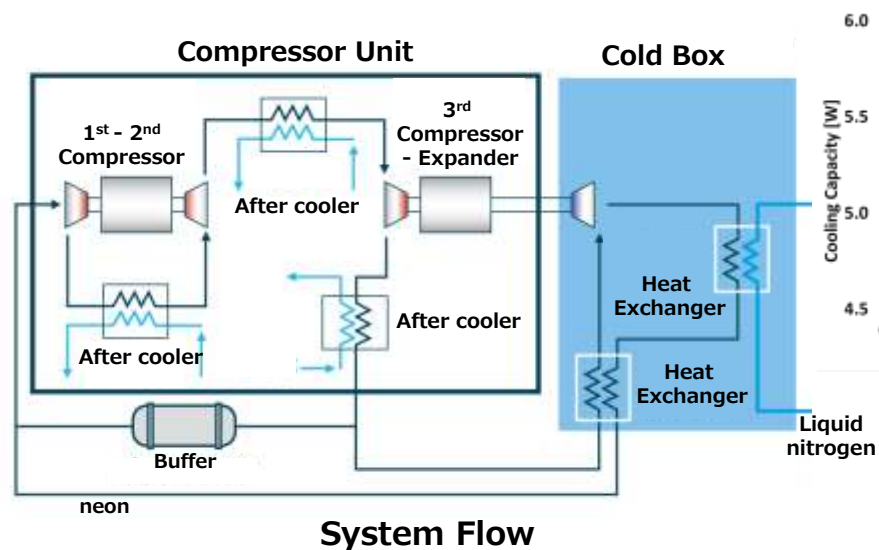
OPEX is decreased long term maintenance interval and reducing troubles. A Target of maintenance interval is close to it of industrial refrigerator.

**Maintenance Interval
= 3000 ~ 4000 hours**

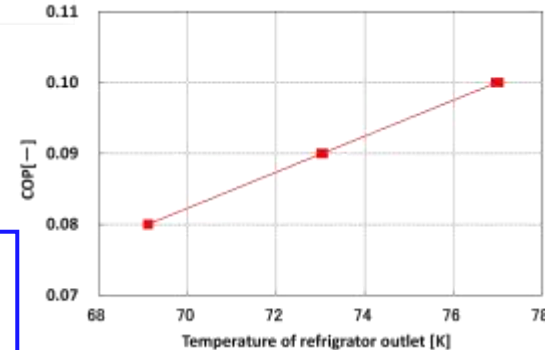


Magnetic bearing

Turbo-Brayton Refrigerator for Demonstration Test



Results of Cooling Capacity

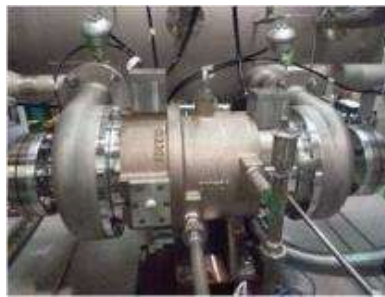


Results of COP

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



Impeller of Compressors, Expander



1st - 2nd Compressor

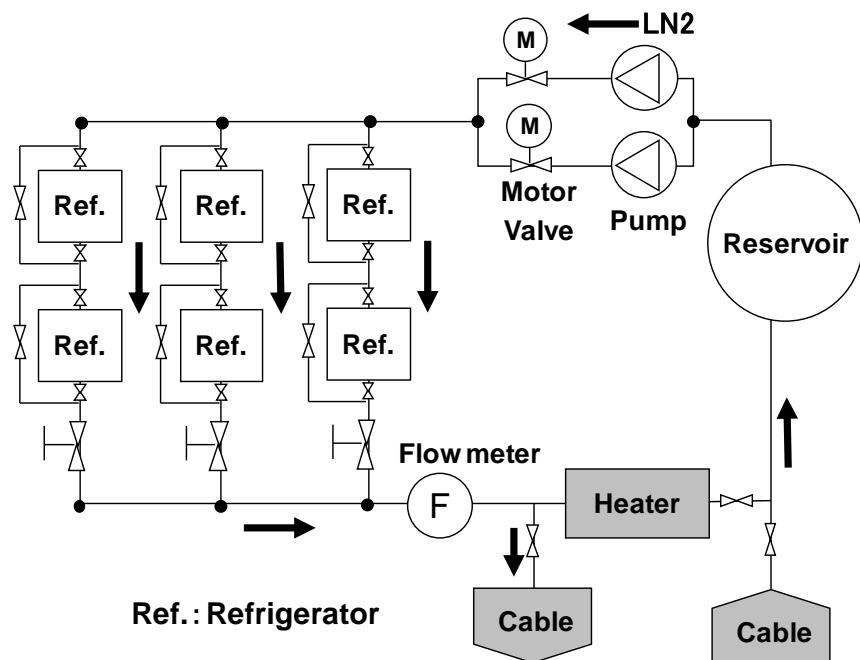


3rd Compressor - Expander

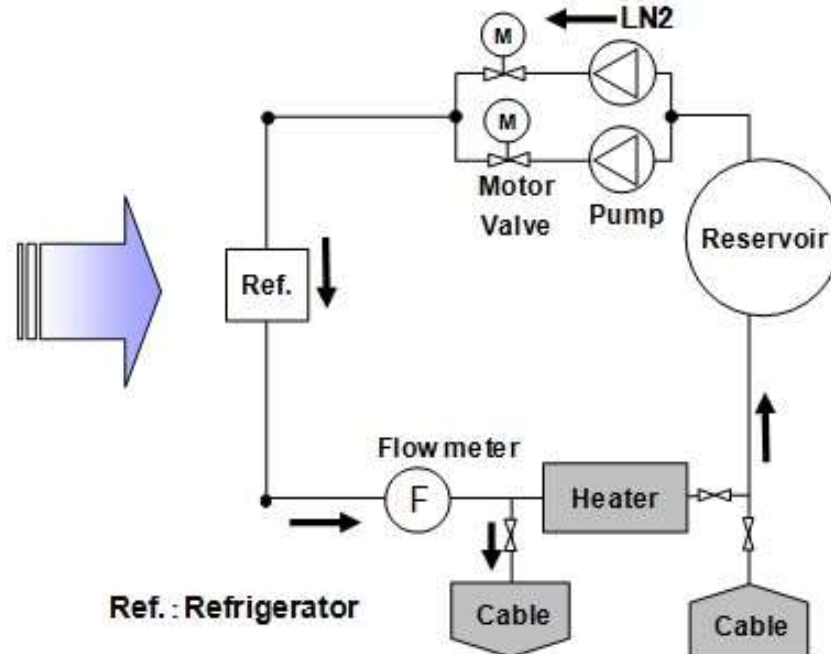


Turbo-Brayton Refrigerator

Cooling System Flow



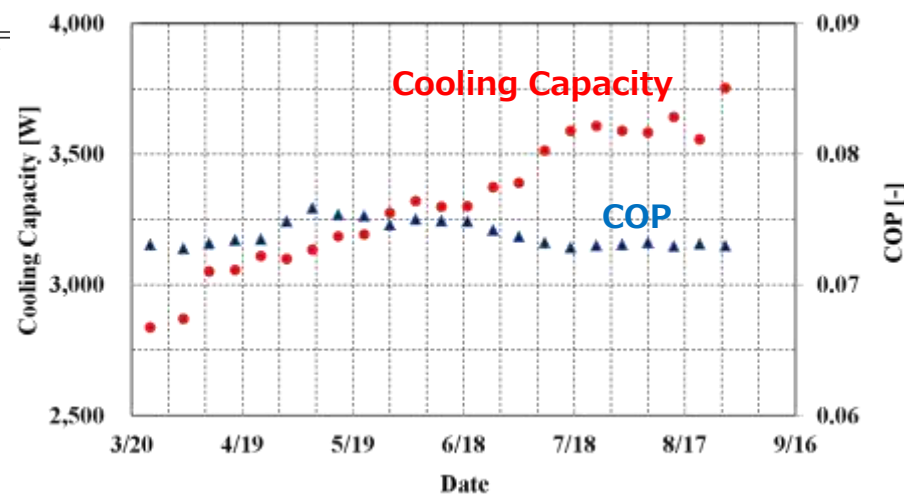
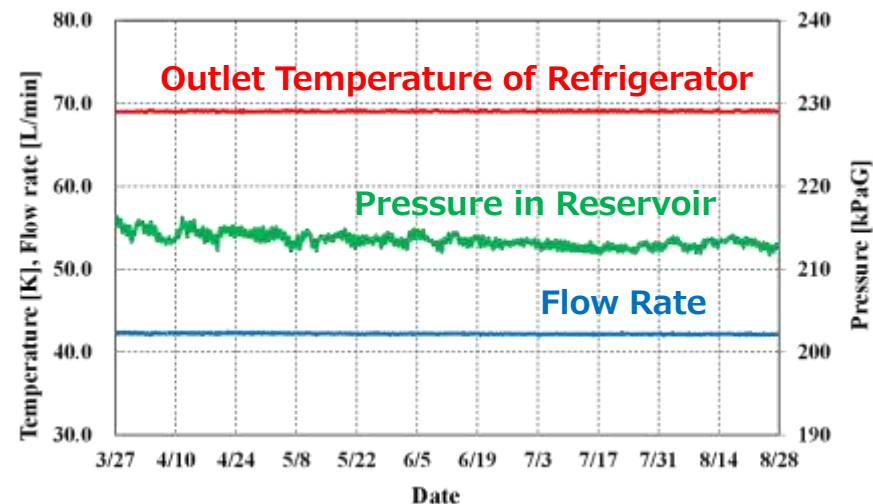
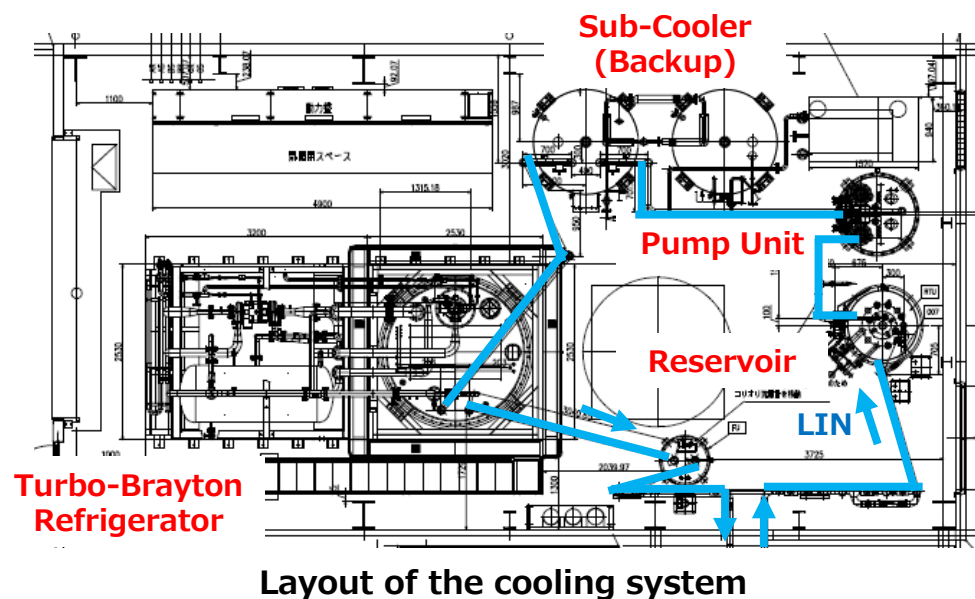
1st Phase



2nd Phase

Test Results of 2nd Phase Project

10,000 hours has passed since starting operation of cooling system of 2nd phase project.



Turbo-Brayton Refrigerator



Pump Unit and Reservoir

Test Results

- 1. About MAYEKAWA**
- 2. Outline of the High Temperature Superconducting (HTS) Cable Project in Japan**
- 3. Turbo-Brayton Refrigerator of HTS Cable Project**
- 4. Turbo-Brayton Refrigerator Commercial Base**
- 5. Conclusion**

Turbo-Brayton Refrigerator Commercial Base

The refrigerator is more compact and more easier operation.

Characteristics

- Compact (adapted marine container size)
- Easy operation
- Saving Energy by high efficiency
- Long in a maintenance interval
- Green (Natural refrigerant)



Indoor Type

Table2. Specifications

Items	Specifications
Cooling capacity	5 kW @ 77 K
COP	0.08 @ 77 K
Dimensions (Outdoor)	2,200 × 3,600 × 2,200 mm
Weight (Outdoor)	5,500 kg
Power supply	AC380 ~ 480 V, 75 kVA
Cooling water	200 L/min (Inlet temperature 32 °C)



Outdoor Type

- 1. About MAYEKAWA**
- 2. Outline of the High Temperature Superconducting (HTS) Cable Project in Japan**
- 3. Turbo-Brayton Refrigerator of HTS Cable Project**
- 4. Turbo-Brayton Refrigerator Commercial Base**
- 5. Conclusion**

Conclusion

- 1. Yokohama project of 1st phase, more than 1 year continuous reliable operation has been verified with successful result. In parallel, a Turbo-Brayton refrigerator was developed in the 1st phase project.**
- 2. Turbo-Brayton refrigerator we developed has been verified a reliability in the continuous HTS Cable system operation on a real grid in Asahi Sub-station. Practical use of HTS Cable will be soon realized by success of the demonstration test.**
- 3. Turbo-Brayton refrigerator commercial base was developed for practical use of HTS Cable. The refrigerator is more compact and more economical.**



Thank you very much.