Turbo-Brayton Refrigerator for Superconducting Cable

Naoko Nakamura

MAYEKAWA

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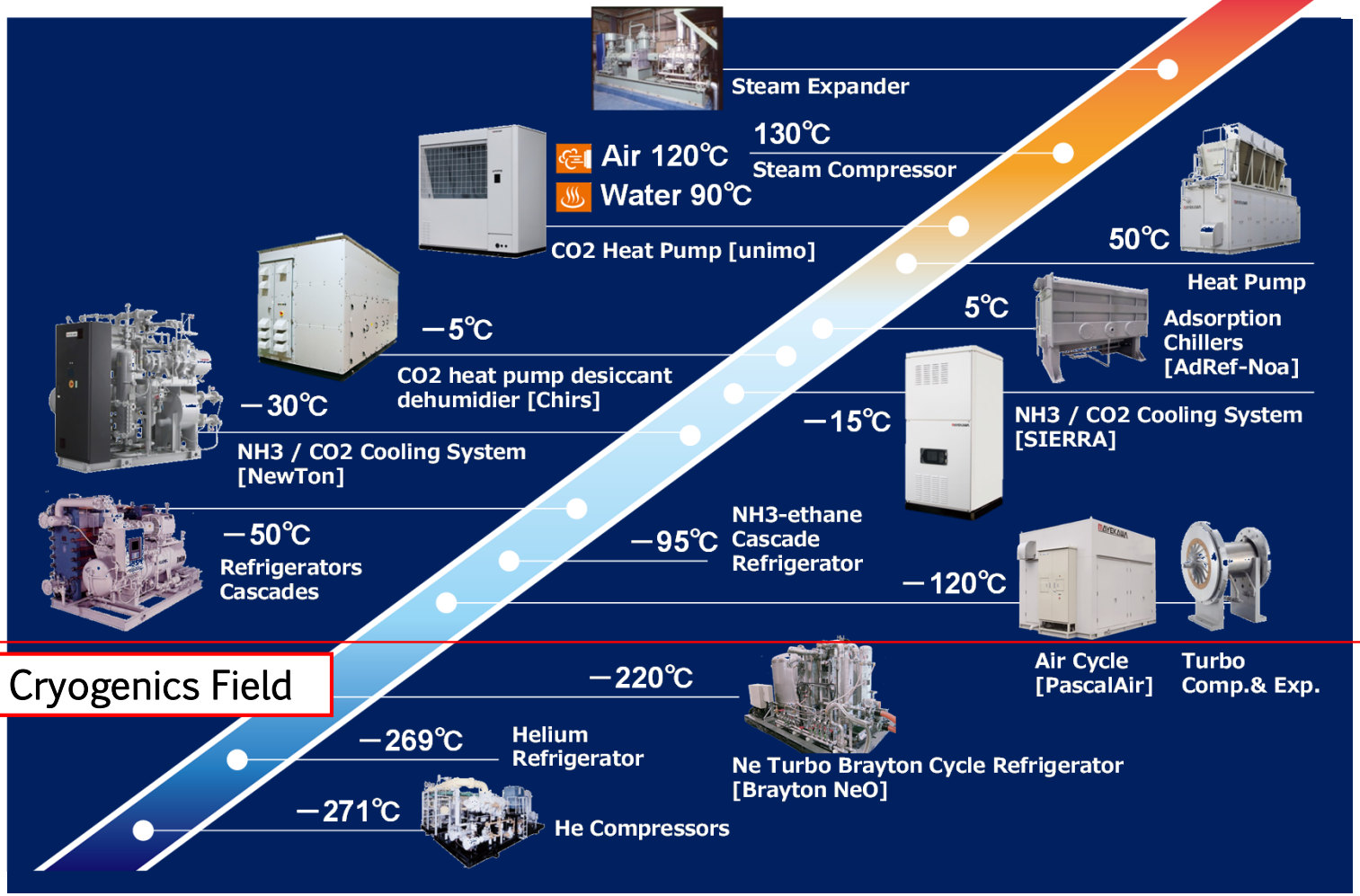
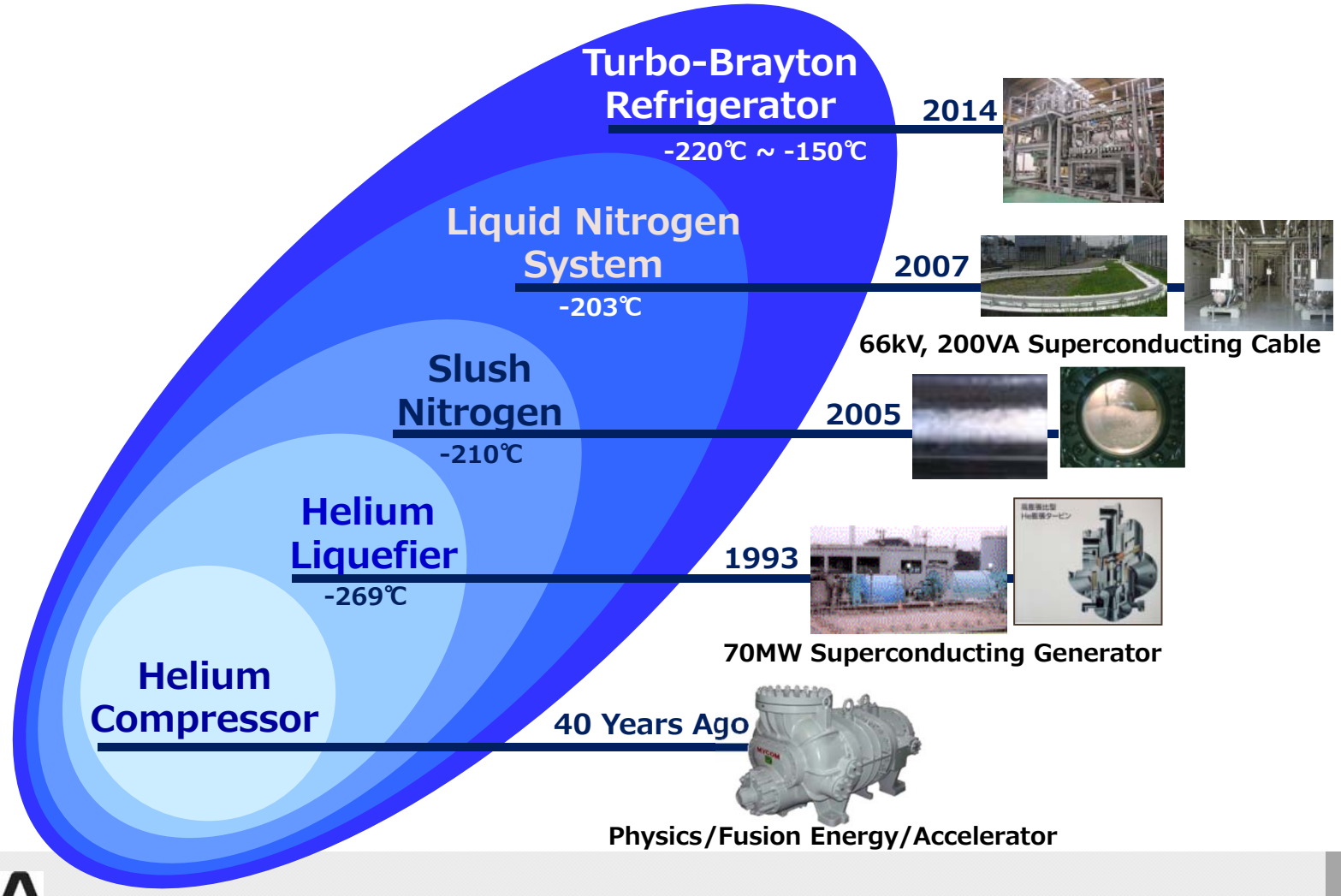
Business Target Range of MAYEKAWA



Cryogenics History of MAYEKAWA



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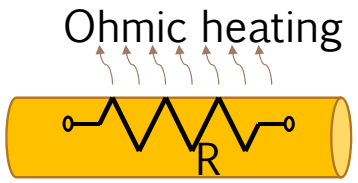
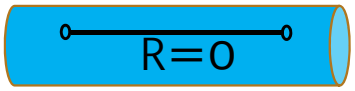
What is Superconductivity？

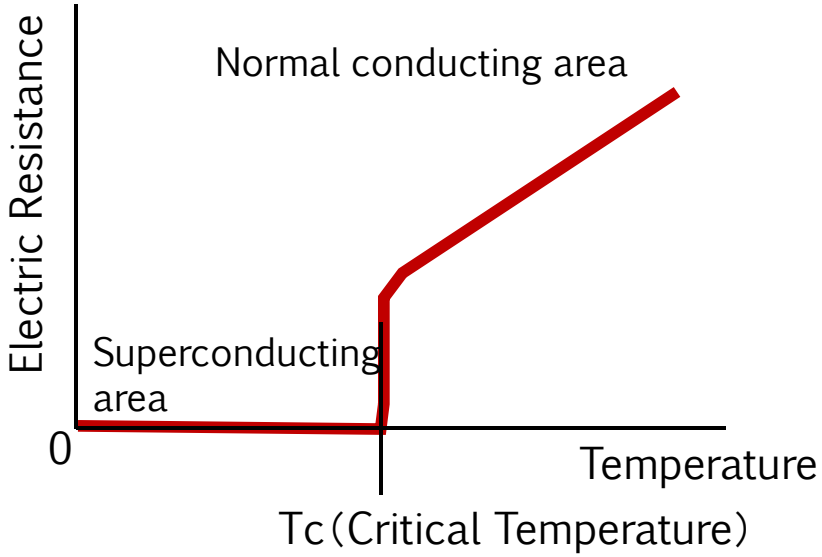
Superconducting transition of a superconductor occurs at its critical temperature, and the resistance becomes Zero.



Normal Conductor



Superconductor



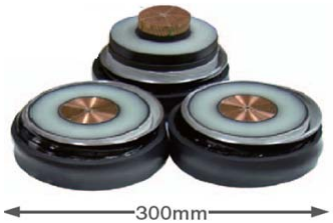
（Representative Application）
MRI （Magnetic Resonance Imaging）
MAGLEV (Magnetic Levitation Railway)

Superconducting material of Tc over -250 ℃ is HTS (High temperature superconductivity).

Superconducting Cable Advantages

By Furukawa Web-Site
https://www.furukawa.co.jp/rd/superconduct/type.html

➢ Saving Space; Smaller Space & Lower installation cost



275 kV XLPE Cable

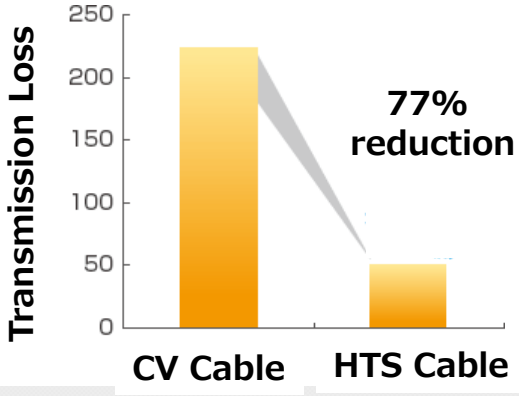
66 kV HTS Cable

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



Outlines of HTS Cable Project

Project Outlines

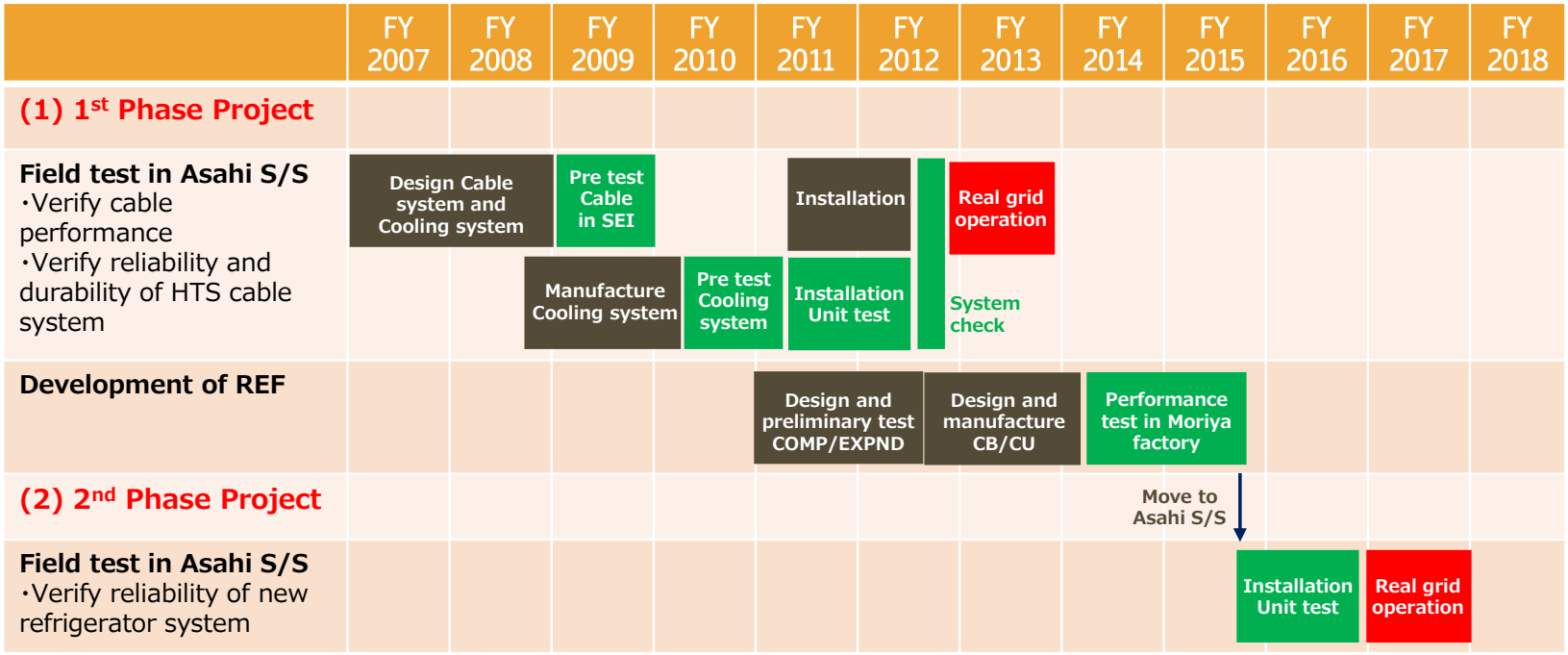
- Asahi S/S, Yokohama, TEPCO's power system
- 66 kV - 2 kA - 200 MVA class HTS cable with 1G DI-BSCCO wire
- Compact 3-in-One cable designed for 150 mm conduit
- Approx. 250 meter cable with a joint and terminations
- Project Member : TEPCO, SEI , MAYEKAWA supported by NEDO, METI

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

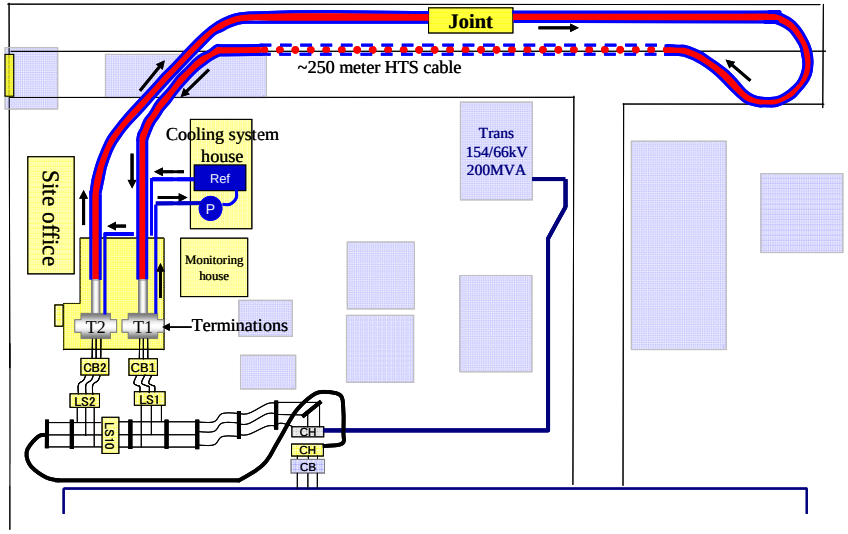
Project Schedule



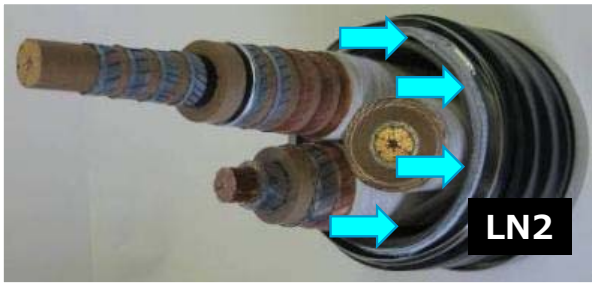
※REF: Refrigerator, COMP: Compressor, EXPND: Expander, CB: Cold Box, CU: Compressor Unit

- **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.**

HTS Cable System



Layout in Asahi S/S



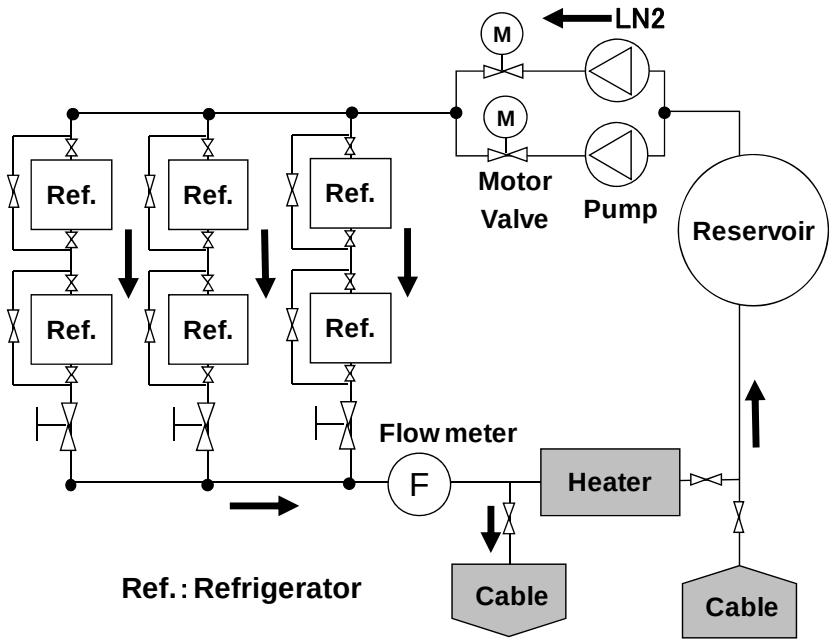
HTS Cable

Stirling Refrigerators

Pump Units

Reservoir

Cooling System



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

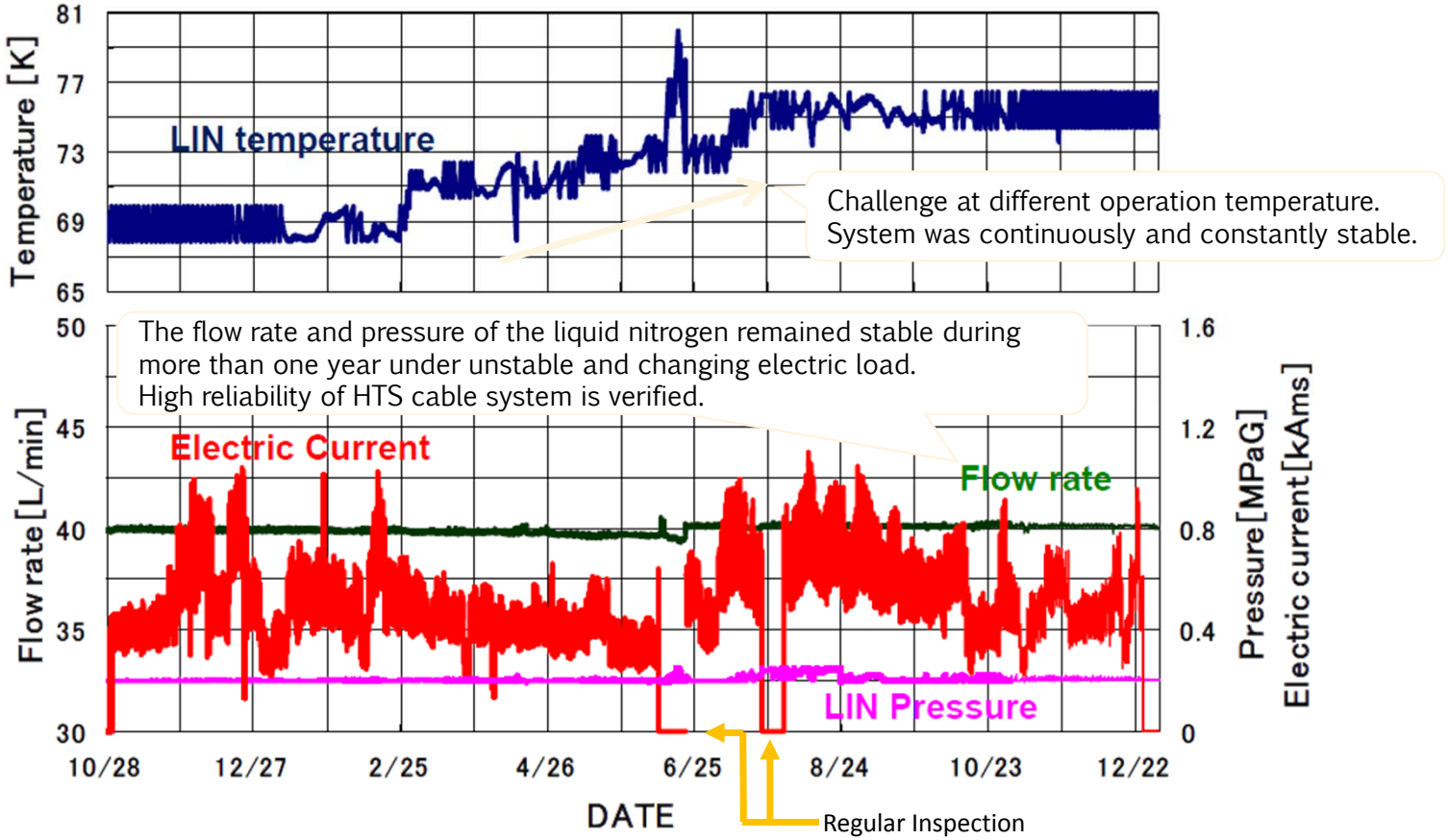
Stirling Refrigerators

Pump Units

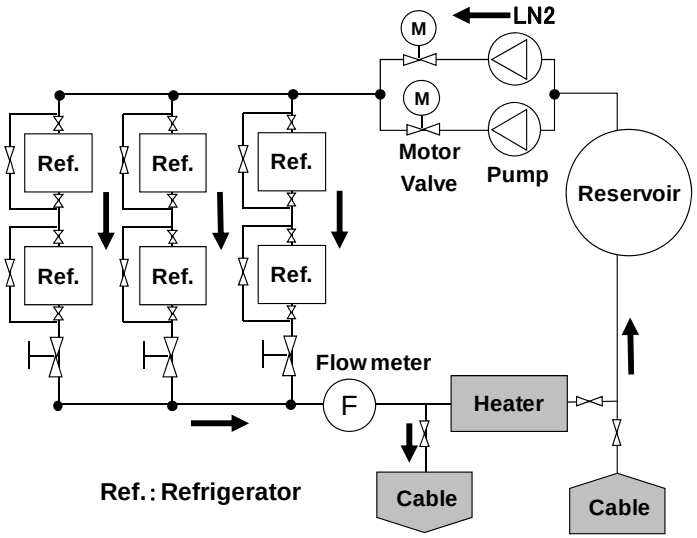
Reservoir

Results of 1st Phase Operation Test

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



Technical Issues



Cooling System Flow of 1st Phase Project

Tabke2. 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 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

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Target Values of Refrigerator

Requirements Performance of Refrigerator for HTS Cable

(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 ross of HTS cable is reduced 50 % compare with conventional cable. OPEX is reduced.

COP = 0.1

↓

Turbo compressor and expander

(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 = 30,000 ~ 40,000 hours

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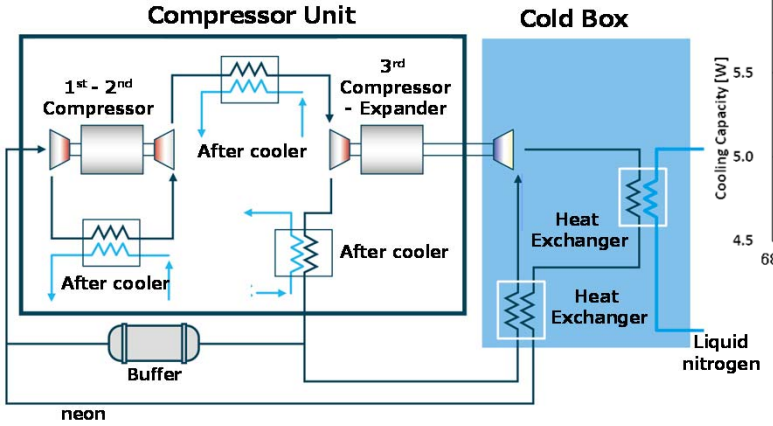
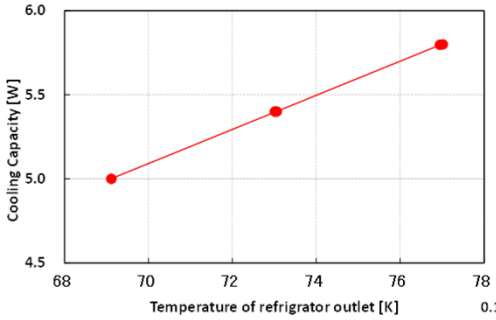
Magnetic bearing

Turbo-Brayton Refrigerator for Demonstration Test

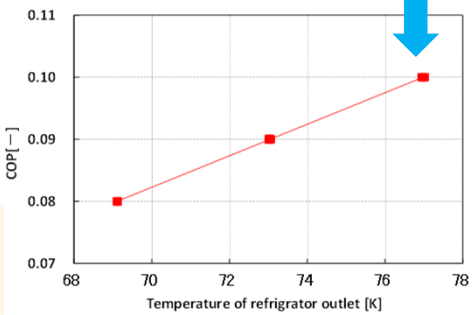


System Flow



Results of Cooling Capacity

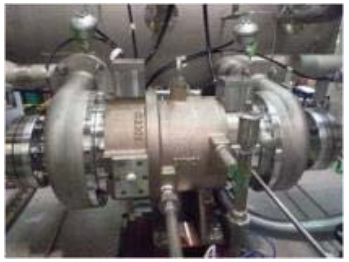
World Highest Efficiency



Results of COP

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

Impeller of Compressors, Expander

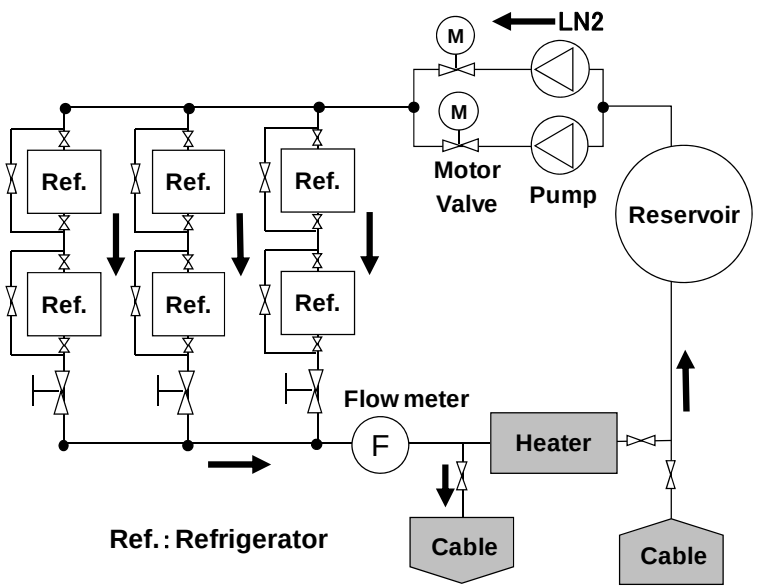


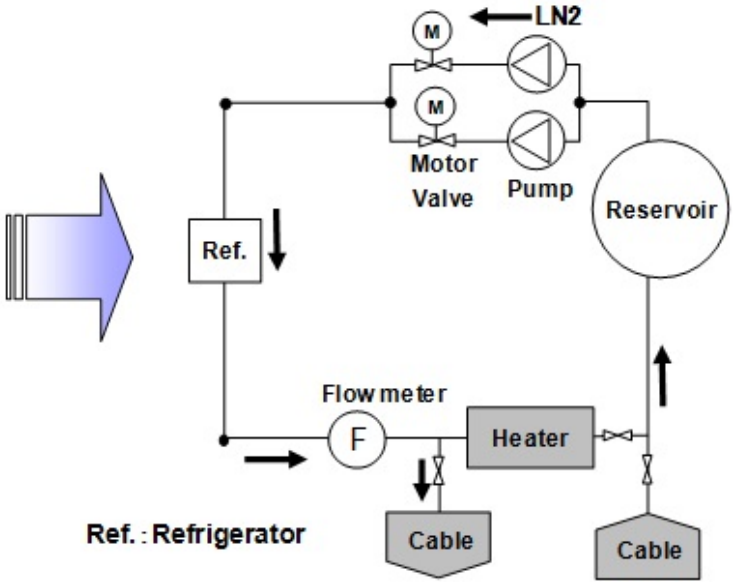
1st – 2nd Compressor

3rd Compressor - Expander

Turbo-Brayton Refrigerator

Cooling System Flow



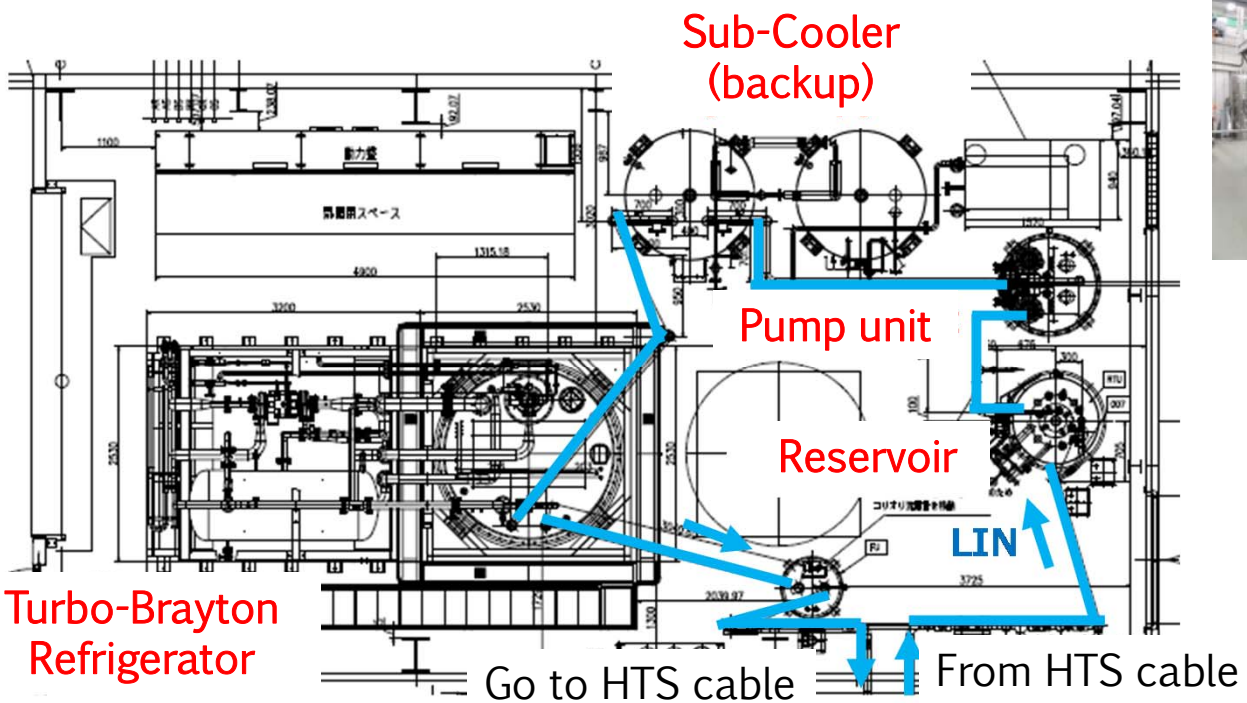


1st Phase

2nd Phase

Layout of Cooling System

LIN: Liquid Nitrogen



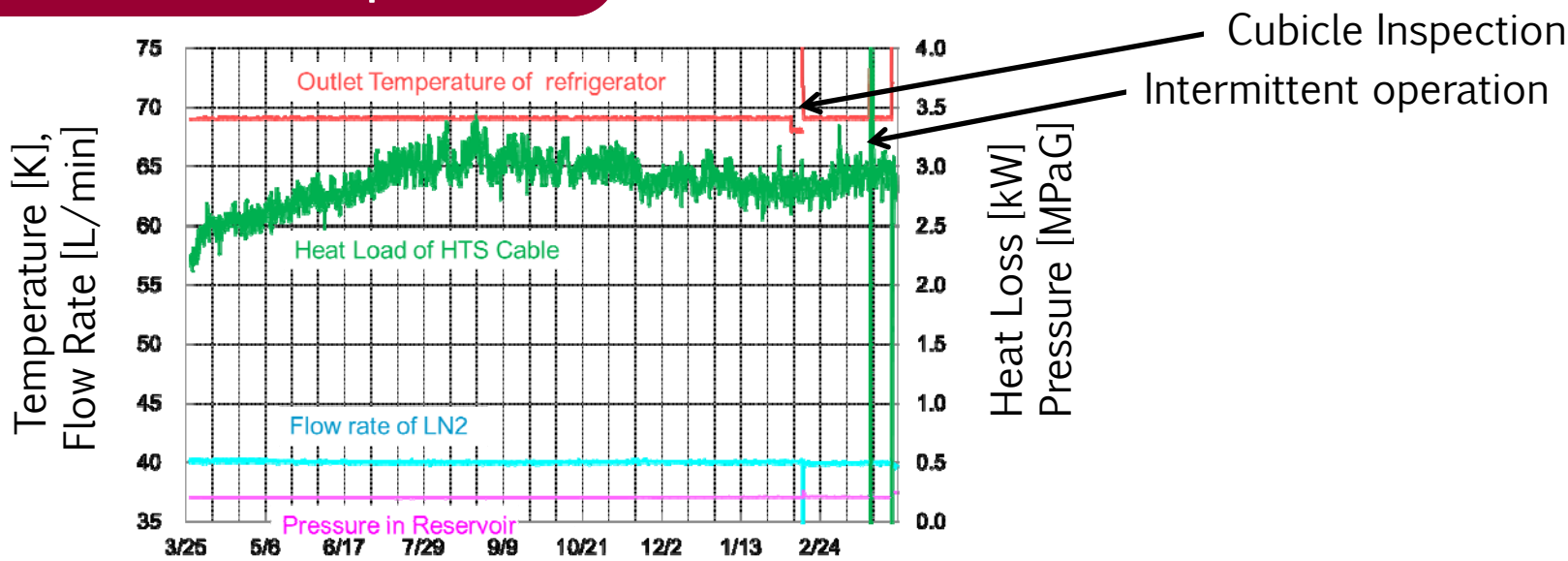
Layout of the cooling system

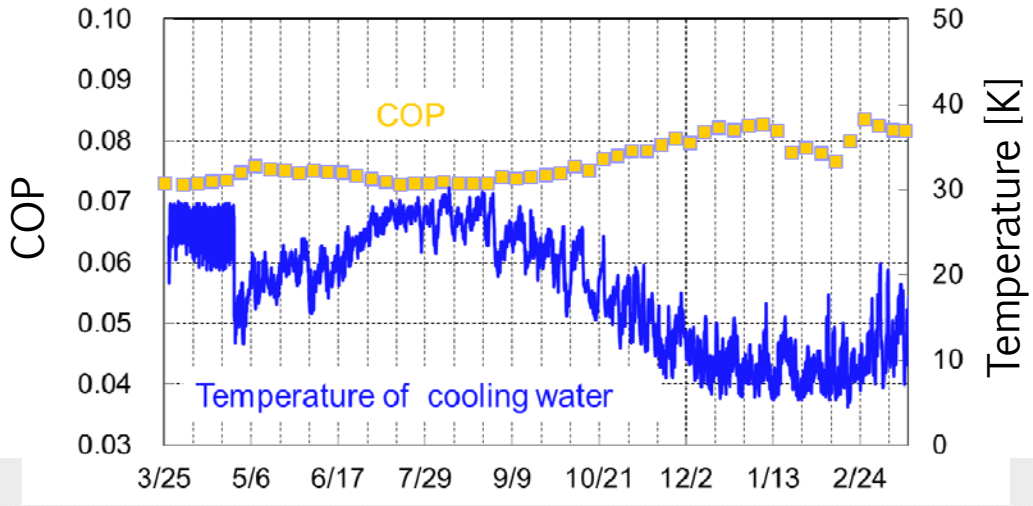
Turbo-Brayton
Refrigerator

Pump Unit and
Reservoir

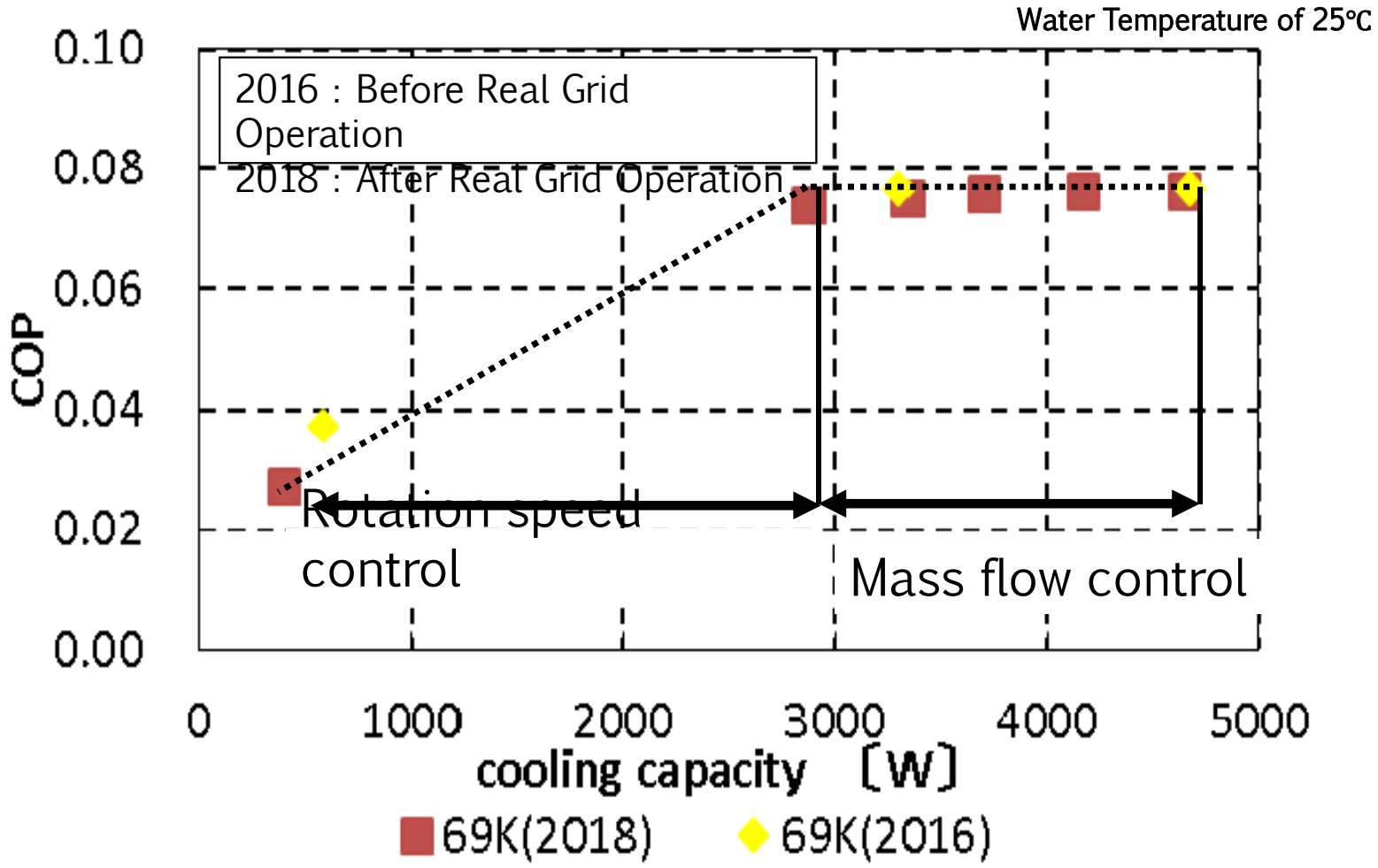
14,600 hours has passed since starting operation of cooling system.

Results of 2nd Phase Operation





Results of Cooling Capacity Control



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 ℃)

Outdoor Type

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Conclusion

1. HTS (High Temperature Superconducting) Cable has advantages of larger amount of power transmission with more compact size and lower voltage. It is necessary a high performance refrigerator for practical use of HTS Cable.

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. This refrigerator is more compact and more economical.

Thank you very much.