Cryomodule for RIKEN QWR

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  - Thermal shield
  - Power coupler

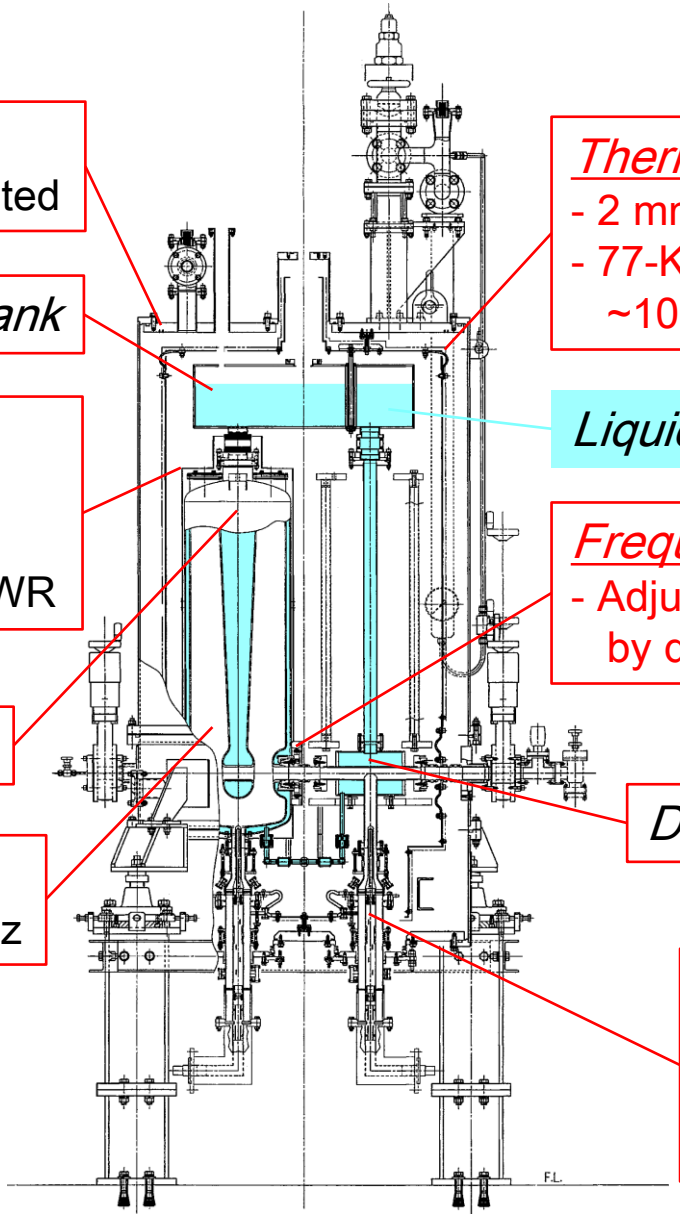
Prototype cryomodule

- Overview
- Results of cooling and excitation test
  - Achieved temperatures of thermal shield
  - Study on thermal conduction
  - Performance of frequency tuner

Overview

Cryomodule which can mount two QWRs

(Presently, one QWR and one dummy cavity are installed)



Vacuum vessel
- Vacuum of QWR is isolated

Helium buffer tank

Magnetic shield
- 2 mm^{t} permalloy
- Enfolding QWR and He jacket
- Mark: 20 mG @ top part of QWR

He jacket

QWR
- Frequency: 75.5 MHz

Thermal shield
- 2 mm^{t} Al
- 77-K GM cryocooler CH-100LT (SHI)
  ~100 W@ 40 K (50 Hz)

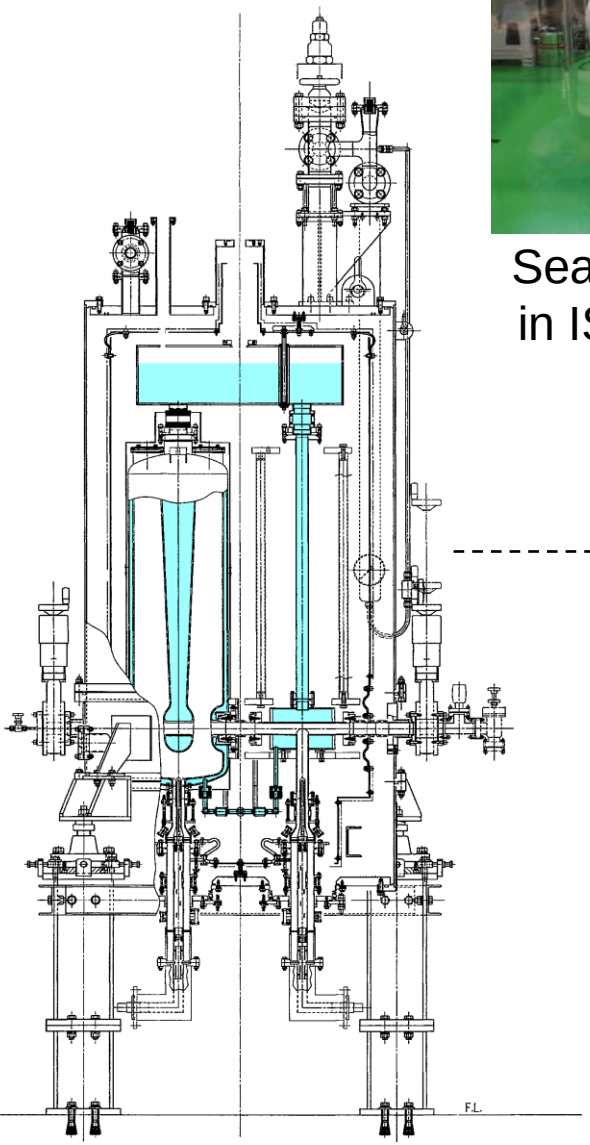
Liquid Helium

Frequency tuner
- Adjustment of gap length of QWR
  by distorting QWR in beam axial direction

Dummy cavity

Power coupler
- Disk-type double vacuum windows
  (40 K / RT)
- Assumed Max. RF power: 10 kW

Assembly of cryomodule



Sealing operation of cavity
in ISO class-1 clean room

After sealing cavity,
assembly of
major parts
in ISO class-7
clean room

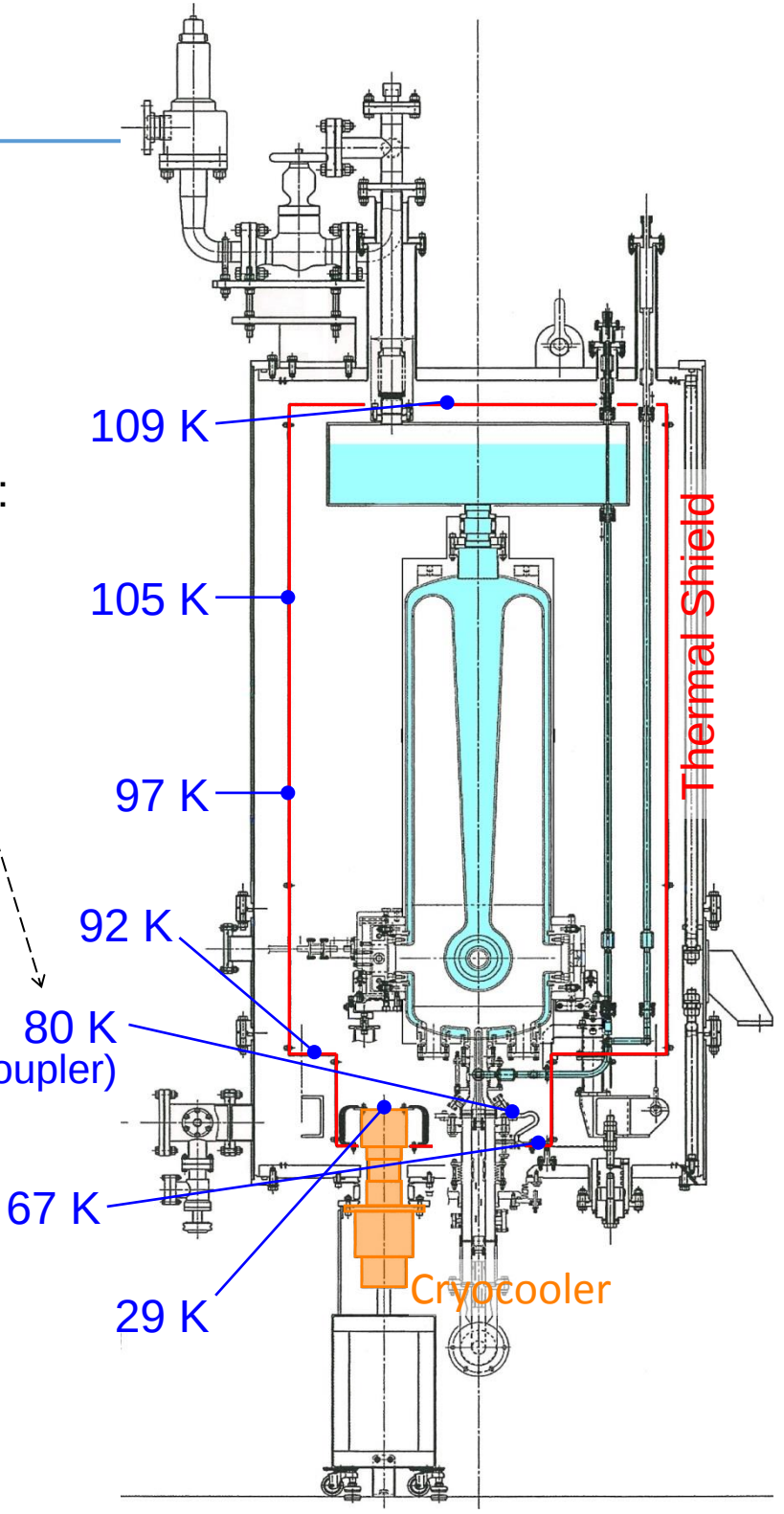
Final assembly at RIKEN

Assembly
completed
on Mar. 2017

Cooling and excitation test

- QWR was successfully cooled down to 4 K
- No apparent negative effect on resonant frequency by the vibration of cryocooler（Δf ~ ±10 Hz）
- Thermal shield and thermal anchor of power coupler: much higher temperatures than expected (assumed temperature of thermal anchor: 40 K)
- Cryocooler: < 30 K

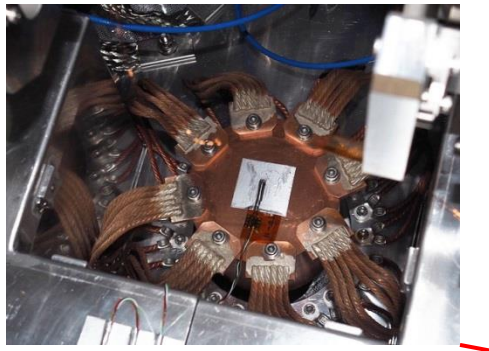
Insufficient thermal contact

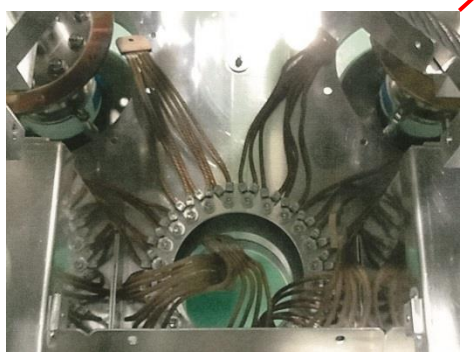


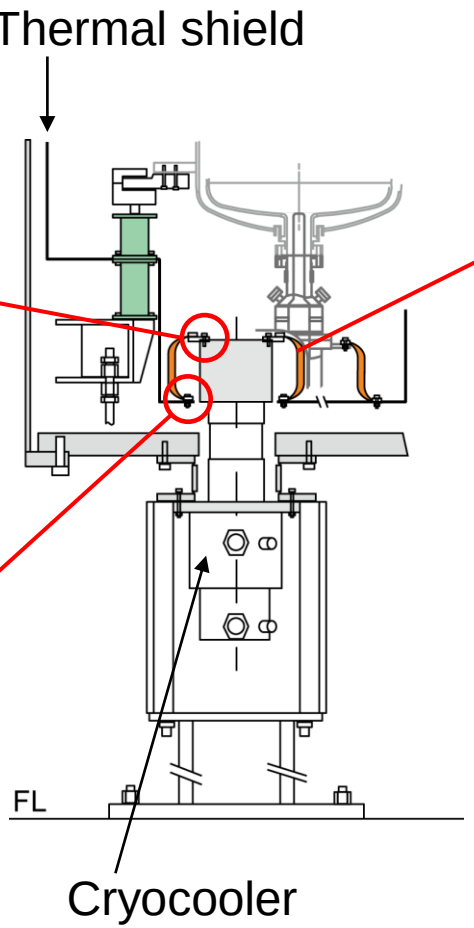
Thermal contact b/w cryocooler and thermal shield

Present conditions:

- Eight sets of thermal conduction wire
- No Apiezon nor indium on contact face
- Tightening torque: 3 N･m
  → No screw loose was observed



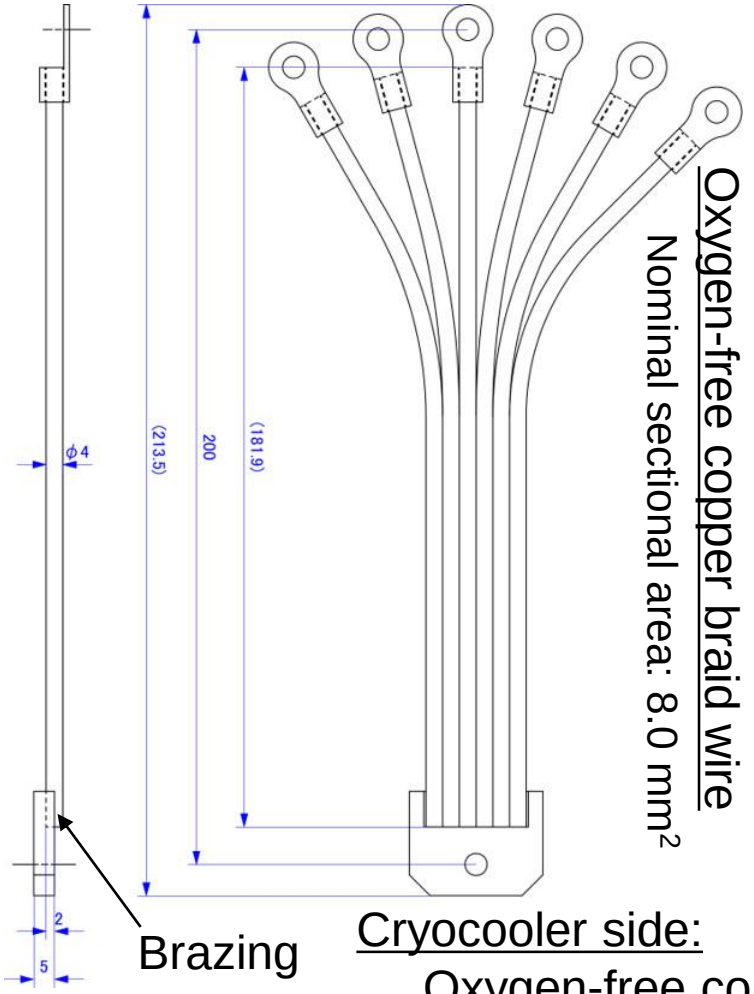




Thermal conduction wire

Thermal shield side:

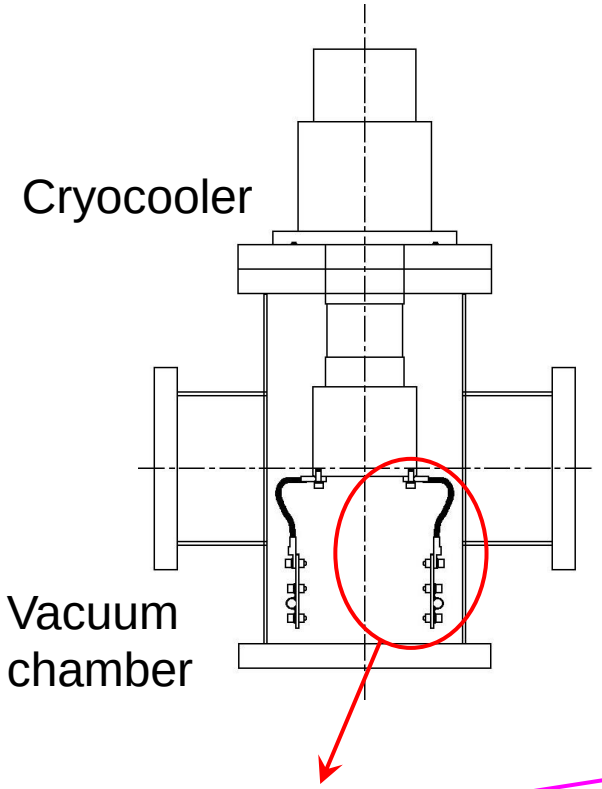
Crimping terminal for copper wire
(Oxygen-free copper)

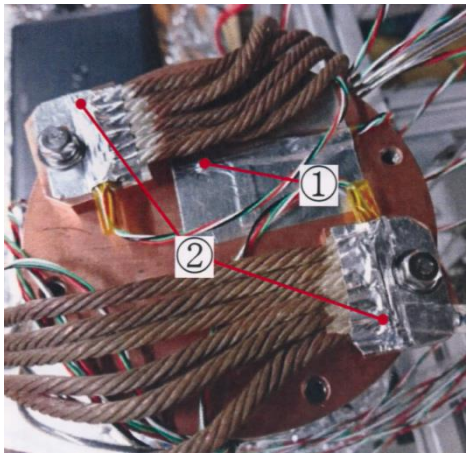


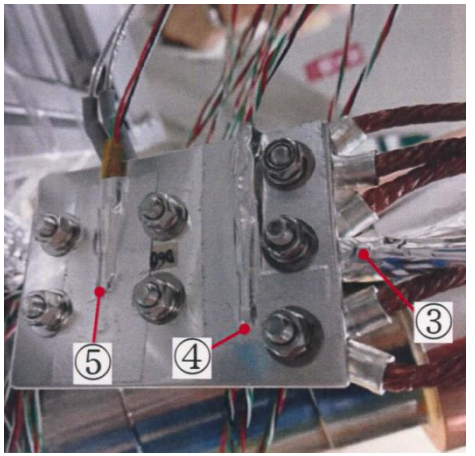
Cryocooler side:

Oxygen-free copper

Cooling test of thermal conduction wire (1)







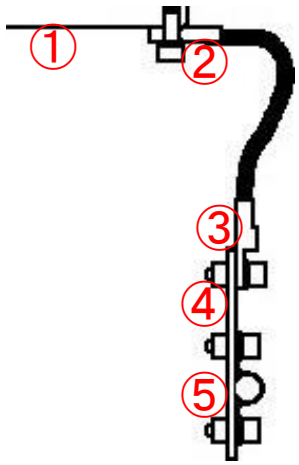
Various connecting conditions

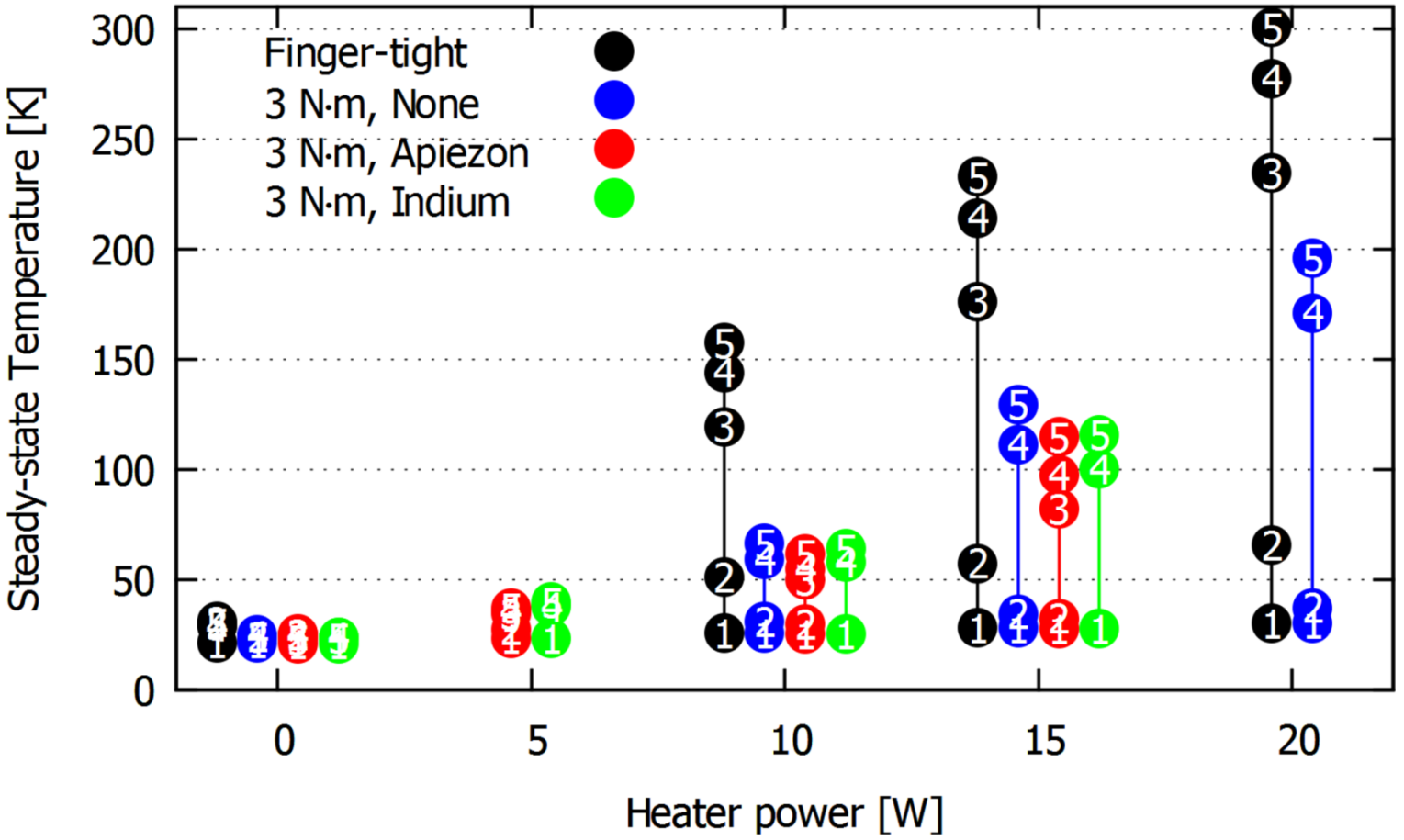
	Tightening torque	Medium on contact face
I	Finger-tight	None
II	3 N･m	None
III	3 N･m	Apiezon-N
IV	3 N･m	Indium

Present condition

①～⑤: Thermosensors (Si-diode)

Cooling test of thermal conduction wire (2)



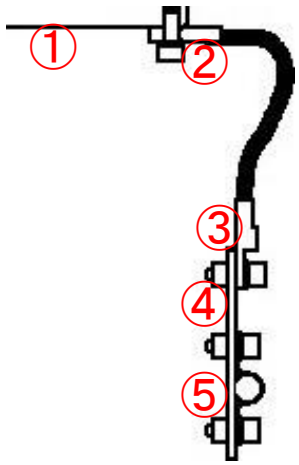


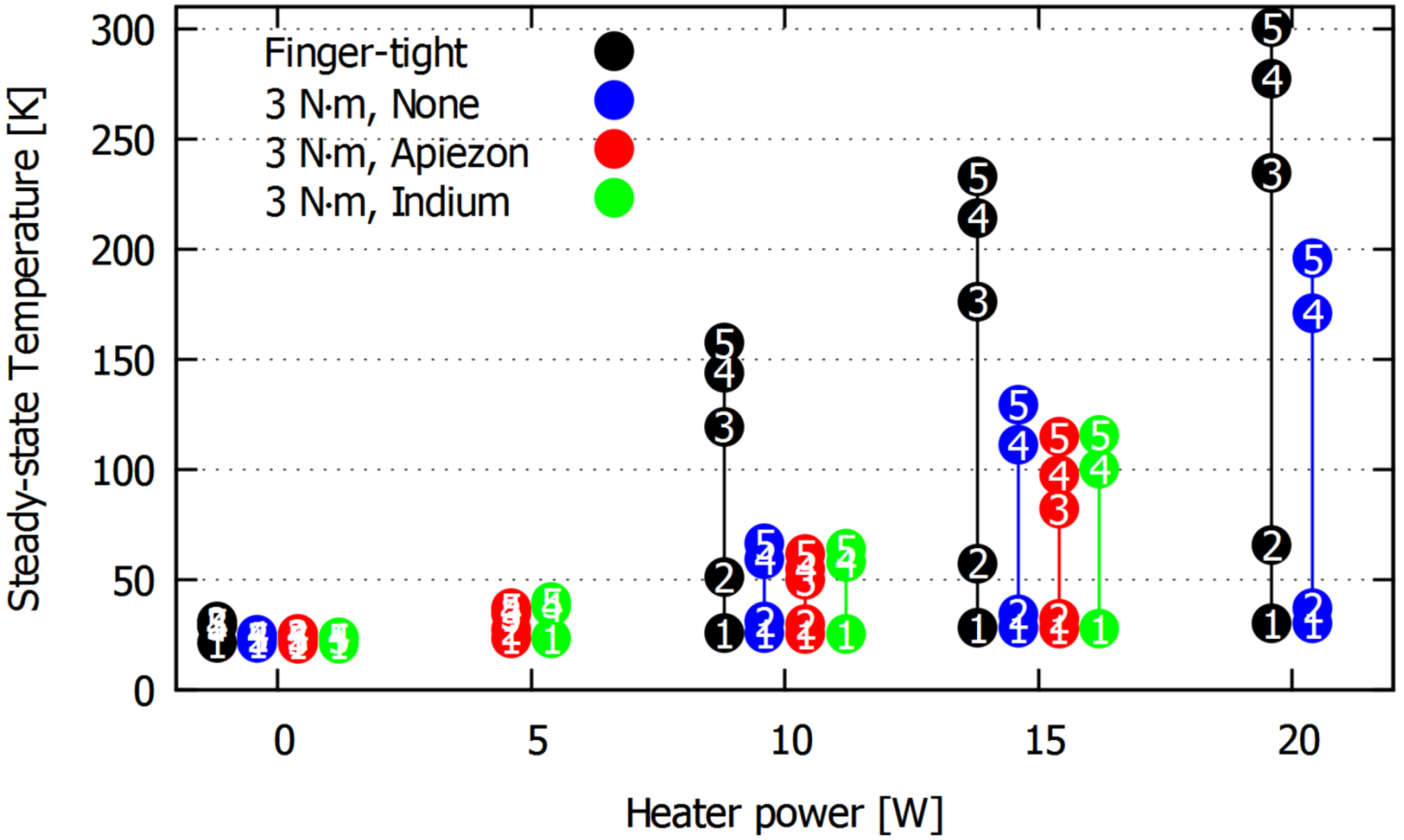
Thermal conduction: Apiezon > Indium > None,
but not so large difference between Apiezon and None.

More importantly, ΔT between both edges of braid wire (② and ③) was too large.

- Application of Apiezon-N on contact face
- Refinement of configuration, increase of the number of thermal conduction wires

Cooling test of thermal conduction wire (2)





Thermal conduction: Apiezon > Indium > None,

Concern:

Thermal contact (number of thermal conduction wires) ↗

↕ Trade-off ?

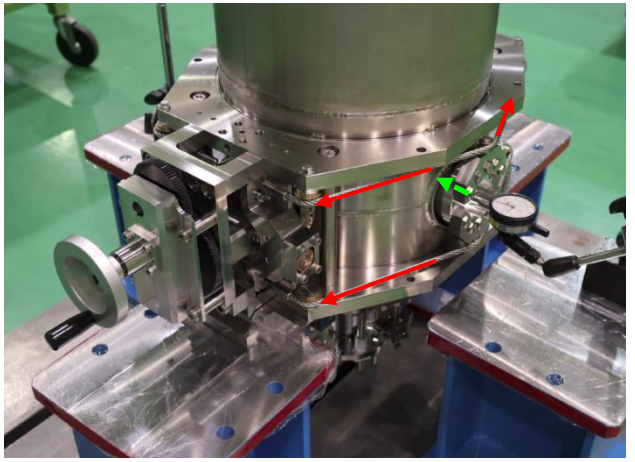
Negative effect on resonant frequency ↗

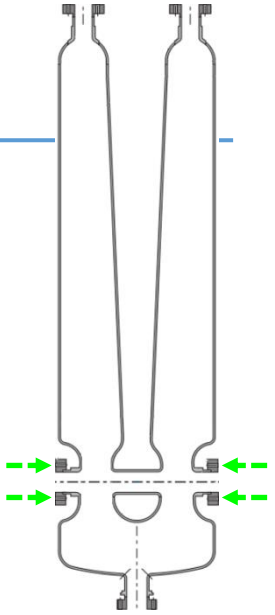
Mo) was too large.

- Applicatio
- Refineme nduction wires

Frequency tuner

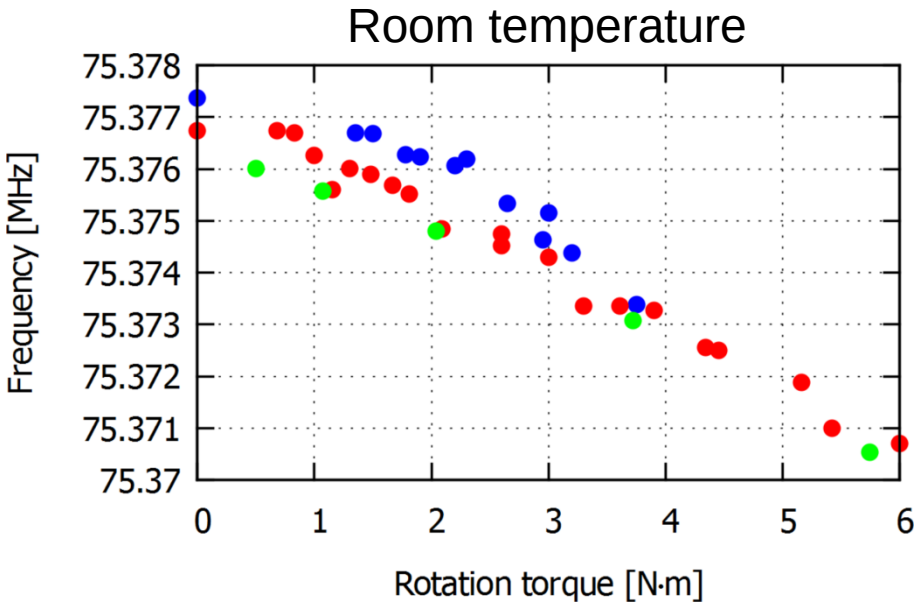
- Driven by stepping motor and piezo actuator
- Pull steel wires to compress cavity in beam axis

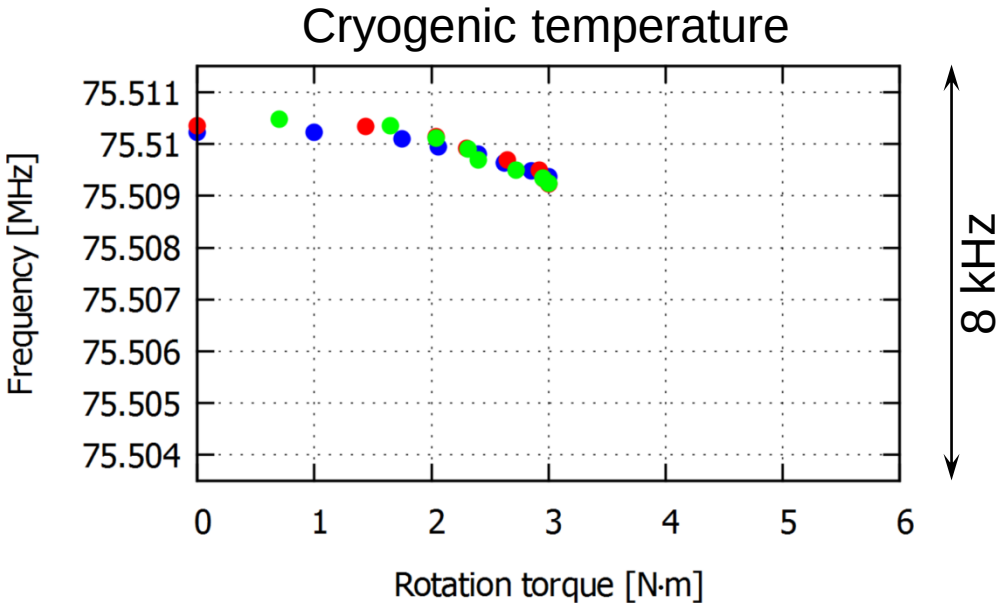




Mitsubishi Heavy Industries Mechatronics Systems, Ltd.,
PCT/JP2016/54710, Feb. 18, JP Patent P5985011, 2016

Tuner test

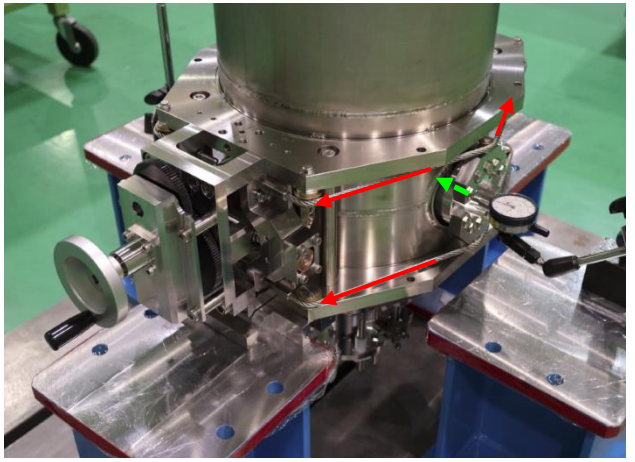


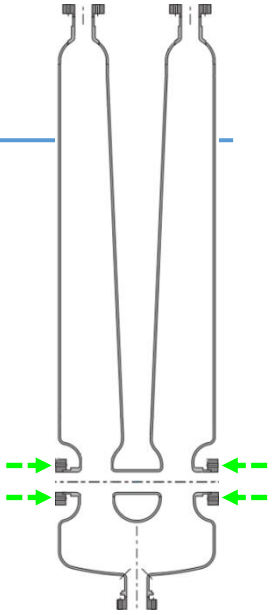


- Frequency tuned successfully

Frequency tuner

- Driven by stepping motor and piezo actuator
- Pull steel wires to compress cavity in beam axis





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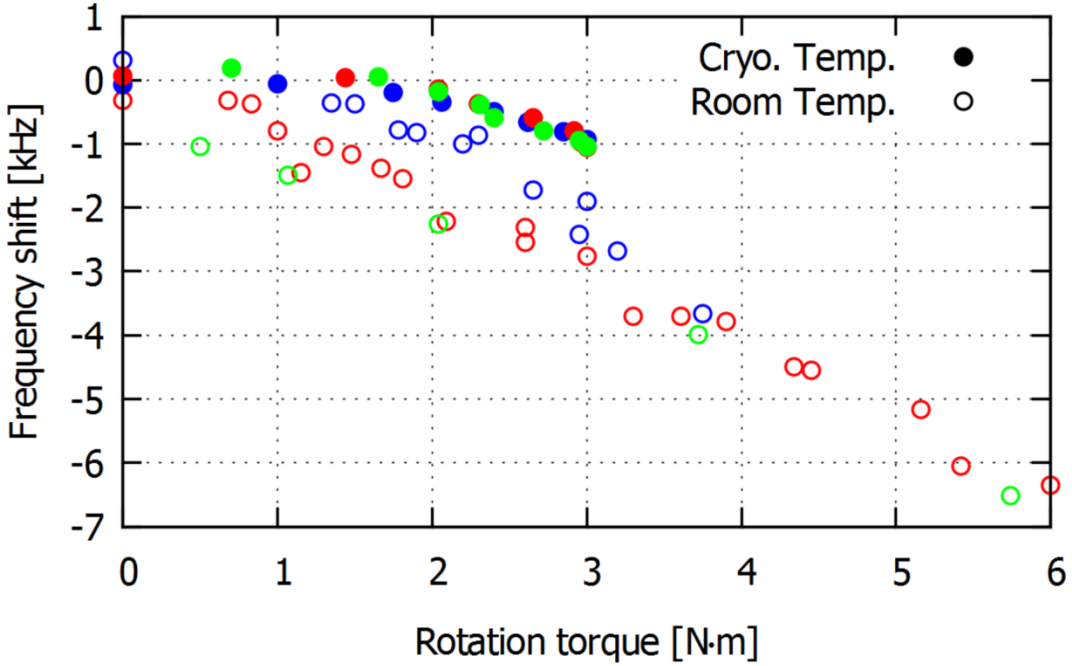


- Frequency tuned successfully
- Less sensitive to rotation torque at cryogenic temperature

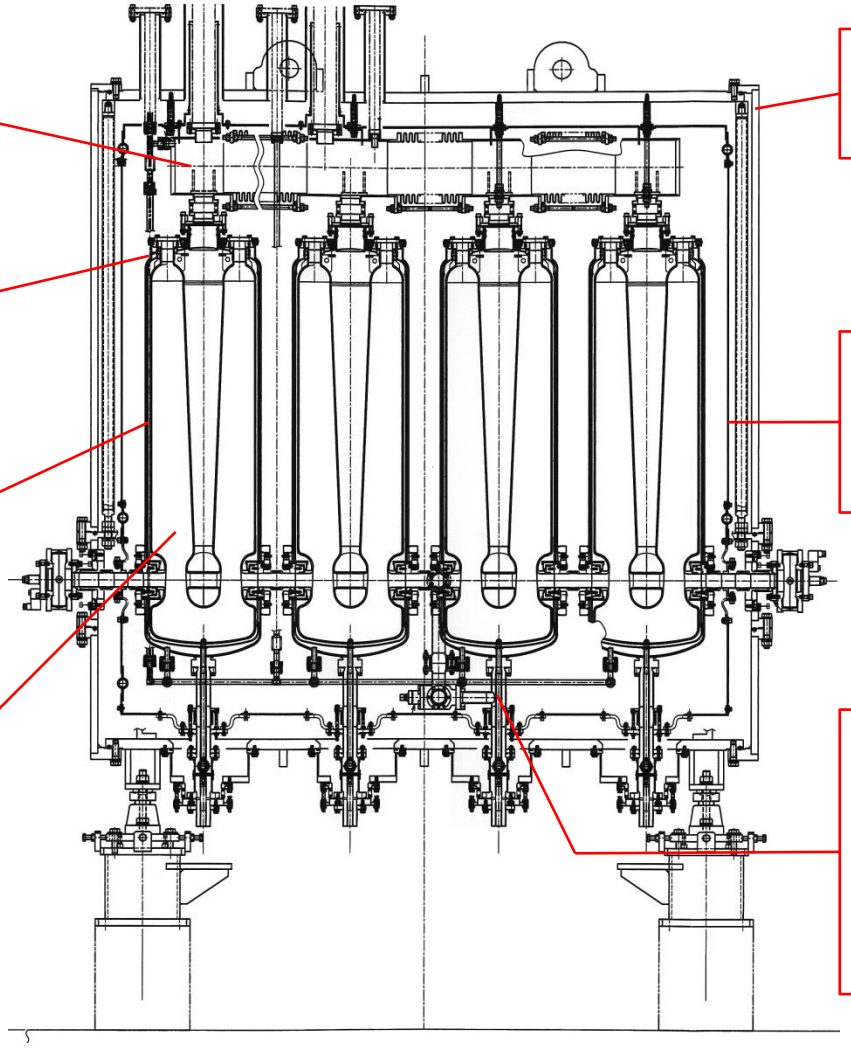
  Something wrong with driving force transmission mechanism ? (unsolved)

Cryomodules for practical use

- Overview
  - Thermal shield
  - Power coupler

Overview

Two cryomodules which mount four QWRs
+
One cryomodule which mounts two QWRs
} Ten QWRs in total



Helium buffer tank

He jacket

Magnetic shield
- 1.5 mm^{t} permalloy
- Installed in He jacket

QWR
- Frequency: 73.0 MHz

Vacuum vessel
- Vacuum of QWR is isolated

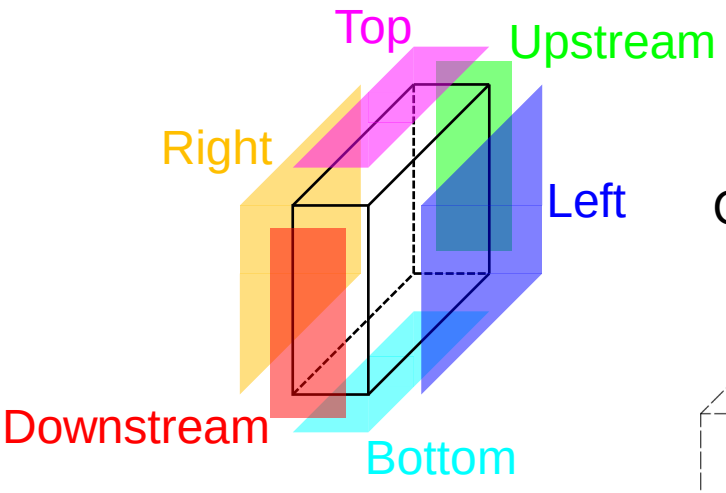
Thermal shield
- 2 mm^{t} Al
- 80 K (LN_2)

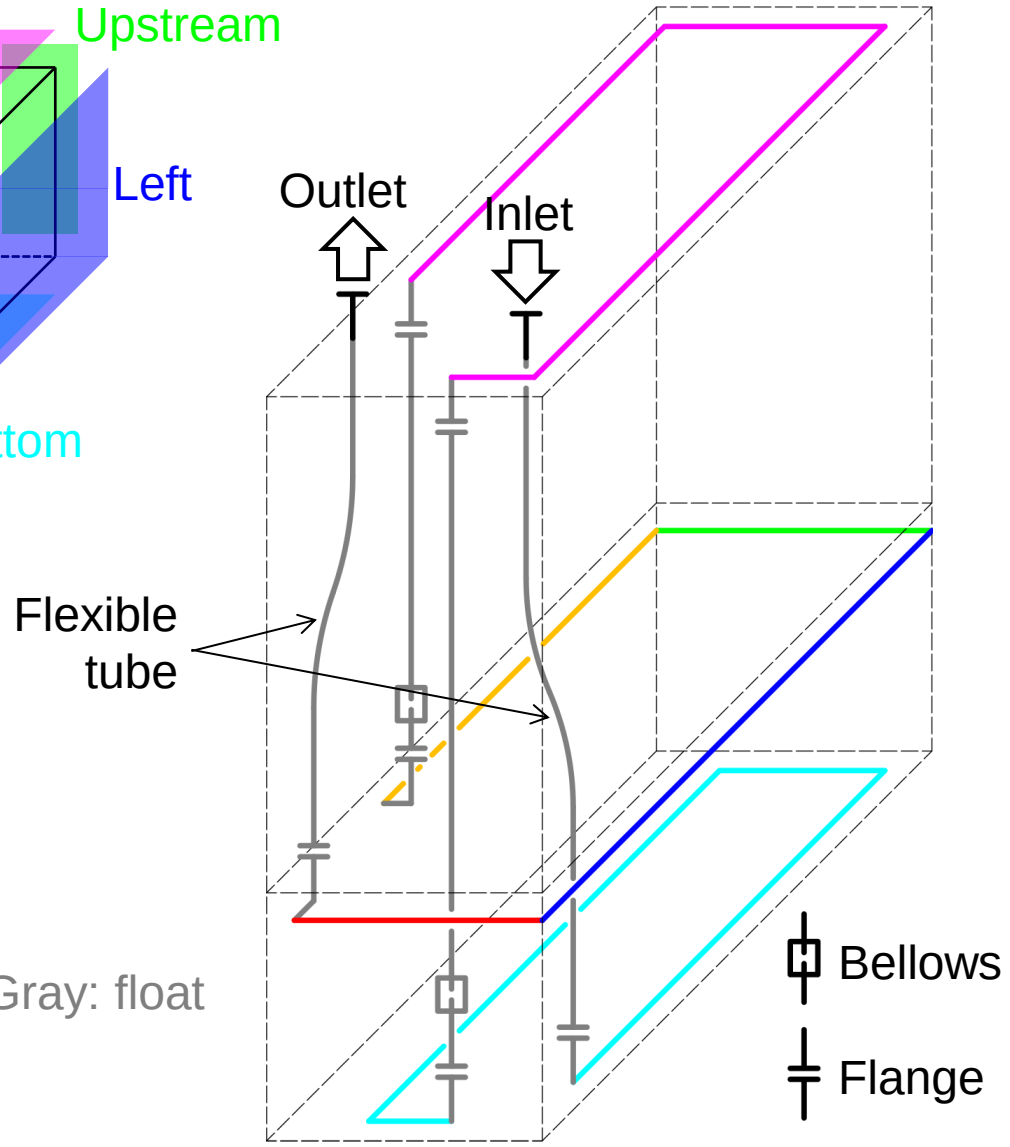
Power coupler
- Disk-type single vacuum window
- Assumed Max. RF power: 6 kW
- QWRs are evacuated from one of power couplers

Installation will be completed by Mar. 2019

Thermal shield

- 2 mm^t Al
- Cooled down to 80 K using LN_2
- Keep space to install cryocooler and connecting structure to thermal shield
  (more thermal conduction wires)





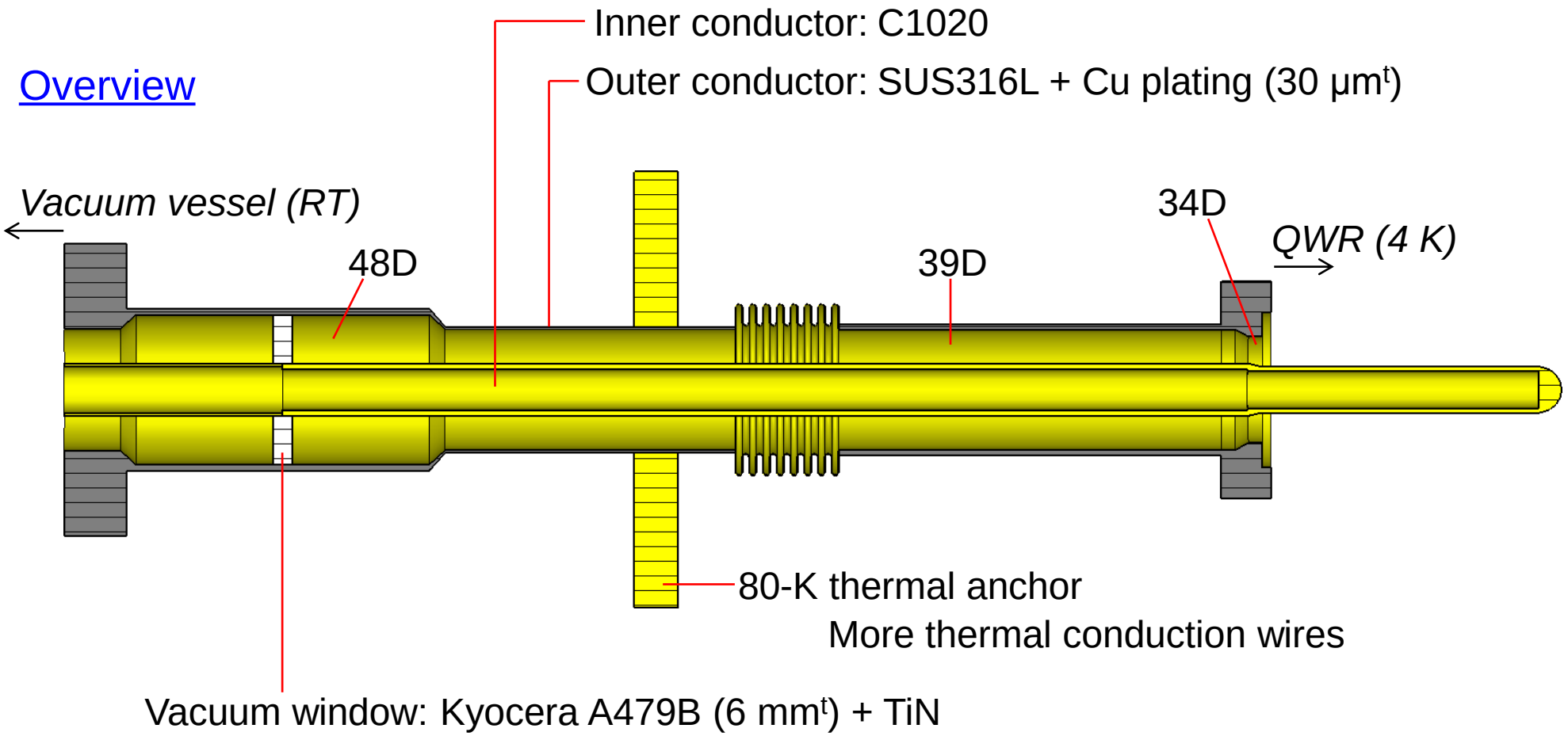
Flow path

Inlet
↓
Bottom part
↓
Top part
↓
Right part
↓
Upstream part
↓
Left part
↓
Downstream part
↓
Outlet

Power coupler (1)

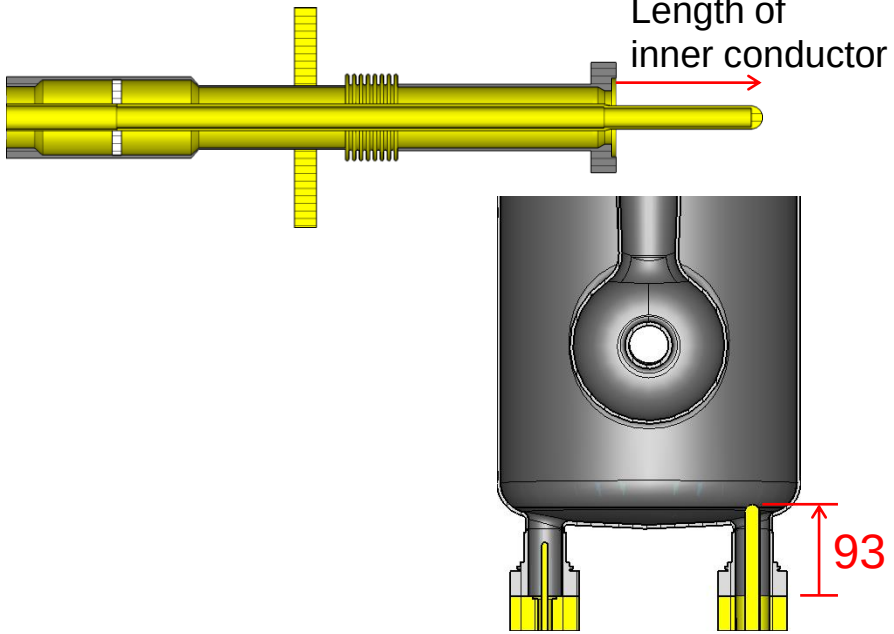
- Disk type single vacuum window
- Variable coupling
- Assumed maximum power: 6 kW

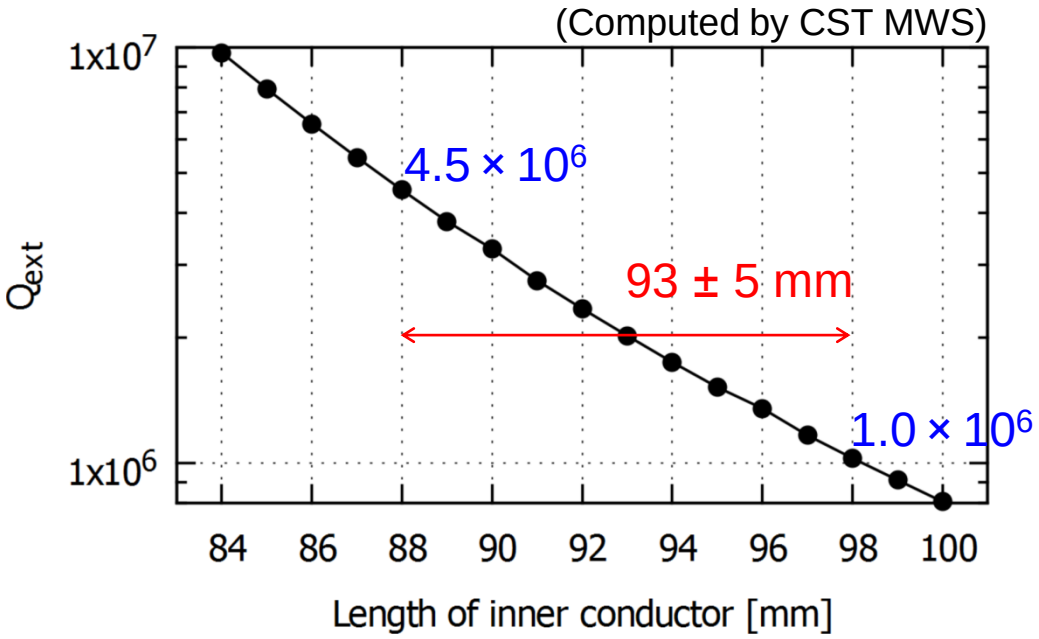
Overview



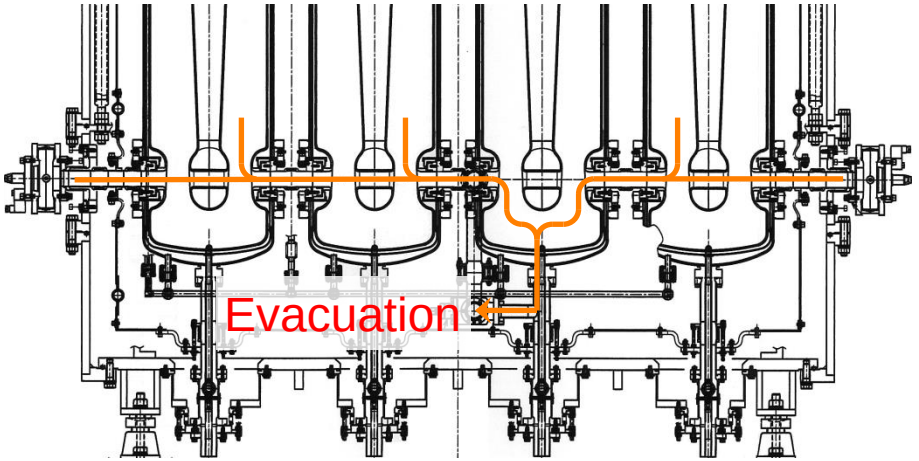
Power coupler (2)

- Variable coupling





- QWRs and beam line are evacuated via one of power couplers



Power couplers are in the making now → RF process will be performed since Apr. 2018

Summary

Prototype cryomodule

Component	2 QWRs (present state: QWR + dummy)
Frequency	75.5 MHz
Power coupler	Vacuum window: Disk type double window (40 K + RT) Assumed maximum RF power: 10 kW
Thermal shield	40 K (Cryocooler)
Magnetic shield	Outside the helium jacket

- Fabrication was completed on Mar. 2017
- Succeeded in cooling and excitation test
  - No apparent negative effect on resonant frequency by the vibration of cryocooler
  - Insufficient cooling of thermal shield → improvement of thermal conduction
  - Performance of frequency tuner at 4 K

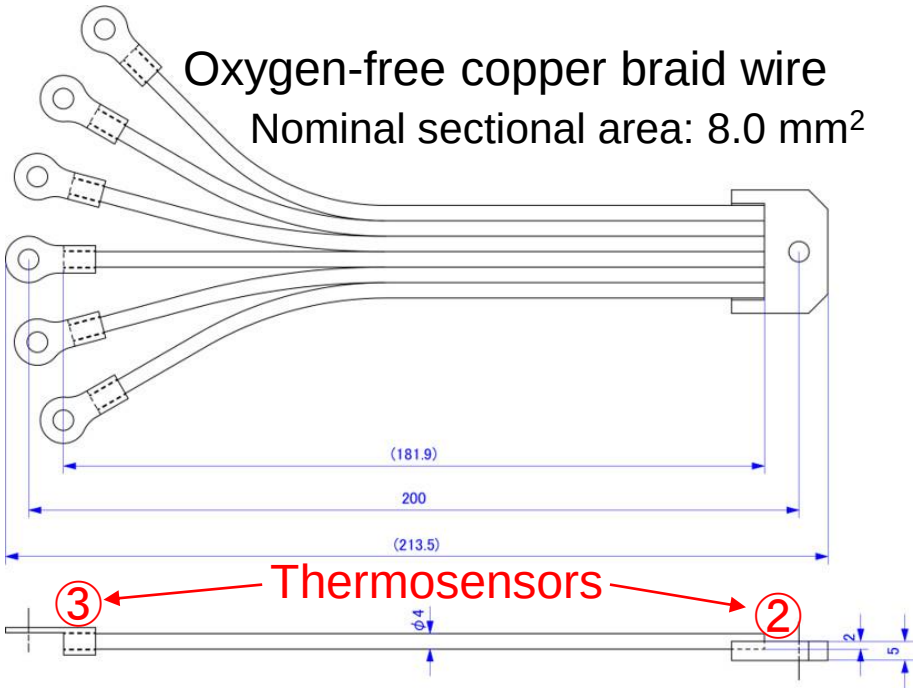
Cryomodules for practical use

Component	(4 QWRs/cryomodule) × 2 + (2 QWRs/cryomodule) × 1
Frequency	73.0 MHz
Power coupler	Vacuum window: Disk type single window Assumed maximum RF power: 6 kW
Thermal shield	80 K (LN_2)
Magnetic shield	Inside the helium jacket

- Installation will be completed by Mar. 2019

Discussion on thermal conduction wire (1)

Thermal conduction wire



Consider only six braid wires
as thermal conduction elements b/w ② and ③
→ Relation b/w Therm. Cond. and heater power:

$$\int_{T_2}^{T_3} \lambda dT = \frac{181.9 \times 10^{-3}}{6 \times 8 \times 10^{-6}} \times P = 3789.6 \times P$$

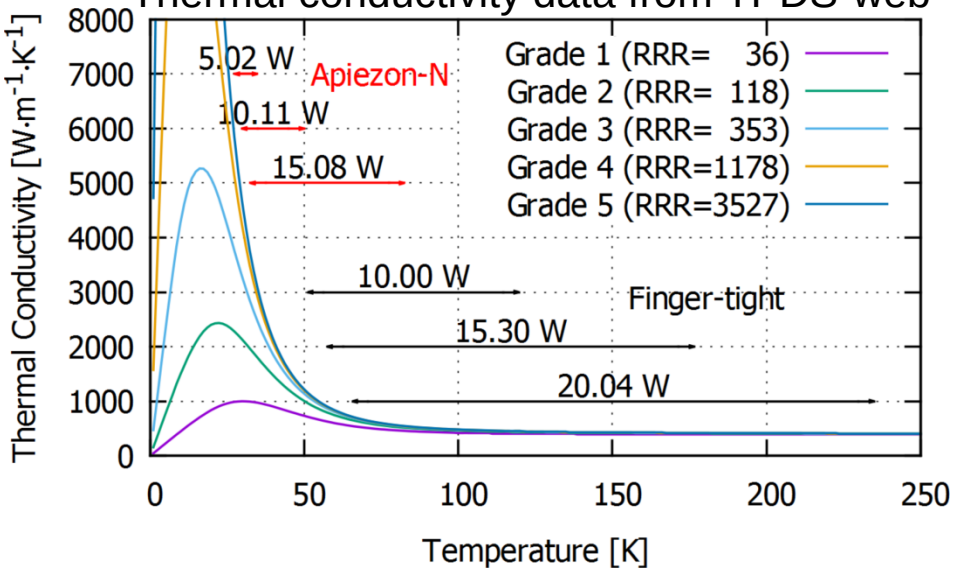
Length of braid wire
Thermal conductivity
Number of braid wires
Sectional area of braid wire
Heater power

Available data of temperatures at ② & ③

(Unfortunately, only six data)

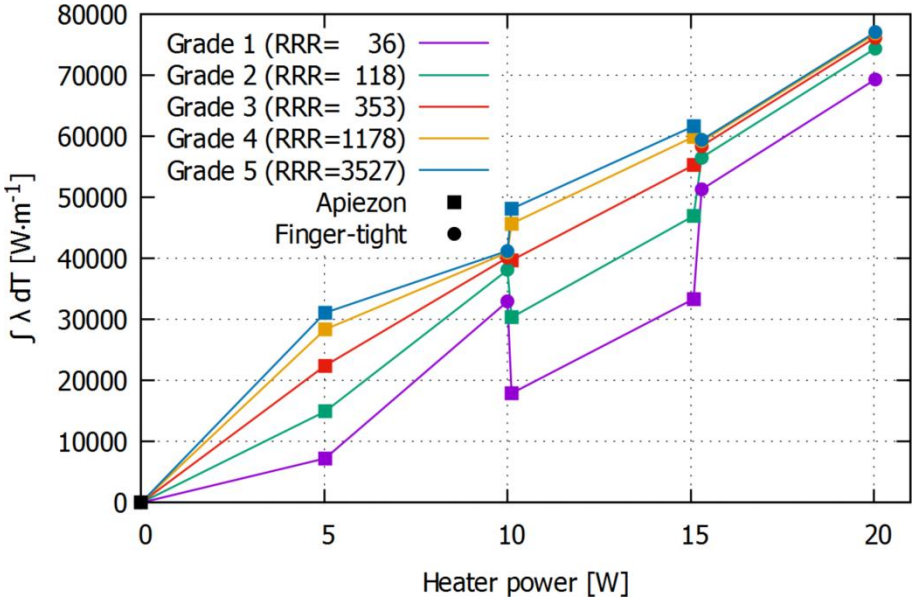
Heater [W]	② [K]	③ [K]	Note
5.02	27.387	34.658	Apiezon-N
10.00	51.193	119.554	Finger-tight
10.11	29.836	49.918	Apiezon-N
15.08	32.453	82.378	Apiezon-N
15.30	57.483	176.483	Finger-tight
20.04	65.730	234.873	Finger-tight

Thermal conductivity data from TPDS-web



For each heater power, derive $\int_{T_2}^{T_3} \lambda dT$
for Grade 1-5 (⟷: integration range)

Discussion on thermal conduction wire (2)



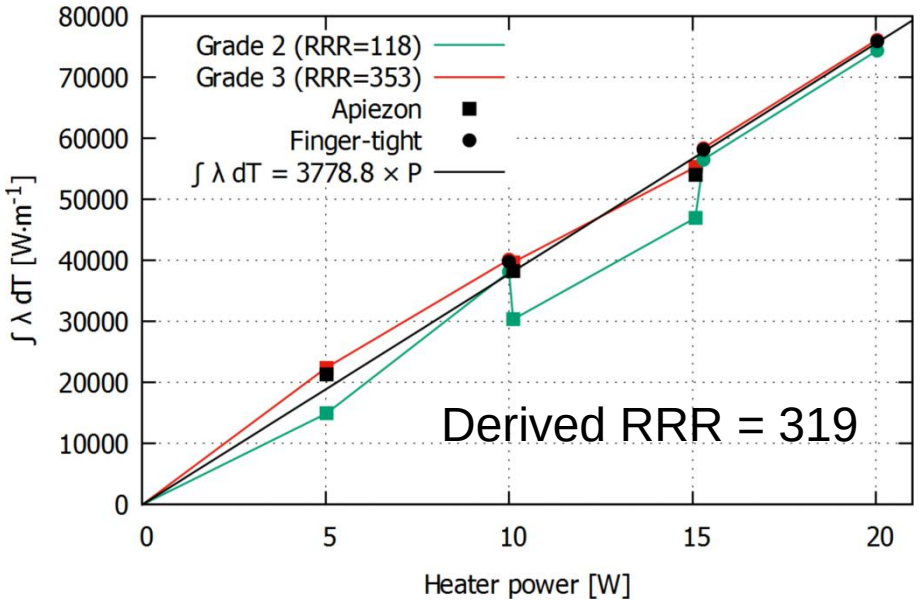
Grade 5 Not proportional

Grade 3 Nearly proportional

Grade 1 Not proportional

Derive most likely RRR of oxygen-free copper braid wire

(least-square method)



Experimentally-derived proportionality factor: 3778.8

Agreed rather well

Geometrically-derived proportionality factor: 3789.6

Test results of frequency tuner (room temperature)