Cooling test of HOM absorber model for cERL in Japan

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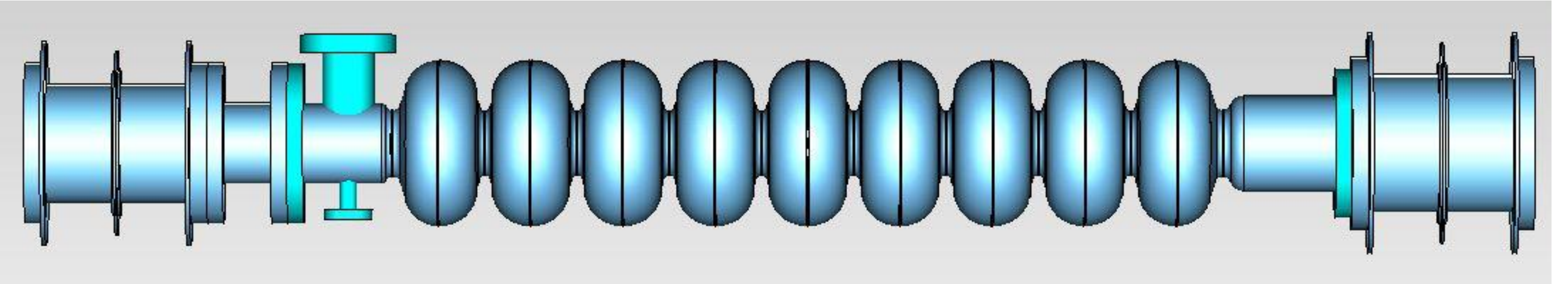
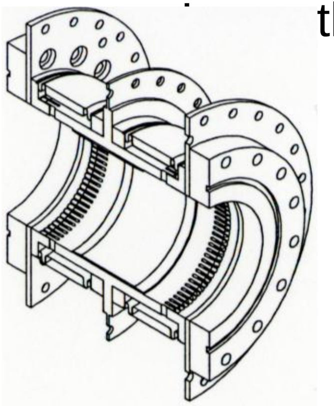
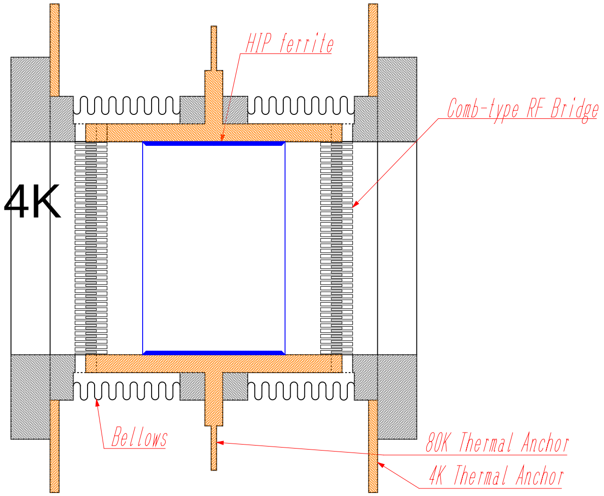
HOM Absorber for cERL



- Requirements for HOM absorber
  - Enough cooling ability with 80K fixed point set in a cryomodule
    - No liquid N2 or Liquid He flow to skirt High Pressure Gas Control Law in Japan
  - As compact as possible
  - HOM power absorption of 100 W
    - ⇒ small heat transfer to 4K
    - thermal resistance between 80K and 4K



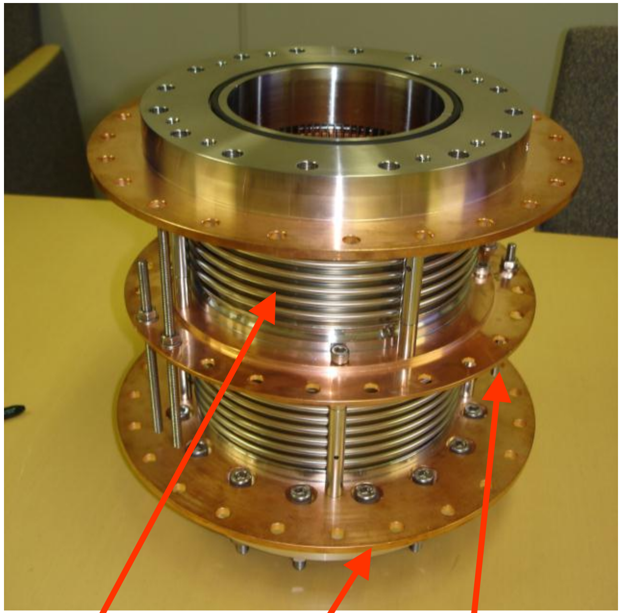


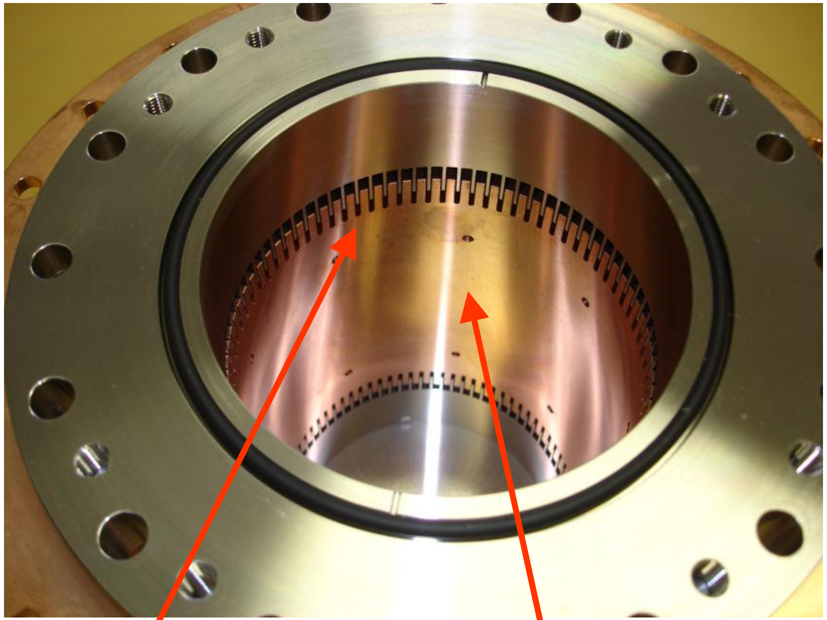
Concepts of HOM Absorber

- HIP ferrite of new-type IB004
  - Firm bonding between ferrite and copper
    - This merit might be demerit because different shrinkage ratios cause stress
    - Will ferrite crack or fall off at low temperature?
- Comb-type RF bridge
  - Lower impedance and lower thermal conductance than finger-type
    - Is thermal conductance still low when combs contact?
    - When ferrite absorbs HOM power, Is heat load to 4K is small enough?
- Two kinds of thermal anchor at 80K and 4K
    - Can HOM absorber be cooled with thermal anchors?
    - What is ferrite temperature in operation?

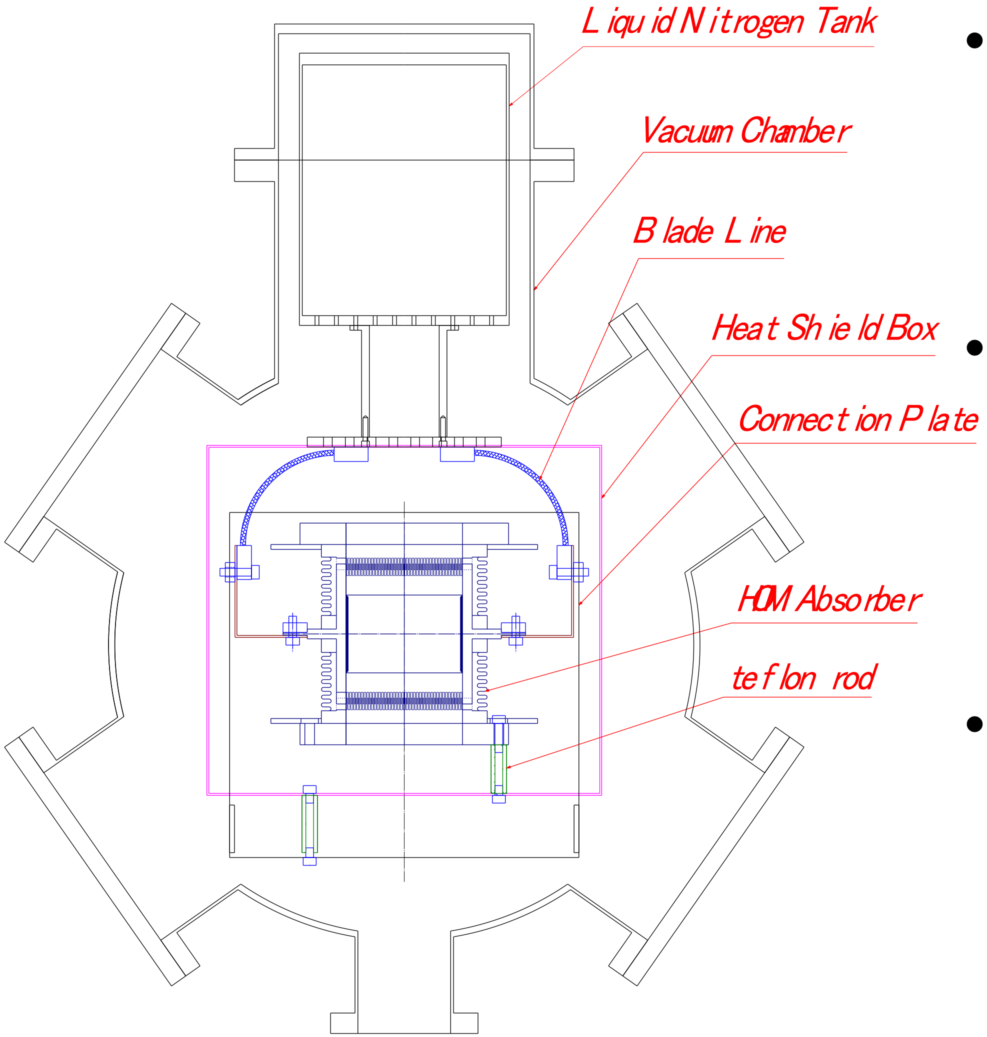
Prototype of HOM Absorber

- Without ferrite
- To test thermal properties





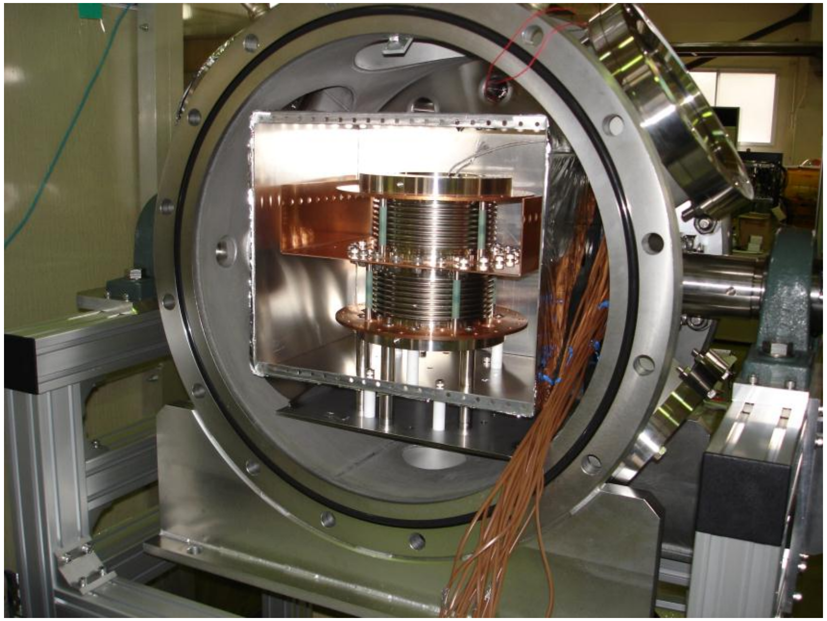
Setup for Cooling Test



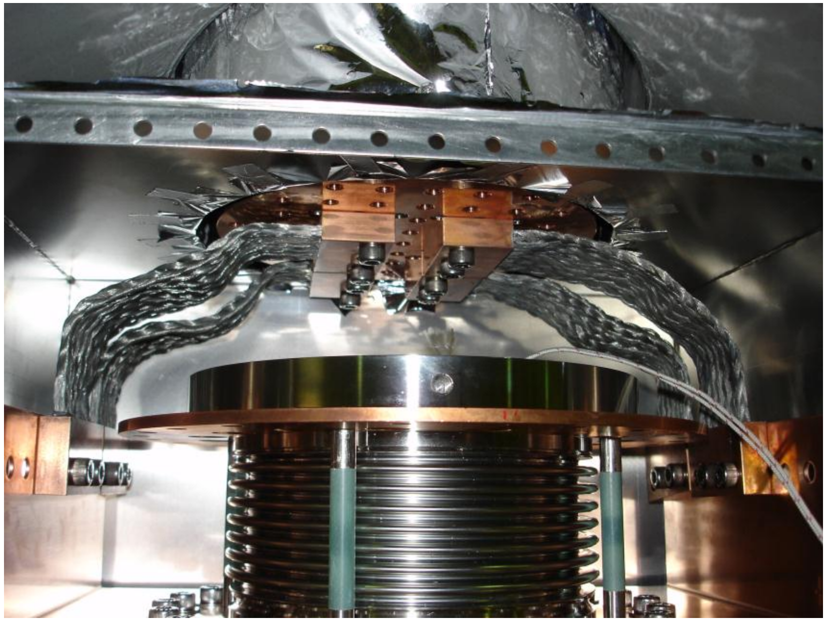
- Use the vacuum chamber for input coupler cooling test
- Use the same size of Cu connection plate to connect between HOM absorber and braid lines
- The number of braid lines is half of the module design due to the lack of space

Setup for Cooling Test

- Use the test stand for input coupler cooling test



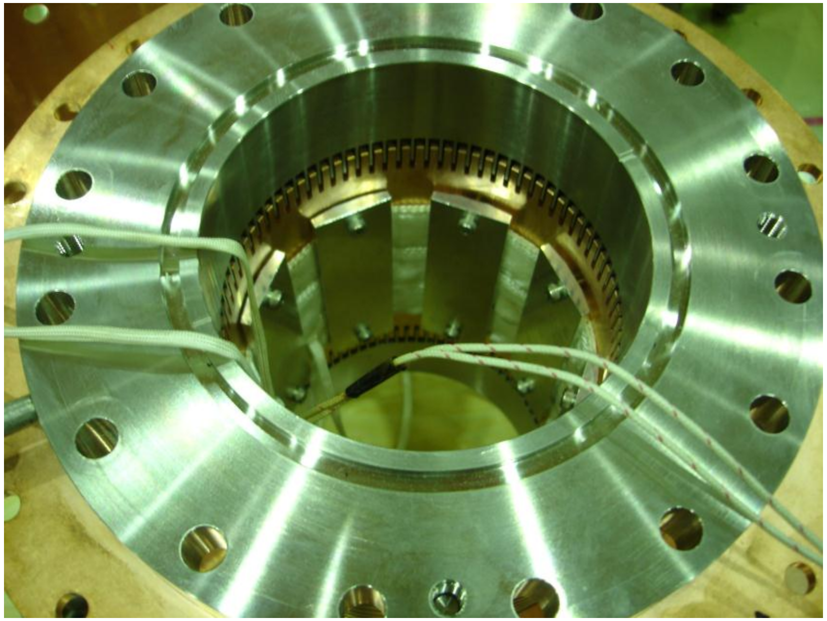
Installed in a heat shield box



Connected to Liq. N_2 tank
with 4 braid lines of $100mm^2$ cross-section and 200mm length

Setup for Cooling Test

Full view without front flange



Ribbon heater is attached at the ferrite position to simulate the HOM power absorption

Estimation of Thermal Resistance

- Estimate the heat transfer to 4K part with HOM power absorption

↓

- Thermal resistance of bellows between 80K anchor and 4K anchor
  - Estimate from bellows size
  - Calculation by heat transfer simulation code
  - Measurement of cooling test

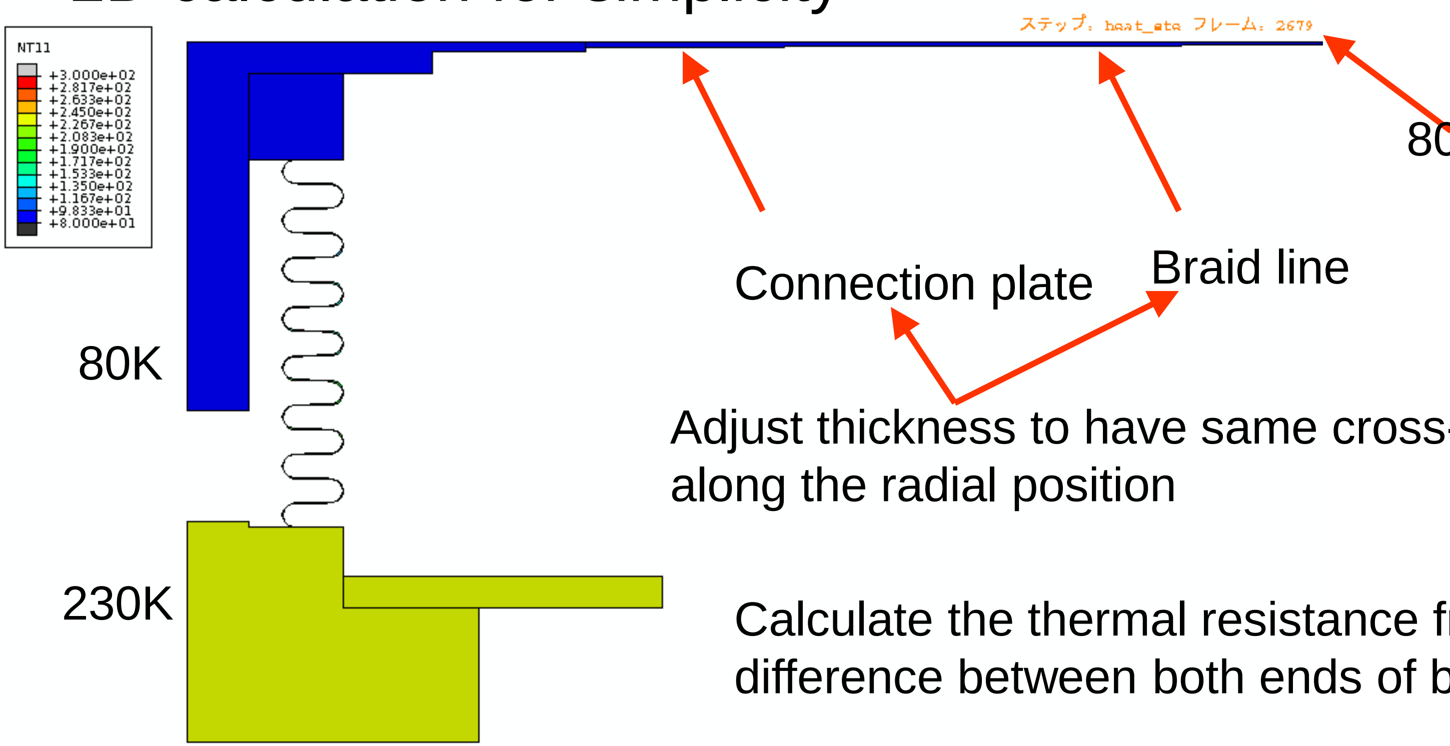
Rough Estimation from bellows size

- Roughly estimate the thermal resistance from SUS thermal properties
- SUS316 thermal conductivity (λ)
  - 13.6W/m・K @276K
  - 7.11W/m・K @80K
- Bellows size
  - Inner diameter φ156.5mm
  - Outer diameter φ176mm
  - Thickness 0.15mm
  - Length 60mm 7-peak
    - ⇒total length (L) 220mm
    - ⇒average diameter 166mm
    - ⇒average cross-section (S) $0.166\pi \times 0.00015 = 7.82 \times 10^{-5} m^2$

- Thermal resistance
  - $R = L/\lambda S = 0.22/(13.6 \times 7.82 \times 10^{-5}) = 207$ K / W @276K
  - $R = L/\lambda S = 0.22/(7.11 \times 7.82 \times 10^{-5}) = 396$ K / W @80K

Simulation code

- ABAQUS code
- Transient heat transfer
- Specific heat of room temperature
- 2D calculation for simplicity



Adjust thickness to have same cross-section along the radial position

Calculate the thermal resistance from Thermal difference between both ends of bellows

48 hours after cooling

Method of calculation

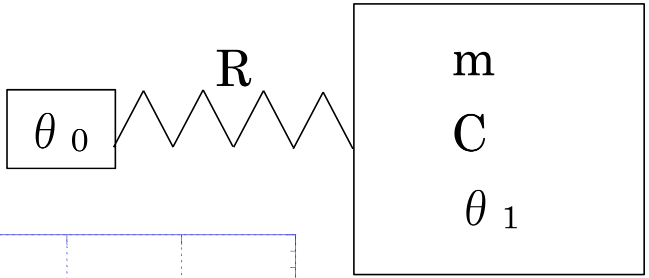
- A body (mass m, specific heat C, temperature θ_1) is connected with bellows of thermal resistance R[K / W] with other body (temperature θ_0)

- Assume temperature θ_1 decreases $d\theta$ during dt

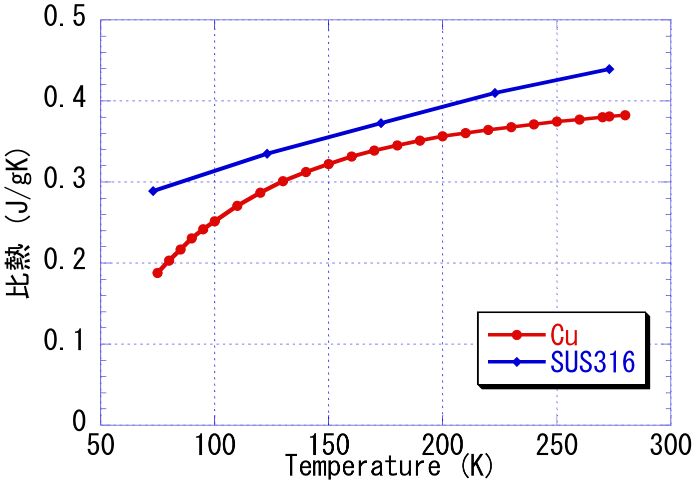
$$\frac{(\theta_1 - \theta_0)dt}{R} = mCd\theta$$

$$R = \frac{(\theta_1 - \theta_0)dt}{mCd\theta}$$

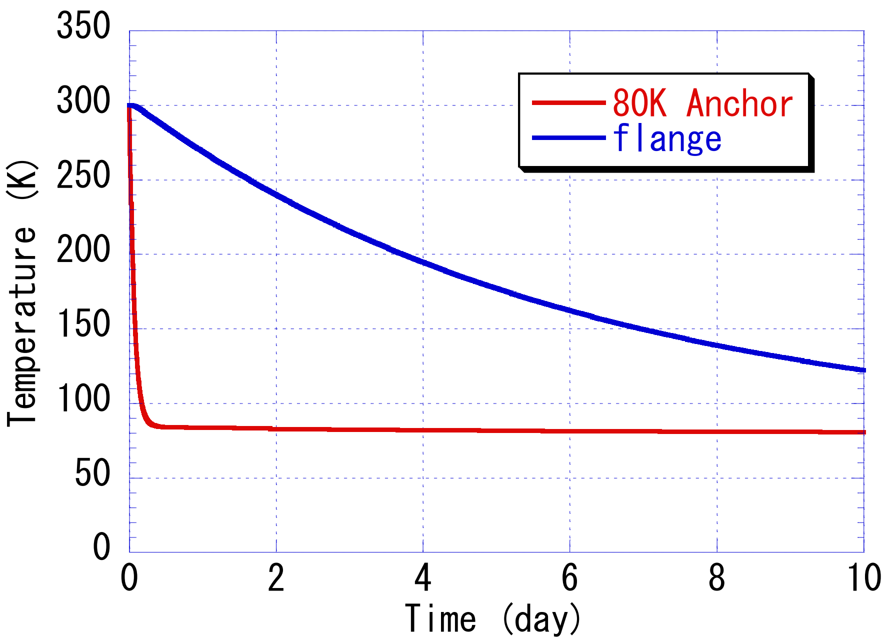
$$R = \frac{\int(\theta_1 - \theta_0)dt}{m\int Cd\theta}$$



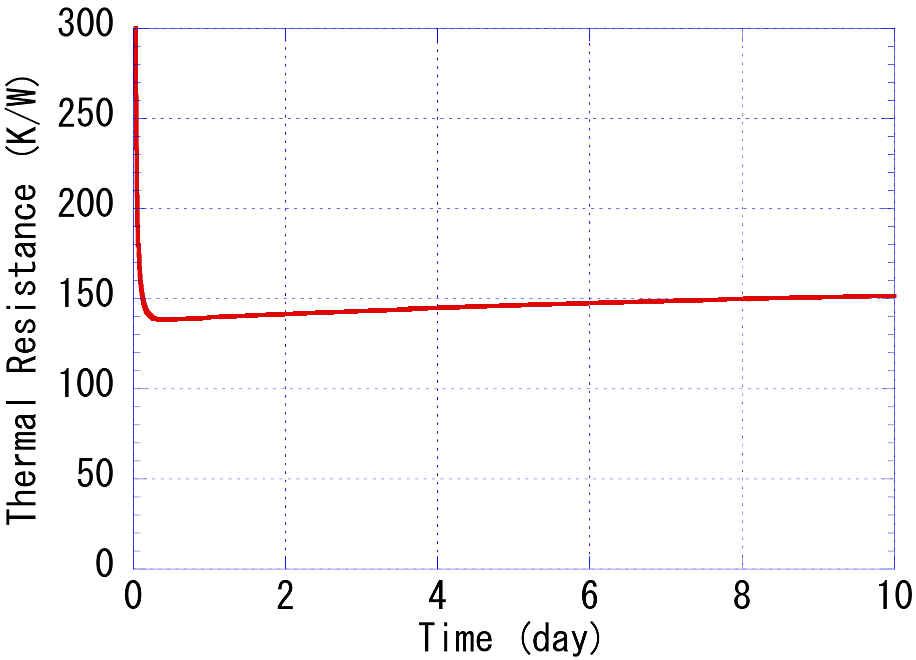
- Basic data
  - Mass of flanges
    - SUS 5562g
    - Cu 1627g
  - Specific heat



Result of calculation



Temperatures of both ends of bellows

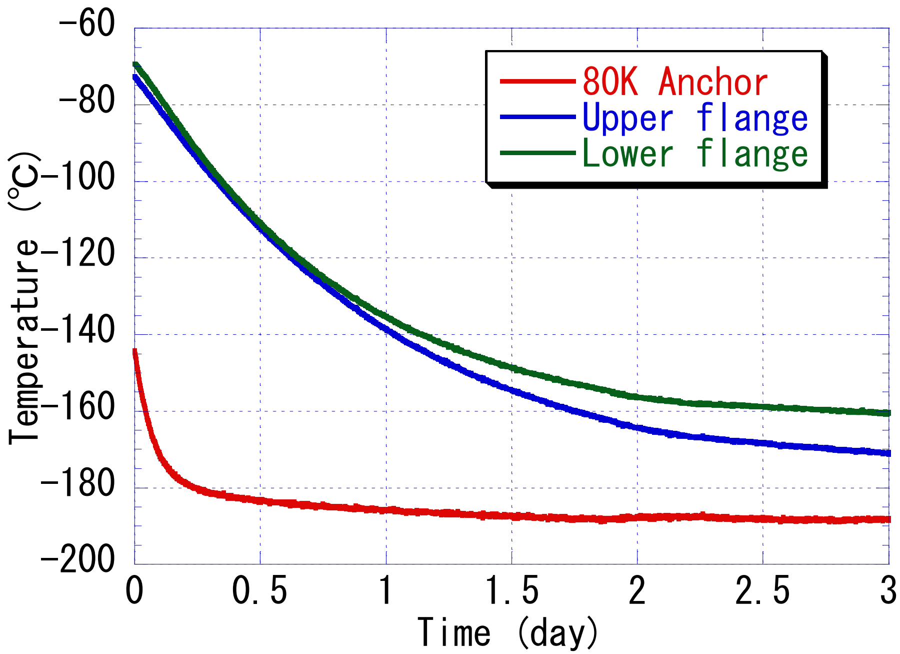


Thermal resistance

- Thermal resistance ∼150 K / W

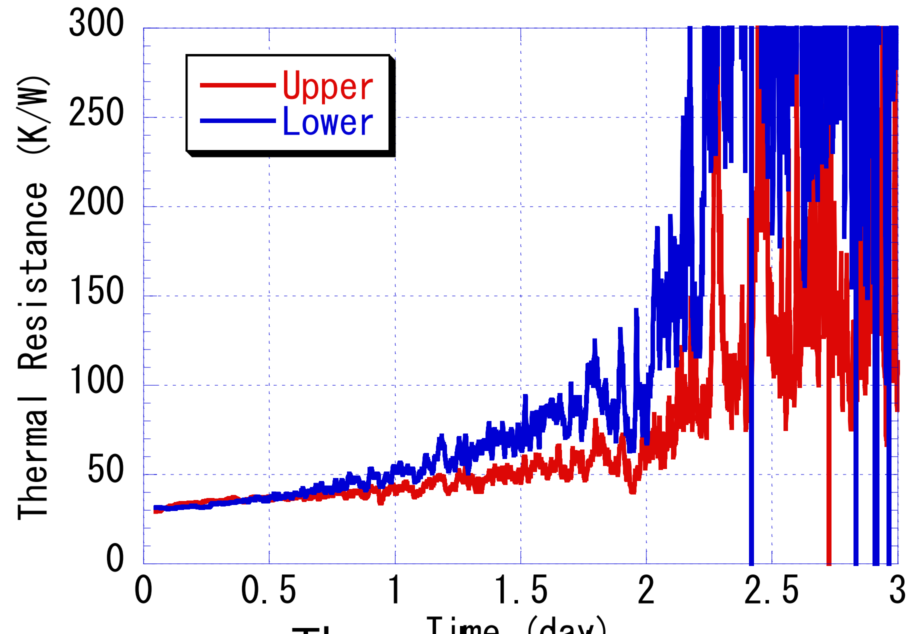
Almost same as rough estimation from bellows size

Measurement of Cooling test



Temperatures of both ends of bellows

Cooling is faster than simulation

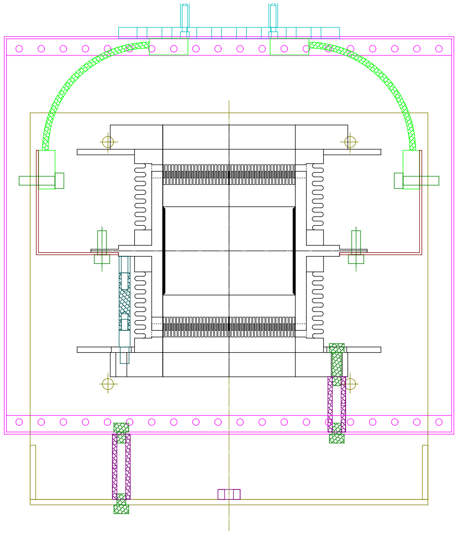


Thermal resistance

- 1/3～1/4 times of simulation result
- Thermal resistance is smaller as the temperature difference is larger

- Heat transfer paths exist besides of bellows

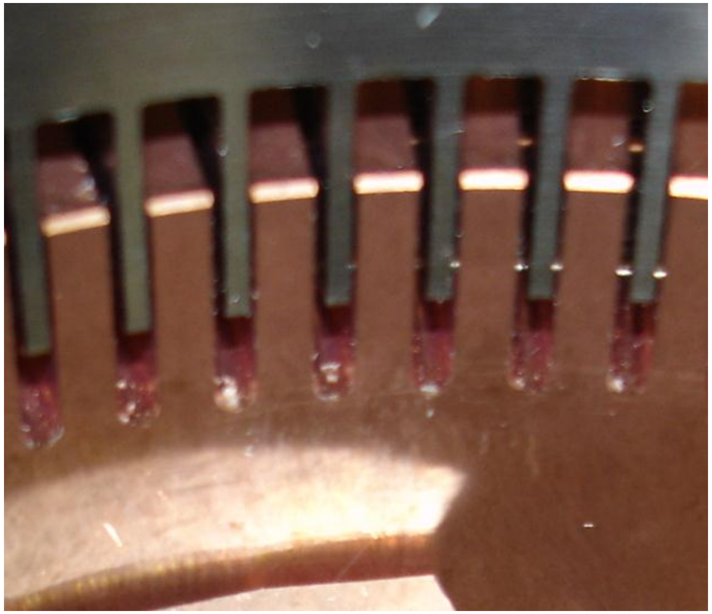
Reasons for small thermal resistance

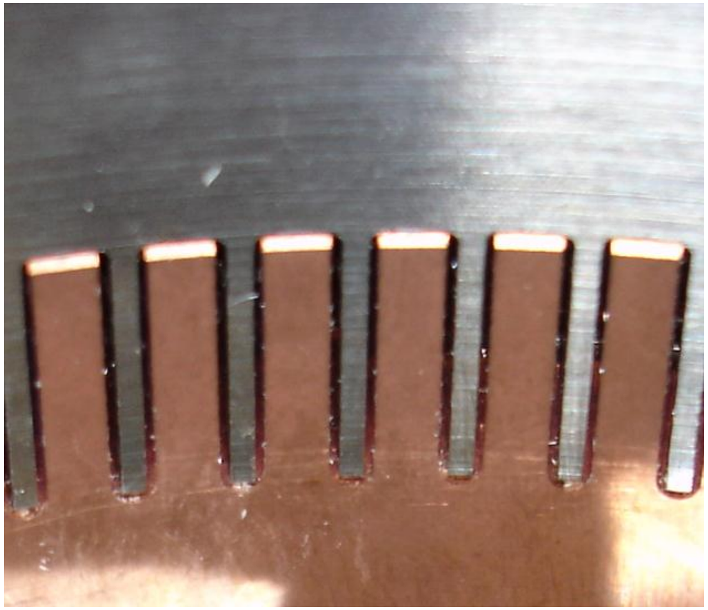


- Radiation heat from heat shield box
  - Cross-section of flange 0.048m^2
  - Temperature at 1-day cooling 80K−130K
  - Estimated radiation is 0.334W⇒150K/W
- Radiation heat between combs
  - Cross-section of comb-type bridge 0.021m^2
  - Temperature at 1-day cooling 80K−130K
  - Estimated radiation is 0.147W⇒340K/W
    - When the temperatures are 80K and 4K, 3440 K/W (can be ignored)
- Support rod
  - 80K anchor and 4K anchor are supported by rods of G10
  - Thermal resistance ～340K/W
- Contact of combs
  - Two types of contact of combs were measured

Longitudinal contact

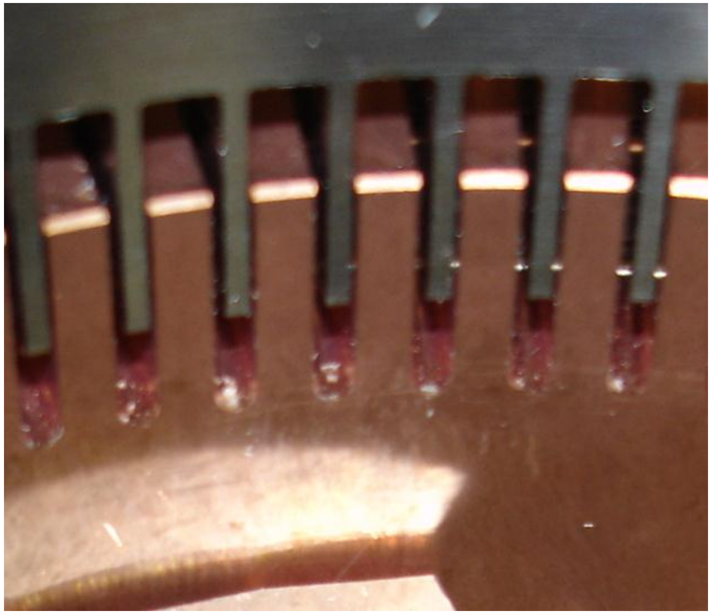
- Shorten the bellows to contact the comb-tops to comb-bottom

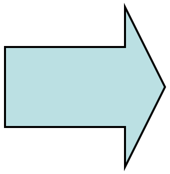


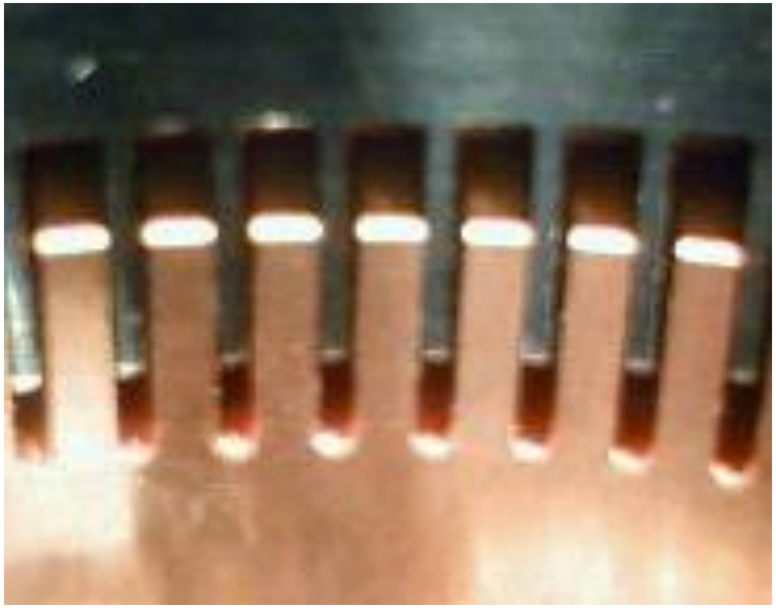


Contact at a tilt

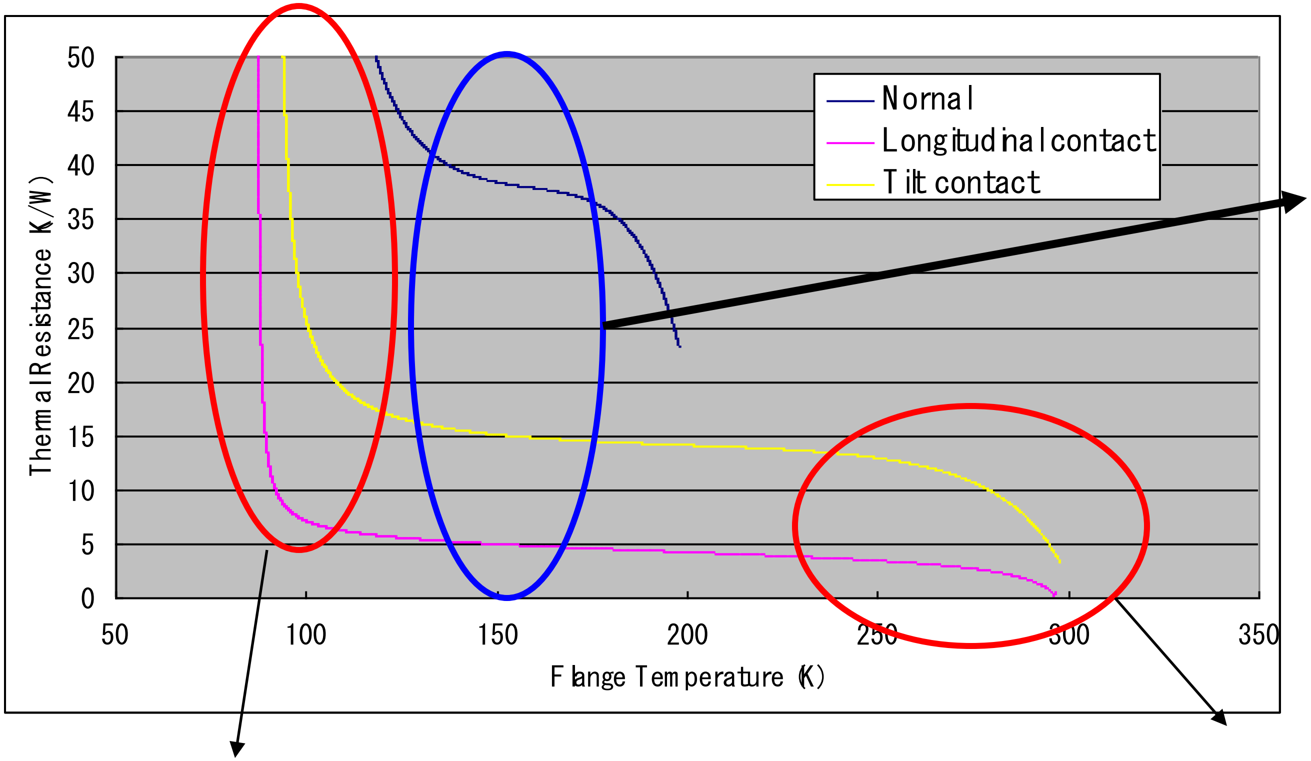
- Tilt the flange to contact the opposite combs at a tilt







Comparison with 3 types of contact



- Precious around here?
- Including heat transfer along support rods

Temperatures of flange and 80K anchor are different after long term of cooling

Apparent temperature difference and no heat transfer⇒high thermal resistance

Probably radiation heat

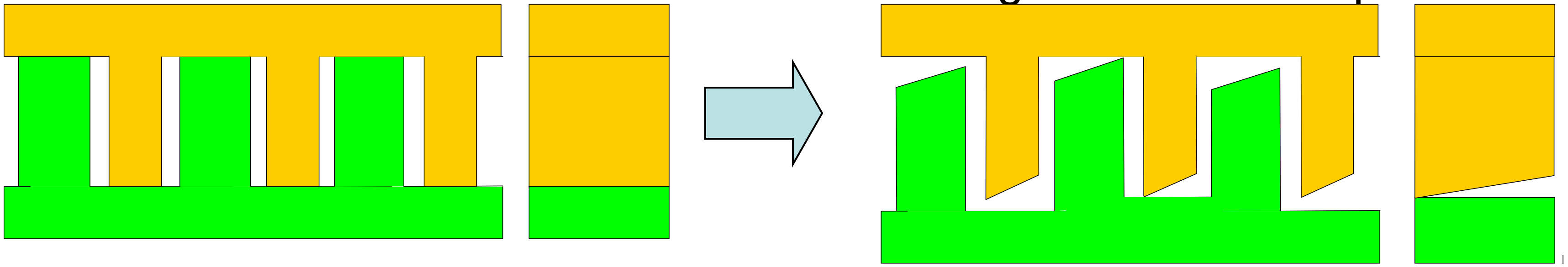
Exist other paths for cooling besides of bellows

Apparently smaller thermal resistance

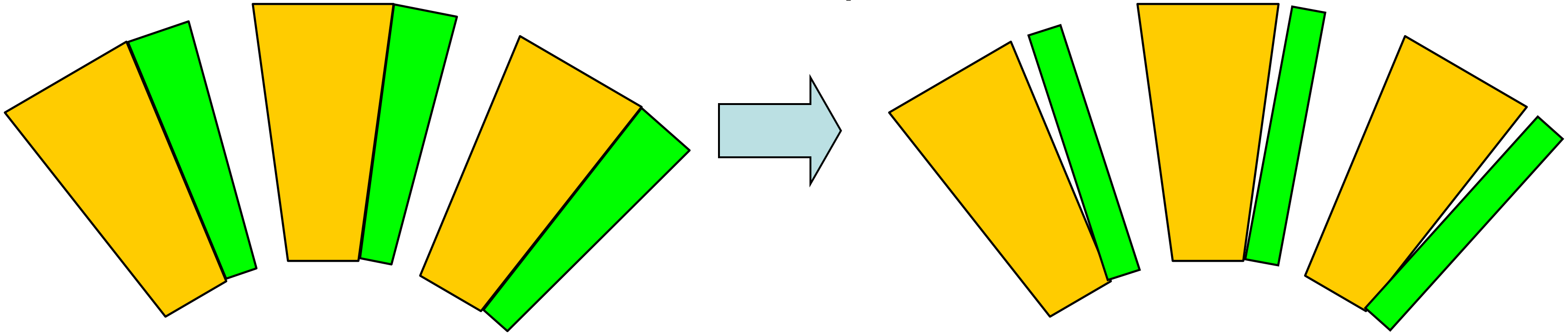
Modify Comb Shape

- Point contact even if combs contact each other

- Brick 　　　　　　　　knife-edge & different depth



- Radial cut 　　　　　　　　parallel cut



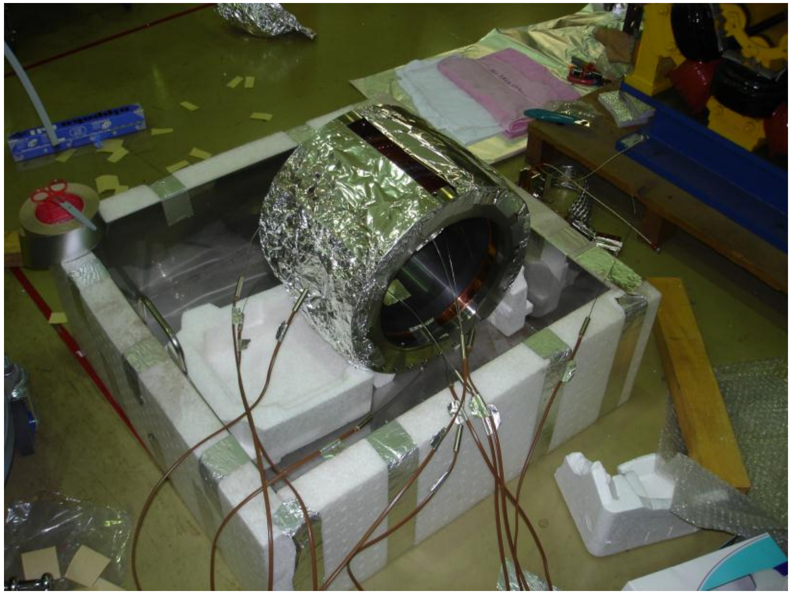
Temperature gap at contact

	Temperature gap (K)	
	38W (meas.)	100W (estimate)
Liq. N_2 tank and braid line	0.7	1.8
Both ends of braid line	37.0	36.5
Braid line and connection plate	2.8	7.4
Both ends of connection plate	9.3	24.5
Connection plate and 80K anchor	1.1	2.9
80K anchor and Cu base of ferrite	0.9	2.4
Total	51.8	75.5

- Heater power 38W
- Total cross-section of braid lines 400 mm^2 and 200 mm
- In actual module 8 braid lines of total cross-section of 800 mm^2 and 150 mm
- Connection plate should be thicker

HIP ferrite crack

- Used KEKB HOM absorber
- Cooled with Liq. N_2

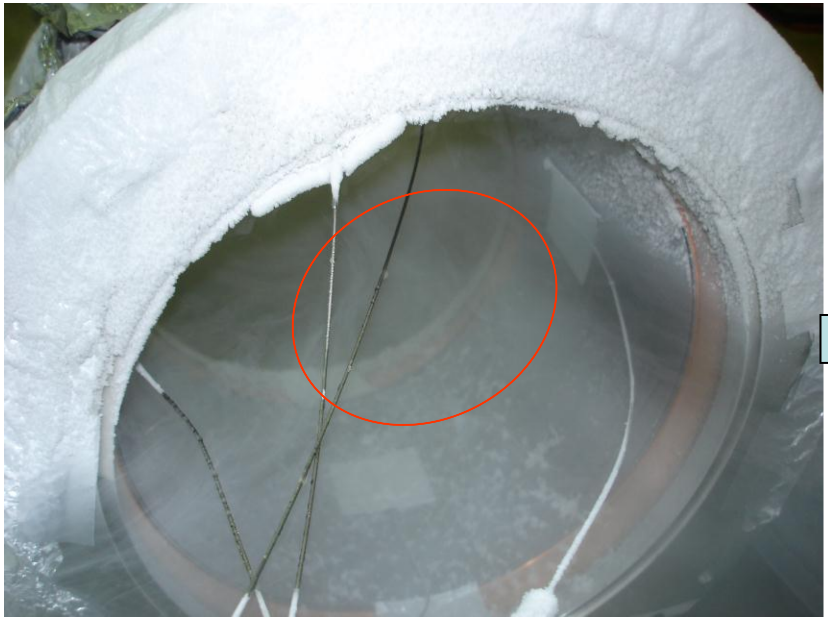


HOM absorber was set in a tank

Liq. N_2 was poured into the tank not to splash directly

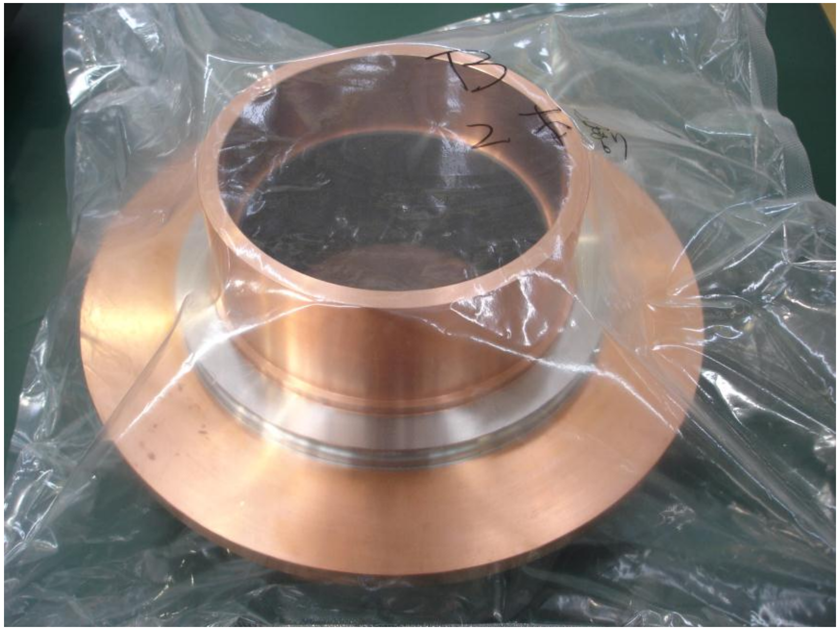
HIP ferrite crack

- When HIP ferrite was soaked in Liq. N_2, edge of HIP ferrite fell off
- Maybe sudden cooling caused nonuniform heat shrink

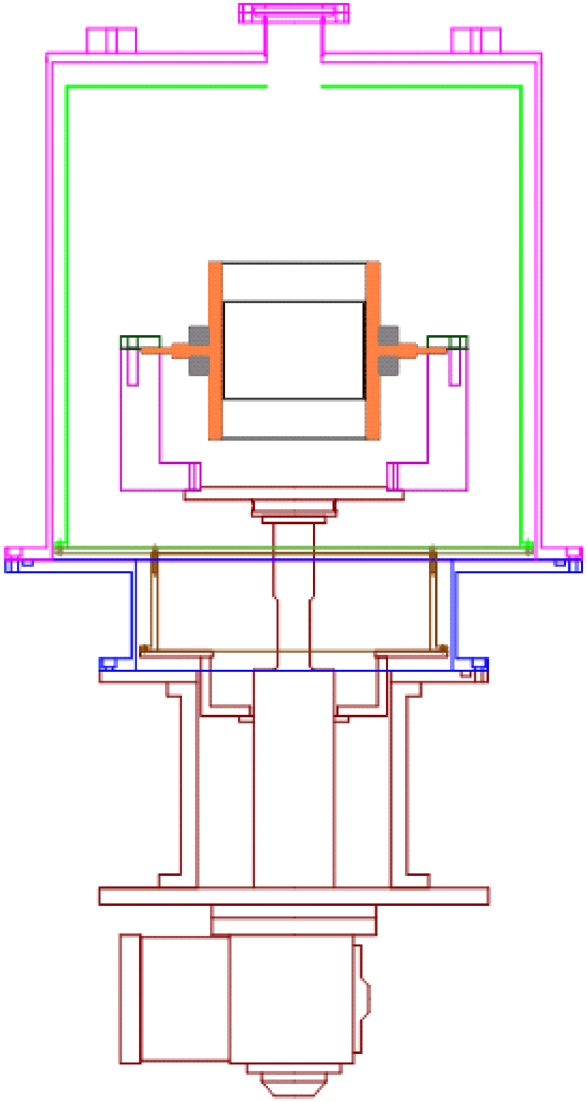


Prototype with ferrite

- Prototype HOM absorber part with ferrite and without flanges and bellows
- Central part of ferrite base
- Before manufacturing combs and 80K anchor



Prototype with ferrite



- Preparing heat cycle test
- Check HIP ferrite not to crack at heat cycle from RT to 80K
- Use GM refrigerator to cool slowly in control

Conclusions

- HOM absorber prototype without ferrite
  - Estimate thermal resistance of bellows and comb-type RF bridge
  - Measured value is lower than calculated
    - There existed thermal paths beside bellows such as heat radiation and support rods
    - More measurement should be carried out.
  - Thermal resistance become low when combs contact.
    - Need to modify comb shape

- Sudden or rapid cooling will crack HIP ferrite
  - We are preparing to research that slow cooling would cause crack or not.
  -

- Thicker heat transfer lines such as braid lines and connection plate will be necessary to cool HOM absorber