Cryogenics
(Helium refrigerator for SRF)

K.Nakanishi, K.Hara, T.Honma, S.Kessoku, H.Nakai, H.Shimizu

(refrigerator group)

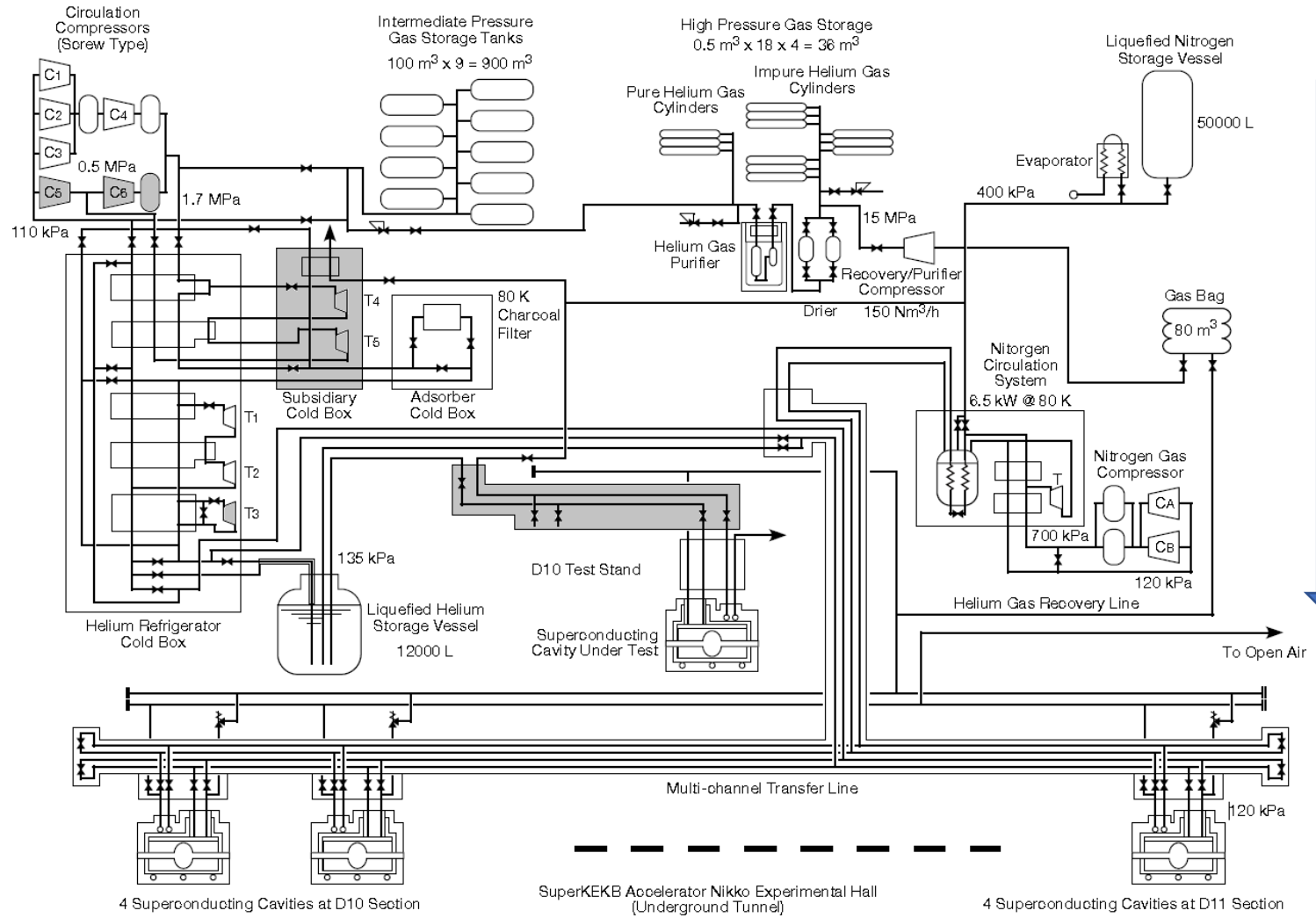
Same slide as last meeting

History of our refrigerator

TRISTAN without Superconducting cavities (SCC)	1986~
TRISTAN with SCC	1988~1995
KEKB with SCC	1998~
KEKB with SCC and Crab cavities	2007~2010
SuperKEKB with SCC	2016~

Same slide as last meeting

Cryogenic system for Superconducting Cavities.



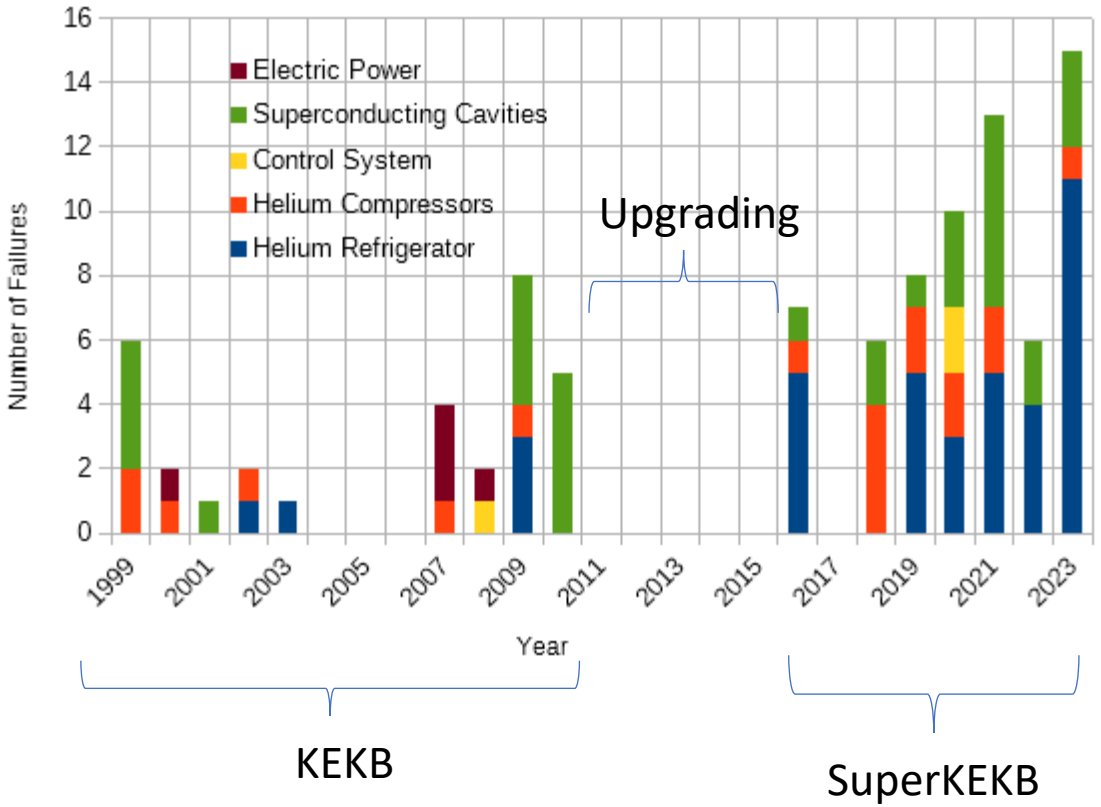
1988
4kW @ 4.4K
(Design)

Compressor (C5,C6) were added.

Supercritical turbine expander (T3) was added.

1989
6.5kW @ 4.4K
(Design)
8.1kW @ 4.4K
(Achieved)

Troubles



The total operation time
TRISTAN : 38,000 hours
KEKB : 62,000 hours
SuperKEKB : 28,000~ hours

Year:
Hour of inhibition/ hour of operation
2016: 0 / 3343
2017: 0 / 0
2018: 0.1 / 4362
2019: 39.4/ 5334
2020: 4 / 5099
2021: 0 / 5292
2022: 3.7 / 3246
2023: 0 / 0
2024: 0 /1200~

In recent years, the number of troubles has been increasing.
However, by preparing spare parts and/or using alternative functions, the operating rate of the refrigerator is maintained still high.
(Hour of inhibition is not hour of repair. If it is in operation even during repair, it is included in the operation time.)

Control system

- Initially a control system EX-1000 which made by Hitachi was adopted in 1988.
- The control system was updated to EX-7000 in 2002.
- EX-8000 was adopted in 2012.

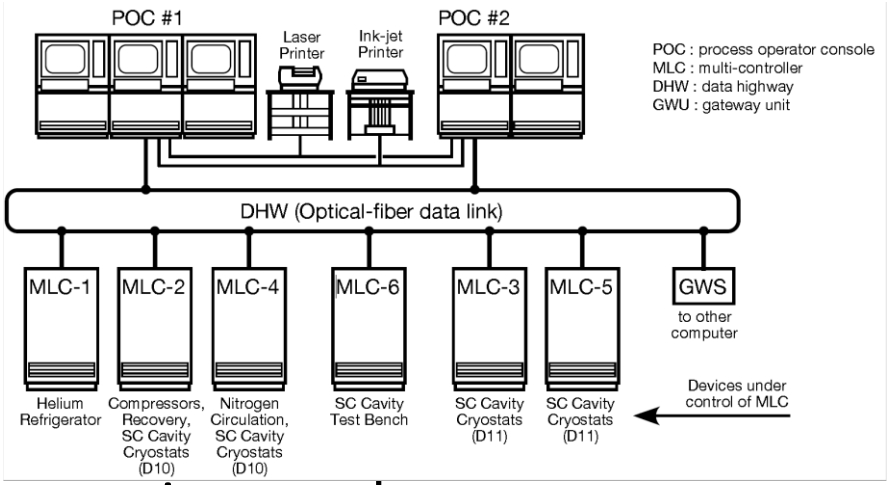
- It’s time to update again.

But the candidate is

so expensive,

working on Windows10,

etc



Small parts are replaced from time to time, and spare components are kept if they are used in large quantities.

Maintenance and Updating

- The cryogenic systems were inspected every year by the prefectural government. The legal inspection is a good guideline for maintenance.
- Check and adjust the actuators of the controlled valves, pressure gauges and thermometers in the inspection cycle. And some one that can not be adjusted is replaced.
- It is recommended to replace the input / output module of the control system every 5 ~ 7 years. (However, the update cycle is often extended.)
- Compressor open inspections are performed at the manufacturer's recommended operation hours or at least every 10 years.
- Since the manufacturer has withdrawn from the refrigerator business, any spare parts are not distributed.→Three spare turbines (T1,T2 and T3)are kept.

How long can we operate after use the spare turbine?

Spare turbines

- I asked the manufacturer if they could produce a new turbine.

→No. They will try to repair that. But they can’t make new one.

- In about 35 years of operation, the turbines have never been damaged. Can't you think that the life of a turbine is more than 35 years?
- If two turbines(T1 and T2) are working, it can be operated as a 4kW refrigerator. And that is enough for SuperKEKB.

We have no choice but to use them carefully.

KEKB (1998~2010)
SuperKEKB (2016~)

Components		Heat loads
Cryostat	30 W/cryostat x 8	240 W
Transfer Lines (380m)		412.4 W
Cold Valves & Joints		147 W
RF Loss	100 W/cavity x 8	800 W
Total		**~1600 W**

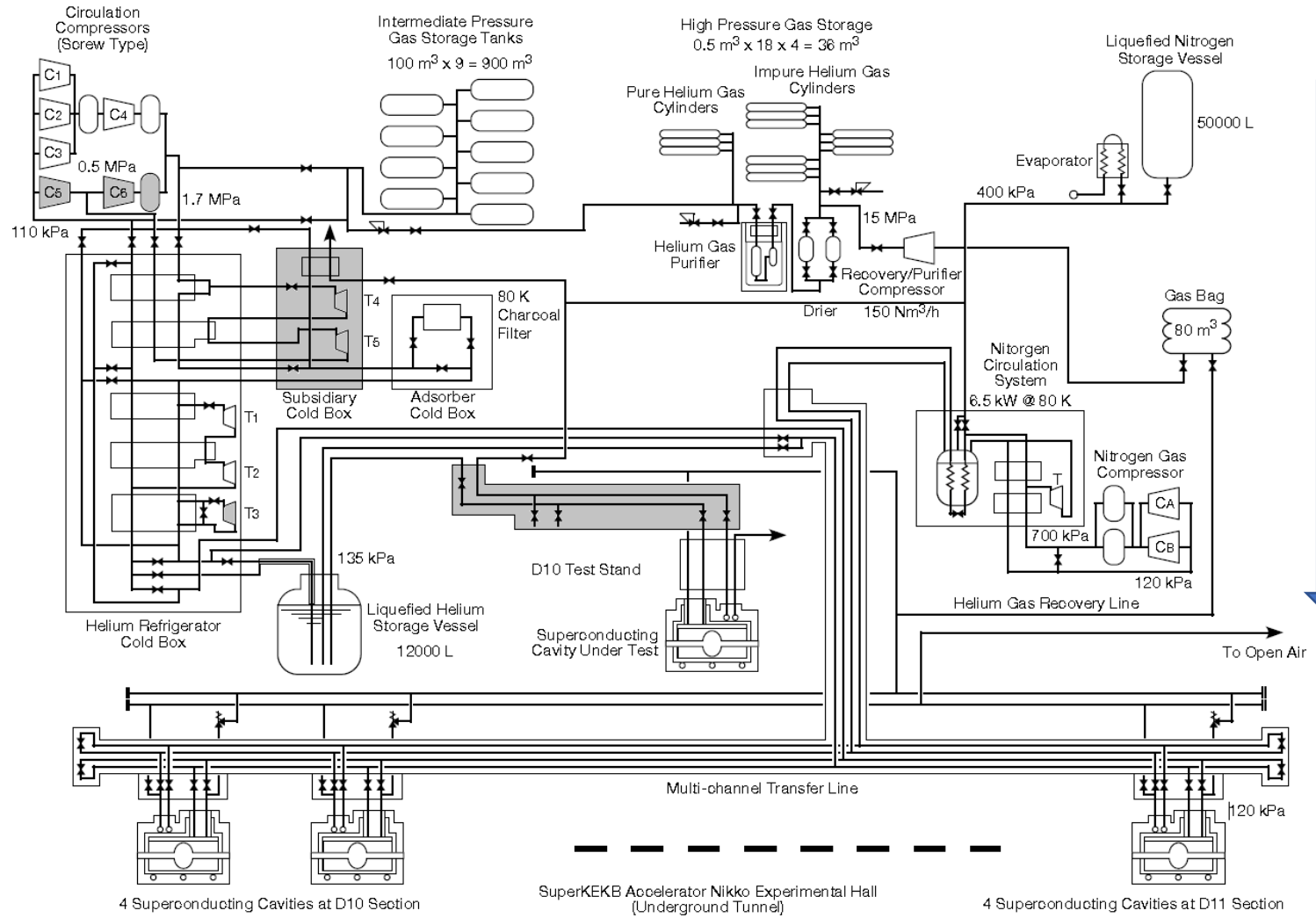
~800W

Compensation heater power is included

- The heat load was smaller than TRISTAN's.
- The RF loss is stable during beam operation.
- The compensation heaters are even used.
- The refrigerator is powerful enough.

Same slide as last meeting

Cryogenic system for Superconducting Cavities.



1988
4kW @ 4.4K
(Design)

Compressor (C5,C6) were added.

Supercritical turbine expander (T3) was added.

1989
6.5kW @ 4.4K
(Design)
8.1kW @ 4.4K
(Achieved)

Compensation heater (1)

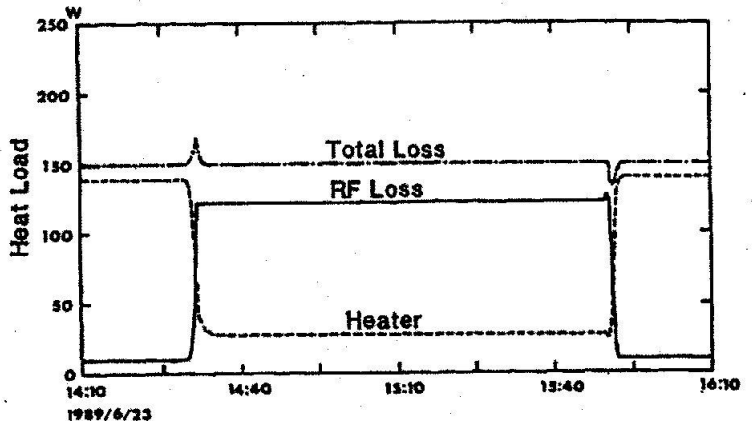
The RF loss of TRISTAN cavities were not constant.

Beam Injection (~30W/cavity)

2minites ⬇

Top energy operation

(90~120W/cavity)



Compensation heaters were working to make the heat load constant.
Compensation heaters are not required for SuperKEKB operation.
But they are still working.

Same slide as last meeting

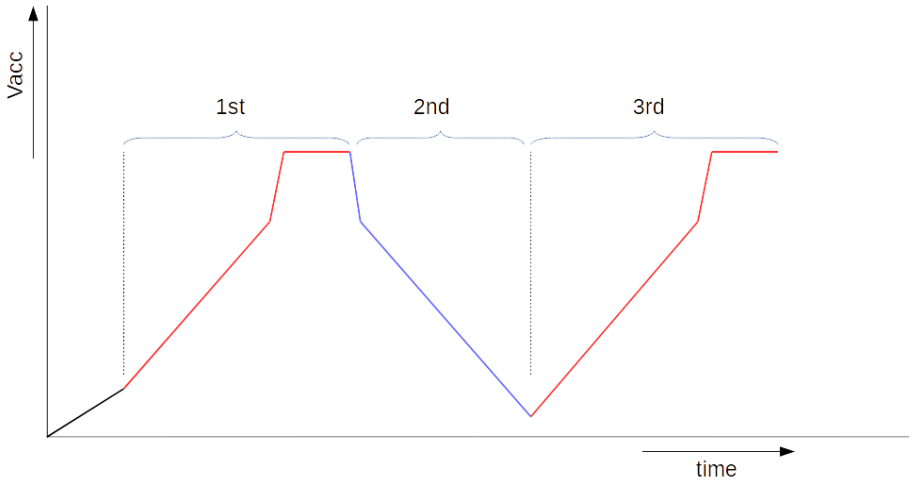
Compensation heater (2)

A member of the Cavity Group told me that the high Vacc operation would deplete the liquefied helium, so the following rules must be followed:

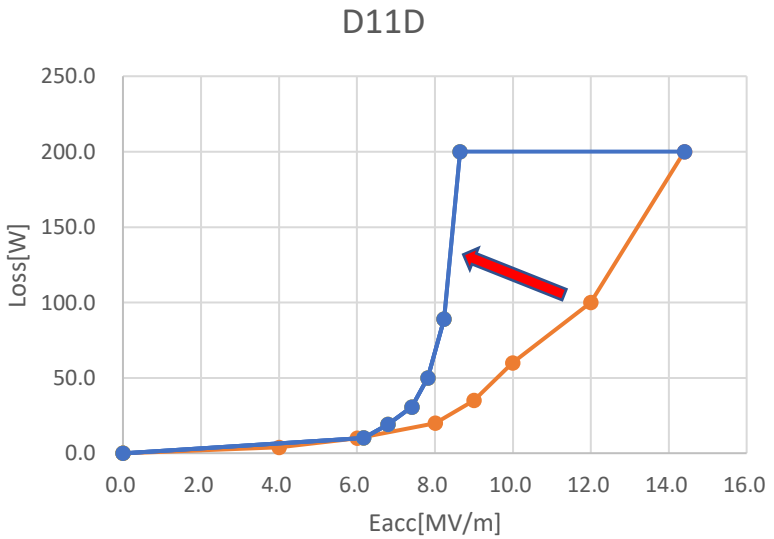
① It should pass through quickly.

② High voltage operation should be limited to no more than two cavities at the same time.

→Controlled by Auto aging program.



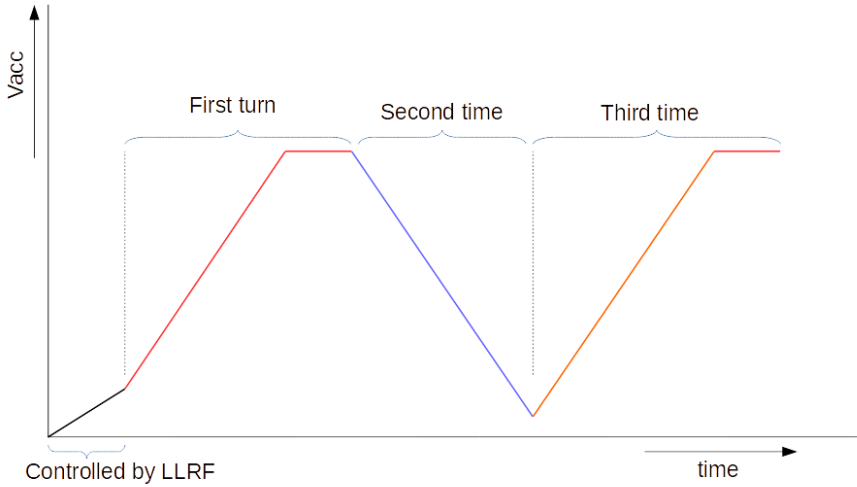
However, Why did the refrigerator detect that the aging operation for cavities was done. The compensation heater doesn't work well.
We found that the RF loss on the cavity wall was not properly evaluated.
Since the data was updated, it will be improved from the next operation.
(Cavity group gave us the Q-Eacc data.)

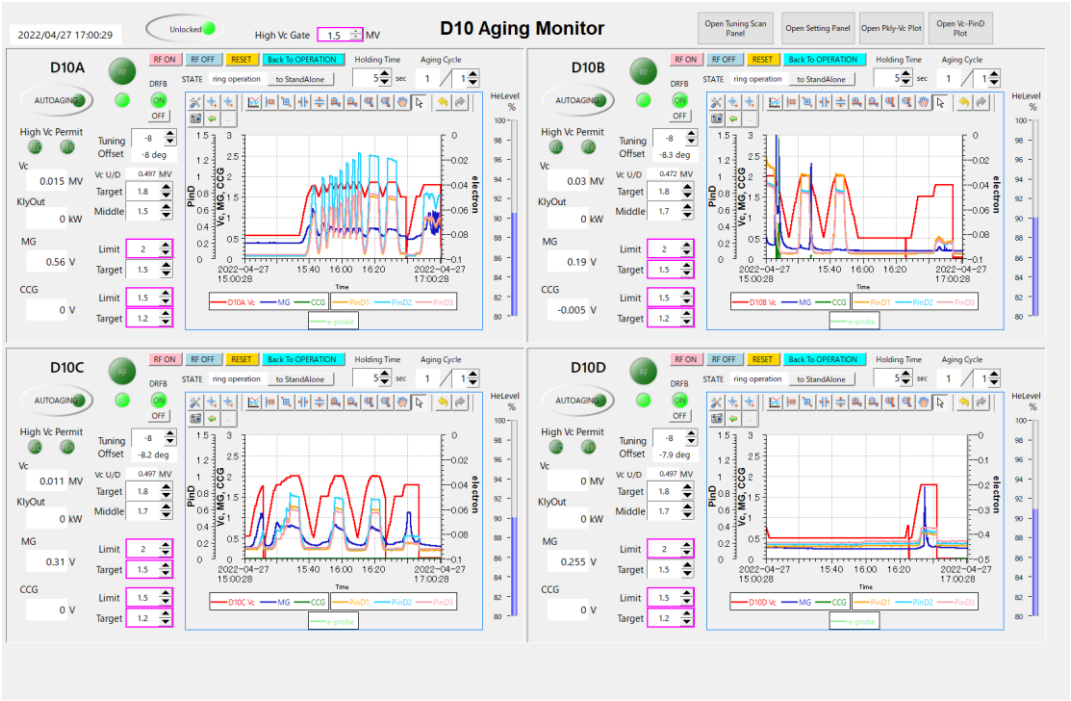


Same slide as last meeting

Auto Aging program

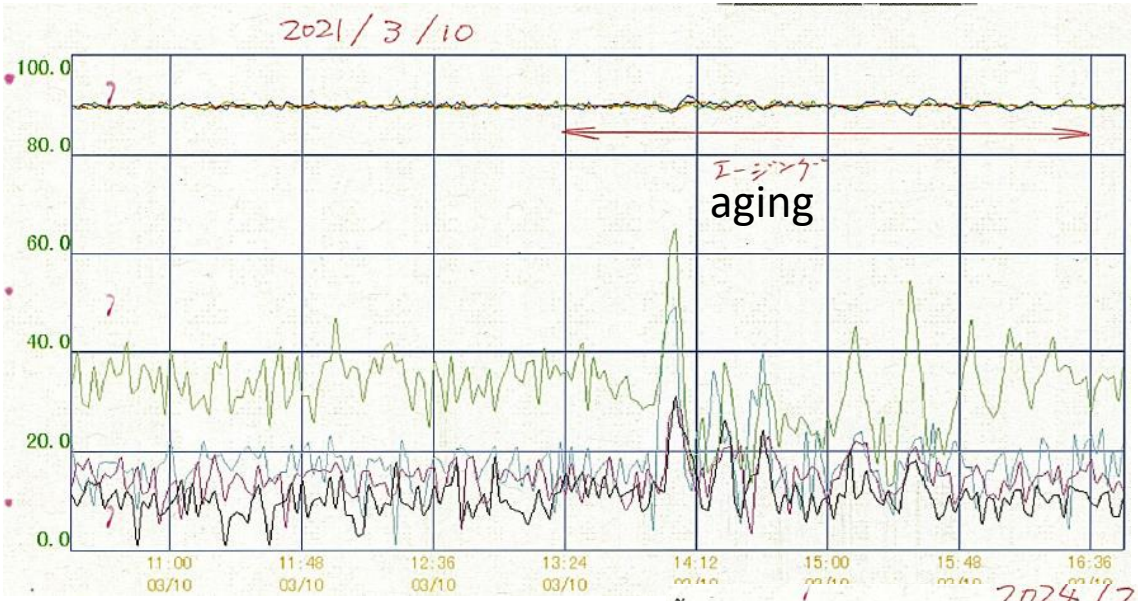
The aging operation of the Superconducting cavity in SuperKEKB is to pass through the specified voltage range six times.
I made the auto aging program.





Cavity group members improved the GUI.

Compensation heater (2)

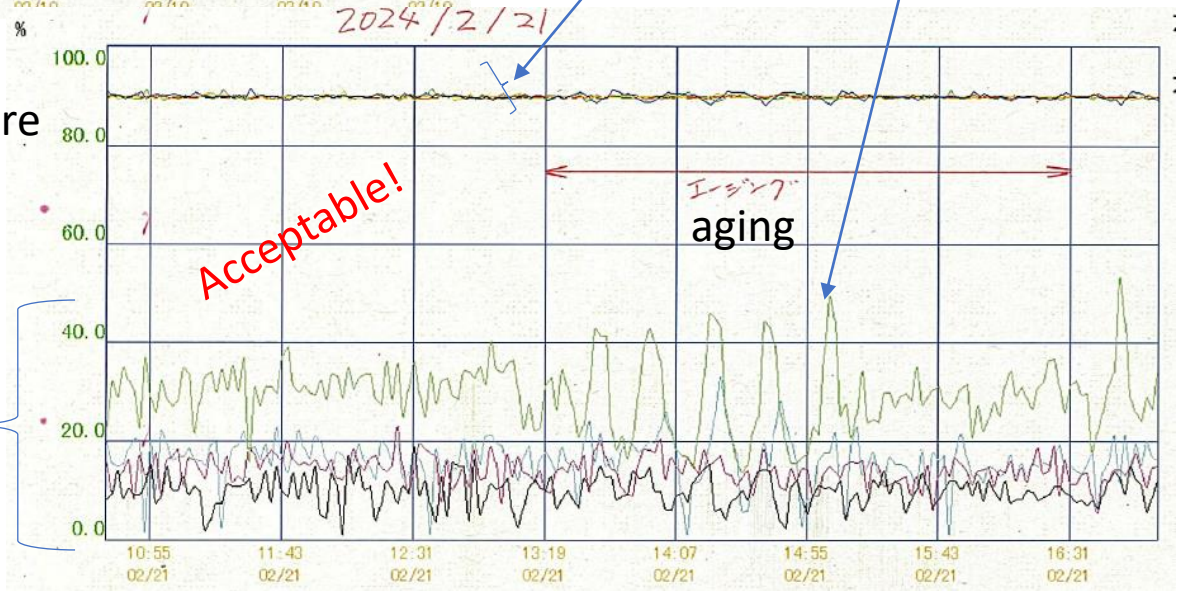


If the total heat load exceeds 100 W, the compensation heater couldn't compensate completely.

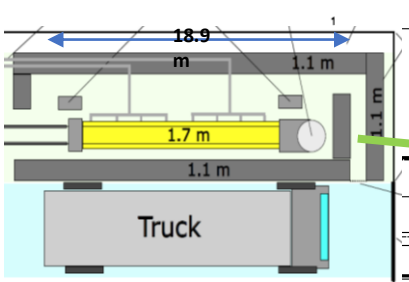
He level [%]

The behaviors of control valves are improved.

Valve opening



The layout of the COI building



Pump for 2K refrigerator
FY2023,FY2027

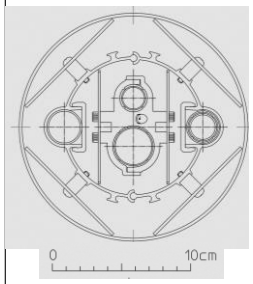
④2K refrigerator
FY2025~

③Liquid helium transfer line(TRT)（~100m)
FY2025~

①Control system update for liquefier and 2K refrigerator
FY2024~

Helium purifier
FY2024

②Helium refrigerator
(LR280:exist)
Change HPGS category.
FY2026



Cross section of the transfer line

We are cooling the superconducting cavities to 2K at STF and cERL.
Recently, we are participating in the ITN(ILC Technology network) project and building a new 2K test station.

Please rest assured, we have enough jobs.

Summary

- In SuperKEKB, superconducting cavities are operated using a cryogenic system constructed for TRISTAN in 1988.
- Periodic update is been doing.
- If a turbine breaks down, a new one cannot be made. But spare turbines are prepared.