Helium refrigerator for SRF

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(refrigerator group)

Superconductivity in Accelerator

In the 1980s, superconducting devices for accelerators were put to practical use. Our refrigerator has left a big milestone as follows:

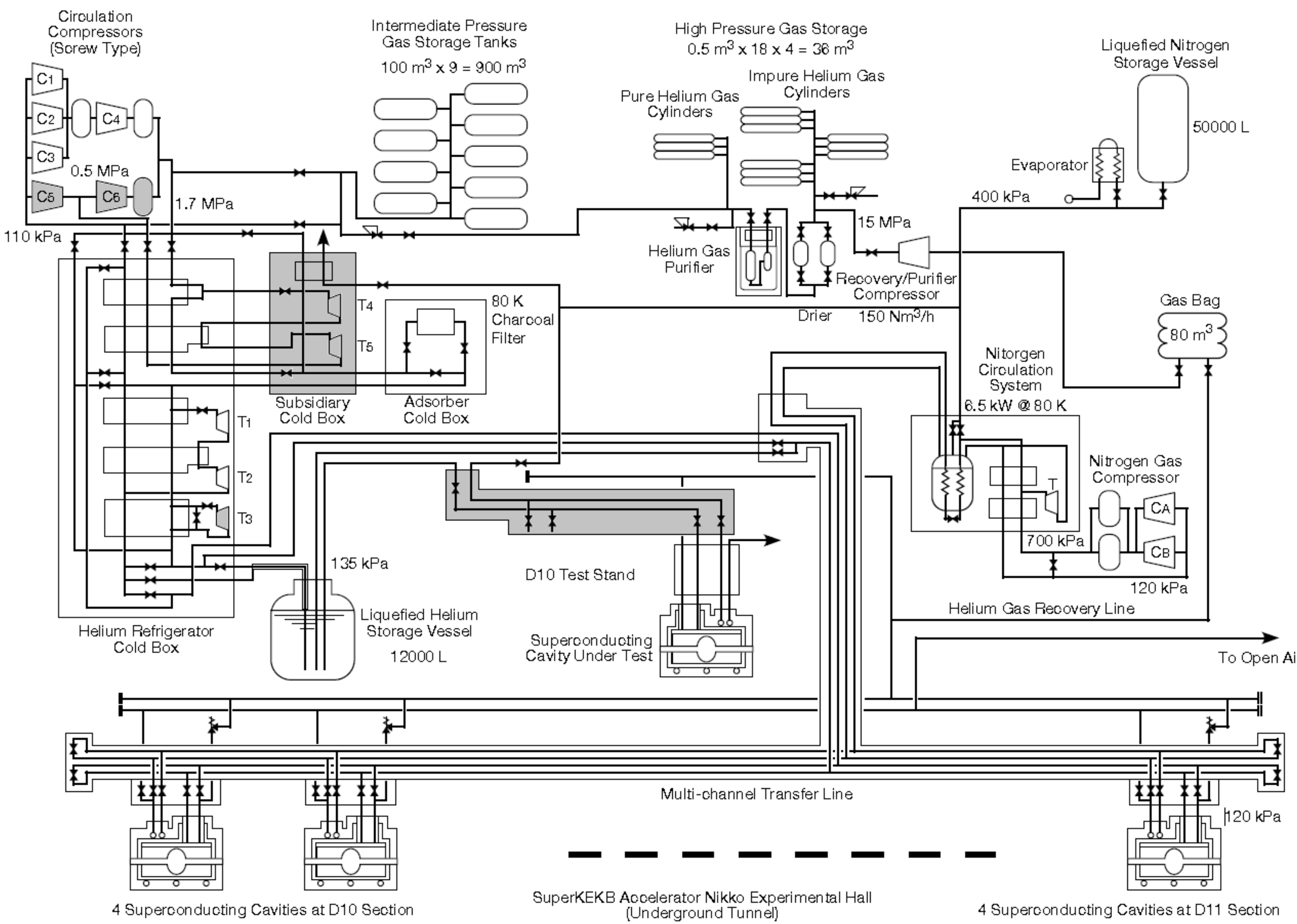
- 1985 : Started to operate Superconducting magnet in Tevatron.
- 1988 : Started to operate Superconducting cavities in TRISTAN at KEK.
- 2011 : Stoped to operate Tevatron.
- 2022 : Refrigerator for TRISTAN is still working in SuperKEKB

We are proud of it, but it also means that our refrigerator is very old.

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~

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)

TRISTAN (1988~1995)

The heat load at 4.4K was quite large.

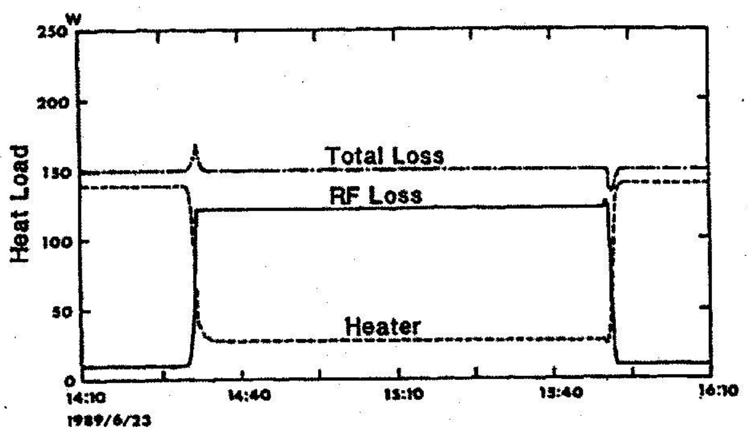
Components		Heat loads
Cryostat	22.8 W/cryostat x 16	364.8 W
Transfer Lines (380m)		412.4 W
Cold Valves & Joints		147 W
RF Loss	90 W/cavity x 32	2880 W
Total		**3804.2 W**

If

150 W/cavity

5700 W

Compensation heater power is included



The RF loss was not constant.

Beam Injection (~30W/cavity)

⬇ 2minites

Top energy operation

(90~120W/cavity)

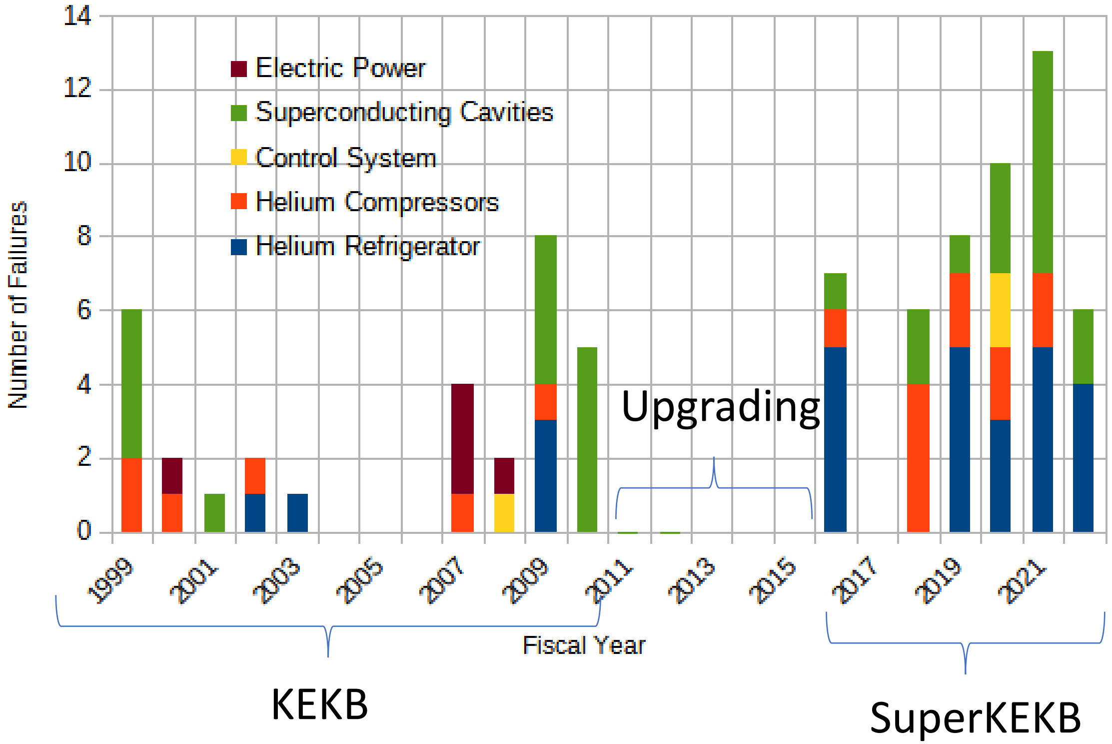
KEKB (1998~2010) SuperKEKB (2016~)

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**

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.

Trouble



The total operation time

TRISTAN : 38,000 hours

KEKB : 62,000 hours

SuperKEKB : 27,000~ 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

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.)

Maintenance and Updating

- Maintenance are carried out in accordance with the High Pressure Gas Safety Act.

Required inspection period

Item	Maintenance cycle
Whole system	1 year
Compressor	2 year
Pressure gauge	2 year
Thermometer	2 year
Cold evaporator	3 year
others	1 year

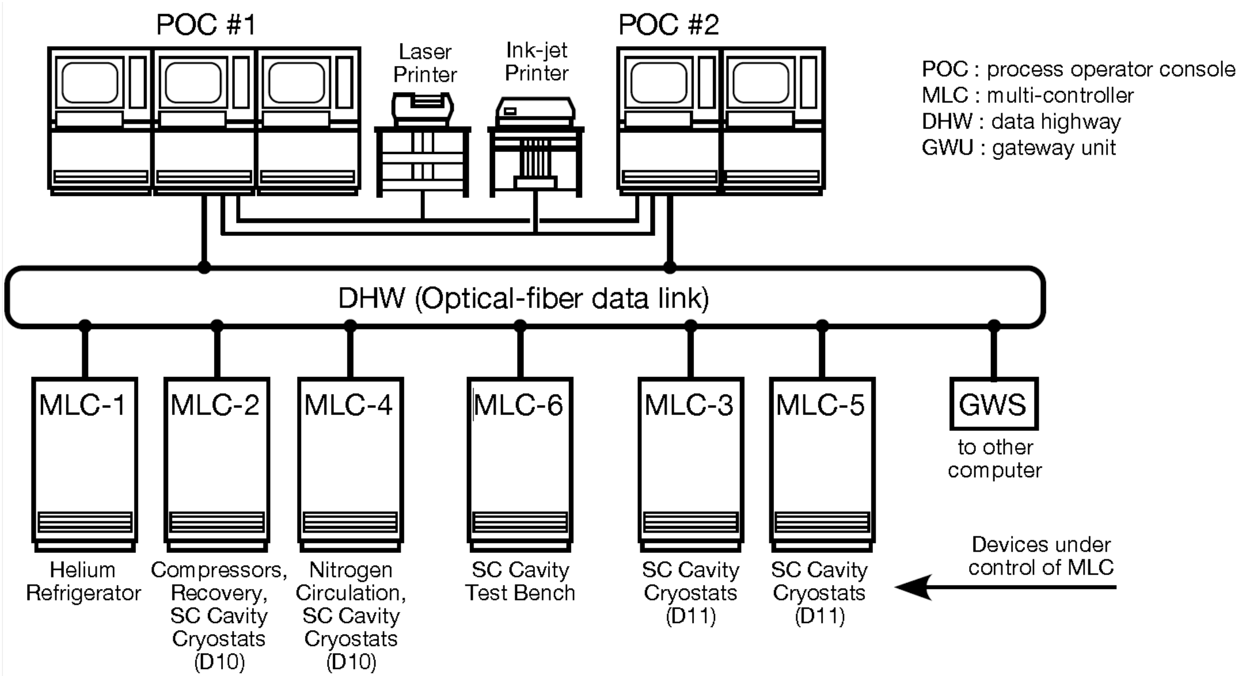
item	Open inspection cycle
Recovery compressor	10 years or 3000 hours operation
Circulating compressor	10 years or 3000 hours operation
others	exemption

Maintenance and Updating

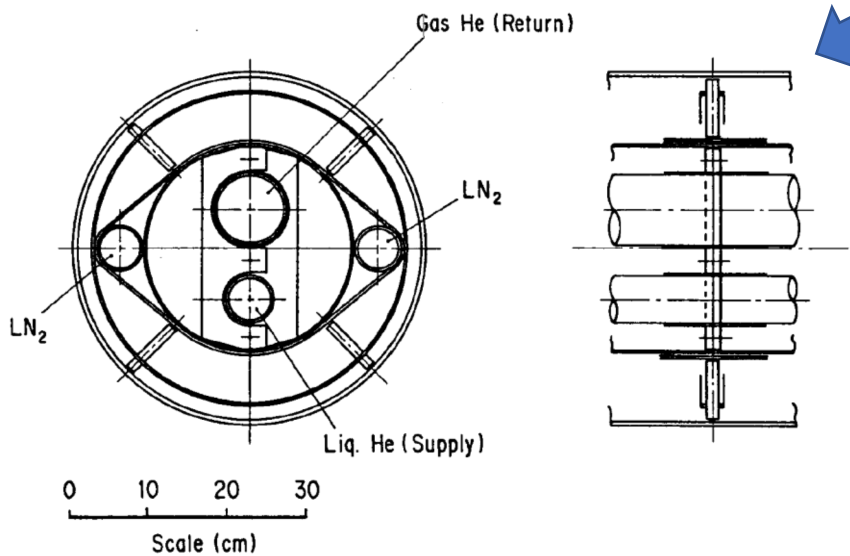
- The cryogenic systems were inspected every year by the prefectural government. The legal inspection is a good guideline for maintenance.
- Check and adjust the actuators of the controlled valves, pressure gauges and thermometers in the inspection cycle. And some one that can not be adjusted is replaced.
- 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 are kept.

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.

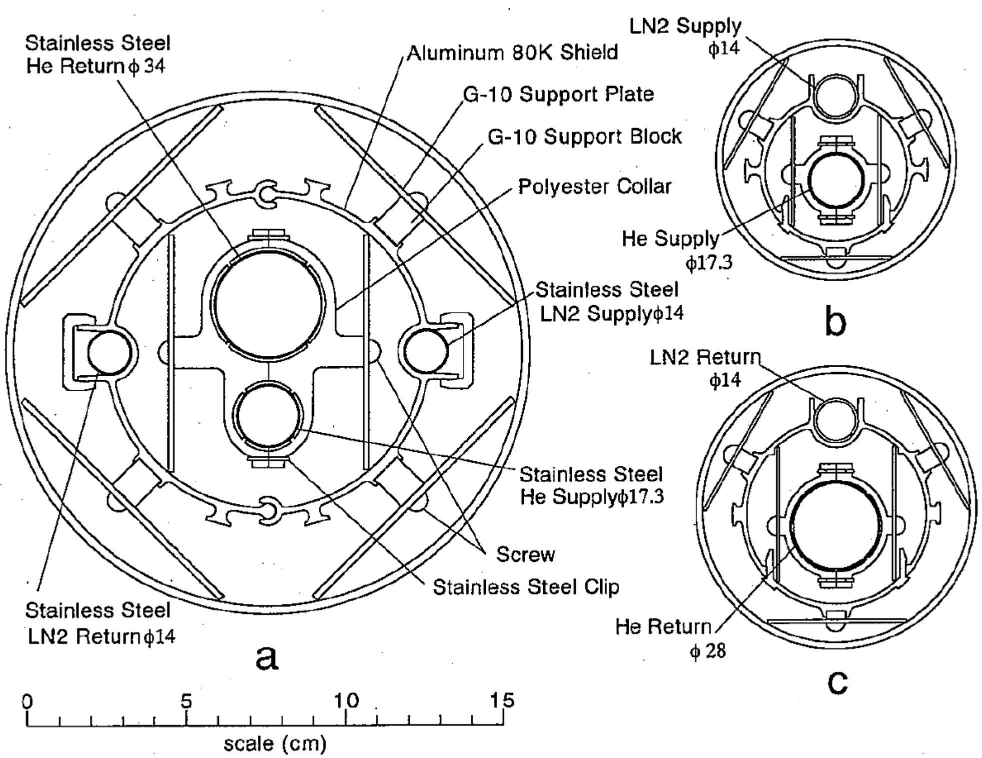


Transfer Line

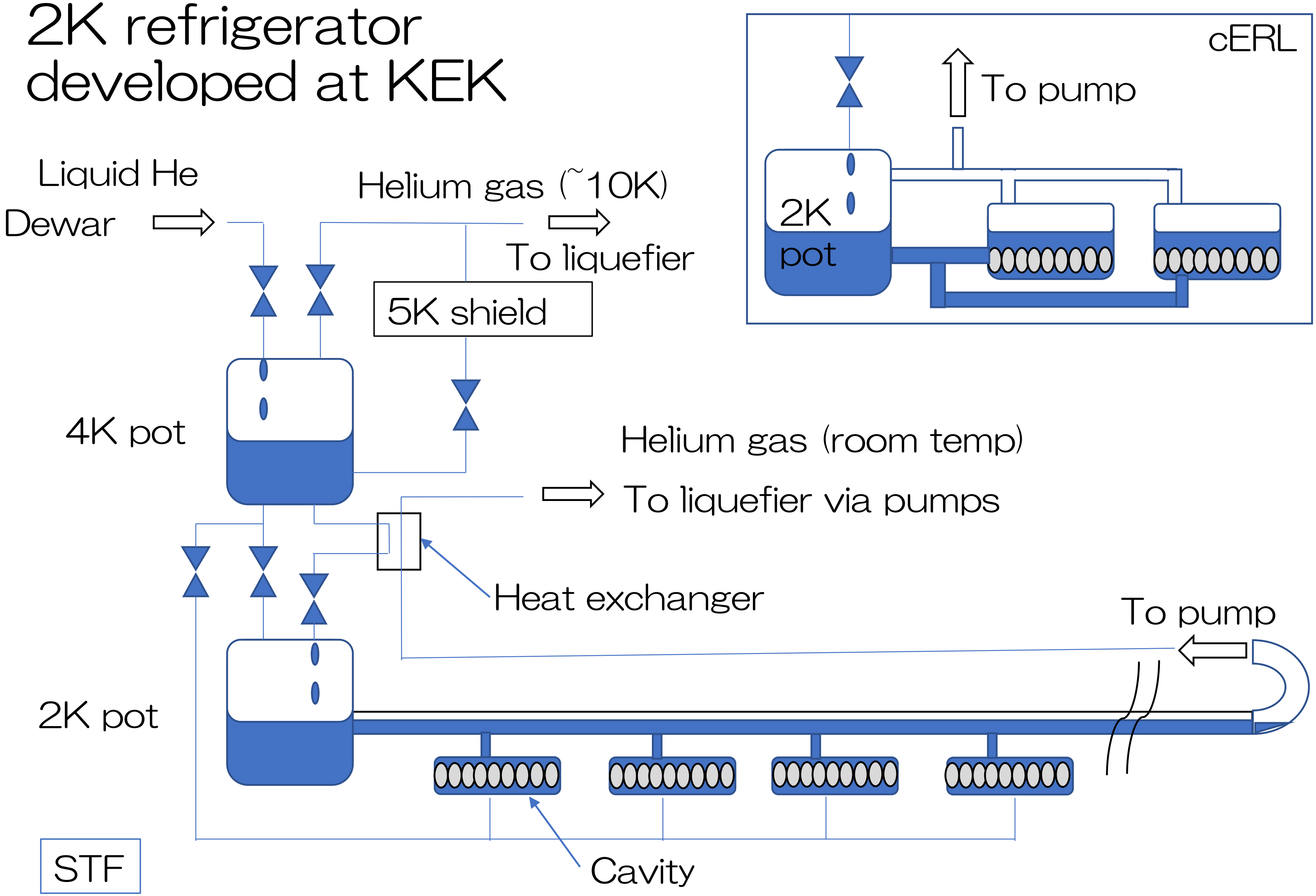


Transfer Line developed for TRISTAN
This transfer line adopted for connection between the liquid helium dewar and the accelerator tunnel.
The heat load is about 1W/m.

Transfer Line developed for KEKB
This transfer line adopted for connection between the liquid helium dewar and the D10 test stand.
The heat load is about 0.05W/m.
Adopted in 2K system(cERL/STF) at KEK.

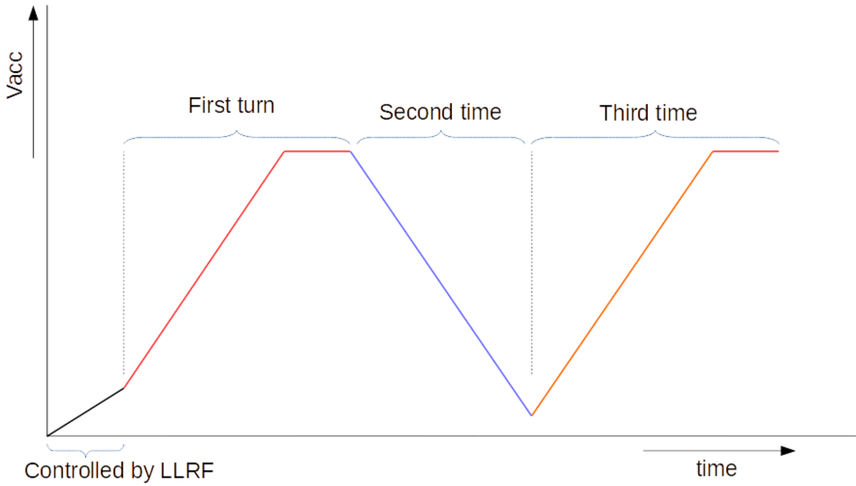


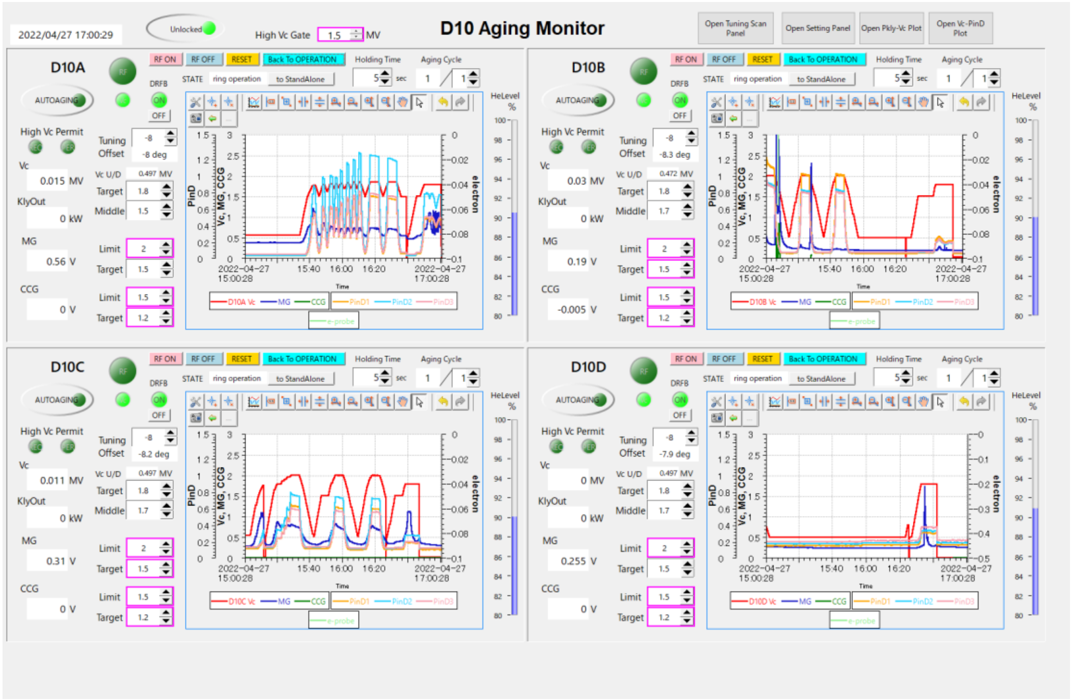
2K refrigerator developed at KEK



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.

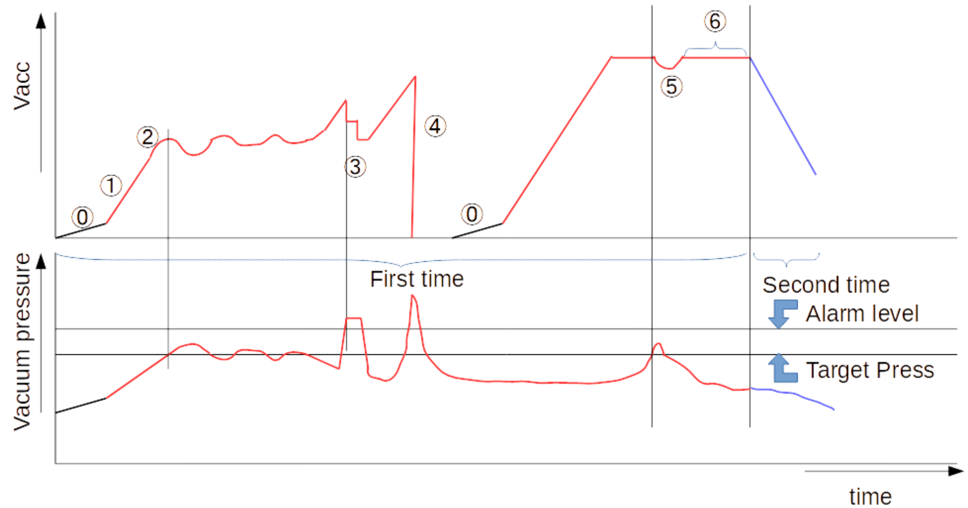




Cavity group members improved the GUI.

Auto Aging program

The aging procedure



⓪ RF system turns on by LLRF.

① When the vacuum pressure is low enough, Vacc rises at maximum rate.

② When the vacuum pressure approaches the target, Vacc rises slowly by PI control.

③ When the vacuum pressure exceeds the alarm level, the cavity voltage is lowered in steps and fixed for 2 seconds.

④ Interlock may stop RF.

⑤ Decrease the cavity voltage if the vacuum pressure exceeds the target value even after the cavity voltage reaches the target value.

⑥ If the cavity voltage can be maintained at the target value for the specified time, the aging pattern of voltage rise will be completed.

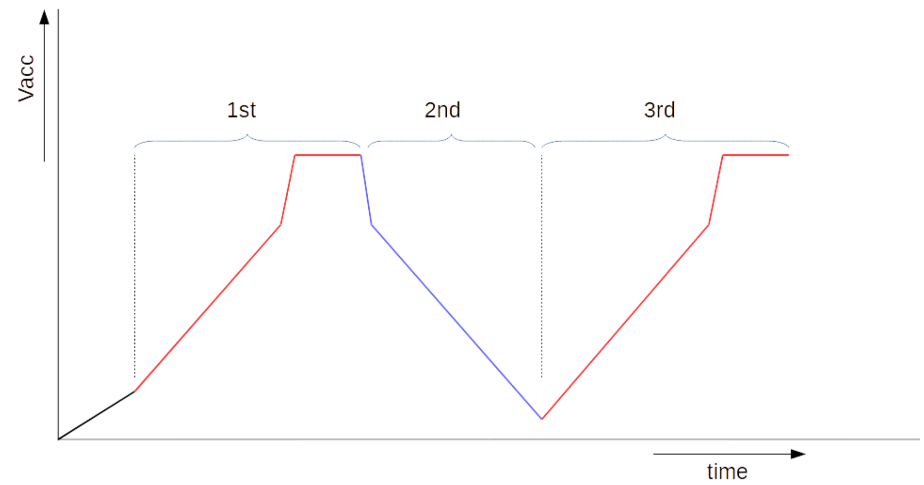
Compensation heater

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.

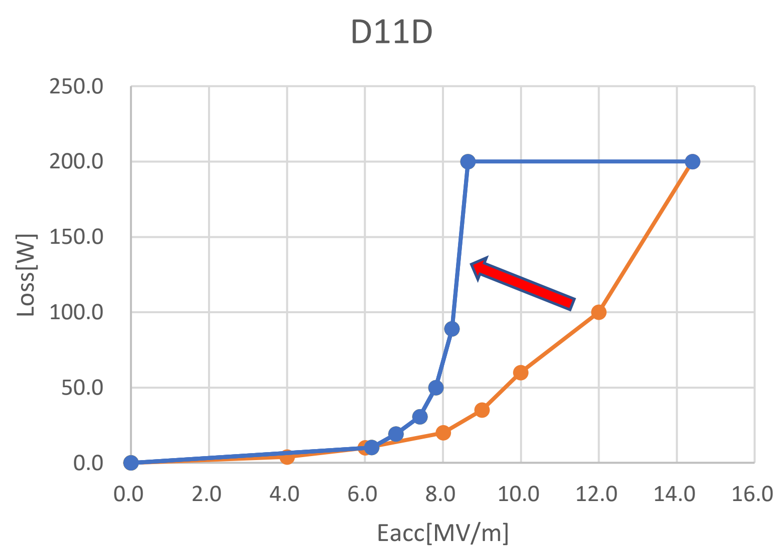


However, Why did the refrigerator detect that the aging operation for cavities was done. The compensation heater doesn't work well.

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.

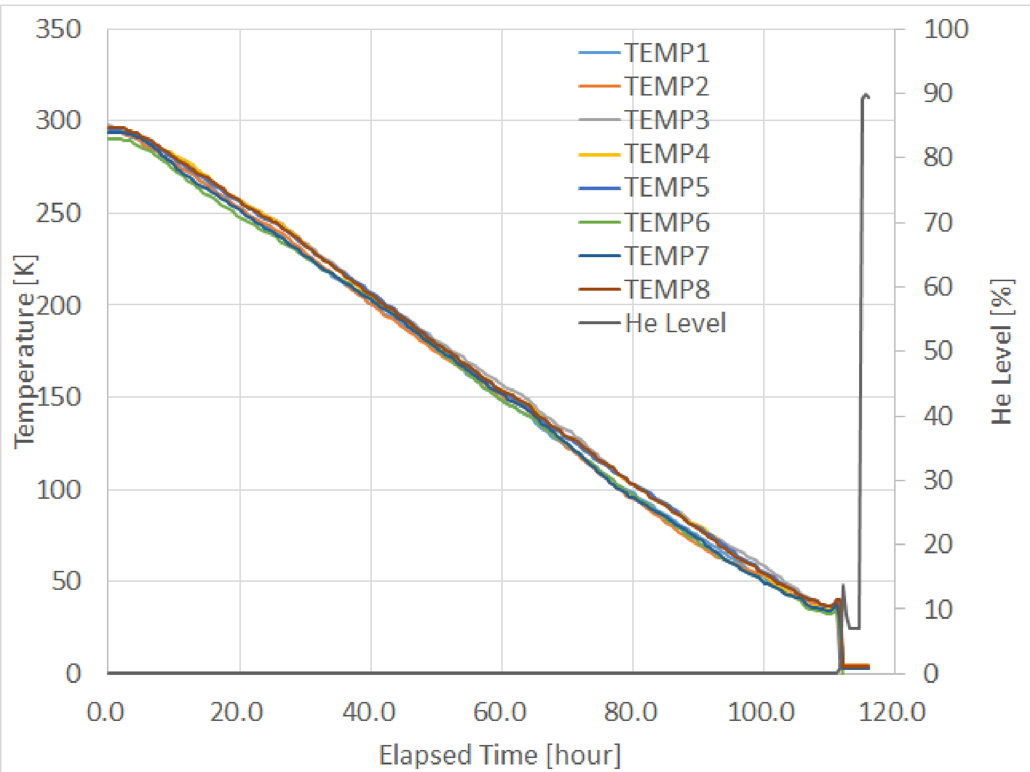
(Cavity group gave us the Q-Eacc data.)



Summary

- In SuperKEKB, superconducting cavities are operated using a cryogenic system constructed for TRISTAN in 1988.
- The refrigerator is powerful enough to cool the superconducting cavities for SuperKEKB.
- Periodic maintenance is done.
- Some spare components are prepared.
- The cryogenic system are very old. However, it is working very stably.
- We are developing some instrument for current and future superconducting cavities.

Cool down



Procedure

Temperature controlled helium gas is supplied from the refrigerator to cool the cavities.

Cooling is started by using helium gas cooled by liquefied nitrogen.

When the cavity temperature reaches 150 K, the turbines were stated.

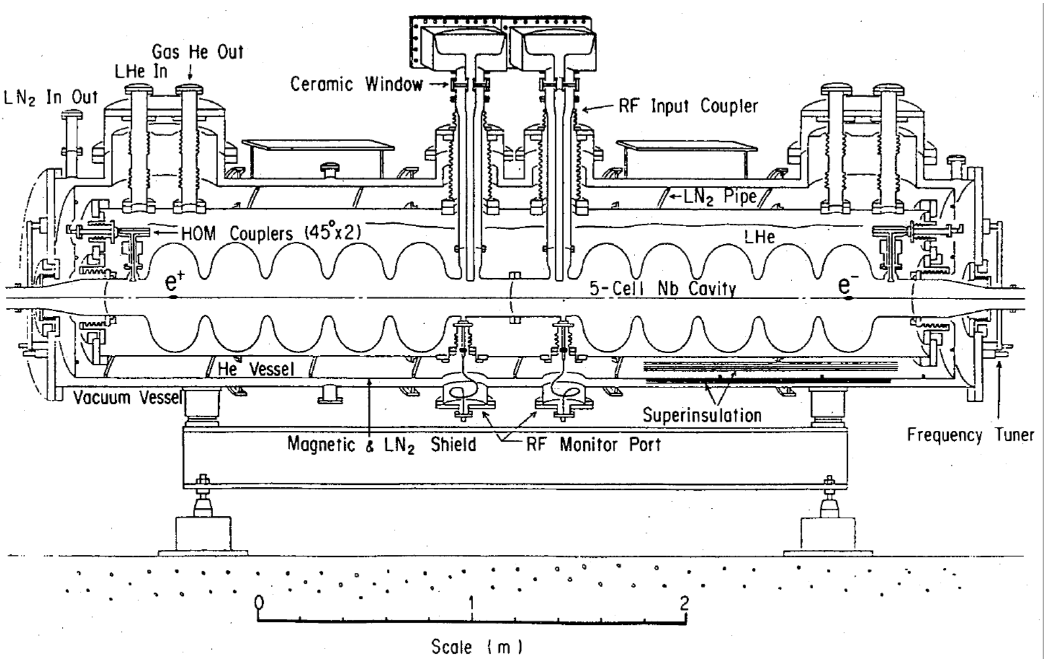
When the cavity temperature reaches 40 K, liquid helium was supplied.

- To reduce deformation due to temperature difference and to suppress vacuum leakage and alignment error, all of cavities cooled down slowly (~2.5K/h) until 40K.

TRISTAN (1988~1995)

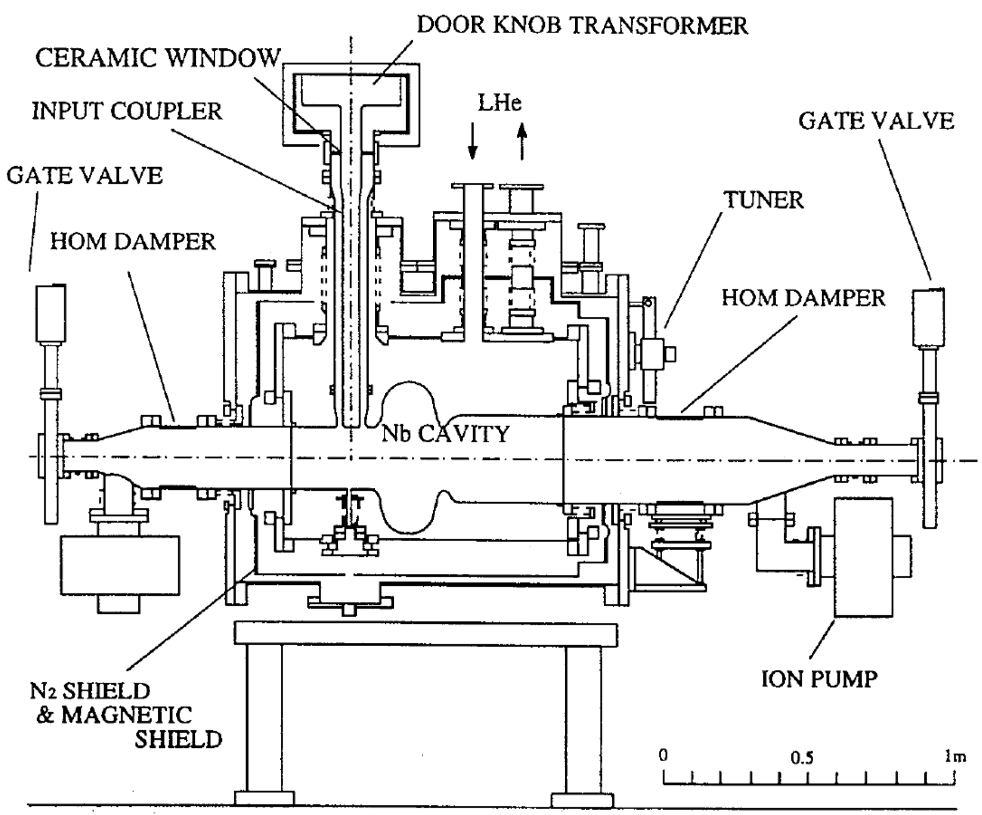
- 32GeV – 32GeV electron-positron collider.
- 8 cryostats were installed. (1988)
- 8 cryostats were added. (1989)

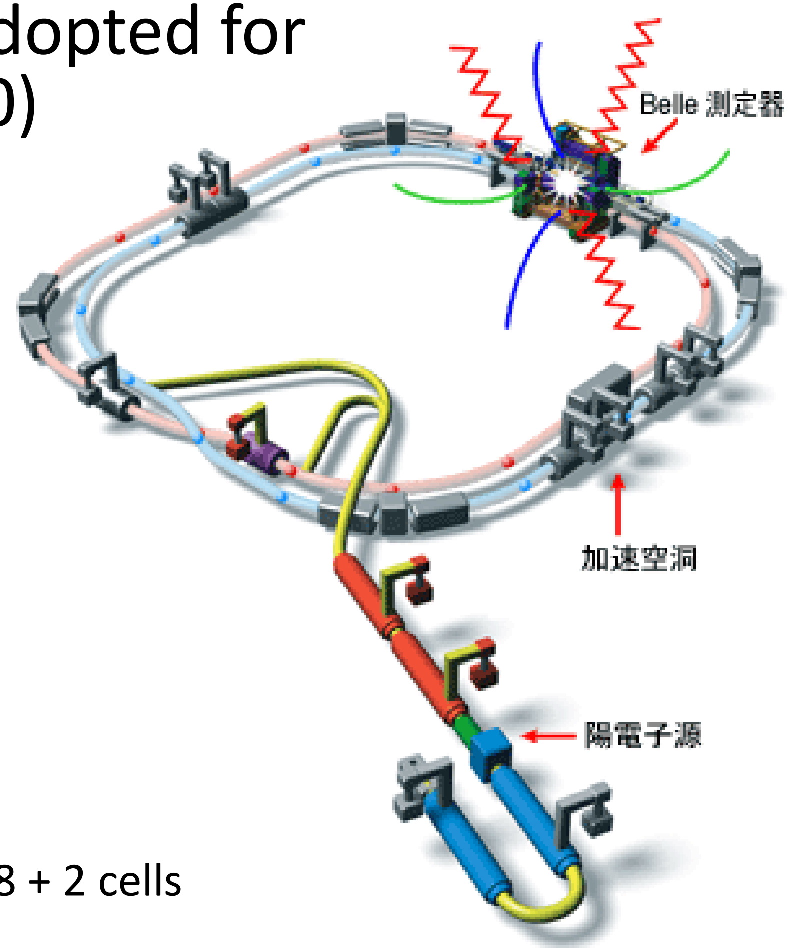
16 cryostat
x 2 cavities/cryostat
x 5 cells/cavity
=160 cells



KEKB (1998~2010)

- 8GeV – 3.5GeV electron-positron collider.
- 8 cryostats for SCC were adopted for HER.
- 2 cryostats for crab cavity were adopted for HER and LER (1 by 1). (2007~2010)

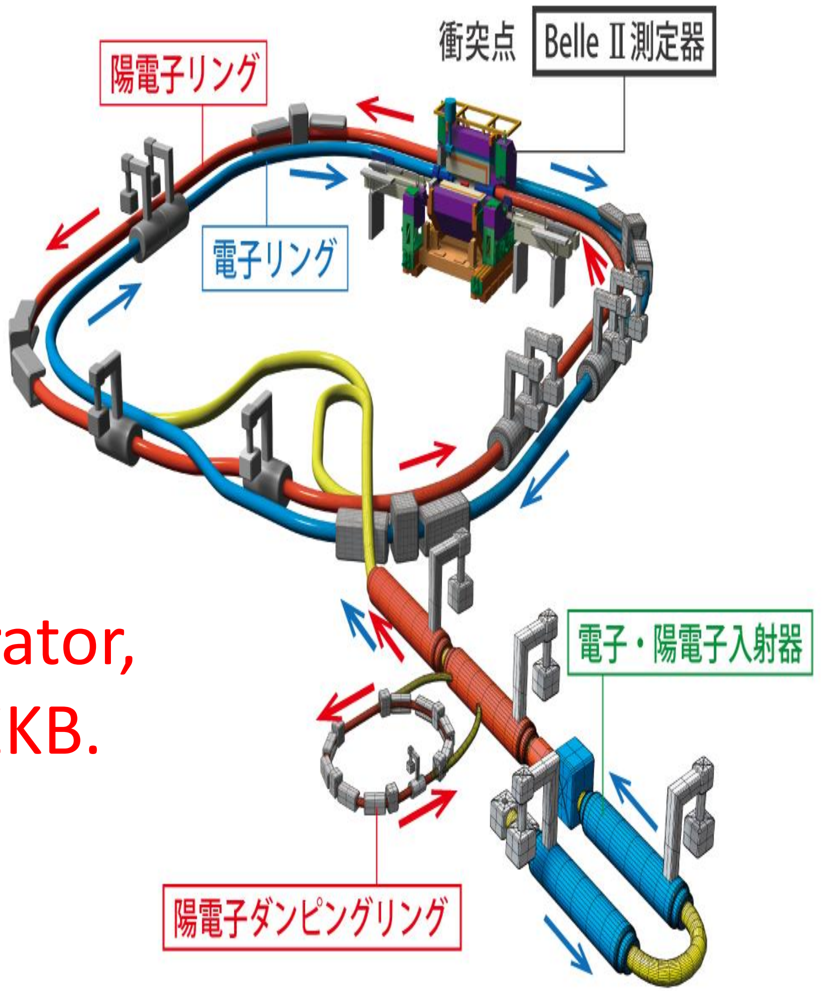




8 + 2 cells

SuperKEKB (2016~)

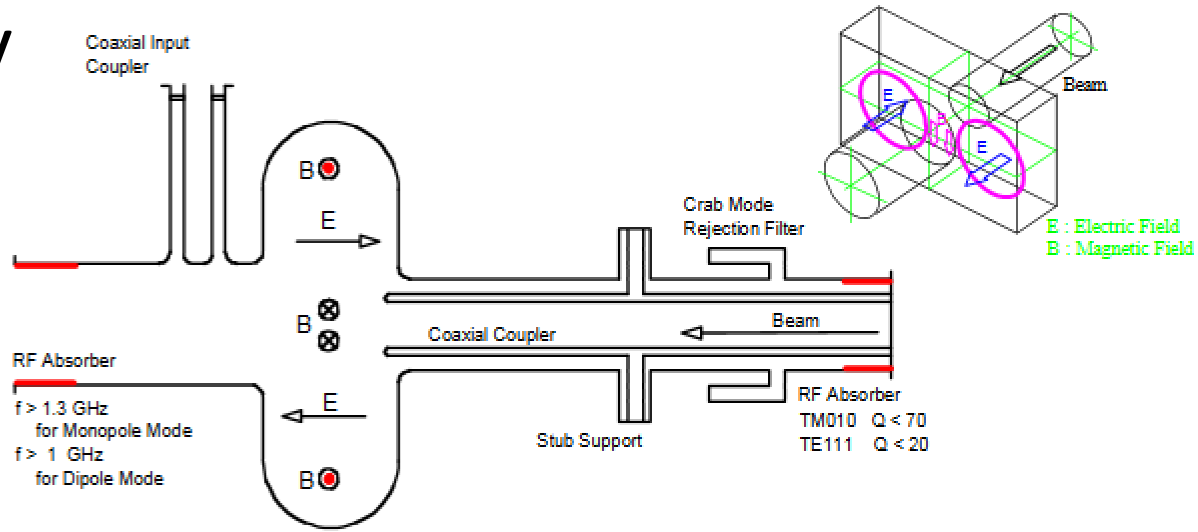
- 7GeV – 4GeV electron-positron collider.
- 8 cryostats for SCC were adopted for HER.
- Crab cavities were removed

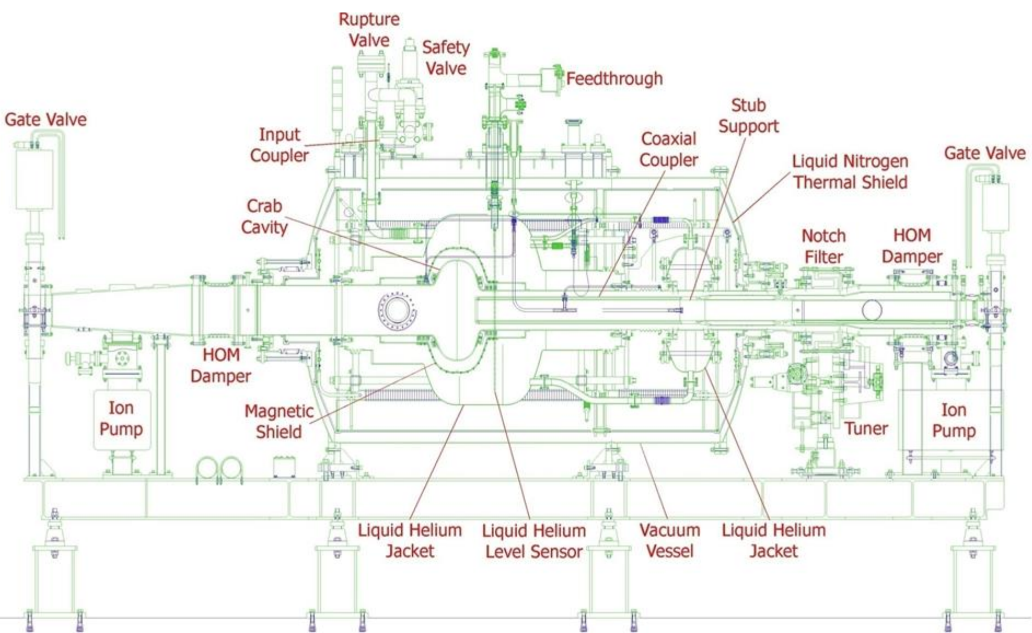


From the viewpoint of the refrigerator, there is almost no change from KEKB.

Crab Cavity

Two crab cavities were adopted in KEKB from2007 to 2010
The coaxial coupler faced in the cavity. It should be superconductor.
To cool it, 5 g/s of liquid He was spend. (~100W)





In SuperKEKB, it was decided not to be used due to the strategy change.
They were removed.