Status of Superconducting Cavity (SCC)

SuperKEKB MAC2018

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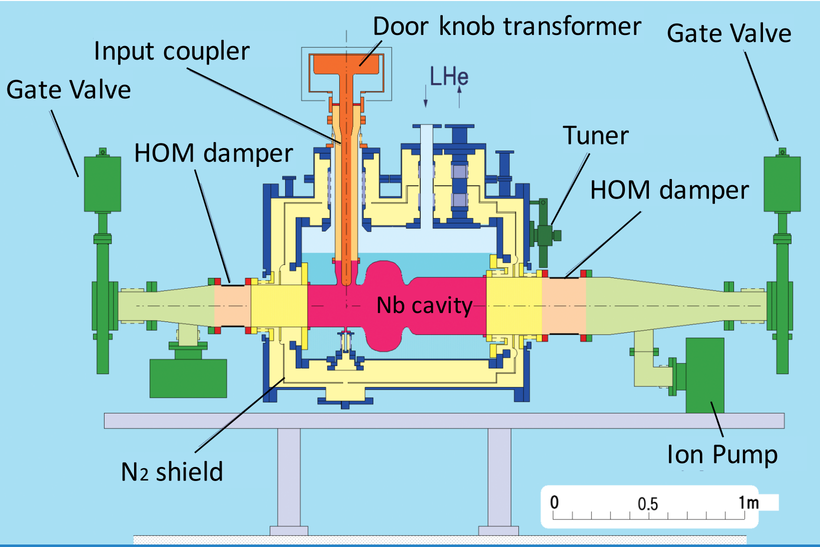
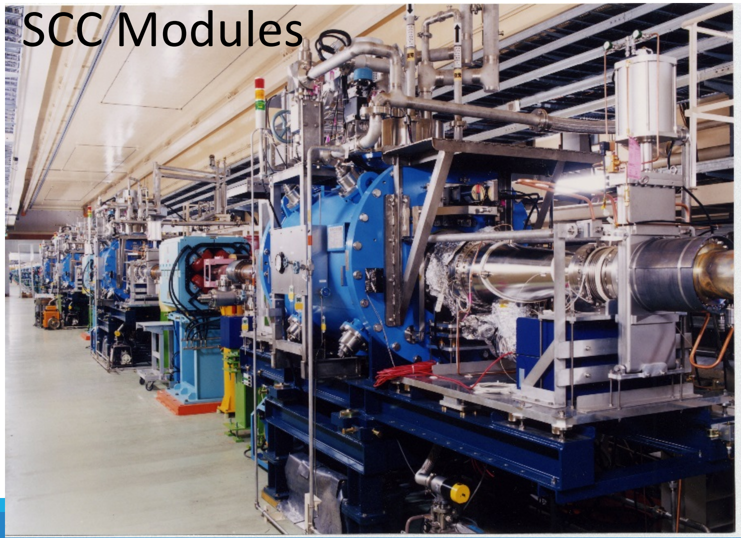
SCC for SuperKEKB

Eight superconducting accelerating cavity (SCC) modules are operating in the electron ring (HER). In HER, RF systems are consist of 8 SCC and 8 normal conducting cavities (ARES).

A 509 MHz single cell cavity with a large iris diameter of 220 mm has ferrite HOM absorbers on both sides and a coaxial-type power coupler. All SCC modules were designed for KEKB and operated under the condition of large beam intensity in KEKB and Phase-1 operation.





Issues for SCC

In a design of SuperKEKB, the total beam power will be 1.5 times larger than that of KEKB achieved due to twice high beam current. The beam power in a SCC module can be kept to be the same as that in KEKB by sharing the power with ARES.

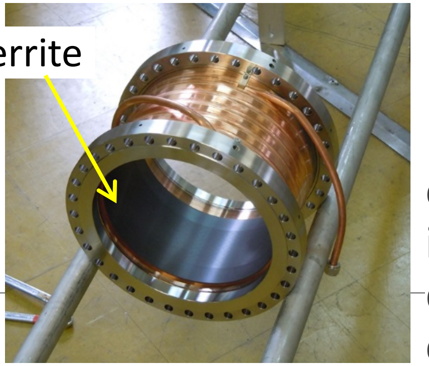
SCC-Related Parameters	KEKB (achieved)	SuperKEKB (design)
Number of Cavities	8	8
Max. Beam Current [A]	1.4	2.6
RF Voltage [MV/cav.]	1.0-1.5	1.5
External Q	5E+4	5E+4
Unloaded Q at 2MV	1E+9	1E+9
Beam Power [kW/cav.]	350-400	400
HOM Power [kW/cav.]	16	37

Main issues for SCC

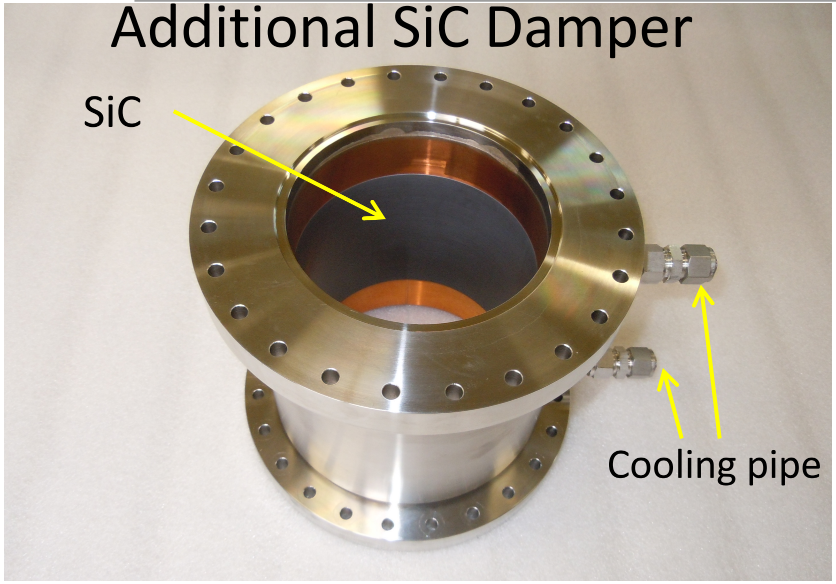
- Large HOM Power
  - ✓ twice high beam current
  - ✓ shorter bunch length
  - ✓ In design current, HOM power in a SCC module is calculated as 37 kW.
- Degradation of Qo
  - ✓ FE caused by vacuum work, He leak and vacuum trouble
- Piezo Tuner Problem
  - ✓ electric breakdown in piezo stacks

HOM Dampers

Existing Ferrite Damper can absorb HOM power up to 2 A operation.



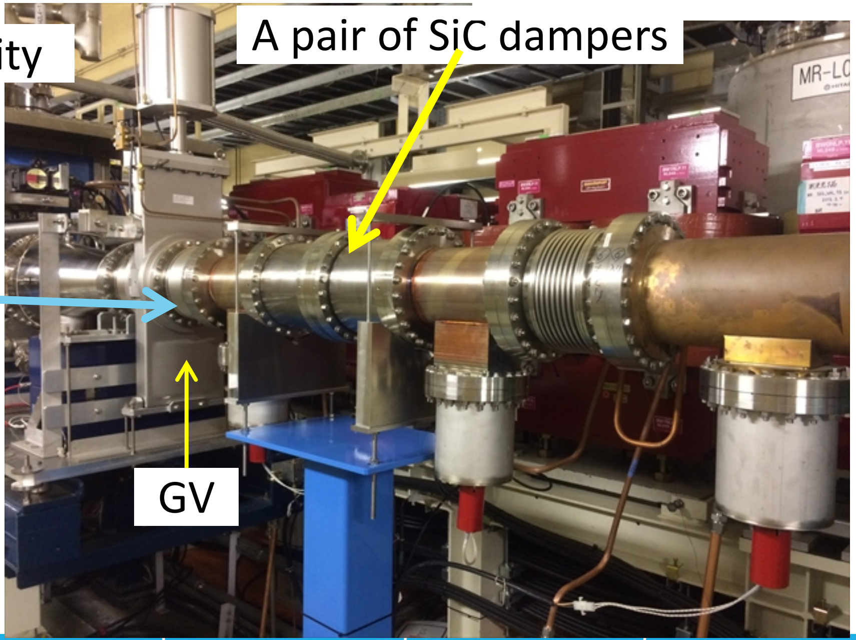
For higher beam current, we need to install additional SiC dampers for all cavity modules.



SiC damper can be installed outside of GV of cavity module. There are no risks due to disassembling of cavity module.

A pair of SiC dampers has been installed downstream of a cavity module last summer.

In Phase-2 operation, beam test will be performed.

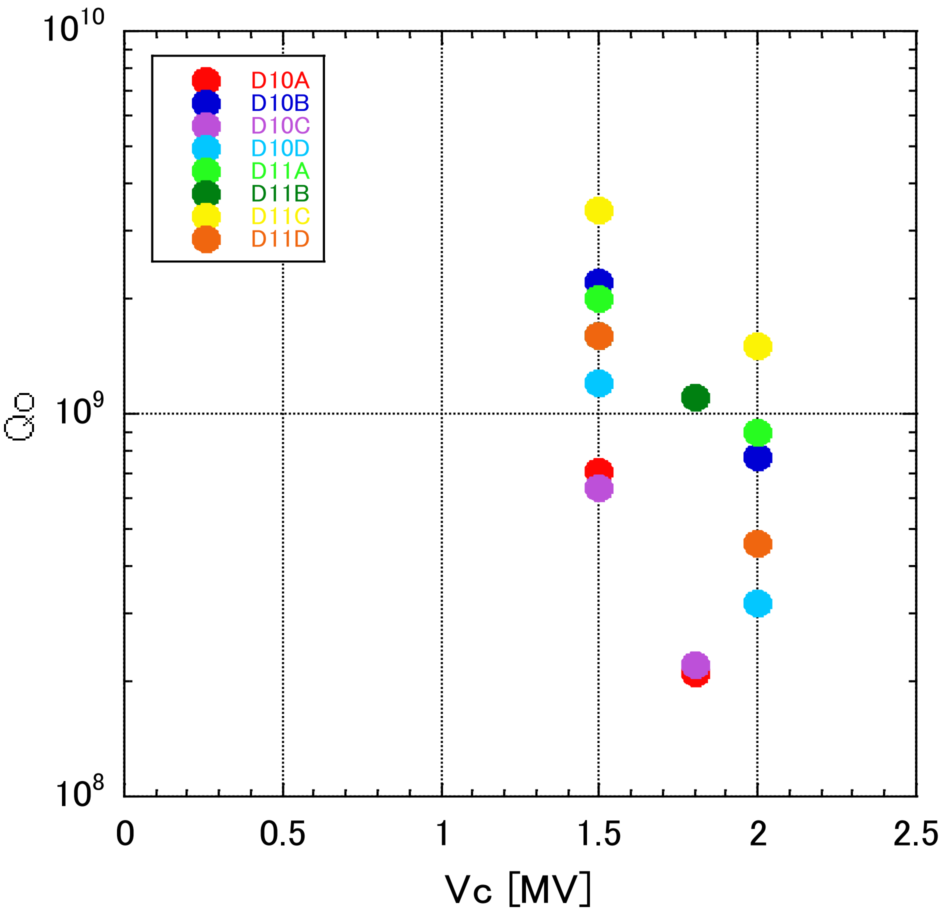


Pabs [kW]	Ferrite SBP	Ferrite LBP	SiC 240mm
Tested max.	19	26	36 (18x2)
Simulation*	9	12	24

* Beam current 2.6A, Bunch length 5mm, Bunch charge 10nC

Degradation of Qo

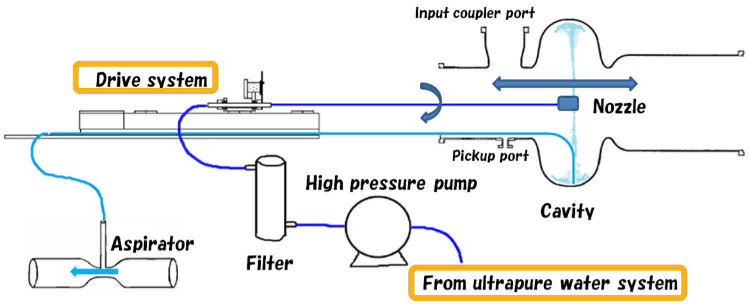
- Several cavity performances are degraded by field emission caused by vacuum work, He leak and vacuum troubles.
- Present cavity performances are acceptable for SuperKEKB operation.
- Further degradation makes the operation difficult.
- Performance recovery is desirable for stable long-term operation.

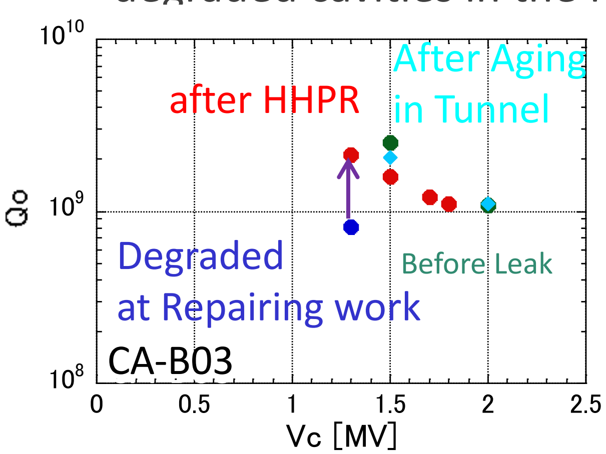


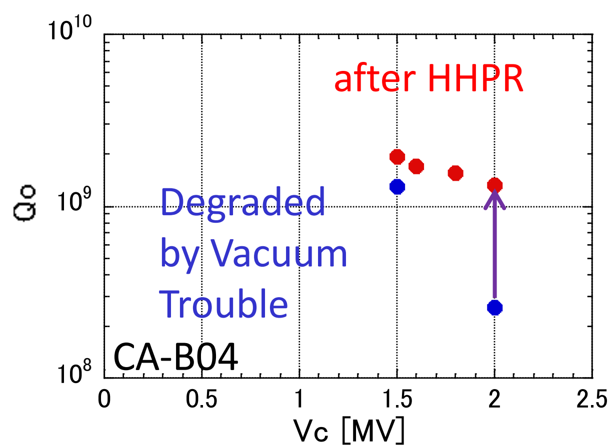
Horizontal High Pressure Rinse (HHPR)

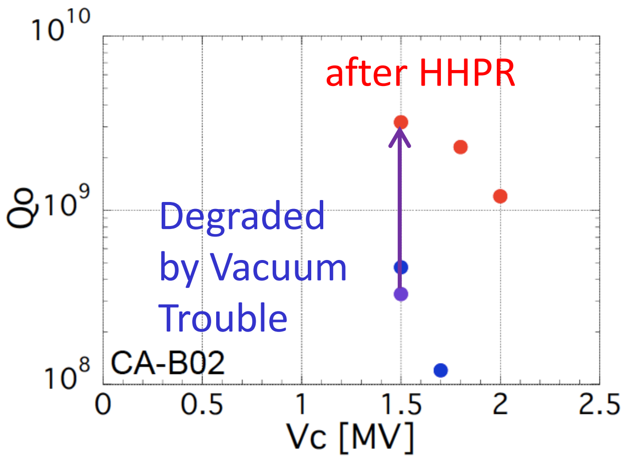
HHPR is established as a recovery method of cavity performance in KEK.

We applied HHPR to three cavities degraded by strong FE. All cavity performances were successfully recovered.
First cavity module has been operated in Phase-1. Second has been installed to replace a degraded cavity last summer. Third is kept as a spare cavity module.
We are planning to apply HHPR to other degraded cavities in the future.









Piezo Tuner Problem

- In the last review, we reported,
  - ✓ Six piezo actuators failed by electric breakdown in 3.5 months operation.
  - ✓ Those actuators were attached to replace old actuators used in the long-term operation.
  - ✓ The new piezo actuators were found to be sensitive to rapid change of voltage at the time of RF On/Off.
  - ✓ Time constant τ of LPFs in the control system should be changed to slow ones. τ = 2 ms -> 20 ms (all cavities) -> 200 ms (two cavities)
- The recommended voltage applying rate by manufacturer is slower than 800V/20ms.
- To optimize the operating condition, the endurance tests of piezo actuators were performed after Phase-1.

Endurance Test of Piezo Actuator

τ [ms]	Voltage [V]	Cycles (On/Off)	Current [mA]	Note
200	560	1000	≤±15	1000 cycles ≈ 10 years operation
200	800	1000	≤±19	800 V is limit of piezo driver.
100	800	1000	≤±36	
20	800	1000	≤±130	Higher than max. current of piezo driver
200	800	12000	≤±69	
200	560	10000	≤±11	Adopted as operating condition

- No electric breakdown was found all tests.
- In the condition of LPF of 20ms, the voltage applying rate is almost the operating limit of the piezo actuator and the current exceeds the limit of the piezo driver.
- The combination of LPF of 200 ms and voltage of 560 V was very stable condition in 10000 cycles. We adopted the combination as the operating condition.

Summary

- Cavity performance after the 1.5-year shutdown

Vc and Qo : almost reproduced the Vc limits and Q factors of Phase-1

- Degraded cavity replacement and HHPR
  - One cavity module degraded by vacuum trouble was replaced with HHPRed one.
  - HHPR was applied to the degraded cavity.
  - Performance was recovered.
- SiC HOM damper
  - A pair of SiC dampers has been installed.
  - In Phase-2 operation, beam test will be performed.
- Piezo actuator
  - The endurance tests for piezo actuators were carried out.
  - The combination of the time constant of LPF of 200 ms and the maximum voltage of 560 V was adopted as the operating condition.

Thank you for your attention!

backup

SuperKEKB Parameters (RF Related)

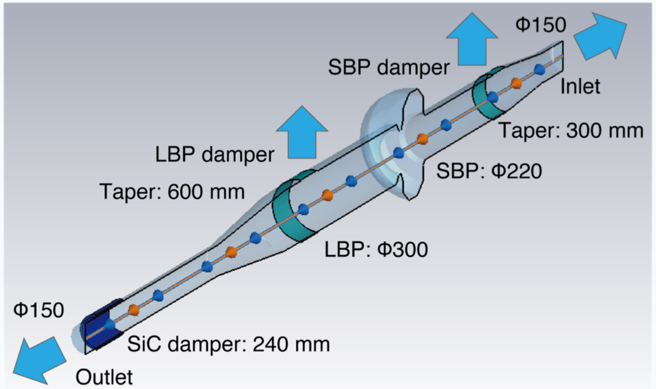
Parameter	unit	KEKB (achieved)				SuperKEKB (design)			
Ring		HER			LER	HER		LER	
Energy	GeV	8.0			3.5	7.0		4.0	
Beam Current	A	1.4			2	2.6		3.6	
Number of Bunches		1585			1585	2500		2500	
Bunch Length	mm	6-7			6-7	5		6	
Total Beam Power	MW	~5.0			~3.5	8.0		8.3	
Total RF Voltage	MV	15.0			8.0	15.8		9.4	
		ARES		SCC	ARES	ARES	SCC	ARES	
Number of Cavities		10	2	8	20	8	8	8	14
Klystron : Cavity		1:2	1:1	1:1	1:2	1:1	1:1	1:2	1:1
RF Voltage (Max.)	MV/cav.	0.5		1.5	0.5	0.5	1.5	0.5	
Beam Power (Max.)	kW/cav.	200	550	400	200	600	400	200	550

Issues for RF systems

- Beam current will be twice of KEKB.
- Bunch length will be short.
- Beam powers is so large, 1.5 times in HER and twice in LER of KEKB.

Power Flow Simulation of Additional SiC Damper

Wake field simulation by CST particle Studio



- Loss Factor including HOM dampers
- Area & Time Integral of Power Flows
  → HOM loads for each part

Another option to reduce HOM power, Large Beam Pipe of 200mm in dia. model

- Same level of ferrite damper loads and outlet power as 240mm SiC model
- Need to replace Q-magnet and beam pipes of ring
- Need to open cavity to the air

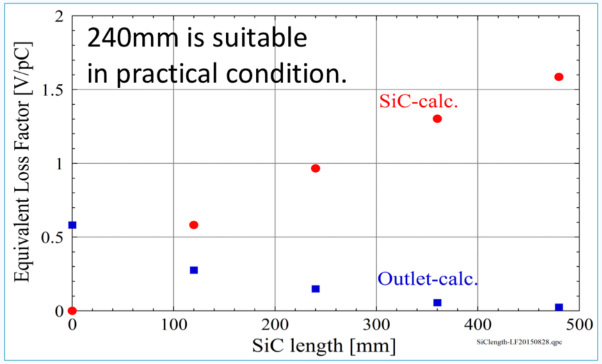
No merit in the model

- Small SBP & LBP damper loads
- Remarkable large outlet energy

→ **Additional SiC Damper at Downstream of Outlet**

	No additional damper		with 240 mm SiC	
	Eq. LF [V/pC]	HOM load [kW]	Eq. LF [V/pC]	HOM load [kW]
Inlet	0.05	1.3	0.05	1.4
Outlet	0.58	15.7	0.15	4.0
SBP damper	0.32	8.6	0.35	9.5
LBP damper	0.43	11.7	0.47	12.8
SiC damper	-	-	0.97	26.1
Total	1.38	37.4	1.99	53.8

Eq.LF vs SiC damper length



SiC damper of 240mm

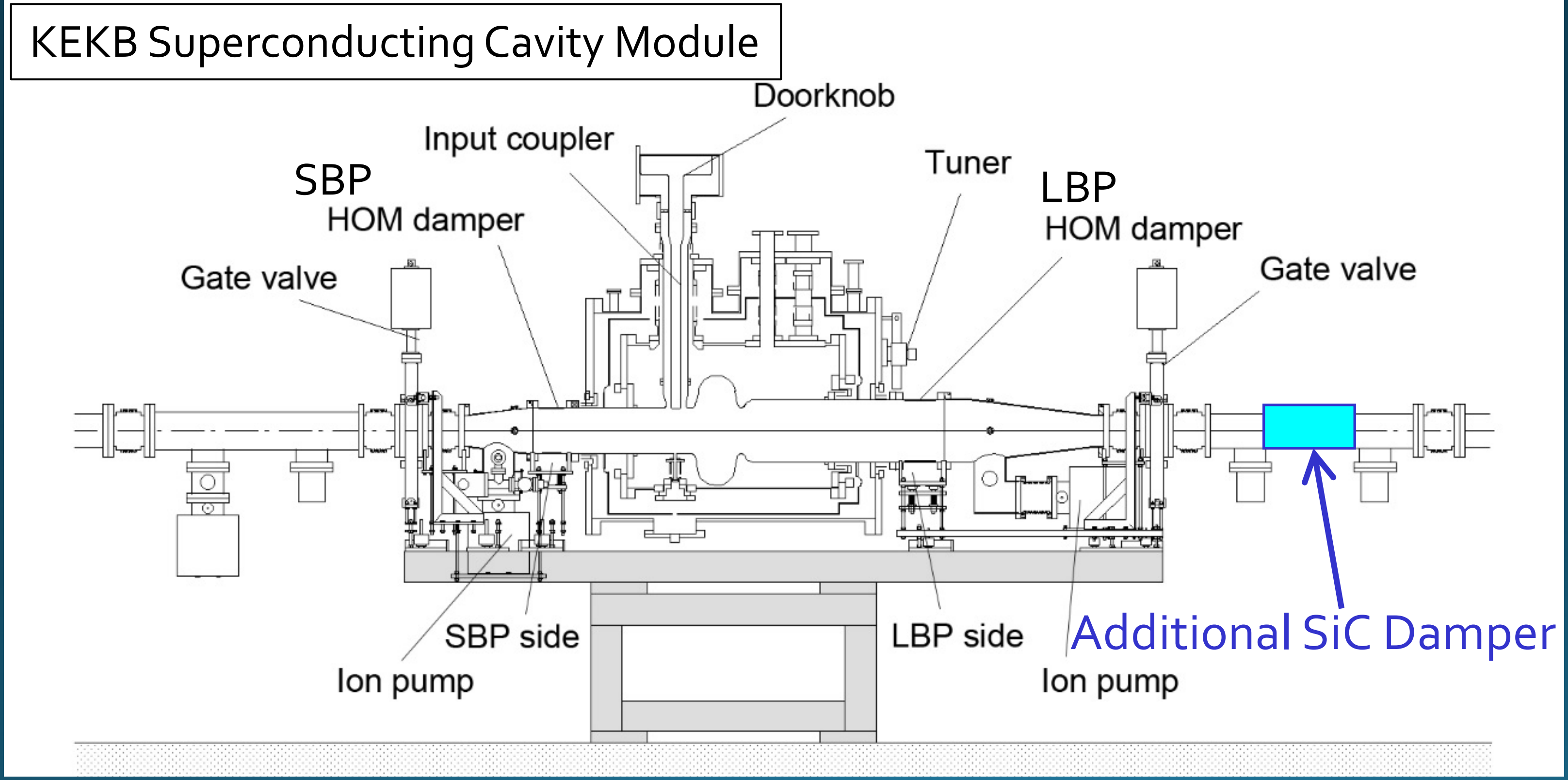
- absorbs effectively outlet power.
- does not change the loads of ferrite dampers. Ferrite temperature will be 100°C, acceptable.
- can be installed without air exposure of cavity.

Advantage of Additional SiC Damper

- Additional SiC Damper

  The damper can be installed outside of gate valve of the cavity module. The cavity surfaces do not need to be exposed to the air.

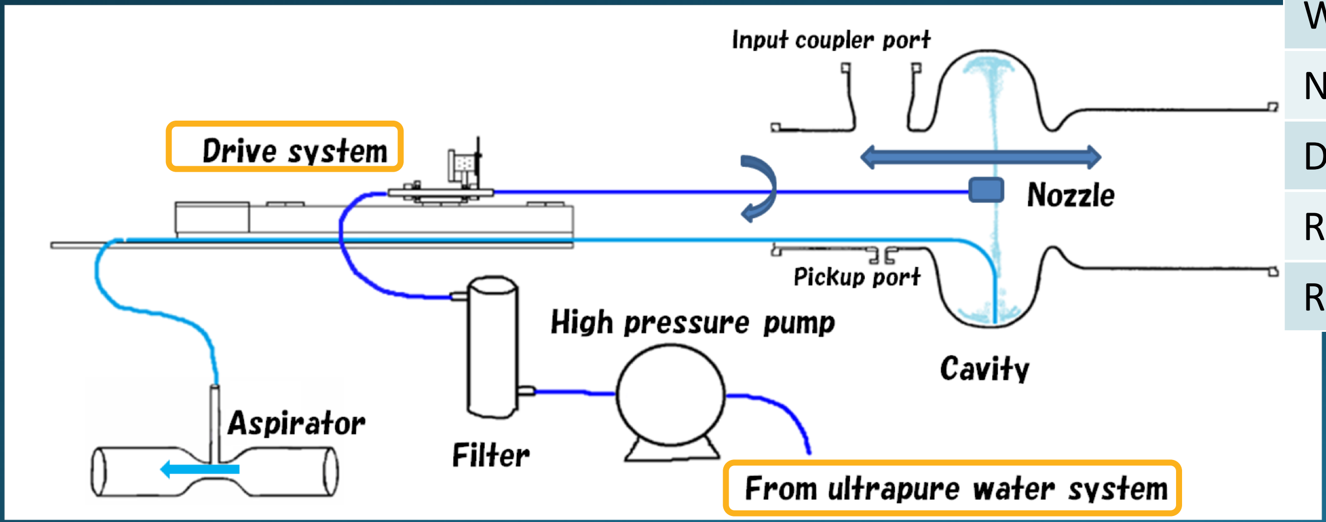
  The risk of degradation of the cavity performance can be avoided.



Horizontal HPR (HHPR) system

- New HPR ultrapure water system was developed.
- The system is equipped with automatic nozzle driving system in horizontal and rotational.
- Input coupler and both end groups, including ferrite HOM damper, taper chamber, bellows chamber, ion pump, vacuum gauges and GV, are removed before HHPR in a clean booth.
- Water in the cell is pumped up by aspiration system during rinsing.
- Only cell and iris area are rinsed.

HHPR Parameters	
Water Pressure	7 MPa
Nozzle	ϕ0.54mm x 6
Driving speed	1 mm/sec.
Rotation speed	6 deg./sec.
Rinsing time	15 min.

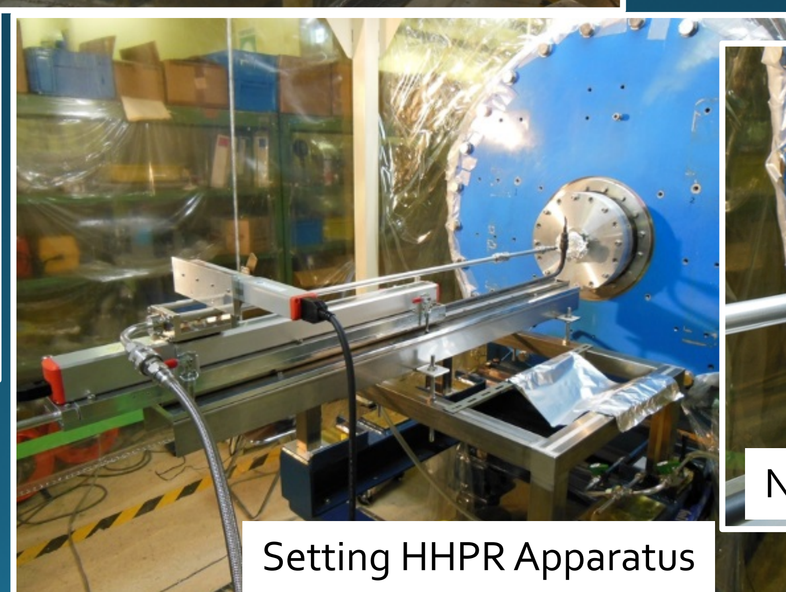


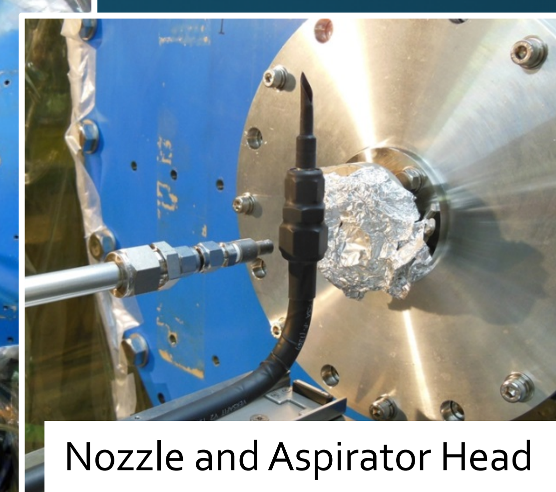
We applied HHPR to degraded cavities.

HHPR Applied to Degraded Cavity


Removing Coupler

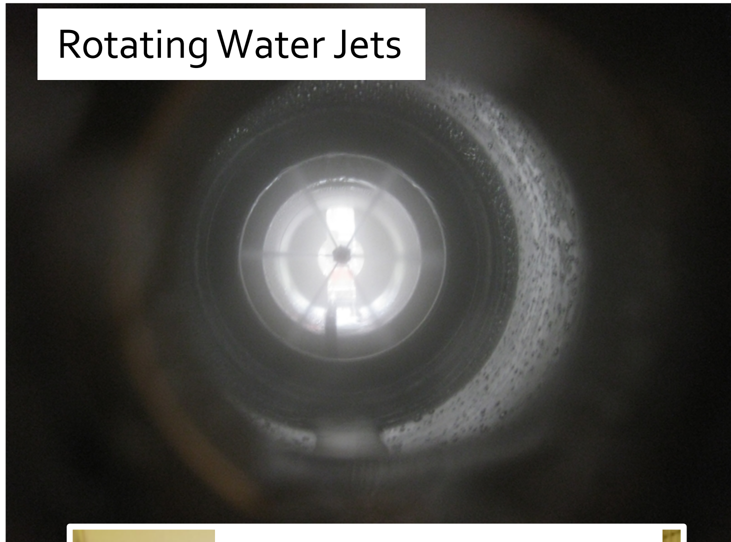

Removing HOM dampers and vacuum system

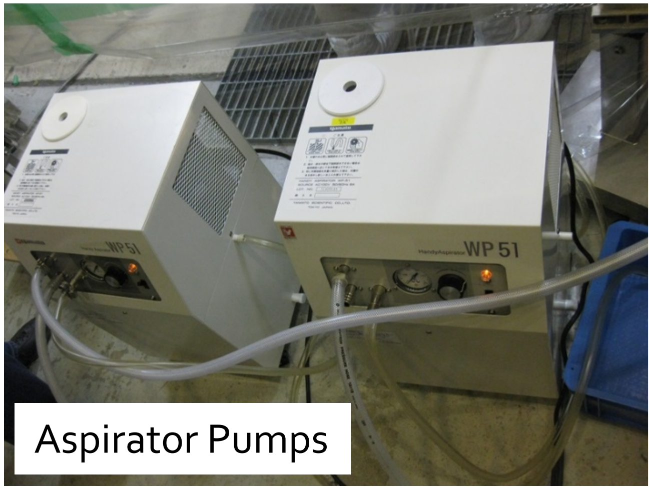

Setting HHPR Apparatus


Nozzle and Aspirator Head

Before HHPR, input coupler and HOM dampers were dismounted in a clean booth.

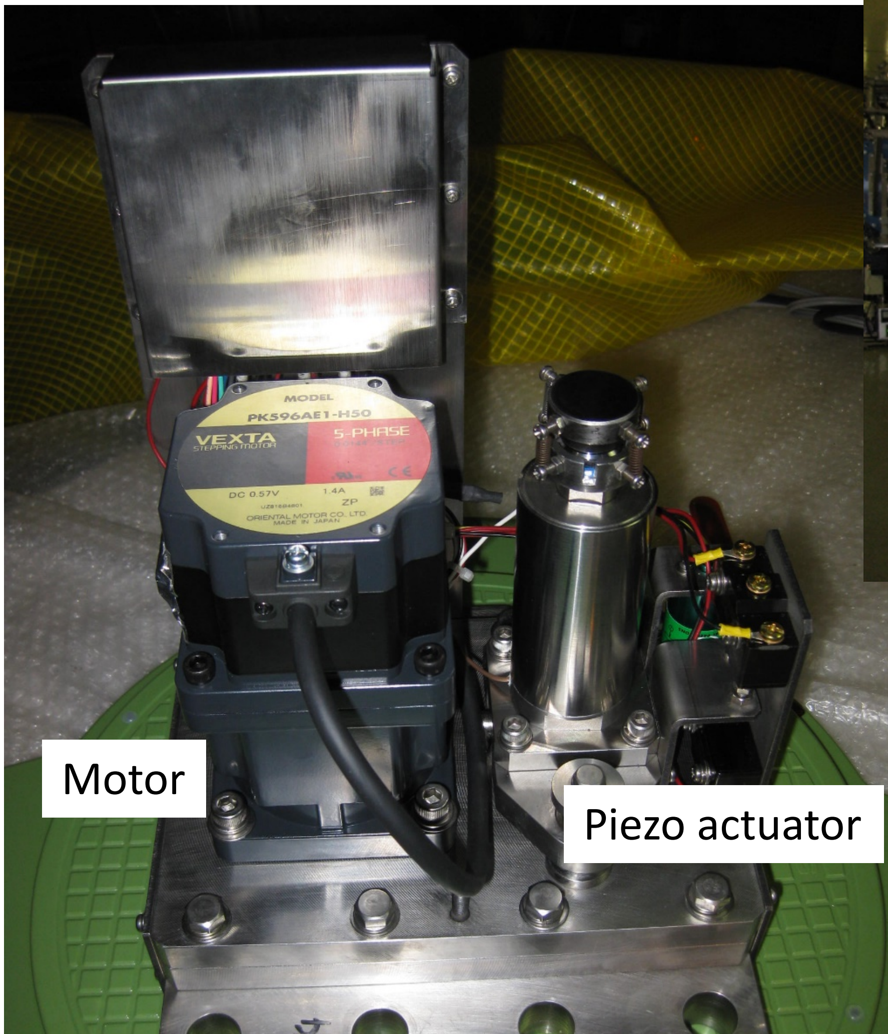
HHPR Applied to Degraded Cavity

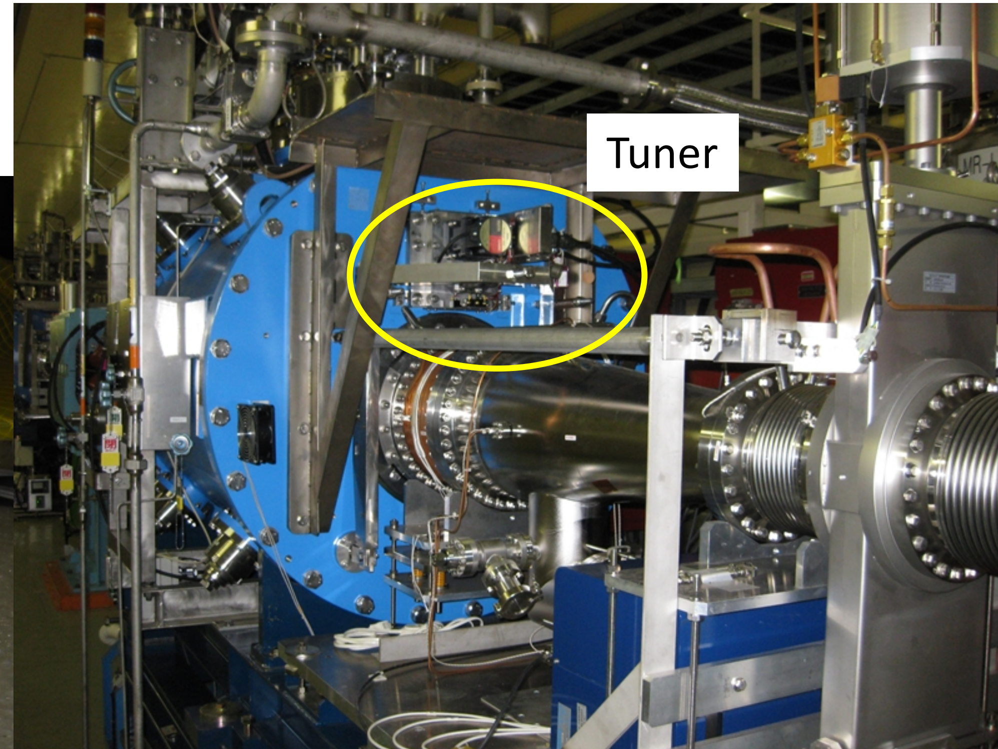




Cavity was dried up by evacuation before setting the coupler and HOM dampers.

Tuner for SCC





Piezo Stroke : 80 µm in 1000 V
44 µm in 560 V

In the usual operation, the stroke is enough for a tuner of our SCC.