DEGRADATION AND RECOVERY OF CAVITY PERFORMANCE IN SRILAC CRYOMODULES AT RIKEN RI-BEAM FACTORY

WEPWB085

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Related papers for SRF' 23: K. Yamada et al., "Operational Experience for RIKEN Superconducting Linear Accelerator" ,MOIXA04
T. Nishi et al., "Development of Non-Destructive Beam Envelope Measurements in SRILAC with Low Beta Heavy Ion Beams Using BPMs" , MOPMB086
K. Ozeki et al., "Present Status of Riken Power Couplers forSRILAC" , WEPWB101

Abstract

The RIKEN superconducting (SC) heavy-ion linear accelerator (SRILAC) has been providing beam supply for super-heavy elements synthesis experiments [1] since its commissioning in January 2020 [2]. However, the long- term operation of SC radio-frequency (RF) cavities leads an increase in the X-ray levels caused by field emissions resulting from changes in the inner surface conditions. More than half of the ten SC 1/4 wavelength resonators (SC-QWRs) of SRILAC, operating at a frequency of 73 MHz, have experienced an increase in X-ray levels, thus, requiring adjustments to the acceleration voltage for continuous operation. While several conditioning methods have been employed for SC cavities, a fully established technique is yet to be determined. To address this, a relatively simple conditioning method was implemented at RIKEN. The proposed method uses high-voltage pulsed power and imposes a low load on the cavities.

[1] H. Sakai et al., Eur. Phys. J. A, vol. 58. pp.238, 2022 [2] K. Yamada et al., SRF' 21, MOOFAV01,pp.167–174.

Introduction and overview of SRILAC

- The RIKEN heavy-ion linac was upgraded to advance the SHE synthesis program beyond nihonium.
- Superconducting linac based on ten SC-QWRs enables to provide ions with A/q=6 with an energy of 6.5 MeV/u.
- The SRILAC is equipped with set of differential pumping systems [5] and no destructive beam monitors like FCs and wire scanners were installed.
- Beam tuning was performed carefully to minimize the beam losses in the SRILAC section [6].

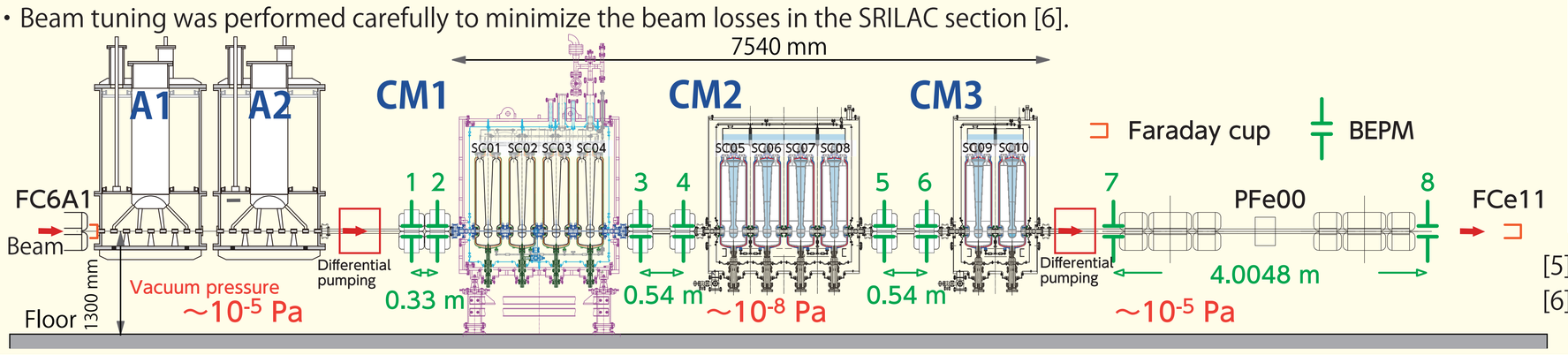


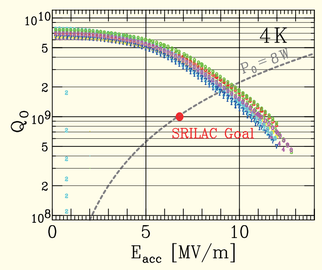
Table 1: SRILAC design parameters

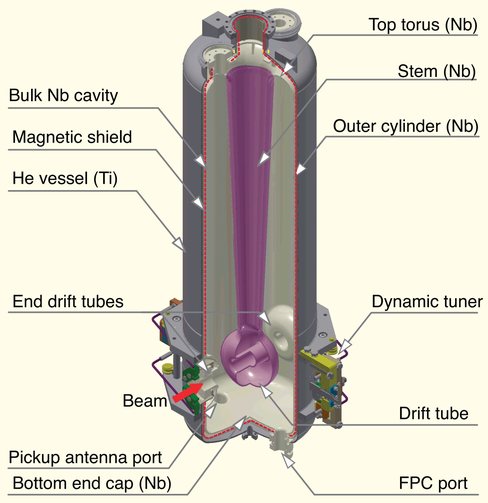
Parameters	
Frequency (MHz)	73.0 (CW)
Maximum operation gap voltage (MV)	2.4
Synchronous phase (°)	–25
β_{opt}	0.078
R_{sh}/Q_0 (Ω)	579
G	22.4
E_{acc} (MV/m)	6.8
E_{peak}/E_{acc}	6.2
B_{peak}/E_{acc} (mT/(MV/m))	9.6
Operating temperature (K)	4.5
Target Q_0	1×10^9
Q_{ext}	$1 - 4.5 \times 10^6$
Amplifier output (kW)	7.5

[5] H. Imao et al., SRF' 19, TIP013, pp.419--423.
[6] T. Nishi et al., this conference, WEPWB101.

RIKEN SC-QWR

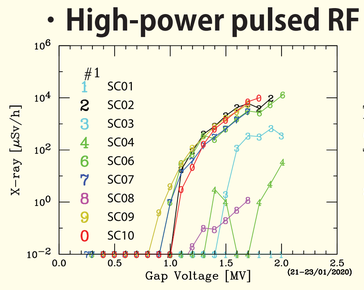
- 73 MHz, **4.5 K**
- Single window coaxial FPC
- Qext = 1 to 4.5 e6
- Local magnetic shield
- BCP1+Annealing+BCP2+ HPR+Baking

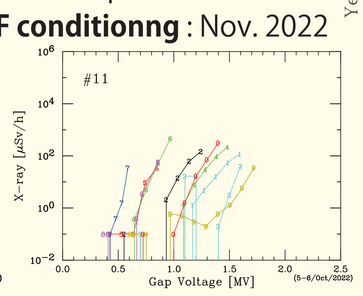


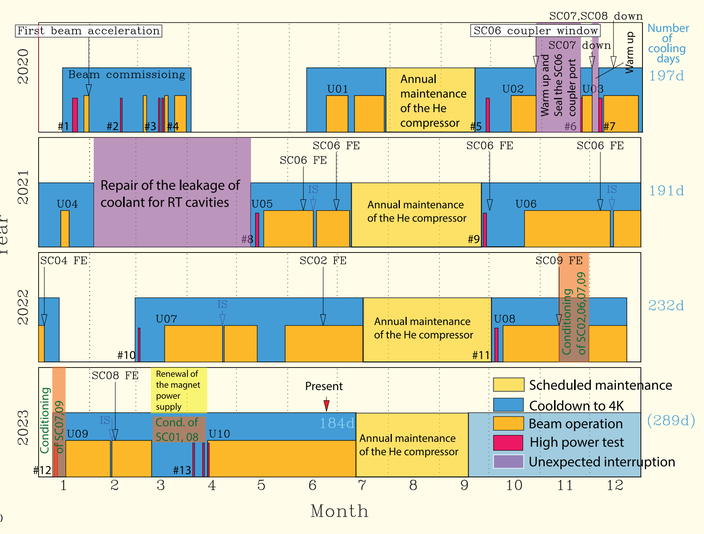


OPERATION HISTORY

- 1st high power RF test:January 2020
- **1st beam : January 2020**
- Vacuum leak from FPC window of SC06
- Ten cavity operation started in May 2021
- MP and FE lowerecd max. acceleration Voltage
- Warm up did not improve the performance
- **High-power pulsed RF conditionng** : Nov. 2022







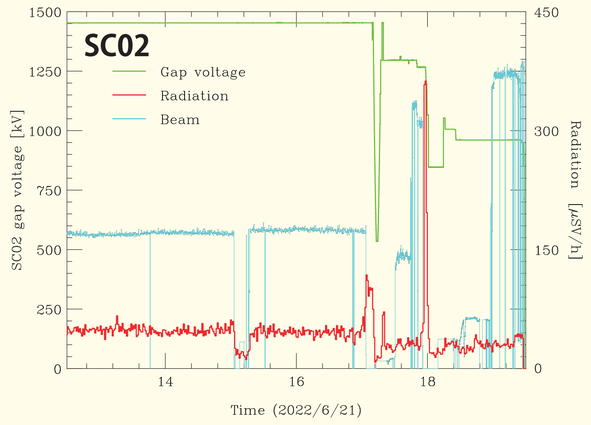
DEGRADATION OF SC-QWRs

- The SC-QWRs experienced continuous degradation after the issue with the coupler window of SC06.
- A gradual increase of the X-ray levels was observed during high-power tests performed routinely after cool-down from room temperature; not so serious.
- We repeatedly encountered sudden increases in the X-ray levels, which were continuously measured for each CM during beam service.

Table 2: Events related to SC-QWRs

Date	Events
10/27/2020	SC06 Vacuum leak
12/1/2020	SC07 down
12/7/2020	SC08 FE increase
12/13/2020	SC07, SC08 down
5/10/2021	10 QWRs operation
6/9/2021	SC06 FE increase
6/29/2021	SC08 FE increase
9/30/2021	SC06 FE increase
12/6/2021	SC06 FE increase
1/3/2022	SC04 FE increase
6/21/2022	SC02 FE increase
11/14/2022	SC09 FE increase
2/15/2023	SC08 FE increase

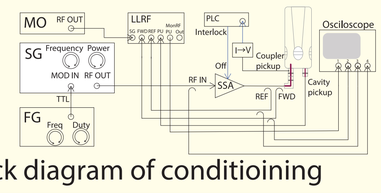
[7]N. Sakamoto et al., SRF' 21, MOPFAV005,pp.316–318.



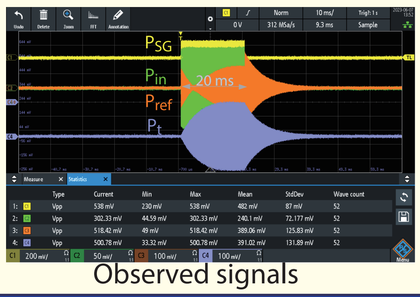
FIRST ATTEMPT ON PERFORMANCE RECOVERY (SC07)

- Conditioning method using high-voltage pulsed RF power, which is relatively simple and imposes a low load on the SC cavities.
- At KEK this method has been adopted to the cERL injector cryomodule, and the cavity performance was successfully recovered [8].
- Pulsed RF power with 1.34 MVp successfully reduced the SC07 X-rays for CW operation.

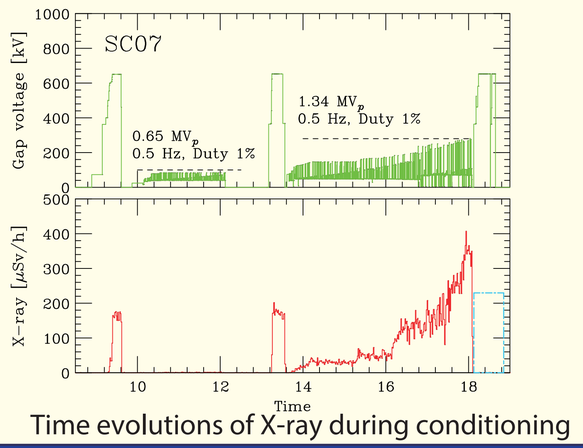
[8] E. Kako et al., SRF' 17, MOPV097,pp.289–293.



Block diagram of conditioning



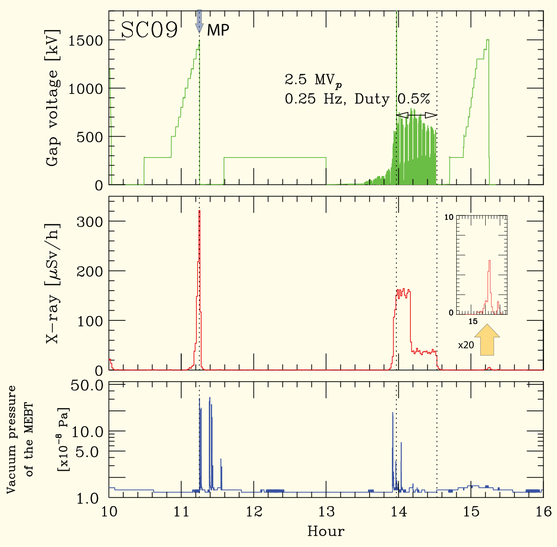
Observed signals



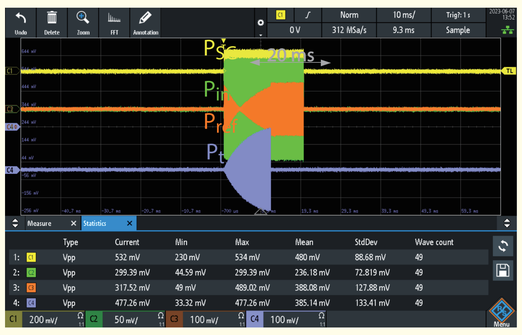
Time evolutions of X-ray during conditioning

WHY THE HIGH-POWER PULSED RF CONDITIONING IS EFFECTIVE TO RIKEN SC-QWRs

- Multipacting (MP), which causes a sudden drop of the gap voltage, is another issue
- Some of the SC-QWRs could not hold required acceleration voltage owing to MP.
- In the X-ray measurement before conditioning, MP occurred at the gap voltage of 1.5 MV and a deterioration of the vacuum pressure of the adjacent MEBT was observed.



- Occasionally, a sudden loss of the pickup signal was observed (see below), accomplished by variation in the vacuum pressure.
- After completing the conditioning, MP occurred scarcely.

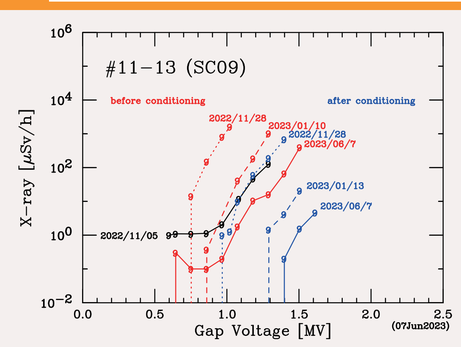


SC09

Table 3: History of the pulsed RF power conditioning. Here V_p^{max} is a maximum pulsed voltage of the SC-QWRs.

Date	Cavity	Time	V_p^{max} [MV]
11/22/2022	SC07	7:37	1.34
11/24/2022	SC06	4:05	1.52
11/28/2022	SC09	1:14	1.57
11/29/2022	SC02	0:37	1.98
1/12/2023	SC07	0:54	1.55
1/13/2023	SC09	1:44	1.99
3/29/2023	SC08	2:35	1.80
4/13/2023	SC01	0:40	2.23
6/7/2023	SC09	1:13	2.54

Hiher peak power



A higher peak power led to a higher onset gap voltage.

SUMMARY AND FUTURE PLAN

- **The SRILAC has been in operation for the past four years.**
- **However, the degree of performance degradation has become a significant issue, jeopardizing the continuity of operations.**
- **Therefore, high-power pulsed RF conditioning was tested to restore the performance.**
- **During the period considered in this study, the proposed method successfully limited the X-ray levels.**
- **Currently, minimal conditioning is being performed to sustain beam operation.**
- **In the near future, we plan to conduct helium processing test using a prototype cavity.**