LONG TERM CAVITY PERFORMANCE IN COMPACT-ERL INJECTOR CRYOMODULE

E. Kako[†], T. Konomi, T. Miura, H. Sakai and K. Umemori
KEK, High Energy Accelerator Research Organization, Tsukuba, Ibaraki, Japan
also at SOKENDAI, The Graduate University for Advanced Studies, Hayama, Kanagawa, Japan

Abstract

After cryomodule assembly and first cool-down tests in 2012, cERL injector cryomodule including three 2-cell cavities has been stably operated with beam for 3.5 years. Remarkable increases of x-ray radiation levels due to field emission were observed during beam operation in June, 2015. High power pulsed RF conditioning as a cure method was applied in the successive cool-down period in 2016, so that degraded cavity performances have almost recovered up to the original levels.

INTRODUCTION

In order to demonstrate an excellent performance for a future project in ERL (Energy Recovery Linac), beam commissioning in compact-ERL (cERL) at KEK has been steadily in progress [1]. The target values of a beam current and beam energy in the cERL are 10 mA and 35 MeV, respectively. Operational beam currents at a beam energy of 20 MeV have increased step by step, up to 10 μA in 2014, 100 μA in 2015 and 1.0 mA in 2016 [2]. An injector cryomodule is required to accelerate CW electron beams of 10 mA from the beam energy of 500 keV to 5.0 MeV [3]. The injector cryomodule consists of three 2-cell cavities [4] equipped with double-feeds input couplers, five antenna-type HOM couplers and a slide-jack tuner with two piezo actuators. Assembly of the injector cryomodule was started in April, 2012, and the completed cryomodule was installed in the accelerator hall in July, 2012 [5]. After this, cool-down cycles of 10 times have been carried out in the injector cryomodule for 5 years. Degradation of cavity performances during long term beam operation and performance recovery by high power pulsed RF conditioning are described in this paper.

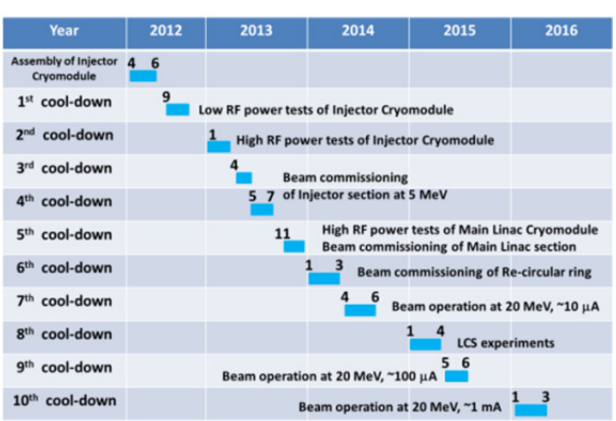

Figure 1: Cool-down cycles of injector cryomodule.

† eiji.kako@kek.jp

INJECTOR CRYOMODULE

History of cool-down cycles in the injector cryomodule is summarized in Figure 1. The injector cryomodule installed in the cERL beam line is shown in Figure 2. After low RF power tests in Sept. of 2012 and high RF power tests [6] in Feb. of 2013, beam commissioning of the injector section at 5 MeV was started in April, 2013. The operational accelerating gradients (Eacc) of three 2-cell cavities were 7.1, 7.5 and 7.1 MV/m in CW operation. The No.1 cavity is driven by a 30 kW klystron, and the No.2 and No.3 cavities are driven by a 300 kW klystron. An injector section, which includes an electron-gun with DC-500 kV, a bunching cavity and an injector cryomodule, is connected with a merger section, as shown in Figure 3. Three x-ray detectors to observe field emission phenomena in three cavities were attached outside of the injector cryomodule. Beam commissioning of re-circular ring with a main-Linac (ML) cryomodule including two 9-cell cavities was started in Dec. of 2013. The beam energy of 20 MeV in the re-circular ring was determined by relatively lower operating Eacc at 8.2 MV/m in two 9-cell cavities to avoid x-rays and dark currents due to heavy field emission [7]. In this case, the injection energy was lowered to 3.0 MeV, instead of 5.0 MeV.

Figure 2: Injector cryomodule installed in beam line.

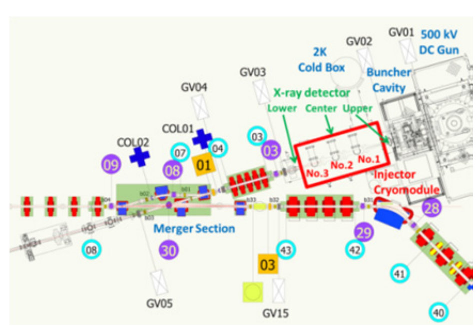

Figure 3: Schematic drawing of injector section.

ISBN 978-3-95450-147-2

LONG TERM BEAM OPERATION

Two periods of cool-down cycles in 2015 are shown in Figure 4. Pumping down of Liq.-He from 4.2 K to 2 K was routinely carried out every morning, and helium temperature was kept at 4.2 K during night. Two quench events occurred during beam operation for total 16 weeks. Severe increases of x-ray radiation levels were observed in 10th -26th June, as shown in Figure 5. An x-ray detector located at the upper-stream (gun-side) of the cryomodule showed about 1000 times larger values by jumping up from 0.1 to higher than 100 mSv/h. It is supposed that contaminated fine particles come from beam pipes of the lower-stream (merger-side) seems to produce many sources of field emitters inside three cavities. It was found that field emitted electrons, which run away from the No.3 cavity, were accelerated by the No. 2 and No.1 cavities. Furthermore, these electrons went toward the upper-stream and finally collided with a cathode surface of the DC-gun. Consequently, the beam operation at 5 MeV could not maintain, so that the beam energy at the injector was lowered up to very a few x-ray radiation level.

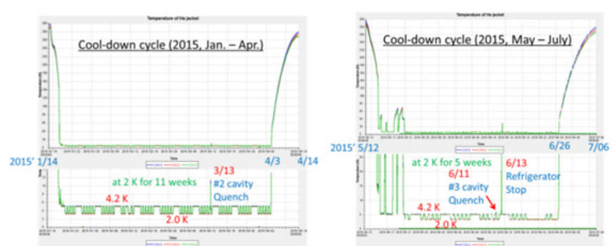

Figure 4: Daily change of cavity temperatures during 8th (left) and 9th cool-down period (right) in 2015.

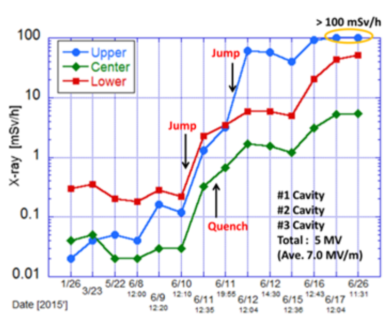

Figure 5: Increase of x-ray radiation levels observed by three detectors located in upper, central and lower-side of injector cryomodule during beam operation at 5 MV driven by three cavities.

PERFORMANCE DEGRADATION

Changes of x-ray radiation levels at 7.0 MV/m in each individual cavity is shown in Figure 6 (left). The radiation levels in all three cavities were lower than 0.01 mSv/h in the initial state. However, the radiation levels around the No.3 cavity close to the merger section increased to 0.5 mSv/h after one-year operation, and then 9 mSv/h after two-year operation, and finally 80 mSv/h. As seen this figure, degradation of cavity performance firstly initiated in the No.3 cavity, and the contamination area seems to have gradually extended toward the No.2 cavity and No.1 cavity. Estimation of Q_0 values was carried out by measurements of a helium-gas flow rate. The Q_0 values at 7.0 MV/m in each cavity are shown in Figure 6 (right). The reason for the low Q_0 values of $2x10^9$ in the initial state was explained due to heating up at an antenna tip of five HOM feedthroughs [6]. The Q_0 values in the No.3 cavity dramatically degraded after the measurement in June 11th, together with heavy x-ray radiations.

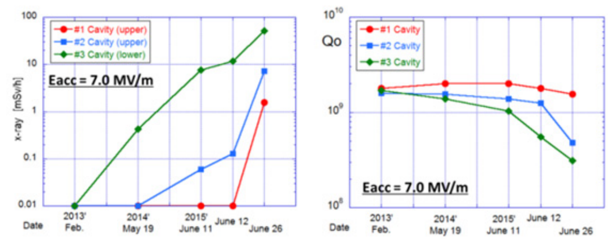

Figure 6: Increase of x-ray radiation levels at 7.0 MV/m by an individual cavity operation (left), and degradation of Q_0 values measured by a helium-gas flow rate (right).

HIGH POWER PULSED CONDITIONING

One of potential methods to cure degraded cavity performances is a pulsed RF conditioning with high power. RF parameters for pulsed conditioning are summarized in Table 1. Two klystrons of 30 kW and 300 kW can supply

Table 1: RF conditioning parameters; Measured loaded Q value (Q_L), Filling time of Eacc (τ-filling), Required RF power for achieving Eacc = 15 MV/m and 20 MV/m.

	No.1 cavity	No.2 cavity	No.3 cavity
Q_L	1.2 x 10^6	5.3 x 10^5	5.4 x 10^5
τ -filling	0.15 msec	0.07 msec	0.07 msec
15 MV/m	12 kW	27 kW	27 kW
20 MV/m	21 kW	47 kW	47 kW

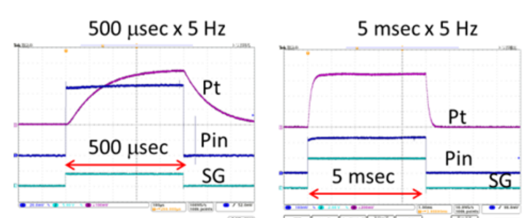

Figure 7: Pulsed waveforms for RF conditioning.

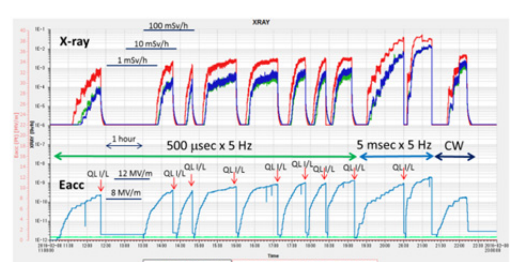

Figure 8: Time evolutions of x-ray radiation levels (top) and accelerating gradients, Eacc, (bottom) during high power pulsed RF conditioning for 11 hours.

enough RF power to the cavities. The RF conditioning was carried out by three steps; 1. short pulse (duty 0.25%), 2. long pulse (duty 2.5%) and 3. CW. The typical pulsed waveforms are shown in Figure 7. Observed x-ray and Eacc during RF conditioning are shown in Figure 8. Here, quench detection by a lower Q_L calculated from a decay time of Eacc in every RF pulse was applied, and it worked very well, effectively.

RECOVERY OF CAVITY PERFORMANCE

After warm-up to room temperature, any changes of x-ray radiation levels did not observed in the beginning of the 10^{th} cool-down, as shown in Figure 9 (left). The x-ray radiation levels dramatically decreased by high power pulsed RF conditioning, as shown in Figure 9 (right). Especially, onset level of x-ray in the No.1 and No.2 cavities successfully improved from 5 MV/m to 8 MV/m by suppression of field emission activities. The x-ray radiation level at 7 MV/m in the No.3 cavity also remarkably lowered from around 100 mSv/h to less than 1 mSv/h. The x-ray radiation levels and the He-gas flow rate during three-cavity operation are shown Figure 10 and Figure 11, respectively. The x-ray radiation levels observed at 5 MV decreased to 0.1~1 mSv/h by pulsed RF conditioning, so that He-gas flow rate was also reduced to about 60 m^3/h, (the maximum cryogenic capacity is about 85 m^3/h.). As the results of conditioning, a stable beam operation at 5 MeV in the injector section become to be possible, again. After beam operation for 9 weeks in the 10^{th} cool-down period, the recovered cavity performances were still maintained without further degradation.

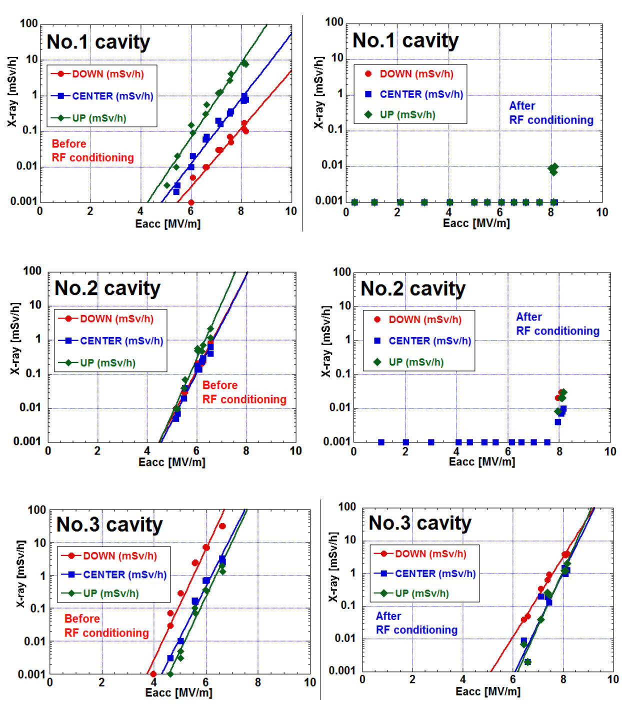

Figure 9: Observation of x-ray radiation levels in CW operation, before (left) and after (right) high power pulsed RF conditioning in an individual cavity; No.1 cavity (top), No.2 cavity (middle) and No.3 cavity (bottom).

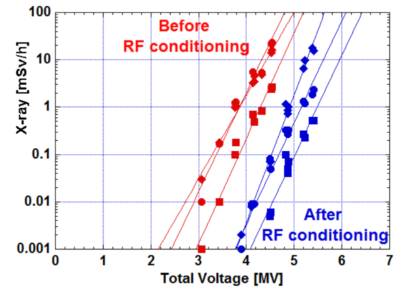

Figure 10: X-ray radiation levels in three-cavity operation before (red) and after (blue) pulsed RF conditioning.

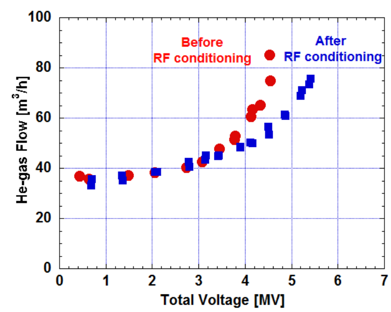

Figure 11: He-gas flow rate in three-cavity operation before (red) and after (blue) pulsed RF conditioning.

SUMMARY

Observation of x-ray radiation levels around the injector cryomodule showed gradual increases during long term beam operation. Cavity performances in the injector cryomodule were seriously degraded due to heavy field emission during beam operation at 5 MeV injection. The degraded cavity performances were successfully recovered by high power pulsed RF conditioning with duty cycles of 0.25% and 2.5%.

REFERENCES

[1] S. Sakanaka, et al., "Recent Progress and Operational Status of the Compact ERL at KEK", Proc. of IPAC2015, Richmond, VA, USA (2015) 1359-1362.

[2] T. Obina, et al., "Recent Developments and Operational Status of the Compact ERL at KEK", in this conference, TUPOW036.

[3] S. Noguchi, et al., "Present Status of Superconducting Cavity System for cERL Injector Linac at KEK", Proc. of IPAC10, Kyoto, Japan (2010) 2944-2946.

[4] K. Watanabe, et al., "Development of the Superconducting RF 2-cell Cavity for cERL Injector at KEK", NIM-A, 714 (2013) 67-82.

[5] E. Kako, et al., "Construction of Injector Cryomodule for cERL at KEK", Proc. of IPAC2012, New Orleans, Louisiana, USA (2012) 2239-2241.

[6] E. Kako, et al., "High Power Tests of Injector Cryomodule for cERL", Proc. of IPAC2013, Shanghai, China (2013) 2340-2342.

[7] K. Umemori, et al., "Operation Status of Compact ERL Main Linac Cryomodule", Proc. of IPAC2014, Dresden, Germany (2014) 2537-2539.

ISBN 978-3-95450-147-2