OPERATION STATUS OF COMPACT ERL MAIN LINAC CRYOMODULE

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Abstract

We developed ERL main linac cryomodule for Compact ERL (cERL) project, which was constructed in KEK. The module includes two 9-cell L-band superconducting cavities. After construction of cERL recirculation loop, beam operation was started. First electron beam successfully passed the main linac cavities. After adjusting beam optics, energy recovery operation was achieved. Main linac cavity was enough stable for ERL beam operation, however, field emission was a problem for long term operation.

COMPACT ERL PROJECT

Compact ERL (cERL)[1, 2] is a test facility, which was constructed on the ERL Test Facility in KEK. Its aim is to demonstrate technologies needed for future multi GeV class ERL. One of critical issues for ERL is development of the superconducting cavities.

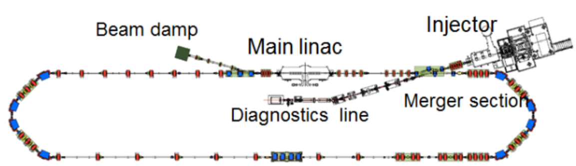

Figure 1: Conceptual layout of the cERL project.

Conceptual layout of the cERL is shown in Figure 1. The cERL main linac cryomodule was assembled and placed inside cERL radiation shield at fall of 2012. First high power test of cryomodule was carried out at December of 2012[x].

After commissioning of injector parts, recirculation ring was constructed during the summer and fall of 2013. Following the second high power test of main linac cryomodule, beam commissioning was started from December of 2013.

Its main parameters are shown in Table 1. Although the target beam parameters are 35MeV and 10mA for the first stage of cERL, current operation is limited to 20MeV and 10 μA. The beam energy was restricted because of severe field emission of main linac cavities. The beam current was limited due to safety reason. In this paper, we present performance of main linac cryomodule under the cERL beam operation.

Table 1: Main Parameters for cERL Project

Beam energy	35 – 245 MeV
Beam current	10 – 100 mA
Normalized emittance	0.1 – 1 mm mrad
Bunch length	1–3ps (usual) 100 fs (bunch compression)

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MAIN LINAC CRYOMODULE

The left of figure 2 shows a schematic view of the main linac cryomodule [3], which contains two 9-cell KEK ERL model-2 cavities [4] mounted with He jackets. Beampipe-type ferrite HOM absorbers [5] are connected at both sides of cavities, to strongly damp HOMs. The HOM absorbers are placed on 80K region. Coaxial input couplers [6] with double ceramic windows feed RF power to the cavities. Frequency tuners [7] control cavity resonant frequencies. Cooling pipes of 80K, 5K and 2K are extended throughout the cryomodule. The 80K line was cooled by Nitrogen, and 5K and 2K lines were cooled by Helium. After filling with 4K liquid He, insides of the He jackets were pumped down and the cavities were cooled down to 2K.

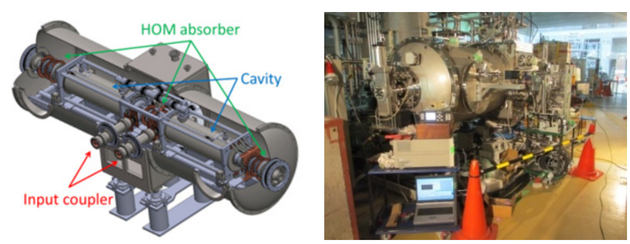

Figure 2: Schematic view of ERL main linac cryomodule (left) and the one placed inside the cERL radiation shielding room (right).

CERL BEAM OPERATION

Main Linac Cryomodule Performance

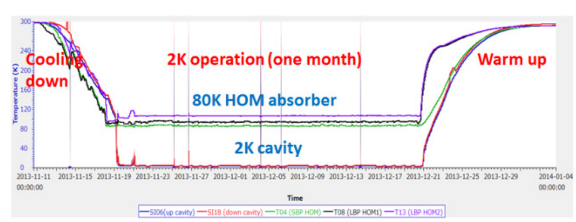

Figure 3: Example of cryogenic operation for the run at December of 2013. Temperatures of cavities are shown by red and blue lines.

Main linac cryomodule was connected to He refrigerator system and cooled down to 2K. Figure 3 shows typical example of cryogenic operation, at December of 2013. The cryomodule was cooled down with cooling rate of less than 3K/hour, in order to avoid thermal stress to the ferrite HOM absorbers.

At the second high power tests, one of main topics was preparation of the digital LLRF system [8]. Cavity fre-

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quencies are controlled by the digital feedback system using the piezo tuners. Also RF amplitude and phase on the main linac cavities are stabilized by the digital feedback system. RF stability of 0.02 % R.M.S. for amplitude and 0.02 degree R.M.S. for phase were achieved. These values satisfied the requirement to the cERL operation. Microphonics was also well suppressed.

Unfortunately, main linac cavity performance was not so good. Severe field emission was observed from low fields, for both cavities. Operation voltage was limited to 8.5 MV for each cavity, to avoid the problem caused by the heavy radiation. Therefore operation energy of cERL beam was limited to 20 MeV; 3 MeV at injector part and 8.5 + 8.5 MeV at main linac part.

cERL Beam Operation

Beam commissioning of cERL recirculation ring started at December of 2013. At first, main linac cavities were detuned and the electron beam passed the cavities. After that, low field was applied to the upper cavity, and acceleration phase was searched. For this aim screen monitors were used. The left of Figure 4 shows example of beam profile at the first arc section. The right of Figure 4 shows beam position, i.e. energy, dependence on RF phase. On crest RF phase can be found from this scan and also acceleration voltage can be checked with the field strength of the bending magnets. These procedures were applied to both cavities.

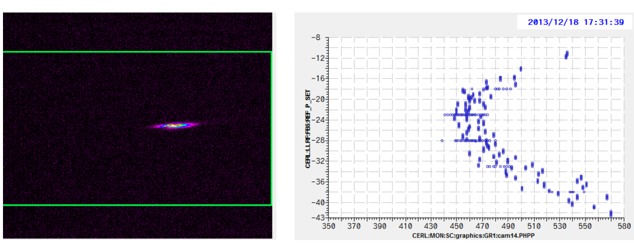

Figure 4: Beam profile observed by a screen monitor at the first arc section (left) and the RF phase scan to find acceleration phase (right).

Precise and dedicated beam tuning had been carried out and electron beam could successfully circulate the ring and reached to the beam dump. For the ERL, adjustment of recirculation loop length is important for energy recovery. Deceleration phase of main cavities were investigated from the position of the screen monitor and the field strength of bending magnet at the beam dump section, while changing the length of recirculation loop by adjusting chicane or arc sections.

Figure 5 shows trials of energy recovery experiment. In the "Beam loading test", electron beam of 6.5 μA CW was accelerated by the upper cavity and then decelerated by the lower one. The beam loading effect can be seen in the figure as the variation of difference between input and reflection power. It is noted that the sign of this variation is opposite between two cavities. On the other hand, in the "Energy recovery test", no variation can be seen within measurement precision. This means energy recovery is successfully performed.

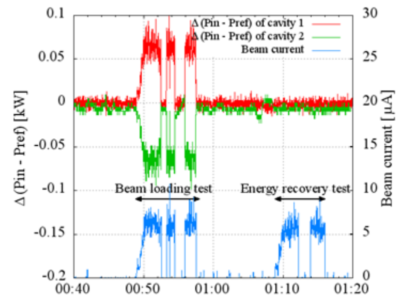

Figure 5: Energy recovery trial. Beam loading effect cannot be seen on "Energy recovery test". In the Beam loading test, upper and lower cavity only accelerates and decelerates electron beams.

LONG TERM CAVITY PERFORMANCE

For the superconducting cavities, especially for CW accelerators, field emission is one of big issue against stable operation. In order to monitor real time radiation status, Si PIN diodes and ALOKA radiation monitors were used. As shown in the left of Figure 6, sixteen sensors were set like a ring, around the beampipe at each side of each cavity. Total 64 sensors were used for monitoring. The right of Figure 6 shows typical radiation distribution measured by Si PIN diodes. They are sensitive to angle information of field emissions. Monitoring this distribution, we can get some information about emitter locations. Two ALOKA monitors were located both end of cryomodule, at almost beamline height, and used also to see radiation information.

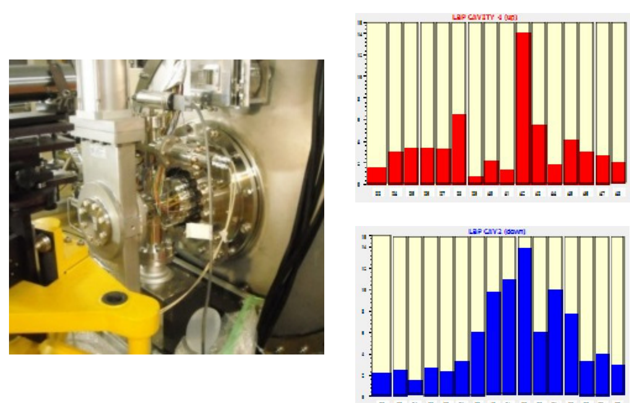

Figure 6: (Left) Si PIN diodes located around beam pipes and (right) example of radiation data taken by those Si PIN diodes.

For the cERL operation, we selected acceleration voltage of 8.5MV for each cavity. This is higher than radiation on-set for both cavities. Thus, our cavities have been operated with field emissions. Even during beam operation, sometimes increases of radiation were observed. Increases of signals were seen both of Si PIN diodes and ALOKA monitors. One radiation history taken by ALOKA monitors is shown in Figure 7. Increase of radiation is observed at February 14.

Q-values of cavities were several times measured. Results are shown in Figure 8. Although radiation existed and Q-values were low from the first high power test at 2012, after some period of beam operation, Q-values became further worse. Reason why field emission became worse is not clear, at present. We will continue more investigations and more dedicated analysis.

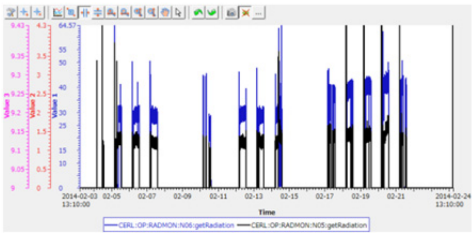

Figure 7: History of radiation status, monitored by ALOKA monitors, during cERL beam operation for three weeks at February of 2014. Radiation increased at February 14. Spikes at the beginning of dairy operation are due to RF aging.

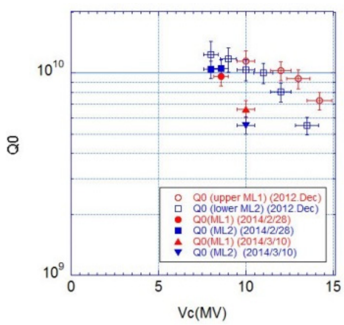

Figure 8: History of Q-values vs acceleration voltage. Red and blue points are for upper and lower cavities, respectively. The Q-values were degraded during beam operation period.

As one trial to suppress field emissions, pulse processing method was applied. Several milliseconds of additional few MV pulses were added to nominal 8.5MV CW RF field. Figure 9 shows the trial of pulse processing to the upper cavity. Figure 9 (a) shows RF field applied on the cavity and (b) shows its pulse structure. Figure 9(c) shows variations of radiation signals monitored by Si diodes during processing. Time period of Figure (a) and (c) are same. It can be seen that several radiation signals became smaller during processing. Radiation becomes about half. Thus, Pulse processing method is considered to be effective to suppress field emissions.

At moment, field emission limits main linac cavity performance. To recover the design acceleration field of 15MV, it is essential to eliminate it. Our ideas of countermeasure against field emission are as following; (a) apply more sophisticated pulse processing, (b) apply He processing, (c) disassemble the cryomodule, apply HPR to the cavities and reassemble it.

It is noted that suppression of field emission is of course essential for CW operation of superconducting cavities, but also recovery method from heavy field emission is important. If an effective recovery method is realized, possibly without disassembling the cryomodule, it is desirable.

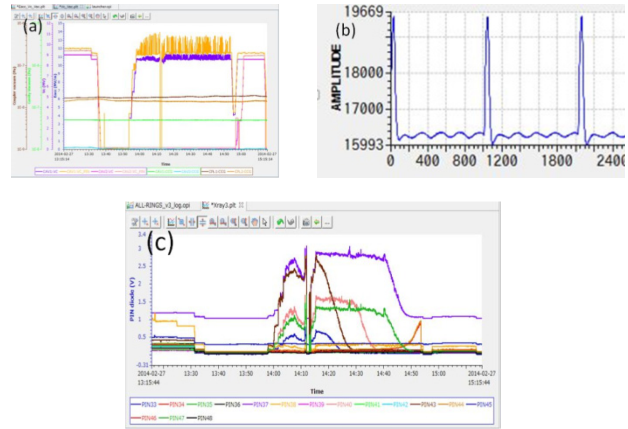

Figure 9: (a) RF field during pulse processing and (b) its magnification. (c) Decrease of radiation signal, observed by Si PIN diodes, during pulse processing.

SUMMARY

The compact ERL in KEK was constructed and beam commissioning has been carried out for recirculation loop. Operation voltage of main linac cavities was restricted to 8.5MV per cavity. After beam tuning, energy recovery operation was successfully performed. RF stability of cavities were enough good for cERL beam operation. Field emission is one big issue for CW operation of ERL cavities. Even during beam operation, increases of radiation were sometimes observed. Pulse processing method was efficient to suppress field emissions.

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