STATUS OF MAIN LINAC CRYOMODULE DEVELOPMENT FOR COMPACT ERL PROJECT

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Abstract

The Compact ERL, which is a test facility of ERL, is under construction at KEK, in Japan. For the main linac, one cryomodule, containing two 9-cell superconducting cavities, is under development. The cryomodule has been designed under High Pressure Gas Safety Act in Japan. Thermal design and cavity alignment have been also carefully considered. Two 9-cell cavities were fabricated and their performances were confirmed by vertical tests. They satisfied ERL main linac specifications. Their accelerating field reached to 25 MV/m without field limits. Two input couplers, three HOM absorbers and two Slide-Jack tuners were also fabricated for the cERL main linac. High power conditioning of input couplers was successfully carried out, at a test stand using a 300 kW klystron. Cooling tolerance and thermal properties were tested for HOM absorbers. Performance studies were applied for the frequency tuner at room temperature condition. Cryomodule assembly is planned this summer. After cooling tests and high power tests, ERL beam operation will be started.

COMPACT ERL PROJECT

Compact ERL (cERL)[1, 2] is a test facility, which is now being 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.

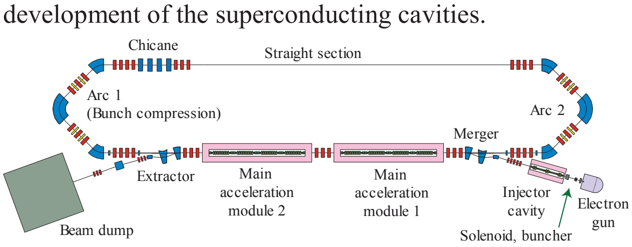

Figure 1: Conceptual layout of the cERL project.

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 – 3 ps (usual) 100 fs (bunch compression)

Conceptual layout of the cERL is shown in Figure 1 and its main parameters are shown in Table 1. At the first stage of cERL, minimum version of ERL will be constructed and electron beams of 10 mA will be accelerated up to 35 MeV. One main linac cryomodule with two 9-cell cavities is now under construction.

CRYOMODULE DESIGN

Figure 2 shows the schematic view of cERL main linac cryomodule. Two 9-cell cavities mounted with He jackets, two input couplers and three HOM (Higher order mode) absorbers are installed into the cryomodule. Slide-Jack type frequency tuners and piezo tuners are also mounted on end of cavities.

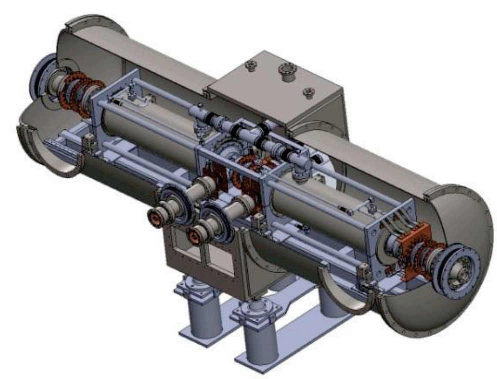

Figure 2: Schematic view of ERL main linac cryomodule.

The superconducting cavities are cooled down to 2 K and operated with CW mode. Dominant cryogenic load comes from cavities. For example, when operated at 15 MV/m, cryogenic loss becomes 25 W for 2 K per one cavity. The cavity is surrounded by He jacket of 300 mm diameter. Since the HOM absorbers and cold windows of input couplers are directly connected to the cavities and placed at 80 K region, 5 K and 80 K thermal anchors are used to suppress heat load to 2 K region.

Final target of alignment after cooling down, is to set the cavities within 1 mm across the beam axis. The cavities are adiabatically fixed by 5 K Ti frame supports, which also act as 5 K He pipes. The frames are also adiabatically and carefully placed on rigid structure of room temperature, which is called as backbone. The backbone is directly fixed to the central part of the vacuum vessel.

MAIN LINAC 9-CELL CAVITY

ERL main linac cavity requires strong HOM damping to avoid BBU instabilities and CW operation at high accelerating gradient of 15 ~ 20 MV/m. Better Q-value is also desirable to reduce cryogenic losses. Focused on HOM damping, we designed KEK-ERL model-2 cavity, which has large iris diameter of 80 mm and realized

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strong HOM damping [3]. On the other hand, E_{peak}/E_{acc} becomes large at iris region. Main parameters are shown in Table 2. Since ERL cavities are operated with CW mode, suppression of field emissions is important issue.

Table 2: Parameters for KEK-ERL model-2 cavity

Frequency	1.3GHz	Coupling	3.8 %
R_{sh}/Q	897 Ω	Geom.Fac.	289 Ω
E_{peak}/E_{acc}	3.0	H_{peak}/E_{acc}	42.5Oe/(MV/m)

Two 9-cell KEK-ERL model-2 cavities, #3 and #4 cavities, were fabricated for cERL main linac. Series of surface treatment were applied to cavities. In order to supress field emissions, low current EP of 32 mA/cm^2 was adopted and flanges were carefully assembled. Two times of vertical tests were performed on each cavity. The requirements for the cERL main linac cavities are as follows; Eacc = 15 ~ 20 MV/m and $Q_0 > 10^{10}$ at 15 MV/m. Figure 3 shows Q-E curves at the second vertical test for each cavity. Eacc reached to 25 MV/m without any field limitation, and Q_0 was also fine. ERL specifications were successfully satisfied. Field emission onsets were 14 MV/m and 22 MV/m for #3 and #4 cavities, respectively. Details of surface treatment and the results of vertical tests are found in [4].

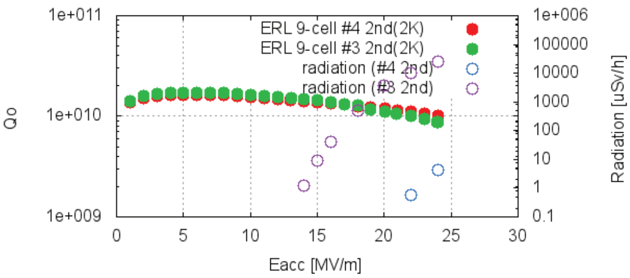

Figure 3: Vertical test results of ERL main linac 9-cell cavities. Left and right axes show Q_0 and radiation dose, respectively.

After vertical tests, the cavities were purged with Ar gas. Then titanium He jackets were welded, as shown in Figure 4. Now cavities are ready for installation into the cryomodule.

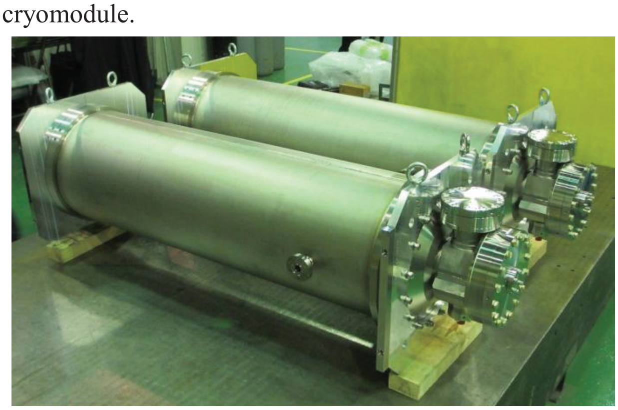

Figure 4: Main linac 9-cell cavities. After the vertical tests, He jackets were welded on them.

INPUT COUPLER

While beam loading is not a matter for main linac coupler owing to energy recovery, compensation of cavity field fluctuation due to microphonic detuning is important to keep the accelerating voltage stable. Assuming Qext of 2x10^7 and 50 Hz detuning, maximum of 20kW RF power is required with reflection condition. Our input coupler has adopted coaxial type double ceramic windows to avoid dust contamination into the cavities [5].

Figure 5: Fabricated input couplers for cERL main linac.

Figure 5 shows fabricated input couplers for cERL. They were connected through waveguide at bottom side and waiting for high power test. The conditioning was done by traveling wave condition, using 300 kW klystron. Requirement of 20 kW standing wave at cERL operation corresponds to 80 kW in pulse and 40 kW in CW modes with traveling wave condition, from a view point of RF field and heat load, respectively.

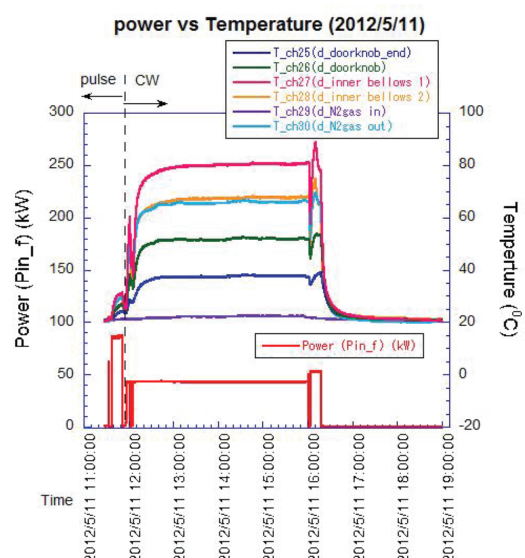

Figure 6: High power test results for cERL main linac input couplers.

High power conditioning started in pulse mode of 10 usec width. Raising the power, arc discharge and electron activities were observed. Vacuum also sometimes increased. After processing these signals were finally disappeared and RF power reached to 100 kW. Then pulse was gradually lengthened.

RF power of 40 kW with CW mode had been successfully kept for four hours, as shown in Figure 6. The highest temperature was observed at bellows of inner conductor, which was cooled by N_2 gas flow. The level of temperature rise was as expected.

HOM ABSORBER

The beampipe HOM absorbers at operating temperature of 80 K are located at both ends of cavities. The HOM load from 100+100 mA electron beams with 3 ps bunch length is estimated to be 150 W per one cavity.

New IB004 ferrite was selected as materials for HOM damping, based on the result of its RF characteristics at low temperature. Ferrite cylinders are bonded on the inner surface of Cu beampipes by HIP (Hot-Isostatic-Pressing). Outside of Cu pipe is covered by bellows and Comb-type RF shield is used for inside, to realize thermal isolation and length and position adjustment.

Using prototype HOM absorber model, several tests were performed [6]. One is the investigation of thermal property. The prototype absorber model was installed into adiabatic vacuum chamber and cooled down to 80 K using liquid nitrogen. Thermal conductance and cooling abilities were estimated by giving heat load to the absorber model using heater. It was found that contact at the tip or side of comb-structure could give large thermal conductance. Shape of the comb-structure was modified to avoid such kind of contact. During the heat cycle test of prototype absorber model, cracks were sometimes observed. Structure of HIP ferrite, especially taper part, which is close to the boundary section, was modified.

Including these modifications, HOM absorbers for cERL were fabricated. Figure 7 shows ferrite and comb-structure of HOM absorber, on which flanges and bellows were later attached.

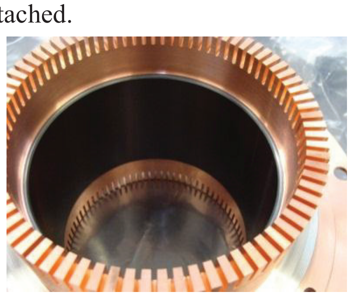

Figure 7: Ferrite and comb-structure of HOM absorber for cERL main linac.

FREQUENCY TUNER

Slide-Jack type mechanical tuner and piezo tuner, which have been developed for KEK STF-baseline cavity [7], are applied for cERL main linac cavity. Mechanical and piezo tuners are used as course and fine tuning of cavity resonant frequency, respectively. Tuner sensitivity to the cavity frequency is about 300 kHz/mm. Total of 3mm stroke of mechanical tuner can change the cavity frequency of about 900 kHz. Selected piezo element has 80 um stroke at room temperature and is expected to be reduced to about 8 um stroke at 5 K.

Using a prototype tuner, performance test was carried out at room temperature. Stroke of 3 mm was confirmed with smooth movement and only small backlash, around 0.4 um, was observed for the mechanical tuner. The piezo stroke of about 80um is also checked and smooth hysteresis curves were obtained.

Two sets of tuners were fabricated for cERL main linac cryomodule. Figure 8 shows the tuner, mounted on the ERL 9-cell cavity for its fitting check.

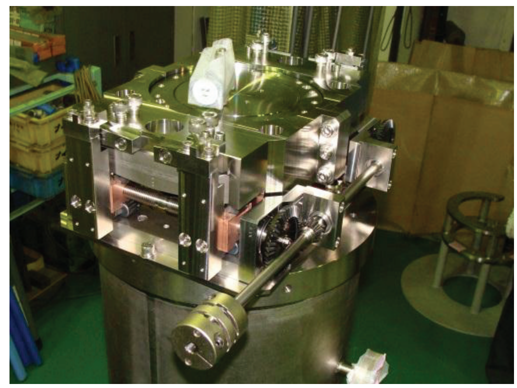

Figure 8: Fabricated frequency tuners for cERL main linac. Tuner is located on the end of the cavity.

SUMMARY AND FUTURE PLAN

The cERL main linac cryomodule is now under construction. Components, such as 9-cell cavities, input couplers, HOM absorbers and frequency tuners were already fabricated. Both cavities reached to 25 MV/m with good Q values. Conditioning of input couplers up to 40 kW CW traveling wave was just finished.

Cryomodule assembly is scheduled at this summer, and cooling test and high power test will follow. Beam operation of main linac will start from next year.

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