CONSTRUCTION OF MAIN LINAC CRYOMODULE FOR COMPACT ERL PROJECT

K. Umemori#, K. Enami, T. Furuya, H. Sakai, M. Satoh, K. Shinoe, KEK, Tsukuba, Ibaraki, Japan
M. Sawamura, JAEA, Tokai, Naka, Ibaraki, Japan
E. Cenni, The Graduate University for Advanced Studies, Tsukuba, Ibaraki, Japan

Abstract

A main linac cryomodule have been constructed for Compact ERL project. It contains two 9-cell cavities, mounted with HOM absorbers and input couplers. After cavity string assembly, they were installed into the vacuum vessel of the cryomodule. It was placed inside radiation shield of cERL and connected to a refrigerator system. The cryomodule was successfully cooled down to 2K and low power and high power measurements were carried out.

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.

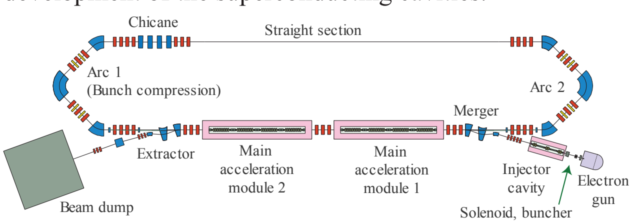

Figure 1: Conceptual layout of the cERL project.

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 have been constructed.

MAIN LINAC CRYOMODULE

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.

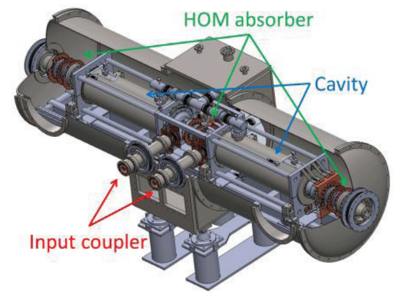

Figure 2: Schematic view of ERL main linac cryomodule.

CRYOMODULE ASSEMBLY

Cavity string assembly was done at class-10 clean room, which was built on ERL development building of KEK. The left of Figure 3 shows the connection of the HOM absorber to the cavity. After this, the cold ceramic windows of input couplers were also mounted. These works were done as carefully as possible, to avoid dust contamination to the cavities. Figure 4 shows the cavity string after completion of string assembly works.

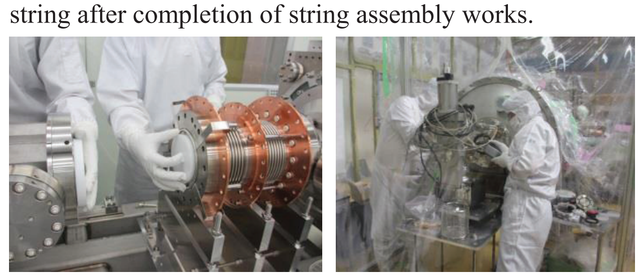

Figure 3: Connection of HOM absorber (left) and gate valve (right).

The next step, the cavity string went out of the clean room and was mounted on a cryomodule central tower. Frequency tuners of coarse mechanical tuners and fine piezo tuners were assembled on one side of the He jackets. After setting the cooling pipes, temperature sensors, magnetic shields, alignment targets and so on, they were covered with the vacuum vessel.

The warm ceramic windows of input couplers were jointed to the cold windows, and gate valves were connected to the both end of the beampipes, which is

kensei.umemori@kek.jp

ISBN 978-3-95450-122-9

shown in the right of Figure 3. These works were performed inside a clean booth to avoid unwanted dust contaminations to the cavities.

Figure 4: After completion of cavity string assembly.

The assembled main linac cryomodule was moved into radiation shield of cERL accelerator, placed on beamline and connected to a refrigerator system, as shown in Figure 5.

The cavities located on upstream and downstream are called as #4 and #3cavities, respectively, according to the manufacturing number.

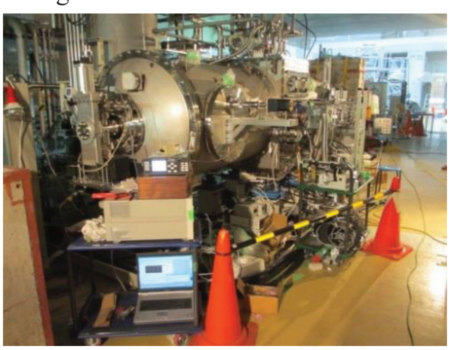

Figure 5: Main linac cryomodule placed inside radiation shield of cERL.

COOLING DOWN OF CRYOMODULE

Figure 6 shows cooling history of the main linac cryomodule, during first low power and high power measurements. Red and blue lines show cavity He jacket temperature, and green, black and purple lines show HOM absorber temperatures.

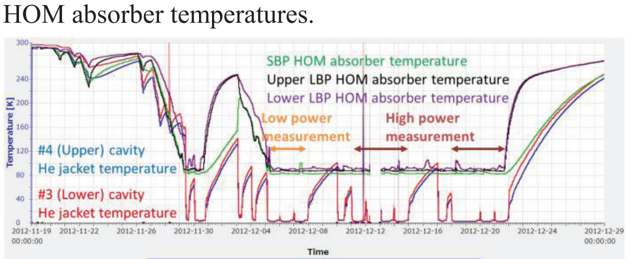

Figure 6: Cooling history of the cryomodule.

Following cooling strategy was required; (1) the HOM absorbers should be cooled down slowly, to avoid cracking on ferrite absorbers. Slope of 3K/hour was required. This rate was used for cooling test of the HOM absorbers. (2) Large temperature difference was avoided among each cooling lines. Typically it was required to be less than 50K.

As shown in Figure 6, the cryomodule was successfully cooled down and the cavity temperatures reached to 2K. During measurements, 80K line was continuously operated, while 5K and 2K lines were not operated during midnight and weekend.

During cooling down procedure, cavity displacements were monitored using the optical and laser targets, set inside the cryomodule. Displacements of cavity center, from room temperature to 2K, were estimated to be less than 0.5 mm. This value is within our alignment tolerance.

LOW POWER MEASUREMENTS

After cooling down to 2K, performances of each component were firstly checked. Components such as the frequency tuner, HOM absorber and input coupler are shown in Figure 7.

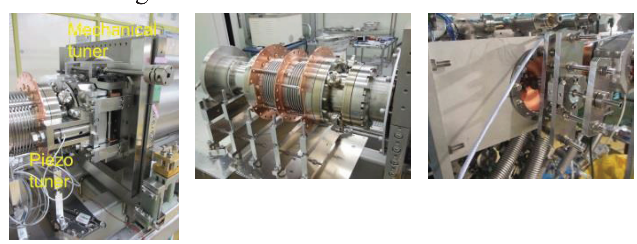

Figure 7: (left) Frequency tuner, (center) HOM absorber and (right) input coupler.

Figure 8 shows performances of frequency tuners; (left) coarse mechanical tuners and (right) fine piezo tuners. Movements of mechanical tuners were smooth enough and their strokes were as expected. The left of Figure 8 shows that the cavities can be successfully tuned to 1.3GHz by mechanical tuners. Performances of piezo tuners were also fine. Their movements were smooth and precise enough. Reproducibility did not show any problems.

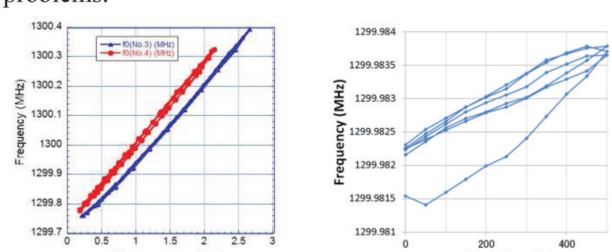

Figure 8: Performances of the mechanical tuners (left) and piezo tuners (right).

For the HOM measurements, one fundamental pickup antenna and three HOM antennas were used for each cavity. The HOM ports were located just side of the HOM absorbers.

Figure 9 shows measured HOM frequencies and their loaded Q-values of #3 cavity. Generally speaking, measured HOM characteristics agree with calculated ones, while detailed analysis are on-going. The ferrite of the HOM absorber seems to work well at 80K.

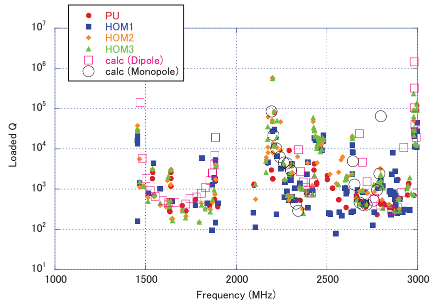

Figure 9: Measured HOM characteristics for #3 cavity, compared with calculated ones. PU means fundamental pickup antenna and HOM1, HOM2 and HOM3 mean HOM probes.

The input couplers were designed to adjust coupling by changing length of inner conductor, in a range of Qext = 1 – 4 x 10^7. Their movements were checked and found that Qext = 8.7 x 10^6 – 3.3 x 10^7 for downstream coupler and Qext = 1.5 -5.3 x 10^7 for upstream coupler.

Performances of all components for the main linac cryomodule were confirmed to be fine.

HIGH POWER MEASUREMENTS

High power measurements were performed using a 30kW IOT. Cavity frequencies were tuned to close to 1.3 GHz. For these tests, cavity resonant frequencies were followed by changing the frequency of a signal generator.

To investigate field emissions, radiation monitors were placed on both sides of the cryomodule near the axis of the cavities.

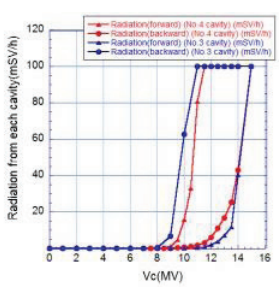

Figure 10: Measured accelerating voltage (Vc) and radiation doses for both cavities.

Figure 10 shows the results from high power measurements. Accelerating voltage, Vc, reached to 16 MV for both cavities. They, however, suffered from heavy field emissions. Unfortunately, field emissions were observed from around 8 MV for both cavities. Relation between Vc and Eacc is indicated as Vc [MV] = 1.038 x Eacc [MV/m].

Figure 11 shows measured cavity unloaded Q-values (Qo) for both cavities. The Q values were estimated from amount of liquid He consumption. For these measurements, static losses were estimated to be around 11 W and subtracted from total losses to lead dynamic losses. Degraded Q-values at higher voltage, Vc > 10 MV, were caused by field emissions.

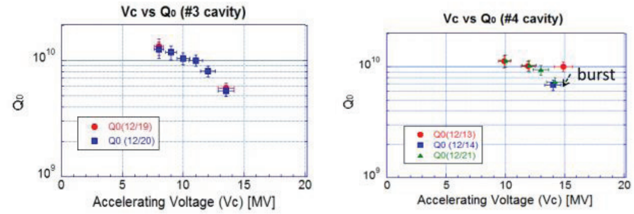

Figure 11: Measured Qo values for #3 cavity (left) and #4 cavity (right).

Vertical test results of these cavities are described at elsewhere [8]. Both cavities had shown good performances. Field emission on-sets had been 14 MV/m and 22 MV/m, and unloaded Q-values had been also fine, Qo > 1 x 10^{10} at 20 MV/m. From these facts, field emissions observed at cryomodule high power tests were most likely induced during module assembly works.

SUMMARY AND FUTURE PLAN

The main linac cryomodule have been constructed for cERL project. Cavity string assembly was carefully done in the clean room. It was installed into vacuum vessel of the cryomodule, placed on the beamline of cERL and connected to the refrigerator system. The cryomodule was successfully cooled down to 2K. Performances of components, such as the input couplers, frequency tuners and HOM absorbers, were confirmed. High power measurements were also carried out. Accelerating voltage of 16 MV was achieved for both cavities. Suppression of field emissions is one of challenges of the future.

Other beam lines of cERL will be constructed this summer and autumn. After that, first energy recovery beam is expected to pass though the cavities.

REFERENCES

[1] R. Hajima *et al.* (ed.), KEK Report 2007-7/ JAEA-Research 2008-032 (2008) [in Japanese].

[2] S. Sakanaka *et al.*, “Progress in Construction of the 35-MeV Compact Energy Recovery Linac at KEK”, in these proceedings, WEPWA015.

[3] K. Umemori *et al.*, “Status of Main Linac Cryomodule Development for Compact ERL Project”, IPAC’12, New Orleans, USA, May 2012, p.67(2012).

[4] K. Umemori *et al.*, “Design of L-band superconducting cavity for the energy recovery linacs”, APAC’07, Indore, India, Feb 2007, p.570 (2007).

[5] M. Sawamura *et al.*, “Cooling properties of HOM absorber model for cERL in Japan”, SRF’2011, Chicago, July, 2011, p.350(2011).

[6] H. Sakai *et al.*, “High power tests of KEK-ERL input coupler for main linac under liquid nitrogen condition”, SRF’2011, Chicago, July, 2011, p.356(2011).

[7] S. Noguchi *et al.*, “New tuners for ILC cavity application”, SRF’07 Beijing, Oct, 2007, WE303.

[8] K. Umemori *et al.*, “Vertical test results for ERL 9-cell cavities for compact ERL project”, IPAC’12, New Orleans, USA, May 2012, p.2227(2012).

ISBN 978-3-95450-122-9