# DEVELOPMENT OF A MAIN LINAC MODULE FOR COMPACT ERL PROJECT

K. Umemori#, T. Furuya, H. Sakai, T. Takahashi, KEK, Tsukuba, Ibaraki, Japan
K. Shinoe, ISSP, University of Tokyo, Kashiwa, Chiba, Japan
M. Sawamura, JAEA, Tokai, Naka, Ibaraki, Japan

*Abstract*

In order to obtain technology needed for construction of the ERL main linac cryomodule, several R&D works have been performed. A prototype of 9-cell superconducting cavity was fabricated. Its performance was confirmed through vertical tests. Prototypes of coupler components were also fabricated and tested at the high power test stand. They could successfully pass the specified RF power. A prototype of HOM absorber without ferrite was made. It is under cooling tests. Design work of cryomodule is in progress.

## INTRODUCTION

The Compact ERL [1] is a test facility to demonstrate the generation and recirculation of high-brightness beam and to show its potential as a future 5-GeV class light source. Figure 1 shows conceptual layout of the Compact ERL. It is planned to be constructed at the East Counter Hall on KEK. Final goals of beam parameters are the beam current of 100 mA with the normalized emittance of 0.1-1.0 mm-mrad. The energy of 200 MeV could be achieved with an option of 2-turn lattice.

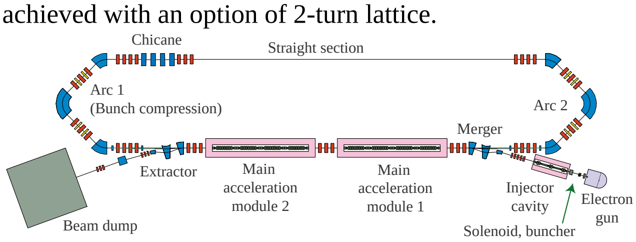


Figure 1 : Conceptual layout of the Compact ERL.

At the first stage of the project, we will start from the beam energy of 35 MeV. The injection beam of 5 MeV will be accelerated and then decelerated at the main linac, where one cryomodule with two 9-cell cavities will be installed. For this aim, several R&D works have been carried out. A superconducting cavity, an input coupler and an HOM absorber were designed with optimization for the ERL operation. A prototype of 9-cell cavity was fabricated and its performance was investigated by vertical tests. After many trials, we recently achieved the specifications for the ERL cavity. For the input coupler, component tests were done for ceramics and bellows, at high power test stand. After some struggles, required RF power could be successfully passed through. A prototype of HOM absorber without ferrite was made. It has been under cooling tests at 80 K, in order to demonstrate its cooling ability. Design of cryomodule has been discussed and is almost finalized.

#kensei.umemori@kek.jp

## SUPERCONDUCTING 9-CELL CAVITY

We had designed the KEK-ERL model-2 cavity, which was optimized for ERL operation, especially for HOM damping. It has large iris diameter of 80 mm and large beampipes with diameters of 100 mm / 120 mm [2]. Accelerating gradient of 15~20 MV/m is required for the ERL cavity. Main parameters of the cavity are listed in Table 1. Due to the large irises, the value of $E_{peak}/E_{acc}$ becomes relatively large. Thus, the suppression of field emissions is one of important issues.

Table 1 : Parameters for KEK-ERL Model-2 Cavity

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

Figure 2 shows the first prototype of the 9-cell cavity. Its main aim is to confirm the design of cavity cell shape. Thus, it does not have He jacket end plates and stiffening rings. Indium seal is used for the flange seal.

Figure 2 : Prototype of KEK-ERL model-2 cavity.

Table 2 : History of Vertical Tests and Surface Treatments

| | Surface treatment | Maximum gradient at final state | Comment |
|---|---|---|---|
| Before vertical tests | EP(130μm), Annealing, EP2(20μm), HPR, Baking | --- | --- |
| 1st test | --- | 15 MV/m | Field emission |
| 2nd test | Baking | 15 MV/m | Field emission |
| 3rd test | HPR, Baking | 15 MV/m | Field emission |
| 4th test | EP2(50μm), HPR, Baking | 17 MV/m | Field emission |
| 5th test | Nothing | 16 MV/m | Field emission (same with 4th) |
| 6th test | Local grinding EP2(50μm), HPR, Baking | No data | Vacuum leak at connector |
| 7th test | EP2(30μm), HPR, Baking | 10 MV/m | Dropped during pass-band measurement |
| 8th test | EP2(20μm), HPR, Baking | No data | Vacuum leak at connector |
| 9th test | EP2(20μm), HPR, Baking | 25 MV/m | Limited by field emission |

A series of surface treatment procedure was applied on the cavity and vertical tests were carried out total of nine times. Its history is summarized on Table 2.

Figure 3 shows the Q0-Eacc curves obtained from the 1st to the 9th vertical tests [3]. Cu flanges were used until the 6th measurement and SUS flanges were used after the 7th measurement. Until the 8th measurement, the accelerating gradients were limited up to 15~17 MV/m. Even the initial state of the 7th test was fine and could reach to 25 MV/m, unfortunate X-ray bursts happened during pass-band measurements, and the final state of cavity was degraded only to 10 MV/m. At 6th and 8th measurements, hard radiation caused vacuum leaks at N-type connectors.

At last, Eacc reached to 25 MV/m at the 9th measurement. Considering the flange losses, the value of Q0 exceeds 1010 at Eacc of 15 MV/m. The specifications for the ERL cavity were satisfied. Careful cavity assembly is essential to reduce field emissions.

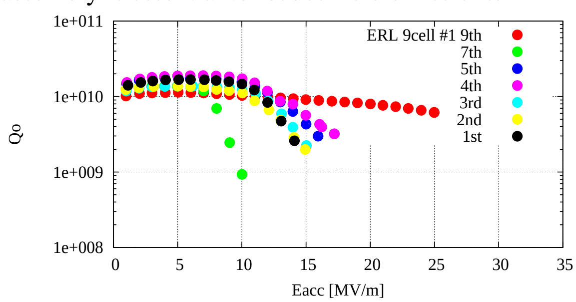


Figure 3 : $Q_0$-$E_{acc}$ curves of vertical tests.

In order to investigate behaviour of field emissions, we have developed the rotating mapping system [4]. X-ray trajectories and temperature mapping can be obtained using Si PIN diodes and carbon resisters, respectively. Left of Figure 4 shows an example of the X-ray mapping. It is obtained at Eacc = 13.9 MV/m of the 4th vertical test. Sharp X-ray peak can be seen at 330 degree of 8-9 iris and broad X-ray signals can be seen at 150 degree of irises of 1-5 cells. After vertical tests, inner surface of the cavity was observed using an inspection camera. As seen in right of Figure 4, a tip was found at 150 degree of 8-9 iris. Its size was several hundreds □m width and several tens □m height. It is considered most probably to be the source of the field emissions.

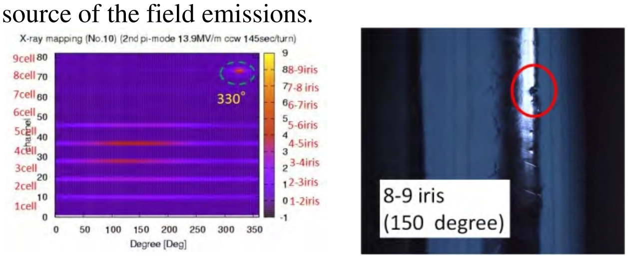


Figure 4: (Left) X-ray mapping data at Eacc=13.9 MV/m. (Right) Picture of cavity inner surface. A tip was found at iris between 8-cell and 9-cell.

The second 9-cell cavity was manufactured last year. It is a prototype for install into the cryomodule. It has He jacket end plates and stiffening rings. For the flange seal, indium coated helicoflex is used. Surface treatment was already finished. It is now waiting a vertical test.

## INPUT COUPLER

A coaxial type power coupler with double ceramics has been designed for the ERL main linac input coupler [5]. Figure 5 shows a schematic view of the input coupler. Maximum RF power of 20 kW CW with standing wave is required. To reduce dynamic losses, HA997 ceramic is used.

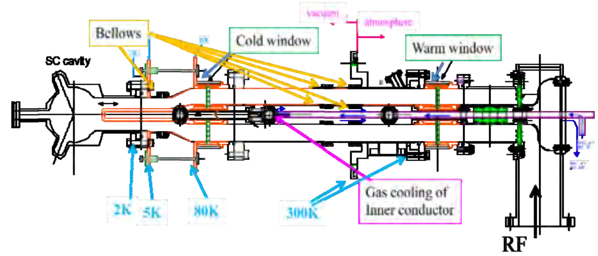


Figure 5 : Schematic design of input coupler.

In order to confirm performances of components, such as ceramics and bellows, we constructed the high power test stand using 30kW IOT, at JAEA, as shown in left of Figure 6. Unfortunately, the first model of window could not pass enough RF power. Even less than 10kW, unexpected RF losses and temperature rises happened and finally the ceramic windows were broken, as shown in right of Figure 6. Through the low level measurements and computer simulations with HFSS and MW-studio, it was found that the dipole resonance existed to be close to 1.3GHz [6]. Temperature dependence was also observed on the resonant frequency. When RF power was applied, temperature became higher and the resonance became closer to 1.3 GHz. Then finally, the dipole resonance was excited and caused the abnormal losses.

The second model of the ceramic window was fabricated with thinner HA997 ceramic, to avoid the dipole resonance from operation frequency of 1.3 GHz. The frequency of the dipole mode was raised about 30 MHz. High power test was performed again and successfully passed 27kW CW standing wave without any abnormal temperature rises.

Bellows of inner conductor is another important component. Applying air cooling of air flow of 90 l/min, its temperature rise was suppressed to adequate level.

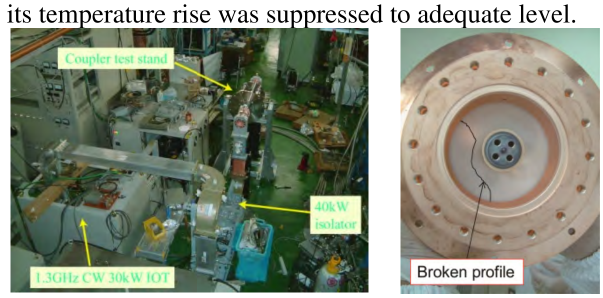


Figure 6 : (Left) Setup of the coupler test stand. (Right) Picture of the cold window with broken profile.

Since the component tests were successfully finished, a prototype of input coupler is now under fabrication. The high power test of it is planned in this autumn. Related to the construction of the Compact ERL, the high power test stand will be moved to KEK East counter hall.

## HOM ABSORBER

The HOM absorbers will be installed into the cryomodule and operated at 80 K. The absorbers, used for HOM damping, should have enough absorption capability at 80 K, for broadband frequency range.

To measure the characteristics of materials at 80 K or even lower, a low temperature measurement system was prepared. Measurements were carried out for around 10 samples. One of the measurement results is shown in Figure 7. Temperature dependences of μ" of ferrite IB004 are plotted for the frequency range from 2 to 10 GHz. It shows that IB004 can be used at 80K. From this result, we decided to use IB004 as an absorber for the ERL main linac.

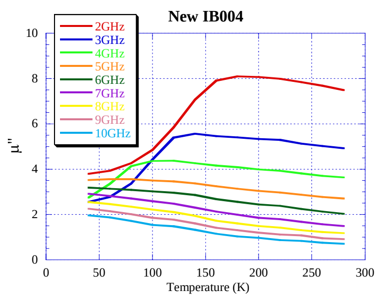


Figure 7 : Temperature dependence of ferrite IB004.

A schematic view and a picture of the prototype HOM absorber without ferrite are shown in Figure 8. A ferrite cylinder with a thickness of 2 mm is bonded on to the inner surface of a Cu beampipe by HIP. The thickness, length and location of the ferrite were carefully optimized.

Cooling test of the prototype HOM absorber without ferrite is in progress at ISSP, University of Tokyo [7]. Its aim is to show cooling ability against 100 W heat load, under vacuum circumstance.

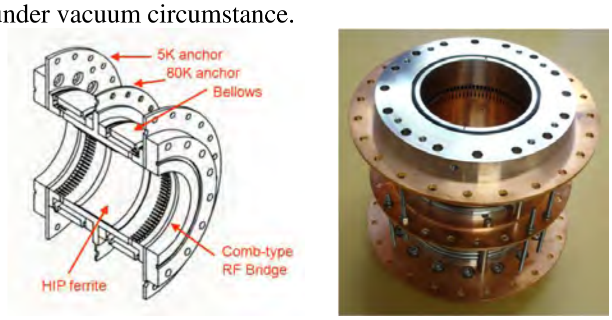


Figure 8 : (Left) Schematic view and (right) a prototype HOM absorber.

Prototype HOM absorber with ferrite is under fabrication.

## CRYOMODULE DESIGN

Design of the first main linac cryomodule for the Compact ERL project is in progress [8]. It contains two 9-cell cavities with input couplers, HOM absorbers and frequency tuners. Each cavity is covered with the Titanium He-jacket, whose diameter is 300mm. They are aligned on Titanium frames and connected each other through the HOM absorber. Slide-jack tuners and piezo tuners are used for frequency tuning. Two cavities will be fabricated at FY2010 and module assembly is scheduled at FY2011.

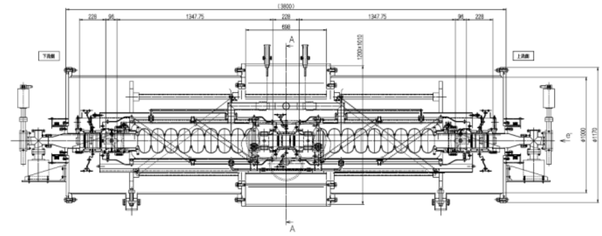

Figure 9 : Design of the prototype module for the Compact ERL main linac.

## SUMMARY

In order to construct the ERL main linac cryomodule for the Compact ERL project, several R&D works have been performed. A prototype of 9-cell superconducting cavity was fabricated. Accelerating gradient reached to 25 MV/m and $Q_0$ value was more than $10^{10}$ at 15 MV/m. Coupler components were also fabricated and tested at the high power test stand. They could successfully pass 27kW CW RF power with standing wave condition. Prototype of HOM absorber was also made. It is under cooling tests at 80 K, to verify its cooling ability against heat load. Design work of cryomodule is in progress. Module assembly is scheduled at FY2011.

## REFERENCES


[1] S. Sakanaka et al., "Status of ERL and cERL project in Japan", in these proceedings.

[2] K. Umemori et al., "Design of L-band superconducting cavity for the energy recovery linacs", APAC'07, Indore, India, Feb 2007, p.570(2007)

[3] K. Umemori et al., "Results of vertical tests for KEK-ERL 9-cell superconducting cavity", IPAC'10, Kyoto, Japan, May 2010, p2956(2010)

[4] H. Sakai et al., "Cavity diagnostics using rotating mapping system for 1.3 GHz ERL-9cell superconducting cavity", IPAC'10, Kyoto, Japan, May 2010, p2950(2010)

[5] H. Sakai et al., "Power coupler development for ERL main linac in Japan", IPAC'10, Kyoto, Japan, May 2010, p2953(2010)

[6] K. Umemori et al., "Observation of resonance mode in coaxial-type input coupler", IPAC'10, Kyoto, Japan, May 2010, p2959(2010)

[7] M. Sawamura et al., "Cooling test of ERL HOM absorber", IPAC'10, Kyoto, Japan, May 2010, p2344(2010)

[8] T. Furuya et al., "Development of a prototype module for the ERL superconducting main linac at KEK", IPAC'10, Kyoto, Japan, May 2010, p2923(2010)