PROGRESS IN CONSTRUCTION OF THE 35-MEV COMPACT ENERGY RECOVERY LINAC AT KEK

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Abstract

The 35-MeV Compact Energy Recovery Linac (cERL) is a superconducting test accelerator for the future 3-GeV ERL project (PEARL) at KEK. During the past year, we have finished key devices such as a 500-kV DC photocathode electron gun and 1.3-GHz superconducting-cavity (SCC) cryomodules for both an injector and a main linac. We installed these devices into a shielding room of the cERL, and carried out high-voltage or high-power tests successfully. A 5-MeV injector of the cERL has been completed and commissioned.

INTRODUCTION

In KEK, we have been proposing to construct a 3-GeV energy recovery linac [1] that can be used as a super-brilliant synchrotron light source as well as a driver for an X-ray free-electron-laser oscillator (XFEL-O). Recently, this project was named as PEARL (Photon Factory ERL Advanced Research Laboratory). To demonstrate the generation and recirculation of low emittance and high current beams which are required for the ERL-based light source, we are constructing the Compact ERL [2] at KEK.

The cERL comprises a 5-MeV injector, a 30 MeV main linac, and a return loop. Principal parameters of the cERL are given in Table 1. In the injector of the cERL, we will produce low-emittance and high-current beams at a kinetic energy of about 5 MeV with a bunch repetition frequency of 1.3 GHz (CW). We plan to construct the cERL in multiple stages: 1) construction of the 5-MeV injector and its commissioning at low currents (< 1 μA), 2) construction of the return loop and its commissioning at modest currents (~10 μA), and 3) upgrade of beam currents. In the next section, we report the construction status of the cERL including the finished construction of the injector. Results of performance tests on the key devices are reported in [3-6]. Some of the results of early commissioning will be reported in [7].

Table 1: Design Parameters of the Compact ERL

Beam energy (at an exit of injector)	5 MeV
(at an exit of the main linac)	35 MeV
Beam current (initial goal)	10 mA
(future goal)	100 mA
Normalized beam emittance	< 1 mm·mrad
Repetition frequency of bunches	1.3 GHz (CW)

Figure 1: Radiation shielding for the Compact ERL.

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CONSTRUCTION STATUS

From March to September in 2012, we constructed a radiation-shielding room with an area of about 60 m × 20 m in the ERL development building of KEK; the shielding consists of many blocks of reinforced concrete (thickness: 1.5 m for side walls and 1 m for roof). Figure 1 shows the completed shielding room. From October 2012 to January 2013, we installed electric lights, an air conditioning system, and a draining system for the cERL.

An injector cryomodule, which houses three two-cell cavities, was assembled from April to June 2012, and the module was installed in the cERL in June 2012 while the shielding was still under construction. Figure 2 shows the injector module as installed in the cERL. The injector module was cooled down to 2K two times in September 2012 and in January 2013 to carry out cryogenic and low-power tests. High power tests [3] of the injector module was carried out successfully in February and in April, 2013. We confirmed that we could keep an accelerating gradient of 7.1 MV/m (CW) in each of three cavities, by which beam acceleration to about 5 MeV is available.

Figure 2: A cryomodule for injector cavities.

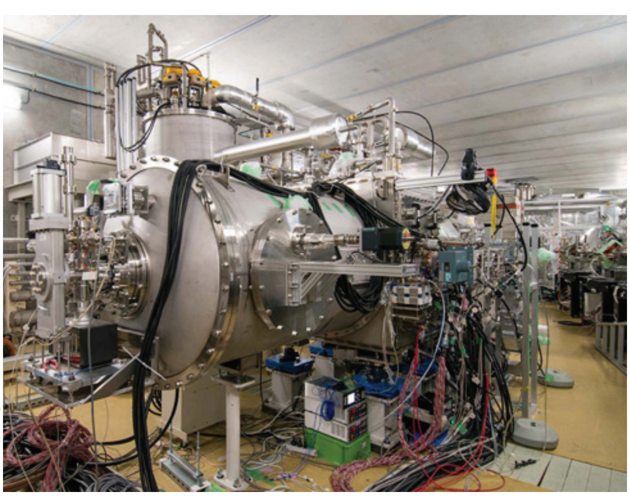

Figure 3: A cryomodule for the main linac.

Another cryomodule for the main linac [4], which houses two 9-cell cavities, was assembled from August to October 2012, and then installed in the cERL (see Fig. 3). We cooled it down to 2K in November 2012, and carried out cryogenic tests, low-power tests, and high-power tests in December 2012. In the high-power tests, we could keep accelerating voltages of 14.2 MV and 13.5 MV in each of two cavities, respectively, for more than 1 hour. However, the onset (about 8-10 MV) of field emissions was lower than expected.

The 500-kV DC photocathode gun was developed at JAEA. In October 2012, beam production at high voltages up to 500 kV was successfully demonstrated [5] at JAEA. Then, the gun was disassembled, transported to KEK, and reassembled. From October 2012 to March 2013, we reassembled everything, baked the chambers out, and carried out high-voltage tests on the ceramic insulator and on the whole gun assembly. Figure 4 shows the DC gun after the installation.

Figure 4: A 500-kV DC photocathode gun.

Following the first gun, the second 500-kV gun is under development at KEK. At present (May 2013), we assembled a high-voltage chamber including a ceramic insulator and carried out vacuum performance tests. A 600-kV high-voltage power supply has also been finished.

To illuminate the photocathode (Gallium Arsenide) of the gun, a fiber-laser system was developed. The drive laser comprises a 1.3-GHz $Nd:YVO_4$ oscillator, both pre- and main-amplifiers using Yb photonic-crystal fibers (at wavelength of 1064 nm), a second-harmonic generator (wavelength: 532 nm), and a pulse shaping system. Average laser power of up to 70 W has been demonstrated at 1064 nm, which allows us to produce beam currents higher than 10 mA. Laser powers of about 100 mW at 532 nm are readily available.

A short (1.12 m) beamline between the gun and the injector module is packed with a laser input chamber, a buncher cavity, screens, stripline beam-position monitors (BPMs), and solenoids. To keep the cathode lifetime, extremely-high vacuum is required in this section while downstream injector module requires dust-free environment. We then pre-assembled this section in a clean room, and installed it in a local clean hut. After the bake out, we achieved ultrahigh vacuum of about 2×10^{-9} Pa in the laser input chamber.

We constructed an injector diagnostic beamline (Fig. 5) which is used to transport accelerated beams from the injector module to an injector dump as well as to measure the various beam properties. The diagnostic beamline is equipped with screen monitors, BPMs, a faraday cup, a slit scanner for emittance measurement, a transverse deflecting cavity, and a beam dump, together with quadrupole and bending magnets, gate valves, vacuum pumps, and other components.

Figure 5: An injector diagnostic beamline.

RF system for the injector and buncher cavities was constructed. We used a 300-kW klystron, a 30-kW klystron, and a 20-kW IOT for rf sources, and an FPGA-based digital low-level system [6] for their control and stabilization. An rf transmission network using waveguides was constructed. Design of the waveguide network in a crowded injector area was especially complicated, which required 3D CAD and negotiation with many staffs.

A cryogenic system for the cERL has been available since 2010. It has a cooling capacity of about 600 W at 4.5K, and that of about 80 W at 2K using eight sets of pumps. After the installations of the injector and the main-linac cryomodules, we connected them to 2K cold boxes, and they were inspected by the authority.

Control system for the cERL, based on the EPICS, was constructed. We also installed a personnel protection system (PPS) and a machine mode system (MMS).

During the period from October 2012 to March 2013, we installed most of the injector components in the shielding room in parallel with the installation of infrastructure. We should also carry out high-voltage test of the electron gun (~10 days), as well as the high-power tests of the injector module (~7 days), the main-linac module (~10 days), and the buncher cavity (~3 days); these tests required keeping us out of the shielding room. Since the installation works were rush and crowded, the safety supervision of them was very important.

We made an application of the cERL injector to the radiation regulation authority, and received an approval of tune-up operation in March 2013. The cERL injector was then inspected by the radiation science center of KEK. Thus, the construction of the cERL injector was completed early in April, 2013. Figure 6 shows the present layout of cERL.

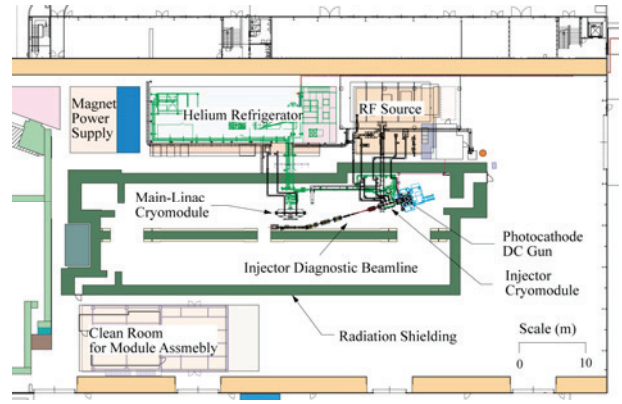

Figure 6: Layout of cERL in May, 2013. An injector has been completed and commissioned.

COMMISSIONING OF INJECTOR

We started commissioning of the cERL injector on April 22, 2013. In the first five days, we could accelerate beams from the DC photocathode gun up to about 5 MeV. Some of the early results of commissioning will be reported in [7]. Tune-up operation of cERL injector is scheduled from April to June, 2013. Then, we will construct the return loop and the main-linac section from July to November, 2013. We will start commissioning of the completed cERL in December 2013.

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REFERENCES

[1] N. Nakamura, "Review of ERL Projects at KEK and Around the World," IPAC2012, New Orleans, May 2012, TUXB02, p. 1040 (2012); http://www.JACoW.org.

[2] S. Sakanaka, H. Kawata, Y. Kobayashi, N. Nakamura, R. Hajima, "Construction Status of the Compact ERL," IPAC2012, New Orleans, May 2012, MOPPP018, p. 607 (2012); http://www.JACoW.org.

[3] E. Kako et al., "High Power Tests of Injector Cryomodule for Compact-ERL," WEPWO013, these proceedings.

[4] K. Umemori et al., "Construction of Main Linac Cryomodule for Compact ERL Project," WEPWO016, these proceedings.

[5] N. Nishimori et al., "Beam generation from a 500 kV DC photoemission electron gun," MOPFI019, these proceedings.

[6] F. Qiu et al., "Evaluation of the Superconducting LLRF system at cERL in KEK," WEPME015, these proceedings.

[7] Tsukasa Miyajima, "Beam Commissioning of Energy Recovery Linacs," FRXBB201, these proceedings.

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