CONSTRUCTION STATUS OF THE COMPACT ERL

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Abstract

Future synchrotron light source based on a 3-GeV energy recovery linac (ERL) is under proposal at KEK [1], and we are conducting extensive R&D efforts. To demonstrate reliable operations of key components for the ERL project, as well as to demonstrate the generation of ultra-low emittance beams, we are constructing the Compact ERL (cERL) [2]. The cERL will also be used to demonstrate the generation of brilliant gamma-rays that is useful for analyzing radioisotopes. Key components, such as a photocathode DC gun, both cryomodules for the injector and the main linac, rf sources, magnets, and beam instrumentations, are under fabrication. Installation of radiation shielding for the cERL started in March, 2012. We report up-to-date status of the cERL.

INTRODUCTION

Energy recovery linacs are expected to bring innovation to materials science. At the High Energy Accelerator Research Organization (KEK), we are proposing to construct a 3-GeV ERL [1] as a future project of the KEK Photon Factory. The same ERL system can also be used as a recirculating linac (without energy recovery), by which we can accelerate electron beams up to 6-7 GeV. Accelerated beams, having extremely low emittances (8-15 pm·rad) and low energy spreads (5×10^{-5} - 2×10^{-4}) at bunch charges of 20-40 pC/bunch, are most suitable to drive the proposed X-ray free-electron-laser oscillator (XFELO) [3].

The key technologies for the ERL are the high-brightness electron gun and superconducting cavities. Then, we have been conducting extensive R&D efforts for these technologies since 2006. We are also constructing the Compact ERL to demonstrate the performance of these key components, as well as to demonstrate the generation of low-emittance and high-current beams. The principal parameters of the cERL are given in Table 1.

Table 1: Principal Parameters of the Compact ERL

Parameter	Value
Beam energy (initial) (maximum)	35 MeV 245 MeV
Injection energy	5 MeV
Beam current (initial goal) (future goal)	10 mA 100 mA
RF frequency	1.3 GHz
Bunch length in rms (usual) (under compression)	1 - 3 ps < 100 fs
Accelerating gradient (main linac)	15 MV/m

DESIGN

Status of R&D effort for each component is reported in [1]. We describe some complement information here.

Injector

Present design of the cERL injector is shown in Fig. 1. It comprises a 500-kV DC photocathode electron gun, a low-energy beam transport line including two focusing solenoids, a 1.3-GHz buncher cavity, screen and laser-input chambers, and an injector cryomodule which houses three 2-cell superconducting cavities. The first 500-kV gun, which was developed at the Japan Atomic Energy Agency (JAEA), is to be installed; the second gun from KEK will be tested a few years later.

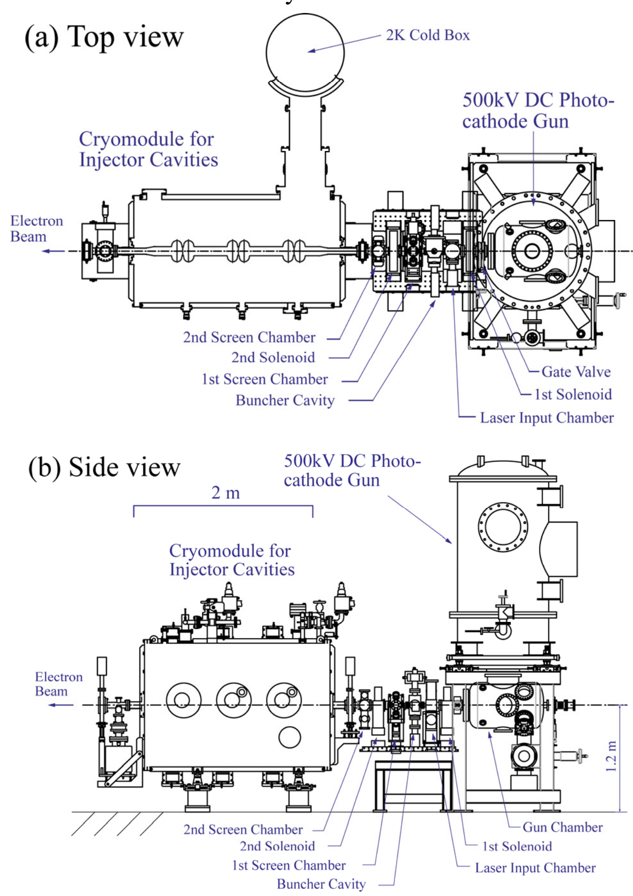

Figure 1: Drawings of the cERL injector.

The cERL injector was primarily designed so as to minimize the normalized beam emittances at an exit of the injector using multi-objective method [4]. Then, the beam optics of the injector was matched to that of the return loop. The parameters of the injector were finally optimized so that the beam emittances were minimized at

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an exit of the main linac of the cERL [5]. Result of an injector simulation under the commissioning optics is shown in Fig. 2. Under the commissioning optics, the normalized emittance of 0.26 mm·mrad has been obtained at the exit of the main linac in a simulation at a bunch charge of 7.7 pC and the beam energy of 35 MeV. Typical parameters of the injector are shown in Table 2.

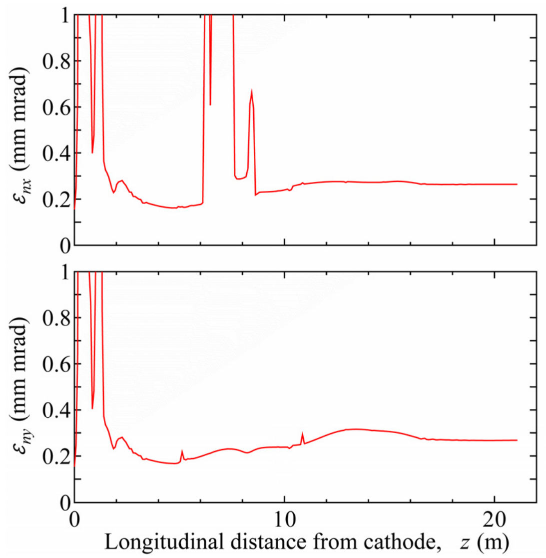

Figure 2: Result of an injector simulation [5] using the GPT code. Horizontal (upper graph) and vertical (lower graph) normalized-emittances are shown as a function of the distance from the cathode. Bunch charge: 7.7 pC, final beam energy: 35 MeV.

Table 2: Typical Design Parameters of the cERL Injector for the Commissioning Optics

Parameter	Value
Gun DC voltage	500 kV
Beam energy of injector	5 MeV
Charge/bunch (for commissioning)	7.7 pC
Full width of laser pulse	16 ps
Spot diameter of laser	0.52 mm
Magnetic fields of solenoids (No. 1, 2)	0.0364, 0.0146 T
RF voltage of buncher cavity	105 kV
E_{acc} of injector cavities (No. 1, 2, 3)	6.84, 7.53, 7.07 MV/m
Offset phases of injector cavities (No. 1, 2, 3)	29.9, -9.8, -10.0 degrees

Return Loop and Overall Layout

Design of the cERL lattice is shown in Fig. 3. Electron beams from the injector are merged into the main linac through a three-dipole merger. The beams are then accelerated up to 35 MeV, and they circulate through a return loop. If the dipoles of the merger is turned off, the beams from the injector can be transported to an injector-diagnostic beamline. We can then measure the beam emittances and the other properties of the injector beams.

For the initial commissioning at a bunch charge of 7.7 pC, we designed the beam optics in the injector and in the return loop consistently [6]. In a low-energy part of the beamline, we used the GPT code for both optics and tracking simulations while including space-charge effect. In a relatively high-energy part, we used the elegant code because it can include wakes due to coherent synchrotron-radiation in bending magnets.

An overall layout of the cERL system is shown in Fig. 4. Various rf cavities of the cERL are driven by several rf sources, as shown in Table 3. Cryomodules for the injector and the main linac are cooled using a 2K helium cryogenic system. The cryogenic system comprises a helium liquefier/refrigerator having a nominal cooling capacity of 600 W at 4.4K, a set of high-performance helium transfer lines, and two 2K helium refrigerator cold boxes and a helium gas pumping system.

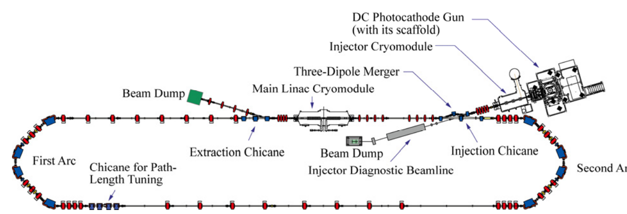

Figure 3: Layout of the Compact ERL (35-MeV version).

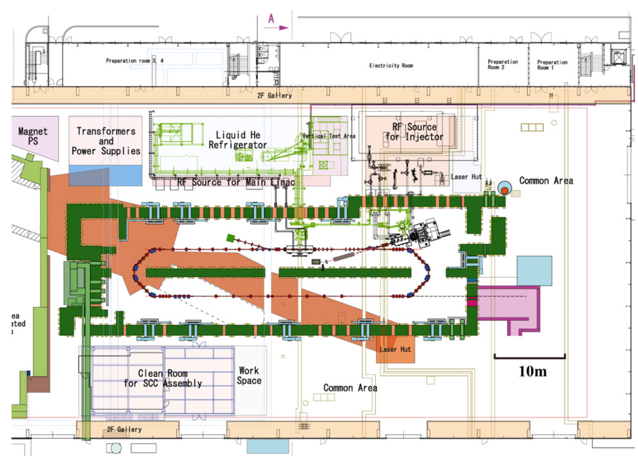

Figure 4: Overall layout of the cERL in the ERL development building at KEK.

Table 3: 1.3-GHz CW RF Sources for the Compact ERL

Cavity	RF source
Buncher	20-kW IOT
Injector cavity No. 1 (SCC)	30-kW klystron
Injector cavities No. 2 and 3 (SCC)	300-kW klystron (with power divider)
Main-linac cavities No. 1 and 2 (SCC)	15-kW IOT each

CONSTRUCTION STATUS

The first 500-kV DC photocathode gun was assembled at JAEA, and it is under high-voltage processing with a cathode electrode and NEG pumps in place. We could keep, for example, high voltage of 440 kV for eight hours stably. Results of high voltage tests were reported in [7]. This gun will be installed in the cERL in October, 2012.

To install into the injector cryomodule [8], three 2-cell cavities were fabricated and tested in a vertical cryostat. The key issue, which allowed us to achieve high field gradient of more than 20 MV/m stably, was an improvement [8] in the feedthroughs for HOM couplers. Six input couplers were also fabricated. Three pairs of input couplers were conditioned up to rf powers of 40 kW (CW) and 200 kW (short pulse) [9]. Then, the assembly of a string of three cavities is underway, as shown in Fig. 5. The injector cryomodule will be finished and to be installed in June, 2012.

Figure 5: Assembly of a string of injector cavities at KEK.

Two 9-cell cavities for the main-linac cryomodule [10] were fabricated and they were successfully tested in a vertical cryostat. Then, the main-linac cryomodule is ready for assembly.

The cryogenic system was installed. Under a test of liquefier/refrigerator, helium liquefaction rate of more than 250 L/h was successfully obtained. We are conducting cooling test down to 2K at the cold boxes.

Radiation shielding for the cERL consists of concrete blocks. Installation of radiation shields started in March, 2012. Figure 6 shows a scene during the installation of the radiation shields. At present (May, 2012), both north and south walls (long sides in Fig. 4) have almost been installed. Construction of the radiation shields will be finished in September, 2012.

Installation of the DC gun, a beamline for the injector, and the main-linac cryomodule will be started from October, 2012. Then, we will carry out cooling test of both injector and main-linac modules. We will also conduct conditioning of the DC gun, as well as rf-conditioning of both cryomodules. We aim at commissioning the injector in the spring of 2013. The main part of the return loop will be installed from July to October, 2013.

Figure 6: Installation of radiation shields for the cERL.

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REFERENCES

[1] N. Nakamura, "Review of ERL Projects at KEK and Around the World", in these proceedings, TUXB02.

[2] R. Hajima et al. (ed.), "Design Study of the Compact ERL", KEK Report 2007-7/JAEA-Research 2008-032 (2008) [in Japanese].

[3] See, for example, R. Colella and A. Luccio, Opt. Commun. **50**, 41 (1984); K.-J. Kim et al., Phys. Rev. Lett. **100**, 244802 (2008); K.-J. Kim and Y.V. Shvyd'ko, Phys. Rev. ST Accel. Beams **12**, 030703 (2009); J. Dai et al., Phys. Rev. Lett. **108**, 034802 (2012); R.R. Lindberg and K.-J. Kim, "Overview of X-ray FEL Oscillator Parameters", in these proceedings.

[4] I.V. Bazarov and C.K. Sinclair, Phys. Rev. ST Accel. Beams **8**, 034202 (2005).

[5] T. Miyajima, "Envelope Matching from Injector to Main Linac for ERL", presentation at ERL11.

[6] Photon Factory Activity Report 2010, p. 138, http://pfwww.kek.jp/acr2010pdf/part_a/pf10aac4.pdf

[7] N. Nishimori et al., "Status of 500-kV DC gun at JAEA", presentation at FLS2012.

[8] E. Kako et al., "Construction of Injector Cryomodule for cERL at KEK", in these proceedings, WEPPC015.

[9] E. Kako et al., "High Power Tests of CW Input Couplers for cERL Injector Cryomodule", in these proceedings, WEPPC012.

[10] K. Umemori et al., "Status of Main Linac Cryomodule Development for Compact ERL Project", in these proceedings, MOOBC012.