STATUS OF ERL AND CERL PROJECTS IN JAPAN

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Abstract

Aiming at constructing a future synchrotron light source based on a 5-GeV energy recovery linac (ERL), we are developing high-brightness DC photocathode guns, gun-drive lasers, superconducting cryomodules, and 1.3 GHz high-power rf sources. We are also constructing the Compact ERL (cERL) at KEK for demonstrating the recirculation of high-brightness beams using these components. We report up-to-date status of the Japanese ERL project.

ERL PROJECT IN JAPAN

Synchrotron light sources based on ERLs are expected to bring innovation to the synchrotron radiation (SR) science [1]. We are proposing to construct a 5-GeV ERL at KEK as a future project of the KEK Photon Factory. The 5-GeV ERL is expected to deliver high-brightness electron beams having normalized beam emittances of 0.1-1 mm·mrad at beam currents of 10-100 mA, as well as to produce ultra-short electron bunches having rms lengths of about 100 fs with bunch charges of higher than 77 pC/bunch. The ERL is also expected to produce high-quality electron beams for a proposed X-ray free-electron laser oscillator (X-FELO) [2]. Typical beam parameters [3] which are required for the X-FELO at a typical photon energy of 12 keV are: the electron beam energy of 7 GeV, the bunch charge of 50 pC, rms bunch length of 1 ps, the normalized beam emittance of 0.2 mm·mrad, the bunch repetition frequency of approximately 1 MHz, and rms energy spread of 2×10^{-4}. We aim at attaining the above-mentioned parameters by operating the same ERL as a recirculating linac [4].

The ERLs are also expected to produce both high-brightness and quasi-monochromatic gamma-rays using the laser Compton scattering. The JAEA is proposing an application of ERLs for detecting radioactive isotopes using such gamma-rays [5]. Both the ERL-based SR source and the gamma-ray source share the common ERL technologies. We are conducting R&D effort for the ERL technologies since 2006.

HIGHLIGNTS OF R&D EFFORT

High-Brightness DC Photocathode Guns

To produce high-brightness electron beams having a repetition frequency of 1.3 GHz, we are developing two 500-kV DC photocathode guns. Design of the first 500-kV gun started in FY2008. Schematic drawing of the first 500-kV gun is shown in Fig. 1. In order to protect a ceramic insulator against electrons emitted from a support rod, the ceramic insulator was divided into several pieces and each piece was covered by a guard ring. Under high-voltage tests, the ceramic insulator with the support rod was successfully conditioned up to the maximum voltage of 550 kV [6].

After above-mentioned high voltage test, cathode and anode electrodes, NEG pumps, and electrostatic shielding meshes, were installed in the vacuum chamber of the gun. After the chamber was baked, vacuum pressure in the chamber reached down to 2×10^{-9} Pa. Then, high voltage conditioning of the assembled gun was carried out. In the summer of 2010, the gun could be conditioned up to the maximum voltage of 380 kV. The maximum voltage was currently limited by local X-ray radiation of approximately 30 μSv/h. As a next step, we first plan to extract beams under the current setup at a lower voltage of 300 kV, and then, we will investigate the source of the radiation. The latest status of the first 500-kV gun is reported in [7].

We also started to develop the second 500-kV gun [8]. The purpose of the second gun is to continue the gun development after one of them has been installed in the Compact ERL. One of the guns can also serve as a backup for the other one when there happens a serious damage in its component such as a ceramic insulator. Both a titanium vacuum chamber and a ceramic insulator have been produced, and vacuum tests [9] of them are in progress.

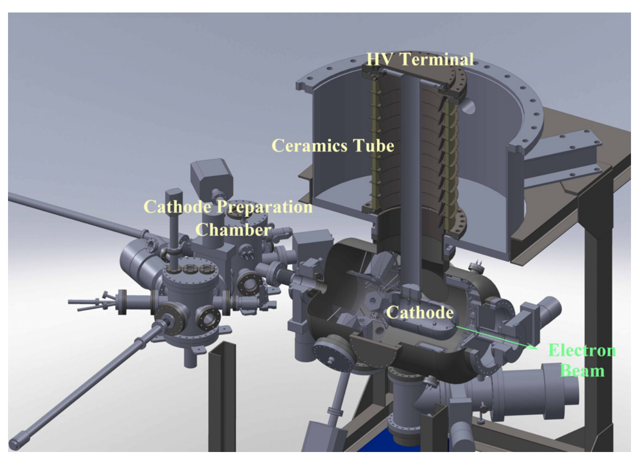

Figure 1: The first 500-kV DC photocathode gun [7].

Gun-Drive Lasers

Negative electron affinity (NEA) photocathodes of the guns are driven by lasers. To produce electron beams of 100 mA, drive lasers for the guns should produce laser pulses having an average power of 15 W with a repetition frequency of 1.3 GHz at a typical wavelength of 530 nm, assuming quantum efficiency of the NEA surface to be

1.5%. To optimize conflicted requirements from low beam emittance and high quantum efficiency, it is desirable that the laser wavelength can be tuned between 500 to 800 nm. We chose a MOPA (Master Oscillator and Power Amplifier) type laser using ytterbium fibers.

In our strategy, we first prepare a reduced drive laser which is needed to test the guns up to the beam current of 10 mA. An average power of 1.5 W is required at 530 nm. We have prepared a 1.3-GHz, 100-mW laser system by assembling commercially available laser oscillator and a fiber amplifier. By reinforcing its fiber amplifier, an average power will be upgraded to 1.5 W in FY2010.

Concurrently, we plan to develop full-featured drive laser within several years. At present, we could demonstrate to produce an average laser power of 10 W (150 nJ/pulse) with a reduced repetition frequency of 85 MHz at a wavelength of 1035 nm [10]. Introducing this laser to a LBO crystal, we could produce the second harmonic (518 nm) light of 4.8 W. A 1.3-GHz fiber-laser oscillator using an active harmonic mode-locking method is also under development.

Superconducting Cavities for the Injector

To pre-accelerate 100-mA beams from a buncher cavity up to the beam energy of 10 MeV (or 5 MeV in cERL), three two-cell superconducting (SC) cavities are used. Using two input couplers per cavity, each coupler should transmit an input power of approximately 170 kW. Average accelerating gradient of about 14.5 MV/m is required. Higher-order modes (HOMs) are damped using improved TESLA-type HOM couplers.

We have produced two prototype cavities. Fig. 2 shows the second prototype cavity where five loop-type HOM couplers and two input-coupler ports are equipped. Under tests in a vertical cryostat, this cavity achieved the field gradient of slightly higher than 40 MV/m without connecting HOM pickups [11]. Tests with HOM pickups are underway. We have also produced two prototype input couplers. These couplers were tested up to an average rf power of 26 kW (peak power: 130 kW). An improvement in some heating locations which were found during this test is under way. Design of a cryomodule which can house three two-cell cavities is in progress.

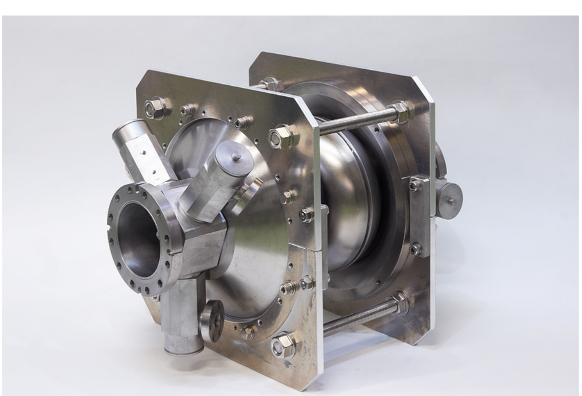

Figure 2: The second prototype cavity for the injector.

Superconducting Cavities for the Main Linac

In the main linac of the 5-GeV ERL, beams are accelerated by a large number of nine-cell cavities. Accelerating gradient of 15-20 MV/m is required. HOMs are damped using ferrite absorbers in the beam pipe.

We have produced two prototype cavities. Under the latest test on the first prototype cavity, we could achieve an accelerating gradient of 25 MV/m. We have also produced prototype input windows. Under high-power tests, the prototype windows could be tested up to an average power of 27 kW in CW mode. Developments of a HOM-absorber assembly and of a cryostat which can house two nine-cell cavities are in progress. Recent development in the main SC cavities is reported in [12].

RF Sources

We have been developing 1.3-GHz rf sources for the ERL since 2007 [13]. Each two-cell cavity of the injector is driven by a 300-kW klystron while each nine-cell cavity of the main linac is driven by a 20-30 kW source.

We have developed a 300-kW CW klystron (Toshiba E37750) for the injector. Under high power tests, this klystron could produce the maximum output power of 305 kW under a cathode voltage of 49.5 kV and a beam current of 9.75 A. We have also developed a 150-kW circulator and the other waveguide components. Using them, the prototype input couplers for the injector were tested under high power.

For the main linac of the cERL, we prepared two rf sources: a 30-kW induction output tube (IOT), VKL-9130 from CPI, and a 35-kW klystron, E3750 from Toshiba. We will evaluate these sources and make a choice for the future ERL project. We are installing one 300-kW klystron, two IOTs, and two 35-kW klystrons for the cERL. Fig. 3 shows the 300-kW klystron which was installed in the East Counter Hall.

The rf voltages in the SC cavities should be stabilized very precisely. Typical stability requirements for the future ERL are 0.01% (rms) for amplitude and 0.01 degrees (rms) for phase. To control rf voltages very precisely, we are developing a digital low-level rf (LLRF) system [14]. Our temporary goals at the cERL are 0.1% (rms) for amplitude and 0.1 degrees (rms), respectively.

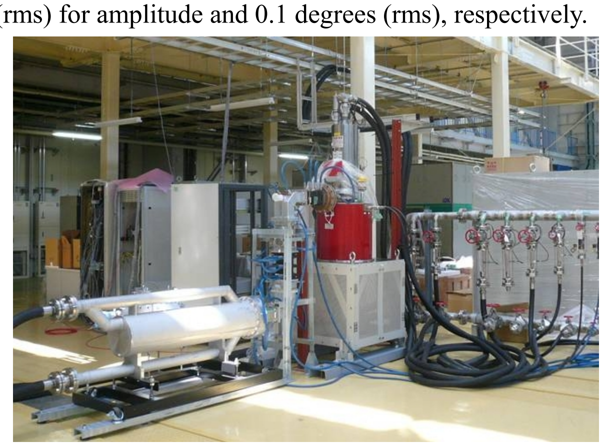

Figure 3: A 300-kW klystron in the East Counter Hall.

THE COMPACT ERL

Design

To demonstrate the generation and recirculation of high-brightness beams using our R&D products, we are constructing the Compact ERL at KEK. Initial goals of the cERL are the beam energy of 35 MeV, the beam current of 10 mA, and the normalized emittance of 1 mm·mrad. The cERL will initially comprise a 5-MeV injector, a main linac with a single cryomodule having two nine-cell cavities, and a single return loop.

After its commissioning, the cERL can be upgraded in two ways. By increasing the number of cryomodules, the beam energy can be upgraded up to 125 MeV. By installing the second return loop, the beam energy can be doubled; this also allows us to investigate the beam dynamic issues concerning the two-loop ERLs. Fig. 4 shows our final planned configuration of the cERL while an initial configuration will be simpler.

We are designing the beam optics for both the initial single-loop configuration (beam energy: 35 MeV) [15] and the double-loop configuration (245 MeV) [16]. Fig. 5 shows an example of the beam optics where we assumed initial conditions at a merging point to be (β_x, α_x, β_y, α_y) = (47.1 m, 1.65, 21.5 m, 5.52) and the maximum beam energy to be 245 MeV. Further matching between the injector and the recirculation loop is in progress.

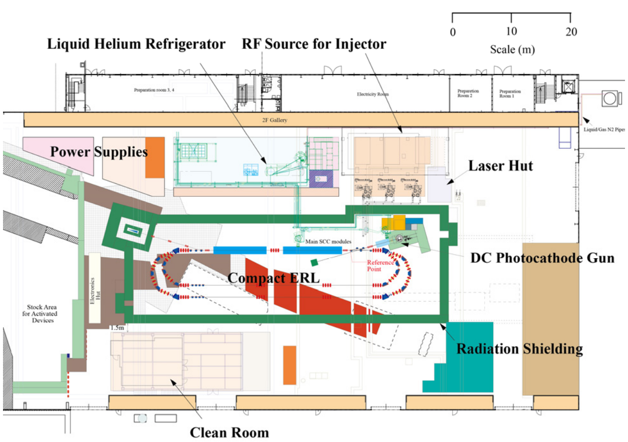

Figure 4: Planned layout of the cERL.

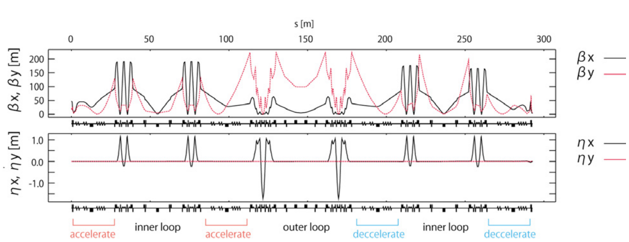

Figure 5: Example of beam optics for the two-loop cERL.

Construction Status

The cERL is being constructed in the East Counter Hall at KEK. During FY2009, we prepared the infrastructure for the cERL which includes: 1) clearing the hall, 2) refurbishing the building, and 3) refurbishing the cooling water system and the electric substation. Fig. 6 shows the interior of the East Counter Hall after its refurbishment.

We also installed a liquid-helium refrigerator system having a cooling capacity of 600 W (at 4 K) and a part of rf sources. These systems are under tests.

According to our current schedule, we will construct a radiation shield during FY2011. At the same time, magnets, vacuum chambers, and the other components will be produced. An injector cryomodule will be finished and tested. During FY2012, most of the components of the cERL will be installed. We will then start commissioning at the end of FY2012.

Figure 6: The inside of the East Counter Hall after its refurbishment.

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