STATUS OF THE ENERGY RECOVERY LINAC PROJECT IN JAPAN

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Abstract

Aiming at the future X-ray source based on the energy recovery linac (ERL), we are making aggressive R&D efforts. Our efforts include the developments of a high-brilliance photo injector, 1.3-GHz superconducting cavities, and planned construction of the Compact ERL. We report the updated status of our ERL project.

INTRODUCTION

The energy recovery linacs are expected to bring innovation both in the synchrotron light sources and in the high-energy colliders. Therefore, positive R&D efforts are in action in several institutes [1-5].

We set the goal at realizing a 5-GeV ERL-based hard X-ray source in Japan, and are conducting R&D efforts. Our efforts include the developments of photocathode DC guns which can produce highly-brilliant electron beams and of the high-gradient superconducting cavities suitable for CW operations. We also plan to construct a test accelerator, the Compact ERL [6], for demonstrating beam operations using these key components.

ELECTRON GUN

A 500-kV, 10-mA DC gun, which is equipped with a negative-electron-affinity (NEA) GaAs photocathode, has been developed [7] for the Compact ERL by a collaboration effort between JAEA, KEK, Hiroshima University, and Nagoya University. A common problem for the high voltage DC guns is that the field-emitted electrons from a center rod, which supports the cathode electrode, can produce a punch-through hole on the ceramic tube, which leads to vacuum leakage. To improve the high-voltage operation by mitigating this effect, we employed a segmented ceramic-insulator tube having guard rings. The guard rings are expected to prevent field-emitted electrons from hitting the ceramic surface directly. Since the extremely low vacuum pressure down to 10^{-10} Pa is required for longer lifetime of GaAs cathode, we adopted titanium alloy with very low outgassing rate for all vacuum chambers. The ceramic insulator, the vacuum chambers, and a Cockcroft-Walton high-voltage power supply, have been delivered and a high-voltage test will be started soon. Up-to-date status of the 500-kV gun development is presented in [7].

In addition to the development of the 500-kV gun, a 250-kV, 50mA prototype gun has been developed at JAEA. Recent measurement of transverse emittance using double slit system is described in [8].

DRIVE LASER

We are challenging to develop an Yb-fiber laser oscillator which can operate at a high repetition rate of up to 1.3 GHz. We have tried two approaches: (1) combination of a 100-MHz ring-cavity fiber laser and a 1.3 GHz external cavity, and (2) a linear-cavity fiber laser oscillator [9]. Using the former system, generation of a 1.3 GHz pulse train was detected, although both its laser power and the stability were not sufficient yet. Using the latter system, a pulse train with a fundamental repetition rate higher than 400 MHz was obtained, as shown in Fig. 1. We will also develop a ring-cavity fiber laser oscillator with 1.3-GHz EO (electro-optic) modulation in addition to these approaches.

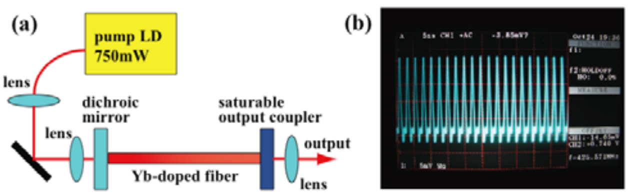

Figure 1: (a) Layout of a linear-cavity fiber laser oscillator, and (b) the output of a 425-MHz pulse train.

SUPERCONDUCTING CAVITIES

Injector Linac

In the injector linac of the Compact ERL, high-current (100 mA max.) electron beams from a buncher cavity will be accelerated to a typical energy of 5 MeV before they merge to the main linac. For this purpose, three two-cell superconducting (SC) cavities, having an rf frequency of 1.3 GHz, are used. To develop these cavities, we fabricated the first prototype cavity. This cavity has two large ports for input couplers and has four HOM couplers. In order to adapt the cavity for CW operation, we improved the designs of HOM couplers from those for the TESLA-type cavity, where the heat losses due to the fundamental mode have been reduced. A picture of the prototype cavity, which was assembled for the vertical test, is shown in Fig. 2.

In the first vertical test of this cavity [10], we could maintain high field gradient of 15.2-15.8 MV/m for 580 minutes under CW operation at the temperature of 1.6-2 K. The measured Q-values under the test are shown by red circles in Fig. 2. We could also achieve the highest field-gradient of 30 MV/m for a very short time. When the field gradients were higher than about 16.5 MV/m, we observed that the Q-values dropped after a short time operation, as indicated by blue squares in Fig. 2. This indicated that a little more improvements are desirable in our HOM couplers. Detail information on the injector-cavity development is reported in [10]. We have also fabricated the second prototype cavity for testing, and are designing a cryomodule for housing three injector cavities.

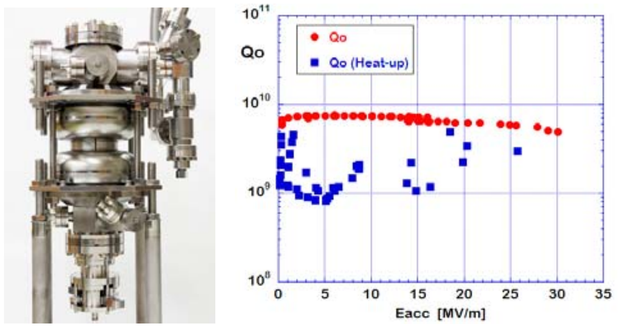

Figure 2: The prototype injector cavity (left) and the result of its vertical test (right).

Main Linac

Nine-cell SC cavities for the main linac are under development. These cavities were designed [11] so that harmful higher-order-modes can be extracted through large beam pipes. We first fabricated two single-cell cavities, having the cell-shapes similar to those of the designed 9-cell cavity, and tested them successfully [12]. Next, we fabricated a prototype 9-cell cavity, and carried out its vertical tests (see Fig. 3).

The result of the first vertical tests is shown in Fig. 4. We successfully tested the prototype cavity up to a field gradient of 15 MV/m at 2K, and achieved an unloaded-Q of higher than 10^{10} at 10 MV/m. We also observed that the Q-value decreased due to field emissions above the field gradient of 10 MV/m, and we are investigating the cause of this problem. These results will be reported in [13]. We are also designing a prototype cryomodule that can house two 9-cell cavities.

Figure 3: Preparation for the vertical testing the 9-cell cavity.

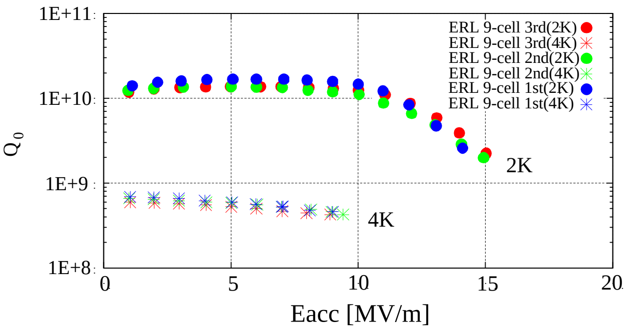

Figure 4: The first result of vertical tests of the prototype 9-cell cavity.

THE COMPACT ERL

In order to demonstrate the generation and recirculation of ultra-low emittance beams using above-mentioned key components, we plan to construct a test accelerator, the Compact ERL. It is to be built in the East Counter Hall at KEK, where the old 100-by-50-meters building will be refurbished for this purpose.

In the current plan of the Compact ERL, the beam energy of the injector is typically 5 MeV using three 2-cell cavities while higher energies can be available with lower currents. The design and the optimization of the injector are underway [14]. In the main linac, we can install two cryomodules, each of which can accommodate four 9-cell cavities. With a typical accelerating gradient of 15 MV/m, the maximum beam energy of 125 MeV is available. We are currently considering three modes of operations, the high current (77 pC/bunch, 1 mm·mrad), the low emittance (7.7 pC/bunch, 0.1 mm·mrad), and the bunch compression (> 77 pC/bunch at low repetition rate) modes. We have optimized the beam optics for the above three modes of operations [15].

We are also considering to upgrade the Compact ERL by installing an additional return loop [16] in future. With this upgrade, we can double the beam energy, and can study such issues as the emittance preservation in two-loop ERLs. The two-loop ERL is a very promising option for cost reduction in the future ERL X-ray sources, and is worth studying.

We have got funds for refurbishing the East Counter Hall including the renewals of both a cooling-water plant and an electrical substation. We have also got funds for equipping a liquid-helium refrigerator having a cooling capacity of approximately 600 W at 4K. These equipments are under design. A work for clearing 10,000 tons of concrete shields, as well as activated components for old proton beamlines, is currently underway in the East Counter Hall.

Figure 5 shows a planned layout of the Compact ERL in the East Counter Hall, where the details will be modified.

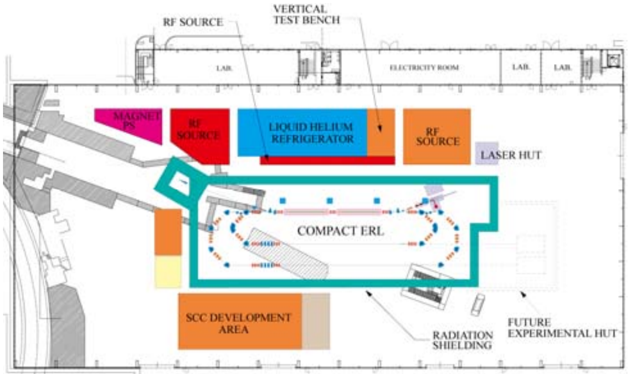

Figure 5: Planned layout of the Compact ERL in the East Counter Hall.

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