PROGRESS IN R&D EFFORTS ON THE ENERGY RECOVERY LINAC IN JAPAN

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Abstract

Future synchrotron light sources based on the energy-recovery linacs (ERLs) are expected to be capable of producing super-brilliant and/or ultra-short pulses of synchrotron radiation. Our Japanese collaboration team is making efforts for realizing an ERL-based hard X-ray source. We report recent progress in our R&D efforts.

INTRODUCTION

Along with mature performance of ring-based synchrotron light sources, the energy-recovery linacs attract our attention as very promising new light sources which can overcome the limitations of ring-based sources. The ERL-based light sources are expected to be capable of producing super-brilliant and/or ultra-short pulses of synchrotron radiation. They are also expected as promising drivers for oscillator-type X-ray free electron lasers [1]. The ERL-based hard X-ray sources are seriously considered at the Cornell University [2], at the Argonne National Laboratory [3], and at KEK/JAEA [4]. The ERLs are also expected as intense electron drivers for cooling ion beams, and serious R&D programs are being conducted at the Brookhaven National Laboratory [5] and at the Jefferson Laboratory [6].

We are aiming at realizing an ERL-based hard X-ray source in Japan, and are conducting R&D efforts. We are currently developing such key components as: (i) photocathode DC guns which are capable of producing ultra-low emittance, high-current beams, (ii) drive lasers for the gun, (iii) both superconducting cavities for the injector linac and for the main linac. We also plan to assemble these key components into the Compact ERL [7], and to demonstrate their operations.

ELECTRON GUN

An electron gun to generate electron beams of high-brightness and high-average current is one of the most essential components for the ERL light source. We employ a photocathode DC gun for the ERL. A 250-kV, 50-mA gun has been developed at JAEA. The gun has been almost assembled and the first photo-current was obtained from a cathode of NEA-GaAs. Apparatuses for beam measurements are under installation. We plan to measure the transverse emittance by a double-slit configuration and to measure the temporal profile with a deflecting cavity. The design of these apparatuses is described in a previous paper [8]. From particle tracking simulations, the normalized transverse emittances are expected to be 0.59 and 0.11 mm·mard for bunch charges of 77 and 7.7 pC, respectively.

In addition to the development of the 250-kV gun, we started to build a 500-kV gun, which will be installed in the Compact ERL. A multiple-stacked cylindrical ceramic for a high-voltage insulator is designed to support 500-kV DC voltage. Studies on photocathode physics and ultra high vacuum to achieve long-life cathode operation are also underway.

DRIVE LASER

Drive lasers for the photocathode DC gun are under development. The requirement for the laser system is a tunable wavelength around 800 nm with an average power of 15 W, a pulse width of 10-20 ps, and a repetition rate of 1.3 GHz. An ytterbium(Yb)-doped fiber-amplifier (YDFA) system is most promising [9,10] because of its scalability to high average power [11]. The tunable wavelength-conversion can be realized with the optical parametric amplifier which is pumped by a frequency-doubled YDFA. The required average power for the YDFA is above 200 W. The National Institute of Advanced Industrial Science and Technology (AIST) has a laser technology for an average power of 30 W at a repetition frequency of 80 MHz with pulse widths of a few picoseconds. Based on this technology, we started to develop a master oscillator and a power amplifier system at AIST in collaboration with ISSP and KEK. We have already succeeded in oscillating a 118-MHz Yb-doped fiber laser oscillator. Figure 1 shows an output of the developed oscillator. We are challenging to upgrade its repetition rate up to 1.3 GHz.

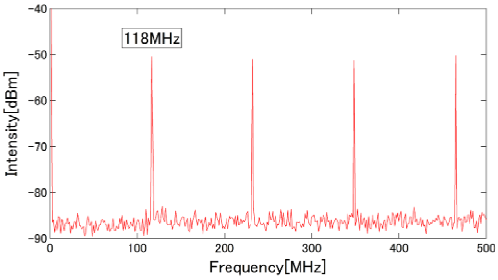

Figure 1: Output of a developed 118-MHz Yb-doped fiber laser oscillator.

SUPERCONDUCTING CAVITIES

Injector Linac

An injector linac for a 5-GeV-class ERL should accelerate electron beams of 100 mA up to the beam energy of about 10 MeV without energy recovery. Hence a power of 1 MW has to be transferred to the beam in CW operation. We designed a new 2-cell cavity and made a prototype as shown in Figure 2. The injector linac consists of three 2-cell cavities, each of which has double power couplers to reduce the power per coupler, as well as to keep a symmetric field configuration around the coupler ports. Main parameters are listed in Table 1.

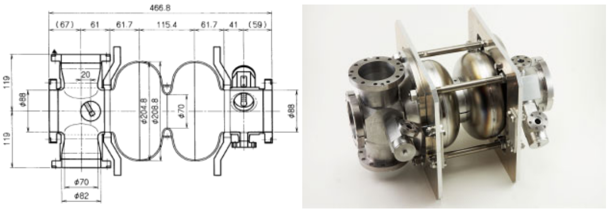

Figure 2: A developed two-cell SC cavity for the injector.

Table 1: Parameters of the SC cavity for the injector linac. Goals at the Compact ERL are shown in parentheses.

Cavity type	2 cell	
Number of cavities	3	
Total accelerating voltage	10 (5)	MV
Beam current	100	mA
R/Q	200	Ω
Cavity loss	5.8 (1.5)	W
Coupler power	170×2 (85×2)	kW
Q_{ext}	1.7×10^5 (8.4×10^4)	

Main Linac

A 9-cell cavity with sufficiently damped higher-order-modes (HOM) was designed for the main linac. To reduce the transverse impedances of its dipole modes, the diameters of both irises and beam pipes of the cavity are chosen to be large. Furthermore, one of the beam pipes has a mode converter called “Eccentric Fluted Beam pipe (EFB)”, in which the quadrupole modes can be partly transformed into dipole modes, and then, can propagate out through the beam pipe [12,13]. The principal parameters are shown in Table 2.

Table 2: Parameters of the 9-cell cavity for the main linac.

Frequency	1.3	GHz
Accelerating gradient	15-20	MV/m
RF power per cavity	20	kW
R/Q	897	Ω
$E_{\mathrm{sp}}/E_{\mathrm{acc}}$	3.0	
$H_{\mathrm{sp}}/E_{\mathrm{acc}}$	42.5	Oe/(MV/m)

Fabrication and surface treatment processes were tested [14,15] on two single-cell cavities named C-single and E-single, which are shown in Fig. 3. C-single has the same cell shape as that of the central cell of the 9-cell structure. E-single has the shape of the end cell which is equipped with beam pipes for the 9-cell cavity. Figure 4 shows the Q-E plot obtained from vertical cold tests. Both the cavities satisfied the specification of 20 MV/m with the unloaded-Q of 1×10^{10}.

Development of a new power coupler for the main linac is in progress. Two ceramic disks of HA997 are used at the both warm end and cold ends of a 60-Ω coaxial antenna coupler. Figure 5 shows a schematic drawing of our test stand for the rf-windows.

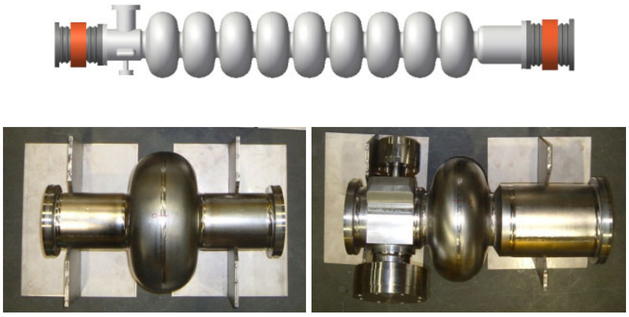

Figure 3: A sketch of the KEK-ERL 9-cell cavity (upper), and two test cavities, C-single (left) and E-single (right).

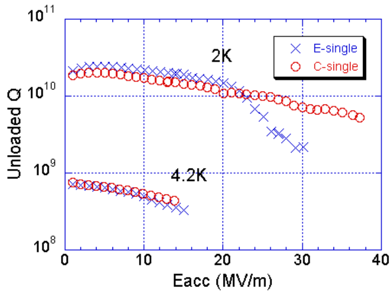

Figure 4: Result of the vertical tests of single-cell cavities.

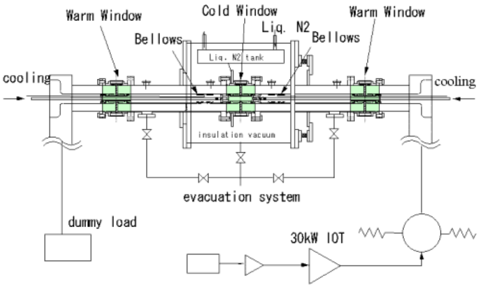

Figure 5: Schematic drawing of a coupler test stand.

DESIGN OF THE COMPACT ERL

We have completed a conceptual design [7] of the Compact ERL, which is a test facility planned to be built at KEK. The plan of the Compact ERL is shown in Fig. 6. Table 3 shows the principal parameters of the Compact ERL, together with those of the ERL-based future light source. The primary purpose of the Compact ERL is to demonstrate reliable operations of the key components, as well as to investigate accelerator physics issues that are critical to build the ERL for the light source.

The Compact ERL can also be used as: (i) an intense terahertz-radiation source using the coherent synchrotron radiation (CSR), and (ii) an ultra-short or a high-intensity X-ray source using Compton backscattering with laser pulses. We anticipate a photon flux density of about 10^{17} photons/s/mrad^2/0.1%b.w. [16] at the photon energy of about 10 meV (~2.4 THz) from compressed bunches having pulse widths of 59 fs (rms) at the beam energy of 155 MeV. The Compact ERL can also provide ultra-short X-ray pulses having the pulse widths of about 110 fs. With the 90° Compton-backscattering configuration, we anticipate a photon flux of 3.5×10^3 photons/pulse/3%b.w. [7] at the beam energy of 60 MeV, the bunch charge of 100 pC, and the laser pulse of 10 mJ/pulse.

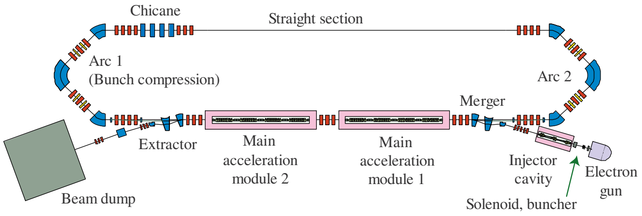

Figure 6: Plan of the Compact ERL.

Table 3: The principal parameters of the Compact ERL and the ERL-based future light source.

	Compact ERL	Light source	
Beam energy	0.065-0.2	5	GeV
Injection energy	5	~10	MeV
Path length	70	1253	m
Beam current	10-100	10-100	mA
Charge per bunch	7.7-77	7.7-77	pC
Normalized emittance	0.1-1	0.1-1	mm·mrad
Bunch length (rms)	0.1-3	0.1-3	ps

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