STATUS OF R&D EFFORTS TOWARD THE ERL-BASED FUTURE LIGHT SOURCE IN JAPAN

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Abstract

The Energy Recovery Linac (ERL) is a very promising synchrotron light source in future. We are contemplating to realize an ERL-based next-generation light source in Japan, under a collaboration between KEK, JAEA, ISSP, and other SR institutes. To this end, we started R&D efforts on its key technologies, including a low-emittance photocathode gun and superconducting cavities. We also plan to assemble these technologies into a small test ERL, and to demonstrate their operations. We report our R&D status.

INTRODUCTION

With the advances of photo-injector and superconducting technologies, a new concept of synchrotron light source, based on the energy recovery linac (ERL) [1], is coming into a reality. In the ERLs, electron beams are produced in a photo-injector, accelerated by superconducting cavities, and used to produce synchrotron radiation (SR) for users. The beams are then deccelerated for energy recovery, and dumped. Since electron beams are almost free from random radiation excitations, the ERLs can produce extremely low-emittance beams that cannot be attained by the storage rings, as well as can provide very-short X-ray pulses that can be used for investigating ultra-fast reactions of materials. Furthermore, it was pointed out [2] that the ERL can be a very promising driver for a regenerative-amplifier free-electron laser [3]. Thus, the ERL is widely noticed as a very promising accelerator for the light sources. New light-source projects based on the ERL are under contemplation at several institutes, including the Cornell University (5-GeV ERL) [4], the Daresbury Laboratory (4GLS) [5], the Argonne National Laboratory (APS upgrade) [6], and the KEK/JAEA (5-GeV ERL) [7,8].

To realize the X-ray sources based on the ERL, exhaustive R&D efforts on their key technologies are required. These R&D's include developing an electron gun that can produce high average currents of 100 mA with extremely low emittance of 1 mm·mrad (normalized) or lower, a high-power drive laser for the gun, and superconducting cavities that can accelerate high-current beams under CW operations. Several institutes conducted serious R&D efforts in recent years, and made remarkable advances.

At KEK, two synchrotron light sources, the 2.5-GeV Photon Factory (PF) and the 6.5-GeV PF-AR, are under operation [9]. As a result of discussions on the future direction of the Photon Factory, we concluded that a 5-GeV class ERL is most promising for the future light source. Then, we organized a Japanese ERL collaboration team, consisting of the members of KEK, JAEA, ISSP, UVSOR, and SPring-8, and then, started R&D efforts for the future ERL light source. We are currently developing the key components, and plan to assemble them into a 100-MeV class test ERL in the near future. The principal parameters of the future light-source ERL, and of the test ERL, are shown in Table 1.

Table 1: Principal parameters of the ERL-based future light source and the test ERL in Japan.

	Future LS	Test ERL	
Beam energy	2.5-5.0	0.06-0.2	GeV
Injection energy	5-10	5-10	MeV
Circumference	1253	68.8	m
Beam current (Max.)	100	10-100	mA
Normalized emittance	0.1-1	0.1-1	mm·mrad
Bunch length	1-0.1	1-0.1	ps
RF frequency	1.3	1.3	GHz
Accelerating gradient	10-20	10-20	MV/m

DC PHOTOCATHODE GUN

A DC photocathode gun for the ERL injector has been developing at JAEA. As a first step toward a 500-kV 100-mA gun, we are constructing a prototype 250-kV 50-mA gun [10], as shown in Fig. 1. The gun is equipped with an NEA photocathode. A photocathode sample is introduced into a load-lock chamber, and cleaned by heating. The cathode is then transferred into a preparation chamber where cesium and oxygen are applied on its surface. The activated cathode is finally transferred to the main chamber for extracting photo-currents. We have successfully carried out a high-voltage test, and are assembling a photocathode preparation chamber.

A photocathode test bench has also been developed to find a cathode material having higher quantum efficiency (QE) and longer lifetime at a wavelength as close as the band-gap energy. We have found [10] that AlGaAs cathode shows twice higher QE and 10 times longer lifetime than those of GaAs.

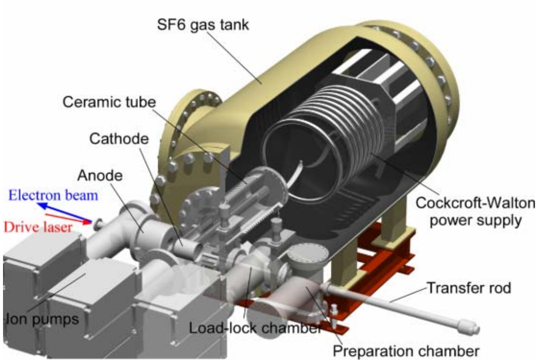

Figure 1: A 250kV, 50mA DC photocathode gun at JAEA.

DRIVE LASER

An ideal laser system for the gun driver must provide enough power to generate electron pulses of 100 mA at a wavelength corresponding to the band-gap energy of an NEA GaAs photo-cathode. These pulses have a repetition rate of 1.3 GHz, pulse widths of 10-20 ps, and must be synchronized to a reference rf signal. By assuming a quantum efficiency of 1% at a wavelength of 800 nm, required average power amounts to 15 W. To minimize the emittance, tunability of the laser wavelength is desirable.

The mode-locked Ti:Sapphire laser is one of the candidates for the drive laser because of its tunability of the wavelength. However, CW operation under high average power is challenging.

From the viewpoint of high average power, ytterbium (Yb) fiber laser is an attractive solution; pulse trains of 131W has already been generated [11]. Several laser systems for the ERL driver, employing this new technology, have been proposed [12,13]. All solutions are MOPA (Master Oscillator and Power Amplifier) system. One is based on Yb:YAG mode-locked oscillator and Yb fiber amplifier [12]. The tunability of the wavelength can be implemented with OPA (Optical Parametric Amplification) by the second harmonic of the fundamental mode of Yb fiber laser. Another solution is employing Ti:Sapphire laser as an oscillator, instead of Yb:YAG [13].

SUPERCONDUCTING CAVITIES

Fundamental design work of 1.3 GHz superconducting (SC) cavities is in progress for both main and injector linacs of the ERL.

Main Linac

The SC cavities for the main linac must produce high accelerating fields of 15-20 MV/m, while avoiding beam breakup (BBU) instabilities. We designed a nine-cell cavity (KEK-ERL model-2 cavity; see Fig. 2 and Table 2) [14,15] that was optimized for the ERL operations from an original TESLA-type cavity. To damp dipole modes which can induce dipole BBU, we put big beam pipes of 100 mm and 120 mm in diameter on each side of the cavity. The impedances of the dipole modes were further reduced by enlarging the diameter of cavity iris from 70 to 80 mm. The diameter of the cavity equator was chosen so that the frequencies of TM020-modes do not coincide with twice the rf frequency. This design pushed up the dipole-mode BBU threshold current to about 600 mA [16] without any HOM randomization. With HOM randomization of 1 MHz, the BBU threshold amounted to about 1.5 A. To achieve excellent HOM damping, development of microwave absorbers is also essential.

In order to damp quadrupole HOMs which can induce quadrupole-mode BBU, we proposed a new idea, an Eccentric Fluted Beam pipe (EFB), shown in Fig. 3. Due to an asymmetry of the EFB, the quadrupole modes can be partly transformed into dipole modes, and then, can propagate through the beam pipes. An effect of the EFB on the accelerating mode can be kept very small. Investigations on the EFB are presented in [17].

Based on the above design, we are fabricating two single-cell and one 9-cell cavities, made of niobium.

Table 2: Geometrical parameters of the 9-cell cavity.

Frequency	1.3	GHz
R/Q	897	Ohms
Geometrical factor	289	Ohms
E_{sp}/E_{acc}	3.0	
H_{sp}/E_{acc}	42.5	Oe/(MV/m)

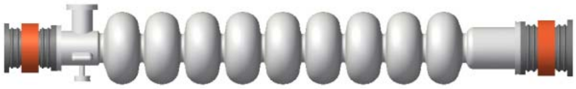

Figure 2: An optimized nine-cell cavity for the main linac, equipped with HOM absorbers on both sides.

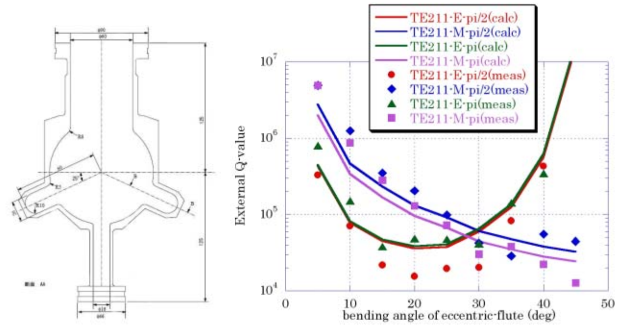

Figure 3: Cross sectional view of the Eccentric Fluted Beam Pipe (left), and both calculated and measured external-Q's for two polarizations of TE211-mode of a 3-cell cavity (right) [17].

Injector Linac

With an injection energy of 10 MeV and a beam current of 100 mA, an rf power of 1 MW has to be delivered to the beams. Key component of the injector linac is an input coupler. To reduce the power of each coupler, we consider using three or four 2-cell cavities, equipped with double input couplers per cavity. Conceptual designs of the cavity, an input coupler, and HOM couplers, started. A prototype cavity is to be fabricated in this year.

BEAM INSTRUMENTATAIONS

We are developing beam instrumentations [18] for the ERL, including SR monitors and beam position monitors. We plan to examine the responses of these devices to short-bunch beams using a test beamline, which was constructed at the end of the beam transport line for the PF storage ring.

DESIGN OF THE TEST ERL

To demonstrate the key technologies described above, as well as to study beam dynamics issues that are useful for the future 5-GeV ERL project, we plan to build a test ERL in a KEK campus. It will comprise an injector linac, one or two cryomodules for the main linac, a recirculating loop, and a beam dump. Principal parameters of the test ERL are given in Table 1. We have designed a lattice of the test ERL (see Fig. 4), and analyzed beam dynamics issues including optimizations of chromaticity correction [19]. We have also investigated [20] an effect of the coherent synchrotron radiation (CSR) on the beam dynamics, and optimized the beam optics for beam recirculation and for bunch compression.

As a candidate site for the test ERL, we have got an approval to use the east counter hall at KEK in the near future. We expect to develop key components within a few years, and to construct the test ERL.

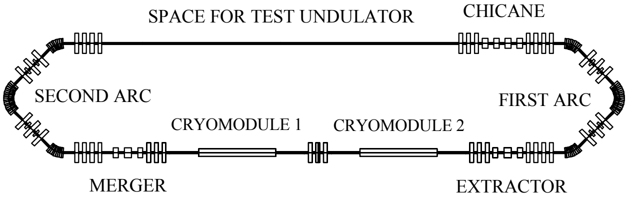

Figure 4: Lattice design of the test ERL.

CONCLUSIONS

We are contemplating to build an ERL-based next-generation synchrotron light source in Japan. To this end, we are conducting R&D efforts for its key technologies including a DC photocathode gun, a high-repetition drive laser, superconducting cavities, and other components. We also plan to demonstrate these technologies in a small test ERL.

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