FUTURE LIGHT SOURCE BASED ON ENERGY RECOVERY LINAC IN JAPAN

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Abstract

After extensive discussions on the future light source of the Photon Factory at the High Energy Accelerator Research Organization (KEK), it has been concluded that a 5 GeV energy recovery linac (ERL) should be the most suitable candidate to foster cutting-edge experiments, as well as to support a large variety of user needs from VUV to X-rays. On the other hand, the Japan Atomic Energy Agency (JAEA), which has built a low energy (17 MeV) ERL, also proposed another 5-6 GeV ERL as a light source. These two institutes, with a participation of some members of the Institute for Solid State Physics (ISSP) of the University of Tokyo, agreed to promote an ERL-based next-generation synchrotron light source in Japan. Before constructing a 5 GeV ERL, it is necessary to develop several critical components, such as an electron gun and superconducting accelerating structures, and to prove their performance. To this end, we plan to construct a test ERL of 200-MeV class at the KEK site. An R&D team for the test ERL is going to be organized in collaboration with accelerator scientists from the other facilities, the UVSOR and the SPring-8.

INTRODUCTION

We have been investigating the feasibility of an energy recovery linac (ERL) as a light source for several years [1-3]. After the discussions on the future light source of the Photon Factory, it has been concluded that a 5 GeV class ERL should be the most suitable candidate to foster cutting-edge experiments, as well as to support a large variety of user needs from VUV to X-rays [4]. A conceptual layout of a 5 GeV ERL, proposed in the feasibility study, is shown in Fig. 1. The principal parameters are also shown in Table 1 [1]. In order to realize this kind of light source, the development of many components that compose the light source is necessary. Investigations into the beam dynamics issues, for example, the energy recovery in rf cavities, the stability of the beams, the conservation of normalized emittance, etc., are also essential. Therefore, construction of a test ERL seems to be inevitable. Both the design concept and the key technologies will be demonstrated by the test ERL. An R&D team for the test ERL is going to be organized in collaboration with accelerator scientists from KEK, JAEA, ISSP, UVSOR and SPring-8. We are planning to construct a 200-MeV class ERL, and to substantiate the principle of the ERL within several years. The principal parameters of the test ERL are also shown in Table 1.

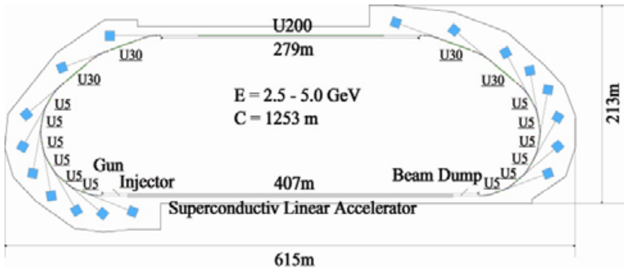


Figure 1: Conceptual layout of 5GeV ERL.

Table 1: Principal parameters of the future light source and the prototype.

	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	100	mA
Normalized emittance	0.1-1	0.1-1	mm·mrad
Energy spread (rms)	5	-	E-5
Bunch length	1-0.1	1-0.1	ps
RF frequency	1.3	1.3	GHz
Accelerating gradient	10-20	10-20	MV/m

DEVELOPMENT OF A PHOTOCATHODE DC GUN

The combination of a DC gun and a photocathode should be an optimum electron source, which fulfils the requirement of ERL light sources: electron beams of high-average current and ultra-small emittance. To demonstrate the ERL-quality electron beams, we are developing a photocathode DC gun at JAEA. The gun consists of a main chamber for DC electrodes, an NEA surface preparation chamber, and a load-lock system for transporting a photocathode between these chambers. A ceramic insulator of the gun and a high voltage stack of 250 kV-50mA power supply are located side-by-side in a pressure vessel, holding 2-atm SF6. A high-voltage test without a beam load has been completed successfully, and assembling of the load-lock system is in progress. We are proposing a superlattice semiconductor for the photocathode, which realizes high-quantum efficiency and small thermal emittance simultaneously [5]. As the first step of the photocathode development, we have fabricated several types of bulk samples, which are GaAs and AlGaAs with different content of aluminum. Measurements of quantum efficiency and life-time of these samples have indicated that AlGaAs has larger quantum efficiency and longer life-time than GaAs. Detail experimental results of photocathode and status of DC gun are presented in an accompanying paper [6].

LATTICE AND BEAM DYNAMICS ISSUES OF THE TEST ERL

In order to prove successful operations of key components, as well as to verify our predictions of accelerator physics issues, we plan to construct a test ERL. The test ERL will comprise a DC photoinjector, a superconducting (SC) injector linac, one or two cryomodules for the main linac, a return loop and a beam dump. An injection energy will initially be 5 MeV, and will be upgraded up to 10-15 MeV. The maximum beam energy will be 60-200 MeV, depending on the number of superconducting cavities in the main linac and on their accelerating gradient (15-20 MV/m). The maximum beam current of 100 mA is anticipated.

An injector design [7], made by the JAEA group, was adopted for our starting point. The design is made up of a 500-kV DC photocathode gun, two solenoids, (temporarily) five three-cell cavities, some quadrupoles and a three-dipole merger. Normalized emittances were predicted to be approximately 1 and 0.1 mm·mrad under bunch charges of 77 and 7.7 pC, respectively, at the end of the merger. Further optimization of this design is underway.

To prove successful operations of SC cavities for the main linac under high beam currents, as well as to verify some predictions of accelerator physics issues, a return loop is necessary. Figure 2 shows our current design. A triple-bend achromat (TBA) lattice was adopted for two arcs because similar lattice will be adopted to our practical 5-GeV ERL. Two cryomodules will finally be installed in one of the straight sections, and a test undulator will be installed in the other straight section in order to evaluate the quality and the stability of emitted photon beams. Figure 3 shows typical optical functions calculated with a computer code SAD.

At a typical rms bunch length of 1 ps under usual beam circulations, an intense CSR (approximately 85 keV/turn at a beam energy of 200 MeV) will be emitted along the arcs. The beam optics should then be optimized so that small beam emittances can be preserved under the CSR. Under the other bunch compression mode, there are such important issues as i) control of R_{56}, T_{566}, and higher terms for achieving shortest bunches, and ii) minimizing emittance growth under more intense CSR. The optimization of beam optics under both operations is underway.

We are also investigating some potential problems under ERL operations such as a beam breakup instability due to cavity HOMs, a resistive-wall beam breakup instability, and an ion trapping.

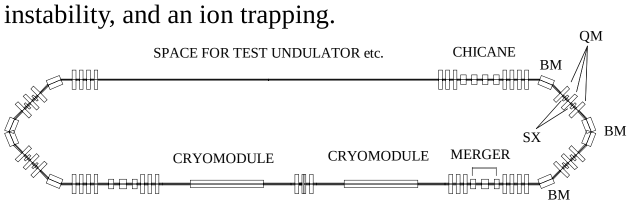
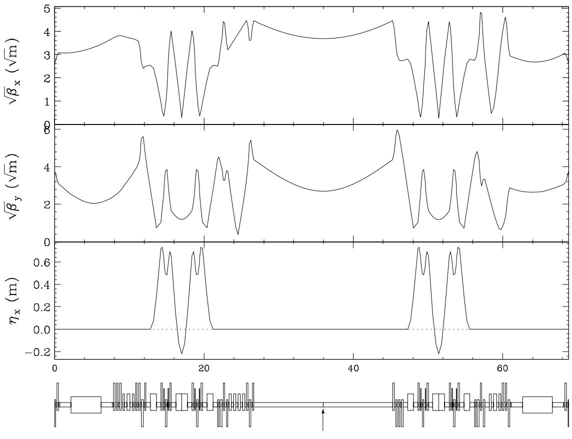


Figure 2: A prototype design of the return loop for the test ERL.



Fugure 3: Typical optical functions along the return loop. Periodic condition was assumed.

DEVELOPMENT OF ACCELERATING STRUCTURES

Two kinds of 1.3 GHz superconducting (SC) linacs are under investigation, i.e., the injector linac and the main linac. The choice of 1.3 GHz allows us to use the SC cavity technology that has been developed for a linear collider [8].

Injector Linac

At a total rf voltage of 10 MV, the injector linac delivers the RF power of 1 MW to the beam of 100 mA in CW mode. Therefore, the most difficulty of the injector linac is the power couplers. To reduce the power of each coupler, a couple of SC cavities of 2 or 3 cell structure with double input couplers is considered as a candidate of the injector linac. Cavity design and fabrication of a prototype cavity will be started soon.

Main Linac

A nine-cell structure with sufficiently damped HOM has been optimized to achieve a stable accelerating gradient of 15-20 MV/m under the beam of 100 mA. A large iris diameter of the cells and large beam pipes on both ends can propagate out the HOMs from the cavity to the absorbers, which is the way that has been successfully used in KEKB SC cavity [9]. Furthermore, an eccentric-fluted beam pipe has been proposed and adopted so as to take out the quadrupole modes [10]. Figure 4 shows the cavity with absorbers on both ends. A Cu-model and a full scale Nb cavities are under fabrication. Geometrical parameters of the cavity are listed in Table 2.

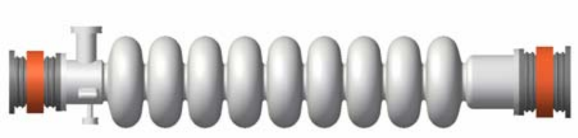


Figure 4: A nine-cell cavity for the main linac. HOM absorbers are on both sides.

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

Frequency	1.3	GHz
Structure	9	cells
Iris diameter	80	mm
Dia. of beam pipes	100, 120	mm
R/Q	897	Ohms
Geometrical factor	289	Ohms
E_{sp}/E_{acc}	3.0	
H_{sp}/E_{acc}	42.5	Oe/(MV/m)

SITE

We have been planning to construct the test ERL in the experimental hall which has been used for the cold neutron science at the KEK Tsukuba campus [4]. However, in the design study, we found that the hall is not large enough to house a 200-MeV class machine. It is almost impossible to equip VUV beamlines around it, and furthermore it is difficult to construct sufficient radiation shields. In the meanwhile, the KEK 12-GeV Proton Synchrotron (PS) was closed, and the research using the PS is moving to the J-PARC project. In the near future, the experimental halls around the PS will be available for new activities of KEK. We are now discussing the possibility to change the site for the test ERL. Figure 5 shows a temporary layout of the test ERL which is fit to the east experimental hall of the PS.

SCHEDULE

A short sketch of the development schedule of the test ERL is shown in Table 3.

Table3: Timetable of development of the test ERL.

2006	"ERL Project Office" started. Design study, R&D (SC RF cavity, Gun).
2007	Design study and R&D for SC RF cavity, a gun, beam diagnostics etc.
2008	Fabrication/Test of components. Cryogenic system.
2009	Installation (in east experimental hall of PS ?).
2010	Commissioning, machine development.
2011	Operation, machine development. Construction of 5GeV ERL.

ACKNOWLEDGMENT

We would like to acknowledge the contributions of members of an ERL development team, consisting of the staff from KEK, JAEA, ISSP, UVSOR, and SPring-8.

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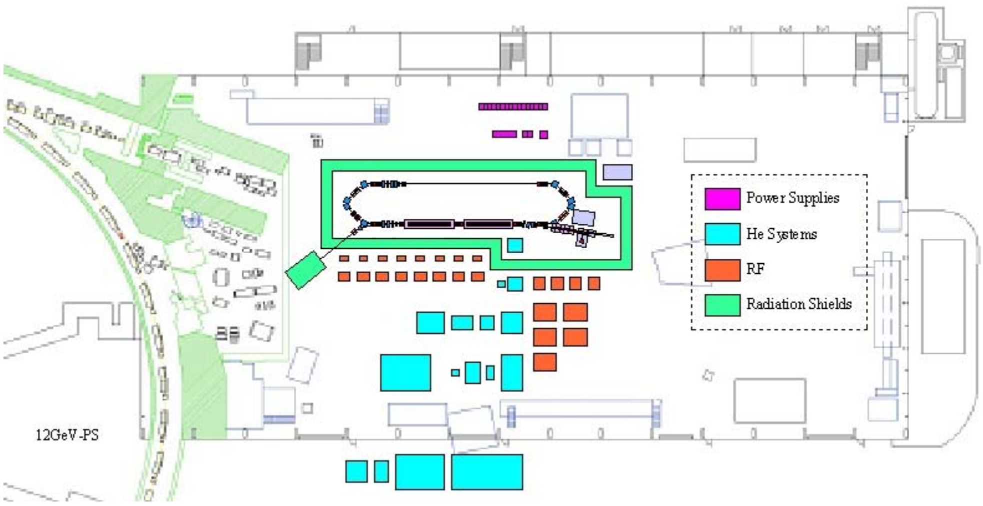

Figure 5: A temporary layout of the test ERL which is fit to the East Experimental Hall of the 12-GeV PS.