STATUS OF HIGH CURRENT R&D ENERGY RECOVERY LINAC AT BROOKHAVEN NATIONAL LABORATORY*

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Abstract

We present the design and the parameters of a small test Energy Recovery Linac (ERL) facility, which is under construction at Collider-Accelerator Department, BNL. This R&D facility has goals to demonstrate CW operation of ERL with average beam current in the range of 0.1 – 1 ampere, combined with very high efficiency of energy recovery. The heart of the facility is a 5-cell 703.75 MHz super-conducting RF linac with HOM damping. Flexible lattice of ERL provides a test-bed for testing issues of transverse and longitudinal instabilities and diagnostics of intense CW e-beam. ERL is also perfectly suited for a far-IR FEL. We present the status and our plans for construction and commissioning of this facility.

INTRODACTION

The R&D ERL facility at BNL aims to demonstrate CW operation of ERL with average beam current in the range of 0.1 - 1 ampere, combined with very high efficiency of energy recovery. Flexible lattice of ERL provides a test-bed for testing issues of transverse and longitudinal instabilities and diagnostics of intense CW e-beam.

The ERL R&D program is pursued by the Collider Accelerator Department (C-AD) at BNL as an important stepping-stone for 10-fold increase of the luminosity of the Relativistic Heavy Ion Collider (RHIC) [1] using relativistic electron cooling [2] of gold ion beams with energy of 100 GeV per nucleon. Furthermore, the ERL R&D program extends toward a possibility of using 10-20 GeV ERL for future electron-hadron/heavy ion collider, eRHIC [3].

These projects are the driving force behind the development of ampere-class ERL technology [4], which will find many applications including light sources and FELs. These programs also define the goals for the R&D ERL development:

Test the key components of the RHIC II electron cooler

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Test the key components of the High Current Energy Recovery Linac based solely on SRF technology

- o 703.75 MHz SRF gun test with 500 mA
- o High current 5-cell SRF linac test with HOM absorbers (one turn - 500 mA, two turns - 1 A)
- o Test the beam current stability criteria for CW beam currents ~ 1 A

Test the key components and scalability for future linac-ring collider eRHIC with

- o 10-25 GeV SRF ERL for eRHIC
- o SRF ERL based an FEL-driver for high current polarized electron gun
- o Test the attainable ranges of electron beam parameters in SRF ERL

The intensive R&D program geared towards the construction of the prototype ERL is under way: from development of high efficiency photo-cathodes [5] to the development of new merging system compatible with emittance compensation [6].

The 703.75 MHz, 1 MW CW RF system for the SRF gun is ready to hook up in Bldg 912. The 50 KW 703.75 MHz RF transmitter for the linac has been installed at the site and is undergoing commissioning.

The lattice of the ERL is designed to fit with the most recent design of SRF injector [8].

LAYOUT AND MAIN COMPONENT OF THE ERL

The base-line design (shown in Fig. 1) has one turn: electrons are generated in the superconducting half-cell gun to about 2.5 MeV and injected through the Z-bend merging system with emittance compensation [6] into the main linac. Linac accelerates electrons 15-20 MeV, which pass through a one turn re-circulating loop with achromatic flexible optics. The path length of the returning loop can be changed by moving right arc like one peace from center of system up to quarter of the RF wave length 11 cm. The electron beam can be return in decelerating and in accelerating phase as well.

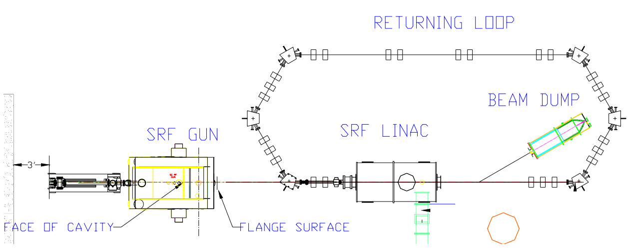

Figure1: Layout of the R&D energy recovery linac in Bldg. 912

In nominal recovery operation regime the path-length of the loop. provides for 180 degrees change of the RF phase, causing electron deceleration (hence energy recovery) down to 2.5 MeV. The decelerated beam separates from the higher energy beam and goes to the beam-dump.

Table 1: Parameters of the R&D ERL in Bldg. 912 in comparacing with requerment parameters for electron cooler for RHIC.

	High Charge	**High Current**	**E-cooler**
Injection energy, MeV	3	2.5	5
Max. beam energy, MeV	20	20	54
Average beam current, A	0.05	0.5	0.5
Bunch rep-rate, MHz	9.4	350	9.4
Charge per bunch, nC	5	1.4	5
Normalized emittance, micron	<5	<3	<4

Two operating modes in terms of charge per bunch are envisaged. In high current mode which is interesting for future high power FEL the energy after the gun is 2.5 MeV, limited by the available RF power (1 MW klystron). In high charge mode which is more interesting for next high energy electron cooling ERL the super-conductive gun accelerates the beam to about 3 MeV, limited by the maximum field in the gun. The main expected parameters of this system are listed in Table 1.

SRF Gun

To test the performance of high-charge SRF laser photocathode gun we are developing in collaboration with AES a ½ cell SRF laser-photocathode gun [7], as shown in Fig. 2.

To provide the necessary beam power, one sees ports for two fundamental power couplers rated at over 0.5 MW each. The design of the beam-pipe allows for all HOMs to couple out to a beam-line ferrite HOM damper. The gun will provide 2.5 MeV the beam at 0.5 amperes with 1 MW RF input power

Merger

One of the novel systems we plan to use for the R&D ERL is a merging system providing achromatic condition for space charge dominated beam and compatible with the emittance compensation scheme [6].

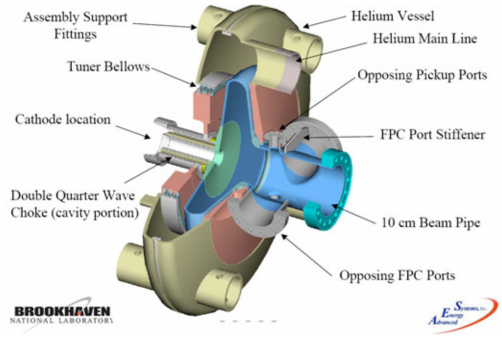

Figure 2: The SRF gun, in helium vessel and choke joint cathode insertion port. The high power fundamental power coupler (FPC) ports are also shown.

In order to reduce differences between vertical and horizontal motion the dipole magnets with similar focusing in both direction (so called chevron dipoles) were used. The emittances evaluation in Z-bend merger system as a result of PARMELA [9] simulation is shown on Fig.3.

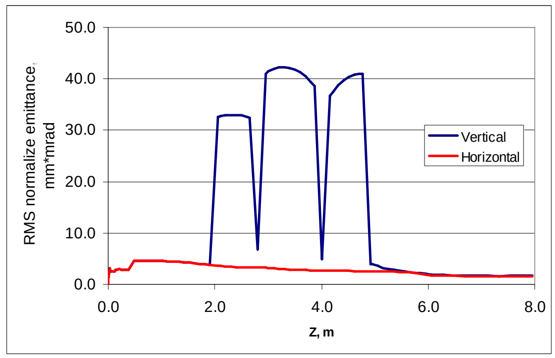

Figure 3: RMS normalized emittances evaluation from cathode (effective thermoemittance) to exit from the linac (E=18 MeV, εx=1.6mm*mrad, εy=1.7mm*mrad).

5-cell SRF Linac

The heart of the ERL facility is 5-cell SRF linac, which is designed for operating with ampere-class CW beam current [7,10]. The cavity was designed as a “single-mode” cavity, in which all Higher Order Modes (HOMs) propagate to HOM ferrite absorbers through the large beam pipe. This design provides for very low Q’s for HOMs and hence very high ERL stability. Measurements of the damped Q and R/Q of the HOMs and simulations show that in nominal operation regime the cavity is stable to over 20 amperes in a one pass ERL and over 2 amperes for two passes ERL.

Figure 4: The ERL cavity following BCP at JLab.

We plan to intentionally tune the lattice of the ERL to a special mode to test the TDBBU predictions for our SRF linac with current limited only to few hundreds of milliamps.
The cavity was built by AES and is undergoing chemistry at Jefferson Laboratory. Figure 4 shows the cavity at JLab after the first BCP. The 5-cell SRF linac built by AES and is planned to be installed and tested in Bldg. 912 this year.

Loop Lattice

The lattice of the ERL loop controls the parameters of a symplectic transport matrix [11], which affect the stability and operation conditions of the ERL. The lattice of the loop is intentionally chosen to be very flexible for the R&D ERL to be a test-bed of new ampere-range of beam currents in ERL technology. The adjustable part of the lattice has two arcs and a straight section. Each arc is an achromat with adjustable longitudinal dispersion. Quadrupoles in the dispersion-free straight section provides for matching of the β-function and for choosing the desirable phase advances independently in horizontal and vertical planes [8]. The threshold of TBBU instability will depend on the values of m_{12} and m_{34}. Hence, we plan to increase these elements to the level of few hundreds of mA, required to observe or to reliably measure TBBU instability threshold and to compare it with the prediction based on the cavity model.

Beam Dump

After a cycle of acceleration and deceleration back to the injection energy 2.5 MeV electron beam goes to beam dump. The beam dump has rocket like shape inside with full water cooled jacket around. This beam dump is an exact copy of that is used for 1MW klystron water cooled collector and this beam dump can accept electron upto 2 MW avrage power CW. In order to avoid very hot spots on a surface of the beam dump the electron beam is over focused by short focal length solenoid. The result of simulation shows on Fig 5 what maximum power density is less 200 W/cm^2 .

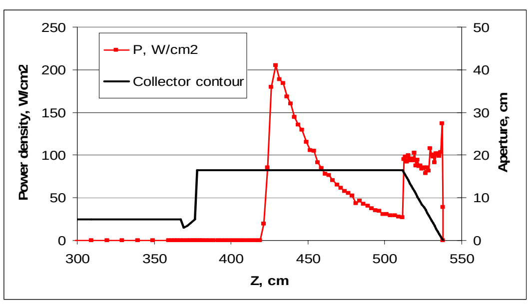

Figure 5: Power density distribution of 1 MW electron beam in the beam dump.

Potential Up-grade of the R&D ERL

We consider the potential extension of this facility into two turn configuration and installation of IR FEL, if funds are available. The shielded vault is designed for ERL with maximum energy of 54 MeV to accommodate these future up-grades. The loop of the ERL is designed to accommodate large energy spread of electron beam in the case of operating a 100-200 kW CW FEL [11].

CONCLUSSIONS

We are designing, constructing, and commissioning a small (about 20 meters in circumference) R&D ERL to test the key issues of amp-class CW electron accelerator with high brightness beams, required for future nuclear physics experiments at RHIC-II and eRHIC. Extensive R&D program on many novel components to be used in the ERL is under way. The prototype ERL will demonstrate the main parameters of the electron beam required for electron cooling.

This facility, planned to be commissioned in 2008, will serve as the test-bet for new range of beam parameters whose application will extend well beyond the goals set forward by Collider Accelerator Department at BNL.

REFERENCES

[1] T. Hallman, T. Kirk, T. Roser and R.G. Milner, “RHIC II/eRHIC White Paper,” Submitted to the NSAC Sub-Committee on Future Facilities, February 15, 2003, http://www.bnl.gov/henp/docs/NSAC_RHICII-eRHIC_2-15-03.pdf

[2] I. Ben-Zvi, “The ERL High Energy Cooler for RHIC”, EPAC2006, p. 940, http://accelconf.web.cern.ch/AccelConf/e06/PAPERS/TUZBPA01.PDF .

[3] Appendix A, “The Linac-Ring Option”, 2005, http://www.agsrhichome.bnl.gov/eRHIC/

[4] I. Ben-Zvi at al., “Extremely High Current, High-Brightness Energy Recovery Linac”, PAC2005.

[5] Multi-Alkali Photocathode Development at BNL, A. Burrill et al., PAC2005.
Study of Secondary Emission Enhanced Photo-injector, X. Chang et al. PAC2005.

[6] D.Kayran, V.N. Litvinenko. “A Methode of Emittance Preservation in ERL Merger System”, FEL2005, pp. 644-647.
V.N. Litvinenko, R. Hajima, D. Kayran, NIM A 557, (2006) pp 165-175.

[7] A. M. M. Todd et al., “State-of-the-Art Electron Guns and Injector Designs for Energy Recovery Linacs”,.PAC2005, p. 2292.

[8] D. Kayran et al, Optics for High Brightness and High Current ERL Project at BNL, PAC 2005, pp. 1775-1777.

[9] L. M. Young, J. H. Billen, "Parmela documentation", LA-UR-96-1835.

[10] R. Calaga et al., “High Current Superconducting Cavities at RHIC”, TUPKF078, Proceedings of EPAC-2004, Geneva, Switzerland, July 5-9, 2004

[11] V. N. Litvinenko et al., FEL 2004, p. 570.