A TEST FACILITY FOR MEIC ERL CIRCULATOR RING BASED ELECTRON COOLER DESIGN*

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Abstract

An electron cooling facility which is capable of delivering a beam with an energy up to 55 MeV and an average current up to 1.5 A at a high bunch repetition rate up to 750 MHz is required for MEIC. The present cooler design concept is based on a magnetized photo-cathode SRF gun, an SRF ERL and a compact circulator ring. In this paper, we present a proposal for a test facility utilizing the JLab FEL ERL for a technology demonstration of this cooler design concept. Beam studies will be performed and supporting technologies will also be developed in this test facility.

INTRODUCTION

The cooling scheme of MEIC, a medium energy electron-ion collider at JLab [1], requires two electron coolers to achieve the high luminosity goal [2,3]. The first one is a traditional low energy (up to 155 keV) cooler of a DC cooling beam used in the pre-booster synchrotron for assisting ion beam accumulation, and is based on well developed technologies [4]. The other one is used in the ion collider ring and covers a medium energy range up to 55 MeV, thus demanding a new class of technologies including a magnetized photo-cathode SRF gun, an SRF ERL, and a compact circulator ring [3].

Such a design concept of a medium energy electron cooler had been, as a matter of the fact, proposed and studied previously for a hadron-hadron collider (RHIC) [5] or electron-proton/ion colliders (HERA [6] and eRHIC [5]), all based on an ERL, either without [5] or with [7] a circulator ring. These earlier studies were mostly at a conceptual level, with R&D efforts on various key cooler components such as SRF linacs. The cooler facility itself, however, has never been built and tested.

At JLab, we plan to create a test facility for the medium energy ERL Circulator Cooler (ERL-CC) of MEIC in the next three years for a demonstration of the design concept and for technology development. The test facility will be based on the JLab FEL driver ERL for maximum reuse of existing equipment, thus reducing the capital cost, and time to completion. The planed tests will focus on a proof-of-principle (P-o-P) experiment for a circulator cooler ring, and through beam physics studies, will provide an evaluation of its technical merit by examining the reduction of the electron beam current from the photo-cathode gun and the SRF linac. In this paper we will present the proposal of this test facility and discuss the scope and the preliminary plan of the tests and beam studies. We will first briefly summarize the ERL-CC design concept in the next section, followed by a description of the proposed test facility. In the fourth section, we will discuss the required pre-test technology development, and end this paper with an outlook.

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ERL CIRCULATOR COOLER

As required by the MEIC design, the electron cooler in the collider ring must deliver a cooling beam with a 2 nC bunch charge at a 750 MHz bunch repetition rate. The energy range of this cooler, up to 55 MeV, rules out any electrostatic apparatus which are used in all low energy coolers for accelerating the electron beam. Therefore, the medium energy electron cooler must rely on RF or SRF technology.

Figure 1 illustrates an electron cooler design concept based on an ERL and a compact circulator ring, the two key technologies adopted for overcoming the two critical challenges, namely, a high (up to 81 MW) beam power and an acceptably long lifetime of the photo-cathode gun [3]. A high charge electron bunch from a magnetized photo-cathode injector is accelerated in an SRF linac to energy up to 55 MV and then sent to a compact circulator ring with an optically matched channel for cooling an ion bunch. The photo-cathode injector and SRF linac ensure a high quality of the bunch (small emittance and energy spread). The electron bunch circulates a large number (10 to 100) of turns inside the circulator ring while continuously cooling ion bunches. This circulator ring enables a reduction of the beam current from the cathode and ERL by a factor equal to the number of turns. The cooling bunch then returns to the SRF linac for energy recovery. The recovered energy will be used to accelerate a new electron bunch from the injector.

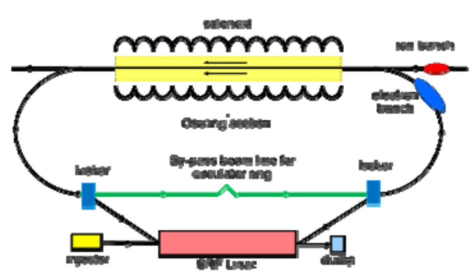

Figure 1: A schematic drawing of an ERL Circulator Ring based electron cooling facility.

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Figure 2 shows an optimization of the location of this cooler: placing the ERL-CC near the vortex of the figure-8 ring so two long cooling channels could be arranged by taking advantage of this unique ring geometry. With such optimization, the cooling efficiency is doubled.

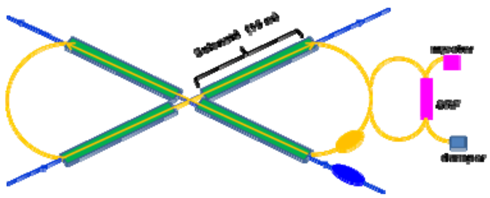

Figure 2: The optimized location of the ERL Circulator Cooler in the MEIC Figure-8 shaped ion collider ring.

Success of the ERL-circulator cooler design concept is measured by the maximum number of circulations in the circulator cooler and applicability of full energy recovery after the circulations. The maximum number above is defined as circulations of the cooling beam in the cooler ring while still preserving sufficiently good beam quality required for achieving high cooling efficiency. It is expected that the cooler performance should be largely determined by key enabling technologies such as an ultra fast kicker and also by collective beam effects such as space charge due to the high bunch charge. The initial beam dynamics simulations [8] have already indicated that the coherent synchrotron radiation effect could also pose a serious issue to the cooler performance, in terms of the "life-time" of the beam emittance.

PROOF-OF-PRINCIPLE EXPERIMENT

Recently, a proof-of-principle (P-o-P) experiment has been proposed in JLab for a demonstration of this new cooler design concept. The JLab FEL driver ERL has been selected as a test facility. A preliminary feasibility study has been completed and an internal retreat has been held recently at JLab, each resulting in a positive outcome.

The primary purpose of this P-o-P experiment is to demonstrate multi circulations of a high intensity electron beam in a compact circulator ring while the beam quality is satisfactorily preserved. The facility will also be used as a test bed for key technology development and testing. The experiment will be carried out in multi phases pending availability of beam time of the JLab FEL facility and support. Specifically, we summarize the goals of the first phase as follows:

1. Demonstrate fast exchange of high repetition rate bunches between the ERL and the circulator ring;
2. Develop and test supporting technologies such as high current ERLs and faster kickers;
3. Study beam dynamics and collective effects in the circulator ring, and determine the maximum number of circulations;
4. Test bunch length change and longitudinal phase matching between the ERL and the circulator ring.

COOLER TEST FACILITY

The JLab FEL is an ERL based light source presently delivering the highest average power laser in infrared (IR) region. Recent, it also has successfully generated an ultra violet (UV) laser. As shown in Figure 3, the facility consists of a 350 kV photo-cathode DC gun, a 9 MeV boosting injector, a three-module SRF linac of 130 MeV capacity, and two recirculators for IR and UV beams respectively. This facility has been chosen for the electron cooler demonstration because it provides a high quality electron beam with energy range and bunch repetition rate similar to the MEIC cooler. This allows maximum reuse of the existing hardware, thus dramatically reducing the capital cost of this experiment.

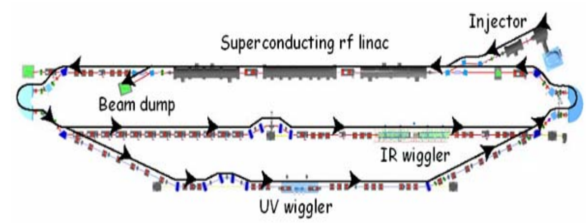

Figure 3: The layout of JLab FEL facility.

The layout of the cooler test facility is shown in Figure 4. The presence of the parallel IR and UV beam lines provides an opportunity for implementation of a compact circulator ring by adding two 180° bends. The photo-cathode injector, SRF linac and their beam line will have no change while providing the electron bunches to the circulator ring. One fast kicker and two septum magnets will be installed in the UV beam line and are responsible for the bunch switching in and out of the circulator ring. The circumference of the circulator ring is about 40 m, and it can hold about 100 bunches if operated at a 750 MHz repetition rate. As part of the initial feasibility study, a linear optics of this circulator ring has been designed. It shows the required 180° arcs fit the space between the two parallel beam lines.

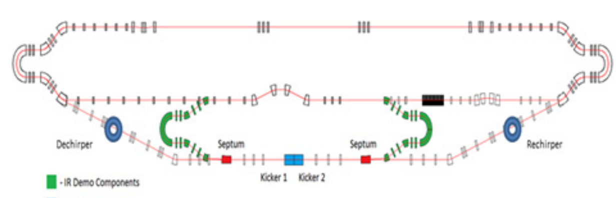

Figure 4: The layout of a test facility for the proof-of-principle experiment.

The aspect ratio of the longitudinal phase space (bunch length and energy spread) of typical ERL-based electron sources does not necessarily correspond to that required by the ERL circulator cooler. It is therefore necessary to transform this aspect ratio – a task readily accomplished through an energy compression system. As shown in Figure 4, a pair of SRF cavities in the UV transport line will be used as de-chirper and re-chirper, and together with the ERL as presently configured so as to produce and

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recover the long, low-energy-spread bunch required for the cooling process.

SCOPE AND TEST PLANS

Both FEL driver ERL performance [9] and the MEIC cooler design parameters [3] are listed in Table 1. These parameters are either overlapping or close to each other.

Table 1: MEIC Cooler and JLab FEL Driver Performance

		FEL ERL	ERL-CR
Energy	MeV	80-210	10-54
Bunch charge	nC	0.135 (0.25)	2
Turns in CR			10 – 100
Bunch frequency	MHz	75	75 - 7.5
Gun current	mA	10	150 – 15
Trans. emit., norm.	µm	10	1-3
Long. emittance	keV-ps	25-75	150
Energy spread	%	0.4	0.01
RMS bunch length	ps	2	100

It is understood the highest achievable bunch charge in the FEL driver ERL is 250 pC, nearly double that of the operating value, however, still a factor of 8 smaller than the 2 nC design value of the cooler. Higher bunch charge will not be possible unless there is an upgrade of the injector/ERL merge beamline and several other parts of the driver ERL. Such an upgrade has not yet been planned. Therefore, the cooler technology demonstration will use a set of reduced machine/beam parameters (mainly the bunch charge). Nevertheless, if we keep the bunch length appropriately short, the bunch intensity (linear charge density) could be made the same as the case of the cooler design; thus a class of collective beam effects could still be studied in this test facility. The following is a list of tests we plan to do:

Test 1: Beam Transfer

High-repetition transfer of high brightness, high power electron beams between an ERL and a circulator ring engenders numerous challenges. In particular, beam losses must be avoided at a few-parts-per-million level, and beam quality must not be compromised. We will test this process using fast kickers and measure the properties of the extracted beam. To test "reinjection" into the ERL, the extraction septum can be de-energized and the bunch trains recombined and recovered to certify that adequate synchronism and stability can be achieved.

Test 2: Longitudinal Match

The change of the cooling beam bunch length – short (2 ps RMS) in the ERL and long (up to 3 cm RMS) in the cooling channel – is accomplished through an energy compression system. Though possible in principle and similar to standard operational practices in an ERL, this has never been done in the manner specifically required for the MEIC cooler. We therefore propose a test of this process. The proper bunch aspect ratio can be diagnosed using a chicane-based measurement of bunch length and momentum spread (employing an existing streak camera to observe the bunch behavior).

Test 3: Circulator Ring Dynamics

Demonstration of the required longitudinal match and the injection/extraction process positions us to test the circulator cooler design concept and performance. We foresee measurements of the circulating beam phase space properties (emittance and energy spread) as function of turns in the circulator ring, and will compare them with beam dynamics simulation results.

TECHNOLOGY DEVELOPMENT

Several technologies must be developed before the test plans of the P-o-P experiment could be executed. Among them, a fast kicker is the most critical one. Presently, it is planed that a set of surplus strip-line kickers from SLAC will be used for this demonstration. Therefore, a high repetition RF source must be developed to drive these kickers. Currently, there are a number of technology options being considered [10], including a harmonic waveform/resonant ring (as the leading candidate), digital signal synthesis with a broadband amplifier and pulse compression-chirp technique. Our R&D plan will be to (1) complete an evaluation of the technology options and then make a selection; (2) perform engineering design; (3) conduct bench testing.

OUTLOOK

With minimal modifications to the JLab FEL facility, and a modest capital cost, we are able to create a test bed for a proof-of-principle test on the ERL circulator cooler concept. The first stage of this technology demonstration will focus on the successful bunch exchange between the ERL and the circulator ring and a proof of multiple circulations in the ring. It is in the plan that, pending development of a magnetized SRF gun and an ultra fast beam kicker, a full ERL circulator cooler that satisfies the MEIC design requirements could be realized and tested in the second phase of this proposal.

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