A FIRST LOOK AT BEAM DIAGNOSTICS FOR THE RHIC ELECTRON COOLING PROJECT*

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Abstract

High energy electron cooling [1] is essential to meet the luminosity specification for RHIC II [2]. In preparation for electron cooling, an Energy Recovery Linac (ERL) test facility [3] is under construction at BNL. A preliminary description of Diagnostics for the ERL was presented at an earlier workshop [4]. A significant portion of the eCooling Diagnostics will be a simple extension of those developed for the ERL test facility. In this paper we present a preliminary report on eCooling Diagnostics. We summarize the planned conventional Diagnostics, and follow with more detailed descriptions of Diagnostics specialized to the requirements of high-energy magnetized cooling.

INTRODUCTION

The RHIC electron cooler is designed to cool 100GeV/nucleon ions using 54MeV electrons. The electron source will be a superconducting RF photocathode gun. The accelerator will be a superconducting energy recovery linac. The frequency of the accelerator is set at 703.75MHz. The maximum electron bunch frequency is 9.38MHz, with bunch charge of 20nC.

Electron cooling at high energy imposes a variety of unique requirements. Of these many requirements, we mention here those that are relevant to the diagnostics discussed in this paper.

While other coolers use DC electron beams, the only way to make a high quality 54MeV beam is with a super-conducting Energy Recovery Linac. High resolution differential current measurement is needed to monitor the efficiency of current recovery.

In typical ERL applications, considerable effort is devoted to generating the shortest possible bunches. In the present application, the need is to match the electron bunch length to that of the ions, as well as to lower the bunch density to insure that Debye shielding doesn't degrade the cooling efficiency. This requires a bunch stretcher, and diagnostics to confirm that the contribution of longitudinal space charge to transverse emittance during bunch stretching is minimized.

Suppression of the transverse temperature of the electron beam in the cooling region requires the generation and transport of magnetized beams, as well as solenoids in the cooling region. Diagnostics are required to measure the *non-magnetized* transverse emittance of the electron beam at the end of the linac matching section, as well as within the solenoid.

Field errors in the cooling solenoids contribute to the transverse temperature of the electron beam [5]. For efficient cooling, local field errors must be at the level of 10^{-5} or less. This requirement is beyond construction tolerances, and will require beam-based diagnostics to permit local correction of field errors.

A layout of the cooler is shown in Figure 1. The magnetized electron beam from the source is accelerated to 54MeV through four superconducting RF cavities, then passes through the stretcher and a bunch rotation cavity (not shown). A dipole in the bend after the cavity has the option to be operated at high field, functioning as a spectrometer to permit energy spread measurement for cavity phasing. The electron and ion beams enter the solenoid from the right. After the solenoids the electron beam enters a second bunch rotation cavity (again not shown). Between the cavity and the compressor there is the option to divert the electron beam to a diagnostic line, where a matching section similar to that at the end of the linac permits measurement of the unmagnetized emittance. A streak camera situated after the compressor permits measurements before the beam re-enters the linac for energy recovery.

CONVENTIONAL DIAGNOSTICS

Preliminary estimates of types and quantities of conventional diagnostics are shown in Table 1.

Table 1: Conventional Diagnostics

Device	**Qty**	Comments
Position/Phase		
BPM (button)	~70	Dual plane
BBU/Energy Feedback	1	Sample scope
Beam Transfer Function	1	Include BTF kicker
Energy Spread	~8	Dispersive BPMs
Phase	~16	BPMs w/ I/Q
Loss		
BLM (PMT/ photodiodes)	~40	20µsec and 1sec
BLM (cable ion chamber)	~10	20µsec and 1sec
Current		
Current	1	DCCT
Differential	1	DCCTs w/ null
Profile		
Flags	4?	Phosphor
Wire Scanner - profile	3?	SEM mode
Wire Scanner - halo	3?	BLM mode
Scraper	2?	SEM + BLM
Synch Light	3?	
Streak Camera	1?	Dual sweep

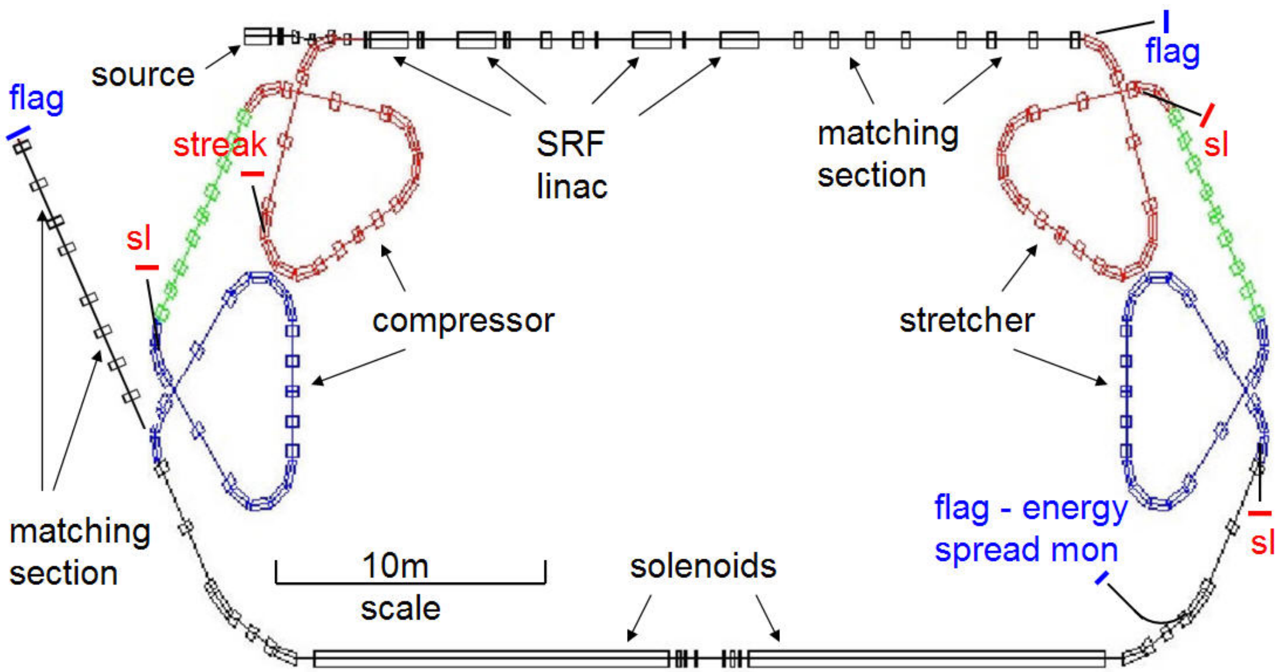

Figure 1: Layout of the RHIC Electron Cooler

Position/Phase monitors

Dual plane button BPMs will be located at every other quadrupole, and at additional locations as needed. BPM electronics will be an adaptation of the SNS electronics [6], modified to the VME form factor. Beam-synchronous digitization and I/Q demodulation will permit phase measurement at any desired BPM location. Pickups at dispersive locations will permit measurement of energy spread.

Possible onset of the BBU instability will be monitored with a stripline pickup. Data acquisition will be accomplished in parallel with a fast (20GHz BW) sampling scope, as well as with a spectrum analyzer. With the addition of a stripline kicker and power amplifier, this pickup will also be used for beam transfer function measurements, and in particular to explore parameters related to the BBU instability.

Loss Monitors

The preliminary plan is to include both local detectors (PMTs and/or photodiodes) for fast high-sensitivity measurements and cable ion to ensure a calibrated measurement and complete coverage.

The loss budget goal is 1uA. The electron beam has enough power to damage the vacuum chamber if it is not adequately protected. The loss monitor system will be able to rapidly shut the beam down when beam loss exceeds a programmable threshold. Shutdown within 10us of beam loss detection is anticipated. The loss signal will be processed using integrating electronics for equipment protection, and a linear and/or logarithmic technique for diagnostics & beam tuning. Similar systems have been used extensively at existing machines such as CEBAF at JLAB.

Current Monitors

The fiducial for current measurement will be a Bergoz Parametric Current Transformer (PCT). By virtue of the BPM processing architecture, current measurement from the sum signals of all BPMs will be available essentially for 'free', and will be calibrated by the PCT.

The differential current measurement (the difference in currents between the accelerated and decelerated beams) will assume increasing importance as commissioning proceeds and beam current increases, both as a measure of the efficiency of current recovery and as an input to the machine protect system. A simple and elegant method is to utilize two toroids in the injection and dump lines, linked with a figure eight winding. The output of one toroid is used to drive a nulling current through the figure eight, and the output of the second toroid is then the differential current measurement. This overcomes the dynamic range problem of measuring a small current difference in the presence of a large current signal. For 100mA beam current the AP specification of 99.9995% current recovery requires measurement resolution of better than 0.5μA. Possible refinements of technique to accomplish this are discussed in detail elsewhere [7].

Profile Monitors

Profile measurements are required to gain information about lattice functions as well as longitudinal and transverse emittance. Preliminary plans for profile monitors include flags, wire scanners, synchrotron light monitors, and a streak camera. Detailed specification of quantities, locations, and measurement requirements is in progress.

SPECIALIZED DIAGNOSTICS

As previously mentioned, electron cooling at high energy imposes several unique requirements upon diagnostics.

Beam-based Alignment

To minimize the contribution to transverse temperature of the electron beam resulting from field errors, beam-based alignment is under consideration. In the proposed method [8] the ion beam serves as the fiducial, is assumed to be perfectly rigid within the solenoid, and is aligned within the solenoid by BPMs at either end. Local dipole correctors and alignment quadrupoles are distributed within the cryostat along the length of the solenoid, at ~15cm intervals. The quadrupoles are designed to permit modulation at a few Hertz, and the resulting position modulation of the ion beam is detected by position monitors located elsewhere in the RHIC ring. The amplitude of position modulation is dependent upon the location of the ion beam in the quadrupole. Application of a swept four-bump of the ion beam position in the solenoid permits locating the magnetic center of that quadrupole relative to the BPMs at either end of the solenoid. The quadrupole can then be modulated in the presence of the electron beam, the position modulation can be detected in the return path of the ERL as a local bump (we note here only that this is non-trivial) is applied to the electron beam position, the position of the electron beam relative to the quadrupole can be determined, and the local dipole correctors can be used to locally align the electron beam relative to the ion beam. Determination of the quality of the alignment is problematic. During studies presently in progress in RHIC the only available means has been measurement repeatability, which is a few tens of microns.

Recombination Monitor

The ion/electron recombination rate is estimated [9] to be ~1MHz for the expected conditions in the RHIC cooling solenoids. The envelope of ions that have captured an electron is shown in Figure 2.

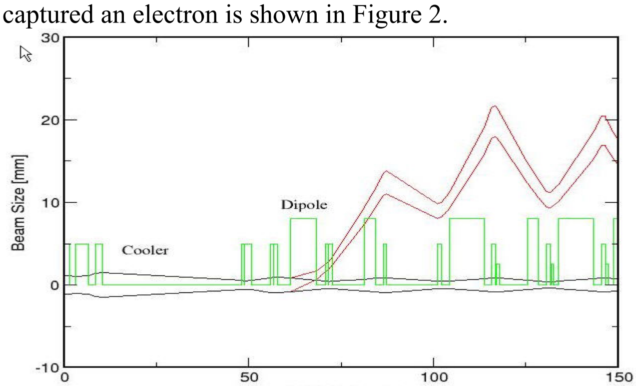

Figure 2: Envelope of recombined ions

Installing a scraper and fast PMT at the location of maximum displacement will permit counting recombined ions. Adjustment of a single in-cryostat local dipole corrector will result in count rate variations approaching 10KHz. This will provide a clean signal for correcting local field errors, and might be used either in combination with quadrupole modulation BBA, or stand-alone. It will also be a useful monitor for matching the longitudinal velocity of the electron beam to the ion beam.

Magnetization Monitor

Adjusting the betatron phase advances in the matching section at the end of the linac to differ by 90 degrees in the horizontal and vertical planes results in a flat beam, which can be observed on the diagnostic flag at the end of that line. From this data one can extract the beam magnetization and the un-magnetized emittance. A similar measurement can be accomplished in the matching section installed in the diagnostic line downstream of the second bunch rotation cavity. The non-magnetized emittance measured here should correspond well to the electron beam emittance within the solenoid, and will permit tuning of the dispersion and phase advance in the stretcher to minimize the contribution of longitudinal space charge to transverse emittance.

CONCLUSION

The diagnostics of a high-energy electron cooling present many challenges: The high-average-current, the energy recovery mode which necessitates non-intercepting diagnostics, the magnetization of the beam and the beam-based alignment requirements in the solenoid. We started the process of defining the various diagnostics for this application and present some new approaches (such as the use of beam-based alignment of the ion and electron beam to the solenoid axis) as well as an outline of our approach to the more conventional diagnostics, adapted to the extreme conditions of ampere-class beams in an ERL.

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