

Beam Diagnostics and Transport Magnet Requirements for the Recirculated Injector

Diagnostic and correction system required for a recirculating injector are presented. A recirculating injector provides a mechanism to increase the injection energy without having to increase the number of accelerating RF modules in the existing CEBAF 6 GeV injector. For the recirculating injector, a 180° bend is to be installed at the end of the present injector. The beam is then sent back to the beginning of the injector superconducting RF section and accelerated a second time. Hardware requirements the recirculated injector are established using prior CEBAF and IR FEL operating experience and simulations performed in Ref. 1.

Injection Recirculation – In addition to existing injector diagnostics, operational experience during the CEBAF Front End Test and with the JLab IR FEL suggests the following diagnostics be provided for injector recirculation commissioning and operation:

1. 4 BPMs/betatron wavelength in each plane; if the phase advances differ significantly, the required number will be dictated by the higher phase advance; for regions of critical operational importance, same principles are used as the existing Injector.
 - 12 new BPMs [18 exist, 30 total]
2. 4 correctors/transverse plane/betatron wavelength for orbit correction; for regions of critical operational importance, same principles are used as the existing Injector.
 - 12 new Vertical Correctors [18 exist, 30 total]
 - 8 new Horizontal Correctors [18 exist, 26 total]
3. 10 beam profile monitors (wire scanners or their equivalent) [5 new, 5 exist]:

- 1 at a high dispersion point of the recirculation (for momentum spread measurement)
 - 2 in the pre-recirculation injection chicane. These will be used to match the beam into the recirculator.
 - 2 in the first half of the recirculator back-leg. These are needed to measure the transverse beam properties after their first pass through the RF module and first mini-ARC.
 - 1 at end of chicane_3, coupled with quad a beginning of chicane_3 for transverse phase space measurements of second pass beam before RF.
 - 4 after the recirculator for matching into the linac. There are already four harps in this region.
4. 3 6 GHz Yao cavities. [1new, 2 existing/relocated].
 - one at entrance to to first RF module to measure timing of the 5MeV beam [insert dumplet to stop second pass beam].
 - one on the recirculator back leg to monitor phasing/bunch length after first pass through RF and first mini-ARC.
 - one after the recirculator, to monitor phasing/bunch length after the recirculator but before injection chicane.
 5. 6 viewers, [3 new, 3 exist] The viewers are needed for quad centering the beam, initial setup, and RF phasing.
 - one 2-beam viewer with hole, at the entrance to the first cryomodule. Steer the pre-circulated beam to the hole and observe the location of the recirculated beam on the viewer.
 - one 2-beam viewer between cryomodules.
 - one 2-beam viewer with hole at the exit of second cryomodule, used for tune up.
 - three additional viewers, one at the end of the first arc, one before the dogleg, and one before the second arc.
 6. two synchrotron light monitors, at a high dispersion point in each arc (for momentum spread/jitter measurement).
 7. 123MeV spectrometer. [instrumentation exist, just need new dipole and location]. The energy of the injected beam needs to be well measured. This energy is used for determining the spin precession and obtaining the proper injection to total energy ratio.
 - Faraday Cup for absolute current measurement. This Faraday cup will be used to cross calibrate BCM cavities post-recirculator.
 8. one insertable (2 kW) dump at the end of the first arc.

9. one BCM cavity [new]. Located after the recirculator, used to monitor injected beam current.

These requirements are summarized in Table 1, summary of outstanding issues and detailed justifications are in the next two sections.

ISSUES:

1. BPMs in RF section will have two beams present. Need to develop technique [software or hardware] to resolve the individual beams.
2. Presently OL04 is operated 10° off crest and the injection chicane has some M_{56} built into the optics. The phase of OL03 and OL04 will be coupled in the recirculator and probably equal. So either both OL03 and OL04 are slight off crest for the second pass beam, or the M_{56} is removed from the injection chicane.
3. Monitoring that the time of arrival of the second pass beam with respect to either the 5MeV beam or the RF phase needs to be thought out.

JUSTIFICATION:

The diagnostic requirements for the proposed injector recirculator for the 12GeV JLAB upgrade are based on operational experience on the CEBAF main machine and the FEL machine. Parmela simulations have been used as to determine diagnostic needs in the recirculator [1].

BPM's and Correctors: The number of BPMs and correctors is the same for the existing injector and are needed so that the beam transport can be properly measured [FOPT], monitored and enough trim magnets to keep the beam near the center of the beam pipe.

Viewers: The three viewers in the RF section will have holes at the center of the viewer. The idea is that the first pass beam is sent through the hole on the viewer and the second pass is observed on the viewer. The other three viewers will be used for quad centering and tune up.

Beam Profilers: For measuring the transverse phase space before chicane1, after the first mini-ARC, after the second mini-ARC before second pass through RF , and after the recirculator.

YAO cavities: For measuring the bunch length and time of arrival of the 5MeV beam, first pass accelerated beam and post-recirculator.

127 MeV Spectrometer with Faraday Cup: Will be used to accurately measure the energy and current coming out of the injector. Without the Faraday cup any BCM device after the recirculator will have suspect calibration due to unknown losses in the recirculator.

Table 1: Injector Recirculation Diagnostic/Correction Components

<i>Component</i>	<i># (in addition to existing Injector to end of Chicane)</i>
Corrector H	8
Corrector V	12
BPM	12
SLM	2
Viewer	3
Profile Monitor	5
BCM	1
Insertable dumps	1
6GHz Yao Cavity	1
123MeV Spectrometer	1 dipole, 1 Faraday Cup

OPERATIONAL SCENARIO:

Tune Up:

The following section describes the gedanken experiment of tuning the beam through the injector recirculator starting at the 5MeV chicane at the entrance to the recirculator.

1. Match the incoming 5MeV beam to the design optics of the recirculator. Use the two wire scanners in the pre-injection chicane in conjunction with quadrupole magnets to determine the incoming beam properties and proper settings of the quadrupole magnets to achieve a match.
2. Transport the beam through the recirculator RF section. Use the three viewers and beam position monitors in the RF section to steer the beam through the RF

section. Adjust trim magnets as needed to steer the beam through the hole in the viewers.

3. Set up the RF phase and drive levels. Adjust the RF phase and drive until the desired beam energy is achieved. The beam position [BPM, SLM, profile monitor] and width at the dispersive location in the first arc will be used to monitor energy and energy spread during this process.
4. Set the bunch length. Using the 6 GHz cavity at the end of the first arc optimize the bunch length of the beam. Adjust phase of 1/4Cryo or recirculator RF to achieve the proper bunch length.
5. Match the 61.5 MeV beam to the design optics of the second arc and RF section. Use the two wire scanners before the pathlength dogleg in conjunction with quadrupole magnets to determine the beam properties at 61.5 MeV. Determine the proper settings for the quadrupole magnets to achieve a match to the second arc.
6. Tune the beam through the second arc and small 61.5 MeV chicane. Use BPMs, viewers and trim magnets to steer the beam to the entrance of the RF section.
7. Verify 61.5 MeV match and rematch if necessary. Use the wire scanner and quadrupole in the 61.5 MeV chicane to verify the beam properties after the second arc and adjust the match into the RF section.
8. Adjust the pathlength such that the recirculated beam traverses the RF section with the proper timing/phase. Use a dispersive location in the injection chicane to establish the optimal pathlength of the recirculated beam. In addition to pathlength, this process will setup transport into the injection chicane.
9. Match the 123 MeV beam to the design optics of the injection chicane. Using the four wire scanners measure the phase space of the beam and obtain the proper quadrupole settings to match the 123 MeV beam into the injector chicane.

Continuous Operations:

The RF section of the recirculated injector has two beams and therefore there are two phases to monitor and adjust along with the total energy gradient. The phase of the first pass beam and its energy will be monitored by the beam position in the first arc. These beam positions will also be used to control the energy of the recirculated injector as well as keeping the phase of the arrival beam on “crest” [by changing the phases of upstream RF components].

The second pass beam will be kept on “crest” by beam positions measured in the injection chicane and adjusting the pathlength via dogleg in the injector chicane. Thus the injection chicane is used to maintain the pathlength of the recirculated beam not the total energy as it is presently configured. The energy of the recirculated injector will be controlled by an energy lock in the first arc of the recirculator.

Bibliography:

[1] Y. Zhang, *et. al.*, “Computer Simulation Studies of Two Injection Options for 12 GeV CEBAF Upgrade”. JLAB-TN-05-054