# IR FEL Injection Line Setup Procedure

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## Overview

Beamline with relevant diagnostics and correction elements is shown in Figure 1. (Nomenclature is to be revised to standard in later versions of this procedure.

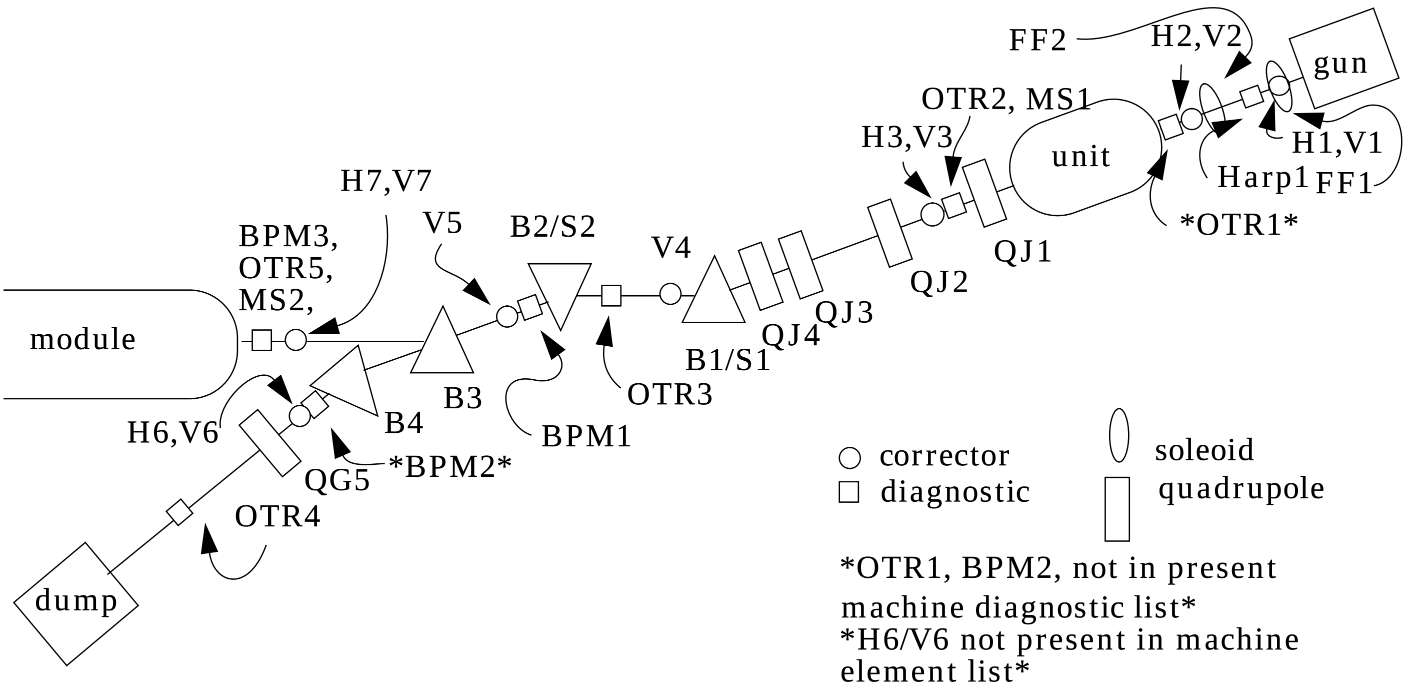


Figure 1: Injection line diagnostic and correction system layout

## 1.0 Purpose:

Initial setup of machine from front flange of injector cryounit to front flange of cryo-module

## 2.0 Prerequisites

1. Beam to Harp1 with appropriate pulse structure
2. Unit with RF on idle
3. Magnets appropriately powered for transport to 10 MeV dump (verify B3 switched out, B4 switched on, quads downloaded).
4. Appropriate valves open, valve upstream of module closed

## 3.0 Beam Through Unit

1. Verify proper beam position at Harp1, or, if new setup, center beam in solenoid FF1.
2. Steer to center of *OTR1* (*not presently in machine diagnostic list*) using H1,V1.
3. Center beam in solenoid FF2 using H1, V1. Note that this may leave beam uncentered in buncher, the consequencs of which must be discussed. Beam centering in FF1 and FF2 is used to define “straight line” injection into the unit.
4. Thread beam through unit to center of downstream viewer OTR2 using H2, V2
5. Power up 1st cavity, dial phase to restore beam to viewer; resteer with H2/V2
6. Power up 2nd cavity, dial phase to restore beam to viewer; resteer with H2/V2
7. Use transient phasing procedure to transient phase unit.
8. Modulate unit RF phase or laser phase and center in unit using H1/V1 and H2/V2.
9. Turn off RF or laser modulation
10. Cross-check beam position on Harp1, OTR1, and OTR2, (recheck centers in FF1 and FF2) noting if the beam has moved from any center of either during Step 7. This indicates an alignment problem with either the beamline or the unit.

## 4.0 Beam into injection line

1. Thread beam to OTR3 using V3 and by varying unit RF gradiants in 0.1 MV/m steps to steer beam horizontally at dispersed location. These 1% changes in energy will move the beam horizontally ~5 mm per step at OTR3, where the dispersion is ~0.5 m. (This step fiducializes the energy to the excitation of dipole B1.)
    a. When the beam appears at OTR3, center it by adjusting the unit gradiants. Aperture scan horizontally using H3, and center beam in any upstream aperture constrictions with H3, while holding beam fixed at OTR3 by adjusting the unit gradiants. (This is to avoid “clipping the corner” at B1). When completed, proceed to 2.
    b. If the beam fails to appear at OTR3, there is a steering error/energy mismatch - probably at B1. Grid search for the beam by scanning the aperture using H3/V3 while stepping the unit gradiants from ~8 MV/m to 12 MV/m in 0.1 MV/m steps. BLMs may provide useful guidance in this activity. When beam is found, proceed to 2.
2. Center in QJ3/4 using H3/V3. After centering in the quad, return beam to horizontal center of OTR3 by adjusting unit gradiants; return beam to vertical center by adjusting V4.
3. Verify that beam has appeared at BPM1.
4. Aperture scan chamber at BPM1 using shunt S1 (or, if substituted, horizontal corrector H4) and vertical corrector V4 to fiducialize/calibrate BPM1.
5. Roughly crest RF cavities/gang phase unit using dispersed beam reading on BPM1 or OTR2 at B2. The dispersion at this point is ~0.5 m. If position has shifted after cresting, adjust unit gradiants to restore beam positions and thereby match beam energy to dipole excitations.

## 5.0 Beam to dump

*If BPM2 (not presently in machine diagnostic list) can be provided, the procedure is as follows:*

1. Using shunt S2 (or horizontal corrector H5, if substituted) and V5, thread beam to *BPM2* (not presently in machine diagnostic list).
2. Aperture scan chamber at BPM2 using shunt S2 (or, if substituted, horizontal corrector H5) and vertical corrector V5 to fiducialize/calibrate BPM2.
3. Thread beam to OTR4 and beyond to dump using *H6/V6* (*not presently in machine element list*). Center beam on OTR4 and at the dump with H6/V6. If this cannot be done, it implies the orbit is not leaving B4 parallel to the beamline axis, possibly due to one of the following:
   a. spurious reading on BPM1 and/or BPM2
   b. dipole string excitation errors, causing mismatch amongst B1, B2 and B4
   c. alignment errors in the beamline.

   Record all observations for off-line analysis.
4. Center beam in QG5 using H6/V6. Note if beam has moved on OTR4 or at the dump. This indicates the orbit is moving parallel to the beamline axis through the quad, possibly due to one of the following:
   a. spurious reading on BPM1 and/or BPM2
   b. dipole string excitation errors, causing mismatch amongst dipoles B1, B2 and B4
   c. alignment errors in the beamline.

   Record all observations for off-line analysis.
5. With beam on OTR4, verify QG5 is set for high-dispersion mode and accurately crest cavities and gang-phase the unit.

*If BPM2 (not presently in machine diagnostic list) cannot be provided, the procedure is as follows:*

1. Using shunt S2 (or horizontal corrector H5, if substituted) and V5 and correctors *H6/V6* (*not presently in the machine element list*), grope blindly to thread beam to OTR4 and beyond to dump. BLMs may provide useful guidance for this activity. Think of playing “Marco Polo” with your kids at the pool...
2. Center beam in QG5 using H6/V6. Note if beam has moved on OTR4 or at the dump. This indicates the orbit is not moving parallel to the beamline axis through the quad, possibly due to one of the following:
   a. spurious reading on BPM1 causing bad launch into the line
   b. dipole string excitation errors, causing mismatch amongst B1, B2 and B4
   c. alignment errors in the beamline.

   Record all observations for off-line analysis. This will be crucial, for without BPM2 the system is badly underconstrained and must be treated completely systematically and in a well-defined way if it is to reproduce.
3. With beam on OTR4, verify QG5 is set for high-dispersion mode and accurately crest cavities and gang-phase the unit.

## 6.0 Set Cryomodule Energy Gain

1. Check for any systematic offsets of S1(H4)/S2(H5)/H6, indicating energy mismatch.
2. Adjust cavity gradients to reduce average shunt/corrector excitation to zero.
3. Verify orbit has not changed following gradient adjustment. A change is indicative of an alignment error in beamline or unit, or dipole/energy mismatch. Record observations for off-line analysis.

## 7.0 Measure Emittance

1. Set QJ1(2?) to zero for emittance measurement mode.
2. Measure emittance using multi-slit MS1 and emittance measurement procedure.
3. Re-match beam envelopes and reset QJ1,2,3,4 to provide design values for injection.

## 8.0 Measure Momentum Spread

1. With emittance data in hand and beam envelopes rematched, (and, having verified above that QG5 is set to high dispersion mode), measure momentum spread, and verify RF phases.

## 9.0 Beam to Module

1. Shut beam off
2. Close injection dump line valves, open valves through cryomodule
3. Verify cryomodule RF on idle
4. Power down dipole string; switch direct bend B3 in and reverse bend B4 out.
5. Standardize dipoles
6. Turn beam on
7. Thread beam to OTR5/BPM3 using S2(H5)/V5. Do not dawdle.
8. Thread beam through module to next diagnostic using H7/V7. Do not dawdle. Use cryomodule setup procedure to transport beam to energy recovery dump.

## 10.0 Comments

When transport of 10 MeV beam to energy recovery dump is accomplished, the Cryomodule Setup Procedure will review certain final details of the injection line setup. These are as follows:

1. Aperture scan of chamber with S2(H5)/V5 to verify OTR and BPM fiducialization/calibration, alignment of beamline from B2 through injection point, and excitation of injection line dipoles
2. Beam emittance at injection point by repeating emittance measurement with MS2
3. Bunch length at injection point using OTR5
4. Momentum spread measurement in energy recovery dump line
5. Measurement of injection line $M_{56}$. Note well that errors in this parameter are due to hardware problems and can be corrected only in hardware. If this is not

possible, they must be compensated by changes in the injector operating point.

If steps 2 or 3 indicate a problem, the injector can be further optimized with beam transported to the energy recovery dump. Emittance measurements/rematches can be performed using MS2; if precision momentum spread measurements are needed, they can be accommodated in the energy recovery dump.