Beam Transport Issues in the Winter/Spring 1999 FEL Run

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Abstract

Beam transport issues addressed during the Winter/Spring 1999 FEL run are documented. These include steering and focussing problems detailed in a previous note [1]. Results of beam transport activities are presented, and recommendations made for future actions.

Activities During the Fall/Winter 1999 FEL Run

Beam transport activities during this run focussed on the implementation of the "FEL Driver Recovery Procedure/Optimization Test Plan, Rev 0.2" [2]. This plan was a response to observations made during the Fall/Winter 1998 FEL run [3]. In this running period, the following meta-process was used to prepare the FEL driver for high power running and remedy certain performance problems.

1) The injection line was resteered to reduce the excitation of the 1F00H and V correctors.
2) The DY5F03 shunt was adjusted to improve the orbit in the second end loop and at reinjection
   a) The RECIRC buss was set to match the beam energy during setup (without lasing), thus centering through the 3F region.
   b) After checking the beam was centered in the upstream trim quads (QH5F01 and 2) and thereby verifying the 5F end-loop dipoles were also properly excited, the DY5F02 shunt was adjusted to center in QH5F03. This process was greatly assisted by the newly available of ITV5F04 and 7.
   c) The RECIRC buss was reset to center the beam in the end loops while lasing.
3) The beam was centered in QB5F05/6 by observing ITV5F07 while steering with the 5F03V and 5F04H correctors.
4) The beam was steered to the center (though the hole) of ITV1F02 using 5F07H and V.
5) The longitudinal match at the 1G dump was verified. While lasing,
   a) the DG3F02H string was adjusted to put the phase on the "short" side of the RF trough,
   b) FELEXT and 1G01H were used to steer beam on ITV1G01 and 2, and
   c) trim quads QH(3/5)F0(2,3) and sextupoles SC(3/5)F0(2/3) were adjusted to give a "best" spot at ITV1G01.

6) Betatron "matching" was crudely performed:
   a) the downstream telescope (2F04-9) quads were adjusted to give "appropriate" spots in the backleg (4F) region, and
   b) the reinjection (5F05-8) telescope was adjusted to give "best" spots at 1F02.
7) Difference orbits measurements were made at 38 and 47 MeV.

Observations and Results

During/after the above actions, the following observations were made/results obtained.

1) The injection orbit was, following the resteer of Activity #1, very messy. It did, however, allow good energy recovery transport and injector performance adequate for FEL operation at high powers.
2) "Little" (~10 cm or less) remnant dispersion was observed in the backleg (4F) region, even with trim quads activated for longitudinal matching [4].
3) The driver could run nearly 4 mA with energy recovery, and supported lasing at ~700 W.
4) Difference orbit measurements [5] suggested the recirculator suffers from quadrupole excitation problems, particularly with quads nominally restricted to 1 A loops.
   a) Michael Teifenback has examined the excitation curves in use in the FEL EPICS implementation. He has observed that they are probably inaccurate in this capacity inasmuch as they are based on 10 A loops of the type used in CEBAF, not 1 A or 5 A loops appropriate to the current limits imposed in the Driver [6].
   b) Jeff Karn has questioned if the "low field" (1 A limited) quads were ever subjected to higher currents following installation, inasmuch as this could alter their excitation behavior [7]. This is in fact the case for at least 1 such quadrupole (QG4F13 [8]); M. Tiefenback has suggested that it is possible that others could have (intermittently) suffered a similar fate [9].
5) HV coupling is a problem for the energy-recovered beam, with the second pass beam at 1F02 an elongated diagonal stripe.
   a) The root cause of this is the scheme implemented to correct coupling of the accelerated beam. The skew quads at 1F01 and 1F02 cancel the RF skew quad imposed by cavity HOM couplers, but, because the energy recovered beam is 180° out of phase with the RF skew quad mode, the error and correction *add* on the second pass [10].
   b) Preliminary investigations of correction schemes for the second pass beam met with little success at alleviating the observed coupling [11].

Conclusions and Conjectures

Based on the above activities and results, the following conclusions are drawn (though they may be no more than cruel fictions!)

1) The current limits encountered during the Fall/Winter 1998 run [12] were due to scraping and orbit problems, not gross beam instability.
2) The badly degraded injector orbit allows 1F00H/V corrector reductions and gives a good energy recovery orbit. This suggests there is a problem local to the injector.
3) Betatron diddling of the type described in Activity #6 was probably a response to the quad excitation problem (Observation #4).

Recommendations

1) Work on the injector!
   a) The orbit is clearly wrong.
      i) The orbit problem almost certainly starts upstream of the unit; the steering in front of the second solenoid needed to offset fundamental power coupler steering in the unit will necessarily be outcoupled to the vertical plane by the solenoid (which is not counterwound). The orbit through the unit is thus likely severely degraded; downstream consequences are unclear.
   b) Multi-slit 2 is not operable, nor is Happek 1. These problems may be related to a), immediately above.
   c) There is reason to believe M_{55} measurements using the injector BCM are inaccurate. As the cavity is at a dispersed location (0F06), the time of flight is affected not only by velocity variations with energy, but by steering generated during RF cavity phase changes. A preliminary look at the numbers suggests that the time of flight error imposed by cavity steering may wash out the time of flight variation due to an energy change. This is simply a symplectic conjugate to the steering problems that corrupt efforts to phase the unit cavities. Our understanding of the injector setup may thus be in question.
2) Get the quads excitation curves right.
3) Measure emittances and beam phase space carefully and match quantitatively.
4) When Recommendations 2) and 3) have been followed, repeat difference orbit measurements to verify the machine is behaving as expected.
5) Develop an effective method for handling the H/V coupling of the energy-recovered beam. This could be a major problem for the three-module upgrade. Obvious solutions in that case are as follows:

a) Provide a skew quad matching system in the recirculator to "pre-stress" the energy recovered beam so it remains well controlled throughout the second pass through the module. This takes space, time, and more modeling capability than I presently have!
b) Develop and install small "RF skew quadrupoles" to be used in the same manner as the existing magnetic skew quads. The phasing of the correction fields would then track the phasing of the error fields. This solution is likely to be expensive but would be conceptually simple.

Acknowledgments

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References

[1] D. Douglas and G. Biallas, "Beam Transport Issues in the Fall/Winter 1998 FEL Run, JLAB-TN-99-007, 9 April, 1999.

[2] D. Douglas, "FEL Driver Recovery Procedure/Optimization Test Plan, Rev 0.2 (1 February 1999), available on the World Wide Web at http://www.jlab.org/~douglas/FEL/procedures/recoveryoptimizerev0_2.pdf .

[3] D. Douglas and G. Biallas, *op. cit.*

[4] This was first reported to me by Phillipe Piot, and has been subsequently verified with a cursory difference orbit measurement.

[5] See D. Douglas, "Preliminary Difference Orbit Measurements in the FEL Driver Recirculation", JLAB-TN in preparation.

[6] M. Tiefenback, private communication.

[7] J. Karn, private communication.

[8] There are many FLOG entries to this effect, see, for example, Entry #4484 (10 March 1999) 4532 (12 March 1999), and 4758 (26 March 1999).

[9] M. Tiefenback, private communication.

[10] See, for example, Figure 3-20, p. 54, of Z. Li, “Beam Dynamics in the CEBAF Superconducting Cavities”, Ph. D. thesis, Dept. of Physics, College of William and Mary, March, 1995.

[11] Kevin Jordan organized getting a Haimson coil installed in a skew quad configuration at 5F07. This was tested and found to have little effect, possibly due to the very low available fields. George Biallas replaced the Haimson with a more robust set of coils, running off the same DB0G01H trim card used to power the Haimson. This has not yet been thoroughly tested.

[12] D. Douglas and G. Biallas, *op. cit.*