Acknowledgments

I would like to thank Leigh Harwood for a useful discussion about this design. The phasing/backphasing scenario is due to him. I would also like to thank attendees at the FEL commissioning/diagnostic meeting, particularly Bob Legg, Geoff Krafft, and George Biallas, for useful interactions about this design. Thanks also to Joe Bisognano for education on relativistic phase slip.

Notes and References

[1] G. Neil, S. Benson, numerous public statements and obvious common sense.

[2] D. Douglas, "Engineering Design Specifications for the IR FEL Driver Transport System", CEBAF-TN-96-026, 6 June 1996.

[3] See, *e.g.*, the simulation on the cebafh cluster in

~douglas/../../../../prinzipal/usr/users/optics/IRFEL_optics/irapr96/baseline/problems/simulation/mis729out

[4] L. Harwood, private communication.

[5] G. Biallas, private communication.

[6] *ibid*.

[7] R. Legg, private communication.

[8] L. Harwood, private communication.

[9] At energies over 5 MeV, CEBAF cavities focus at all phases; the variation of focussing with phase goes at twice the phase offset (it is doubly periodic over 360^o of rf phase variation). See Z. Li, "Beam Dynamics in the CEBAF Superconducting Cavities", Ph.D thesis, College of William and Mary, 1995.

[10] DIMAD input is in

~douglas/../../../../prinzipal/usr/users/optics/IRFEL_optics/irapr96/baseline/problems/phasing/temptest

and output is in

~douglas/../../../../prinzipal/usr/users/optics/IRFEL_optics/irapr96/baseline/problems/phasing/temptestout

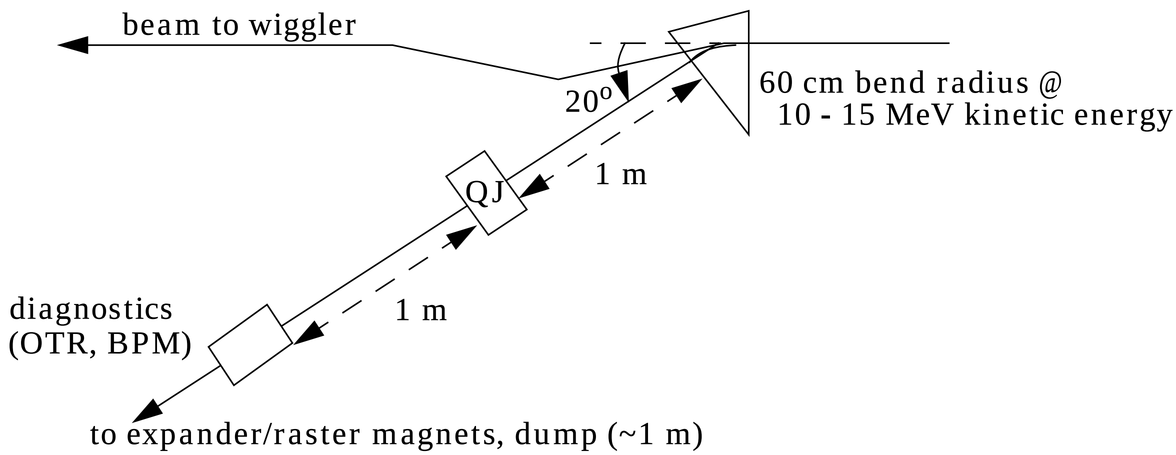

Figure 1: Layout of energy recovery dump.

Summary

The layout of this region downstream of the final dipole will be a 1 m drift, followed by a QJ, followed by a 1 m drift, followed by a diagnostic package for phasing and momentum spread evaluation (an OTR and a BPM would be sufficient). The usual dump configuration (with expander quad doublet, raster magnets, and dump) is placed 1 m after the diagnostic. See Figure 1.

During normal running for energy recovery, the QJ is unexcited, the beam envelopes at the dump are of order 10 m, and the dispersion at the dump is of order 1 m. This leads, without use of the expander quads, to a nominal full horizontal spot size of ~8 cm and full vertical spot size of ~1 cm on dump. This assumes a direct sum of spot size from dispersion with 7% full momentum spread (after energy compression during energy recovery) and 4 sigmas of 13 mm-mrad normalized emittance.

For phasing, the QJ is excited to generate ~1 m of dispersion at the diagnostic package and to control vertical beam size; in this case the beam envelopes are ~2 m at the observation point for the various phasing scenarios discussed above. This will provide adequate resolution for phasing the cavities to the 10^{o} level (including relativistic phase slip).

The only design specification changing as a consequence of this study is that for the peak field of the injection/extraction line dipoles. We now require they provide 50% overhead to cover all phasing needs. Previous design requirements called for a 0.6 m bend radius at a kinetic energy of 10 MeV. This translates to a field of 0.58366 kg. We now require a peak field of 0.87549 kg, a factor of 1.5 higher.

in the extraction chicane, would require vacuum system and magnet redesign, and would have negative cost and schedule impact.

4. Phasing could be done in the dump line exciting only one cavity at a time. In this case, 14 MeV beam would be generated with a single cavity, which would be crested individually. Alternatively, multiple cavities could be run at lower gradient and individually phased (*e.g.*, 4 cavities at a quarter the nominal gradient) to reduce cavity steering effects [7]. This will lead to an incremental relativistic phase slip of ~2^o per cavity, with the first cavity properly phased and the final cavity ~14^o off crest. The cumulative energy error would be of order 1%. This scenario requires that the final dipole be able to run 40-50% above nominal, a more modest dynamic range requirement than in 1.
5. Phasing could be done in the dump line by exciting cavities in pairs, phasing one and back phasing the other [8]. By maximizing the energy gain of one and canceling it with the other, the energy at the dump remains 10 MeV, but all cavities are locked in phase.

A July 30 1996 FEL commissioning meeting developed a consensus that 4 and 5 were adequate and desirable. The dump line is therefore to be capable of supporting these options.

When beam is propagated through the system with a model of either scenario 4 or 5, beam envelopes (in either plane) at the front end of the dump dipole are of order 10-15 m and either moderately convergent or divergent, depending on which cavities are excited (module front or back end) and which scenario is used (5 provides twice the cavity focussing of 4 [9]). The sector dipole focuses the beam strongly horizontally, and generates about 1/3 radian of dispersive slope. The beam is, in fact, overfocussed horizontally, so at a downstream location with 1 m of dispersion, the beam envelopes are large (~20 m) and diverging both horizontally and vertically. This is not desirable for phasing.

The problem is readily remedied by introducing a single quadrupole 1 m downstream of the dipole, and taking a observation point 1 m downstream of the quadrupole. By exciting the quadrupole to be vertically focussing (a “k” of -5/m^2 at 10 to 14 MeV seems adequate, implying the quadrupole should be a QJ), the horizontal dispersion is enhanced, the vertical beam envelopes focussed, and the overfocussing of the horizontal beam envelopes corrected. The resulting optics provide 1 m of dispersion and beam envelopes of ~2 m at an observation point 1 m after the quadrupole. These values are ideal for phasing.

A DIMAD model of the line is available on the cebafh cluster [10]. A sketch is given in Figure 1, below.

Energy-Recovery Dump Transport Design

D. Douglas

Abstract

We describe a design for beam transport to the 10 MeV energy recovery dump.

Requirements

The 10 MeV energy recovery dump transport must provide

- loss free transport of the energy recovered beam from the cryomodule to the dump, and
- a means of roughly phasing (to ~10^{o}) cryomodule cavities prior to transport through the wiggler.

This latter requirement is driven by congestion in the driver lattice layout. There is no other location upstream of the wiggler at which the beam can conveniently be phased, and transport of unphased beam through the wiggler is deemed undesirable due to potential losses and radiation damage [1].

Design Description

The general layout of this region has been given elsewhere [2]. Here we concentrate on the transport from the linac axis to the energy-recovery dump. A single 20^{o} sector dipole (a copy of the injection line bends) will direct the energy-recovered beam from the linac axis toward the dump. DIMAD simulation indicates that the energy-recovered beam will be well confined during transport from the module to the dump even without any intervening optics; beam envelope functions some 3 m downstream of the dipole (at the nominal dump position) are ~10 m and the dispersion is ~1 m [3].

The problem of primary interest here is that of rough-phasing the cavities prior to transport through the wiggler. This phasing can be done several ways.

1. The final dipole could be run up a factor of 4 in field to bend the 42 MeV beam. Phasing would then proceed as in the CEBA injector at the 0L08 spectrometer. This, however, forces an undesirably large dynamic range for this magnet [4].
2. The final dipole could be replaced by a “more robust” rectangular dipole with greater dynamic range. Phasing then proceeds as in 1. This would require a redesign of the layout of the extraction chicane (which is presently a carbon-copy of the injection line) and a new class of dipoles for the driver. This may have desirable optical results but has negative cost and schedule impact [5].
3. The final dipole could be surrounded by other dipoles, which would be unexcited during normal operation but run up to provide 20^{o} of bending for full energy beam for phasing [6]. Phasing then proceeds as in 1. This may lead to congestion