Table 2: String and Shunt Stability, Range, and Resolution Requirements

Power Supply	Stability	Minimum Resolution
injection line/reinjection chicane	10^{-4}	16 bits
extraction chicane	10^{-4}	16 bits
optical cavity chicane	10^{-5}	16 bits
main dipole string	10^{-5}	16 bits

Power Supply	Range	Stability	Minimum Resolution
optical cavity chicane	3% (±1.5 %)	10^{-4}	16 bits
reverse bends	2% (±1 %)	10^{-4}	16 bits
west/east π-bends	1% (±0.5 %)	10^{-4}	16 bits

Acknowledgments

Thanks to Bob Legg and Kevin Jordan for motivating this note and to George Biallas for a useful discussion about powering of the extraction chicane and phasing dipoles.

References

[1] D. Douglas, "IR FEL Driver Accelerator Design", CEBAF-TN-96-050, 27 September 1996.

[2] D. Douglas, "Error Estimates for the IR FEL Transport System", CEBAF-TN-96-035, 15 July 1996.

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

[4] D. Douglas, "Beam Transport to the 'First Light' Dump", CEBAF-TN-96-056, 24 October 1996.

[5] D. Douglas, "10 MeV Diagnostic Dump Transport Design", CEBAF-TN-96-039, 26 July 1996; D. Douglas, "Energy-Recovery Dump Transport Design", CEBAF-TN-96-040, 31 July 1996; D. Douglas, "Final (*hopefully!*) Energy Recovery Dump Transport Design", CEBAF-TN-96-048, 4 September 1996.

[6] Similar effects dictated the arc dipole excitation scheme employed in the nuclear physics accelerator.

Stability, Resolution, and Shunt Range Specifications

The stability requirements for all strings and shunts have been discussed elsewhere [2]. Here, we note two new features of the configuration that have not yet been discussed. First, the 10^{-4} stability specification for the injection/extraction strings was set assuming all dipoles track in an achromatic configuration. Since this specification was made, new operational modes for these lines, using dispersed transport, have been developed [5]. *We now explicitly state the assumption that the momentum resolution required of any dispersed measurement in these lines will not exceed the limit imposed by this 10^{-4} stability specification*. In particular, both beam lines support measurement modes with 1 m of horizontal dispersion. In these modes, beam motion of 100 μm will occur as a consequence of power supply ripple. This limits momentum spread resolutions to values larger than 1×10^{-4} in cw and/or non-line-locked operational modes. We assume either the spot size/motion will be momentum dominated at the 10^{-3} level (which is readily resolved) or that operation will be line-locked so that 60 Hz motion will be unimportant at either the injector setup dump or the energy recovery dump.

Secondly, we note that decoupling the optical cavity chicanes from the main dipole string enhances possible longitudinal beam motion due to power supply ripple [6]. In the original design, the net M_{56} from linac to wiggler was -0.3 m; the net M_{56} from wiggler to linac was +0.2 m. The total M_{56} from linac to reinjection was therefore -0.1 m. Moreover, all bending elements in this transport were in series, so that the longitudinal positional jitter (for 10^{-5} dipole string stability) was of order 0.1 m x 10^{-5}, or only 1 μm. Now, the optical cavity chicanes are on a separate string from the recirculation dipoles. The net M_{56}, linac to arc, is -0.6 m; the net M_{56} through the arc is +0.5 m. Each of these string is now separately powered, and can in principle move in a manner uncorrelated, or even anticorrelated, with the other. Thus, the ripple-driven longitudinal positional jitter can be as large as (0.6 m + 0.5 m) x 10^{-5}, or 10 μm - an order of magnitude larger. If the optical cavity chicane power supply is stable only to 10^{-4}, the longitudinal jitter would be dominated by the chicane contribution, and would jump to ~30 μm at the wiggler (from dipole ripple alone - a similar contribution comes from RF jitter!) and ~60 μm at the arc. The value at the reinjection point could then be as large at 65 μm.

A conceptually similar (though numerically much smaller) contribution arises from the shunt on the second optical cavity chicane. This shunt has a full range of 3% and is stable to 10^{-4}; it drives a chicane with M_{56} of -0.3 m and thus can in principle add positional jitter of 0.3 m x 0.03 x 10^{-4}, or ~ 1 μm, to the total.

None of these effects are overwhelmingly large; we mention them only because they do represent fundamental limits on beam stability and bunch length in a machine with extremely aggressive performance criteria in these areas. Table 2 summarizes string and shunt stability, range, and resolution requirements.

Main Dipole String. The reverse bends and π-bends are to be run on a single string to relax tracking and stability requirements [2] and to allow de-activation of the first reverse bend. The individual π-bends and all reverse bends (in series) will be on shunts to allow matching of dipole excitations amongst the various families. When the beam is run to the first light dump, the string is deactivated and the field in the first reverse bend brought to zero. Note that operational demands may require

1. the first reverse bend have a trim coil and/or embedded Hall probe to insure the remnant field is adequately small when the main dipole string is switched out, and to insure the magnet reproduces well enough, and
2. appropriate magnet standardization and reproducibility must be enforced every time the machine is switched between operating modes.

Table 1 summarizes the string, shunt, and switch requirements.

Table 1: Summary of string, shunt, and switch requirements

<u>power supply strings</u> - 4

- injection line/reinjection chicane
- extraction chicane
- optical cavity chicanes
- main dipole string

<u>shunts</u> - 4

- second optical cavity chicane
- all reverse bends (in series)
- west π-bend
- east π-bend

<u>trim coils/Hall probes</u> - 4

- common injection line bend
- phasing dipoles (in series)
- first extraction line dipole
- first reverse bend

<u>switches</u> 2

- common injection line dipole/injection line reverse bend
- extraction chicane/phasing dipole pair

<u>variances from baseline design</u>:

- 2 additional horizontal correctors + 2 additional trim channels (injection line)
- trim coils on dipoles may be driven by trim channels (4 additional)

The string/shunt configuration details are as follows.

Injection String. The two independent injection line dipoles, the two independent reinjection chicane dipoles, and the final (common) injection line dipole are to be powered in series. This configuration allows the use of less stable power supplies than are required for independent powering [2]. The common dipole is to be cross-switched with a reverse bend directing beam to the 10 MeV injector set-up dump. When the switch is set in nominal mode, beam is directed to the cryomodule; when the switch is set in injector setup mode, the common dipole is unexcited and the reverse bend directs beam to the dump.

Note that operational demands may require

1. the common dipole have trim coils and/or an embedded Hall probe to insure the remnant field is adequately small when the reverse bend is switched in and to insure the magnet reproducibility is adequate, and
2. appropriate magnet standardization and reproducibility must be enforced every time the machine is switched between operating modes.

<u>Note well the following variance from the previously defined baseline</u>: *This configuration deviates from that previously specified* [3]. *We now require an additional pair of horizontal correctors in the injection line, one adjacent to each of the two independent injection dipoles. This eliminates a prior need for shunts on each of these magnets, and simplifies beamline operation and reproducibility during orbit correction, but increases the trim channel and horizontal corrector count by 2 each.*

Extraction String/Phasing Dipole Pair. The extraction dipole chicane is to be powered in series, as was the injection/reinjection string, again to relax power supply stability requirements [2]. A pair of beam phasing dipoles surround the first extraction chicane dipole, and is used to direct 42 MeV beam to the energy recovery dump for RF phasing. As stability requirements on these dipoles are identical to those on the extraction string (see discussion below), the two strings can be cross-switched. During phasing, the extraction chicane is switched out and unexcited, and the phasing dipoles are excited. During normal operation, the extraction chicane is excited, and the phasing dipoles are switched out and unexcited.

As the phasing dipoles are to be used to set the beam energy, they should cross-calibrate well with the extraction chicane dipoles. Operational demands may require

1. the phasing dipoles and first extraction chicane dipole have trim coils and/or embedded Hall probes to insure the remnant fields are adequately small when the various strings are switched in and out, and to insure the magnets reproduce sufficiently well, and
2. appropriate magnet standardization and reproducibility must be enforced every time the machine is switched between operating modes.

Optical Cavity Chicanes. The optical cavity chicanes are to be run on a single string to relax tracking and stability requirements [2]. The second optical cavity chicane must be on a shunt, to accommodate the reduced beam central energy downstream of the FEL.

Specifications for IR FEL Driver Dipole Strings

D. Douglas

Abstract

We provide the beam transport system design specifications for main dipole strings and shunts in the IR FEL driver.

Introduction

Detailed descriptions of the IR FEL driver beam transport system and its error sensitivities and specifications have been given [1, 2, 3]. In this note, we detail the dipole string powering specifications and shunt configurations for the lattice of 16 May 1996 [1].

Description of Dipole Strings and Shunts

Figure 1 presents the dipole string and shunt configurations for the IR FEL driver. This configuration meets the following requirements:

1. the two optical chicanes can be separately adjusted to accommodate the different beam central energies encountered before and after lasing,
2. transport to the straight ahead dump can be provided without introducing differential history amongst the reverse bends [4],
3. different dipole families can be matched using beam-based measurements, and
4. injection/extraction chicanes can be powered in different operational modes to accommodate beam properties measurements.

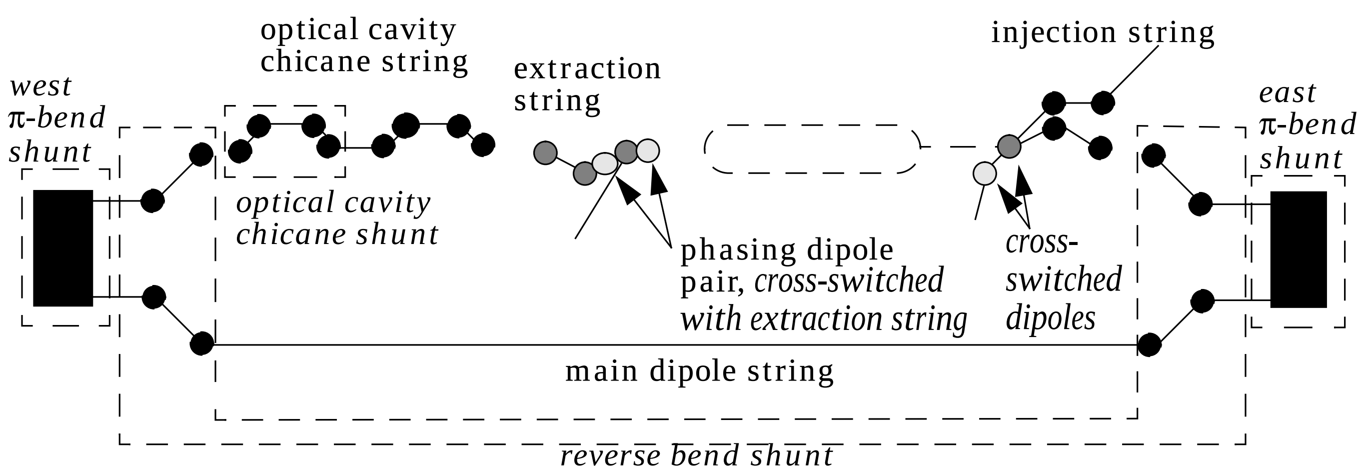

Figure 1: Dipole string and shunt configurations for IR FEL driver transport system.