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Lattice Design and Injection Issues for the 2 TeV SSCL High Energy Booster to Collider Injection Lines

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Abstract

An intensive and systematic lattice design study for the 2 TeV injection lines from the High Energy Booster (HEB) to the Collider rings has led to a compact resistive magnet solution which is a one piece achromat having beta function transitions on both ends and a pseudo-periodic structure in between. A comparison between several possible solutions concentrated on the desired optical flexibility and major technical problems associated with the huge amount of beam energy (6.55MJ) in the HEB and mechanical interferences. The HEB extraction and Collider injection schemes were designed with kicker misfire control and aperture limits on both the HEB and the Collider sides.

I. INTRODUCTION

The High Energy Booster (HEB) ring is the last booster of the 20 TeV Superconducting Super Collider. The HEB west long straight section where extraction takes place, is directly over the two Collider rings, in the west utility straight section, where injection occurs. The vertical separation between HEB and the bottom Collider is 14m, which is determined by radiation safety requirements. The elevation separation between the two Colliders is 0.9m.

There are two beam lines to transfer both the clockwise (CW) and counterclockwise (CCW) extracted HEB beams to top Collider and bottom Collider respectively. Most of the difficulties of lattice design for these lines come from the very confined space limits. In 1991, a resistive magnet solution was proposed [1]. However, the use of iron-dominated magnets, limited to 1.8T, basically filled about 1/2 of the length of the transfer line with dipoles. The consequent restrictions on the placement of quadrupoles resulted in an irregular beta function and limited tuning flexibility. An intense study of lattice design was performed in 1992 [2], which resulted in several different designs: a lattice with two "M=-I" achromats; a hybrid solution (using superconducting and resistive magnets); and a compact resistive magnet solution. The compact "one piece" resistive solution has been adopted for its optical flexibility, few problems of physical interference, operational reliability, and cost saving.

Operational reliability and safety is a major concern of this transfer system design. The HEB extraction and Collider injection aperture limits have been carefully examined to avoid quenching of magnets by mis-steered beam and beam halos.

HEB extraction and Collider injection kickers have been carefully segmented to reduce the strength of a single kicker unit so to prevent equipment damage, especially Collider elements, by mis-steered beam due to single kicker misfire or prefire, which will likely happen once in a while. A bump scheme is also incorporated for HEB extraction serving the same purpose. Since all magnets in the transfer line are warm, one can consider implementation of a collimator system to further protect Collider elements from HEB kicker misfires [3].

II. LATTICE DESIGN STUDY

The design study here in many ways is an effort to solve inter-accelerator transfer line optical problems dealing with an insufficient length (phase advance) and strict matching requirements. The basic optical design goals of these lines are (a) Centroid matching, *i.e.*, closed orbit matching; (b) β matching; and (c) Dispersion function matching. By dealing with η and β matching differently, one can work as follows: (1) η matching first, β matching second; (2) β matching first, η matching second; or (3) simultaneous η and β matching.

The compact resistive lattice is a one piece β & η matching lattice with mixed η and β matching to overcome the shortage of phase advance. Instead of making "Optical Insults" (highly irregular β matching section), two quadrupoles are used at each end to reduce the maximum β amplitude, and to present reasonable β functions to start a periodical oscillation. A pseudo-periodic structure is created in the middle part to provide optical flexibility of the lattice. Figure 1 shows the lattice functions of the compact resistive design. It is easy to count how many variables are needed to match the HEB to Collider directly: two for η, four for Twiss parameters. Practically, one quadrupole on each side is added to have some preliminary control of β amplitudes which are the extensions of β oscillation in straight sections of these rings.

To cancel dispersion more naturally, one has to pay attention to the 2π phase shift between the two major bending centers. On one hand, one has to push bends to both ends to save total bending power, on the other hand, one has to maneuver "tails" of each bending group (parts close to center) to balance the group bend center position. The final matching of six parameters in most cases is accomplished by varying gradients of the "six quadrupoles" in the middle of the line. However two quadrupoles, one at each end play an important role in shaping the β oscillation wave forms in the center part. Itera-

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tions usually are carried on to make β oscillation in the middle part more nearly a periodical structure.

For comparison, the two, -I achromats lattice is depicted in Figure.2. This lattice has the advantage of separating η and β matching. However, study shows, due to the insufficient length of the line, that orthogonal control of η and β is limited to a small range. Spatial interference problems, cost increases and the difficulty to collimate the beam in the lines using superconducting magnets brought the abandonment of this approach.

III. OPTICAL FLEXIBILITY

In actual machine operation, the matching conditions on both the HEB and Collider sides may change to what may be good for the machine tuning. It is ideal to fit these tuning processes without moving quadrupoles around in beam lines. In our case, the lattice structures are irregular, and in most of the designs there are no orthogonal controls on β & η. Matching or tuning totally depends on computer fitting. Therefore we must ask what is the tuning flexibility?

The optical or tuning flexibility of the beam line may be defined as: "the matching range of HEB & Collider operating points which the beam line can accommodate". The criterion set for matching is the maximum allowed emittance dilution in the following machines (here, Collider rings), when a perfect matching is not possible. The limits for beamline tuning are: (a) Quadrupole gradient strength limit, which is a technical limit; and (b) Maximum betatron amplitude along the line, a consideration from beamline aperture and error sensitivity requirements. Figure 3 illustrates the above conceptions. We have to link changes on β or η values to emittance dilution properly. The allowed maximum fractional emittance dilution is <10%. This roughly corresponds in one transverse direction to +50% β mismatching, or to 1m η mismatching at the Collider input [2].

Results of fitting calculations for various designs have been compared. Fitting has been made to deal with mathematical problems, quadruples can be grouped in different ways or in different fitting order *etc*. An amazing result is the one piece solution always allows good matching while the other solutions may result in some degree of dilution. It is believed the pseudo-periodical structure helps to accommodate a wide range of matching conditions, by allowing β amplitudes up and down in the central part of the line. For example, a 0.3m η error initiated in HEB side will result in -0.8m η at Collider side. Now if a +1m η value is required to be matched at the Collider side, this will be a much more difficult condition. It is observed that the pseudo-periodical structure allows the β amplitude to blow up in the middle so as to meet the matching requirements. In the example shown in Figure 4, different β match conditions are imposed as well. This represents one of the worst cases. The peak β amplitude increases from ~200m to 600m, one quadrupole field gradient is tuned up to 40T/m (27% more than design value). But the matching is good, while β and gradient values are still within beamline "tuning limits".

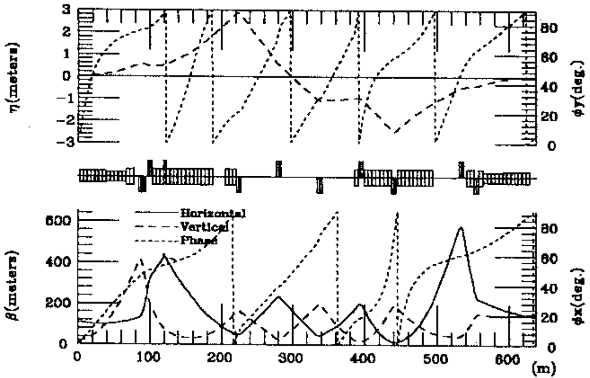

Figure 1 Lattice Functions of Compact Resistive Solution

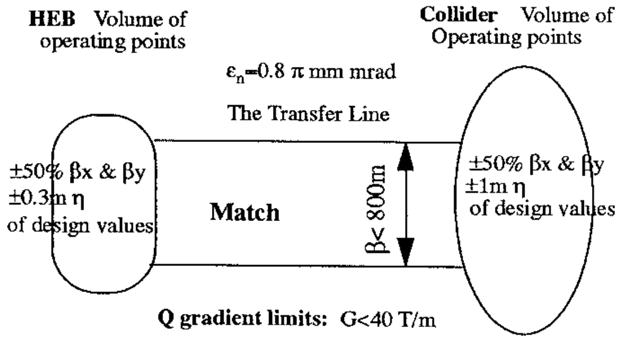

Figure 3 Optical Flexibility for Compact Resistive Solution

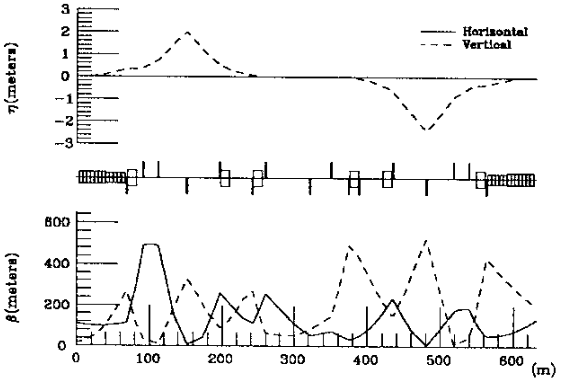

Figure 2 β & η Functions of −I Lattice

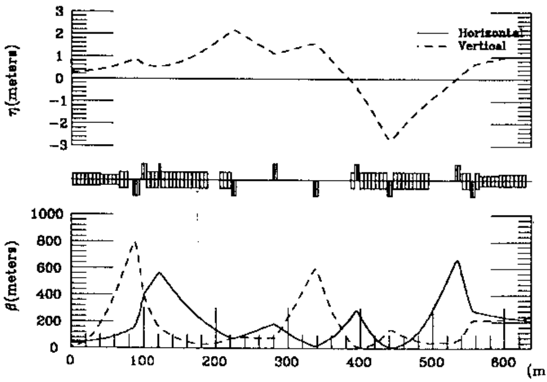

Figure 4 0.3m η & −50%β at HEB matching to 1m η & +50%β at Collider(Nine Gradients varied)

IV. HEB KICKER EXTRACTION SCHEME

The HEB extraction is performed by a combination of a local "three" bump scheme, Figure 7, and a set of fast pulsed kicker magnets, Figure 6, for clockwise (CW) and counter-clockwise (CCW) extraction to the HEB to Collider (HTC) transfer line. The local bump scheme moves the HEB closed orbit towards the magnetic septum of the Lambertson magnets[3], Figure 3. The horizontal "three" bump magnets are found in standard superconducting spools along with other HEB correction elements. Their strengths are: BMP1 -0.250T-m, BMP2 +0.515 T-m, and BMP3 -0.432 T-m. The CW extraction kickers then move the extracted beam into the field region of the Lambertson magnets, and beam bends downward towards the top Collider, and similarly for CCW extraction. The extraction kickers (6, CW) and (8, CCW) are chosen such that their kick/module is 25 μr. This segmentation of the kickers, along with 3.8mm bump, serves to mute the effect of a single kicker mis/prefire and minimize the effect of a two kicker mis/prefire in terms of the resultant "free" β oscillations of beam centroid. These mis/prefires are treated elsewhere [3]. The extraction kickers have a rise time of 1.7 μs and flat top time of 36 μs. The nominal 1% total output deviation (TOD) on flat top ripple, droop, pulse to pulse reproducibility, will require a transverse damper in the Collider to compensate this effect. Other extraction kicker parameters are as follows: magnet field length of 1.0m, and slot length of 1.5m, and nominal magnetic field of 1.67 KG. It should be noted that the first Lambertson magnet is "rolled", or rotated, so that any residual horizontal angle from kickers is canceled.

V. COLLIDER KICKER INJECTION SCHEME

The Collider injection is performed as follows. The beam in the HTC transfer line is moved towards the Collider closed orbit by the quadrupole "steering", due to off axis beam centroid through Collider quadrupoles QU3B and QU4B just downstream of the injection Lambertsons. The injection kickers, then bend the injected beam on axis. The last Lambertson is "rolled" to cancel any residual angle of kicker and quadrupole steering. The injection kicker parameters are given in Figure 8. The beam positions at injection Lambertson and QU3B interface are given in Figure 5, with care to consider kicker mis/prefire from HEB extraction kickers as well as from Collider injection kickers, and timing errors[3].

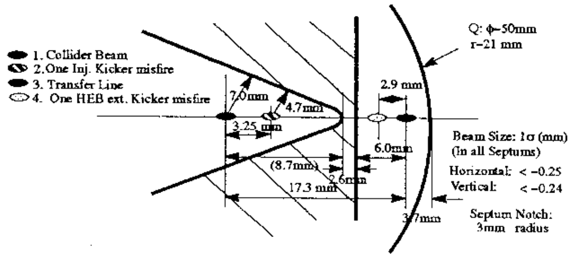

Figure 5. Collider Injection Lambertson Magnet and Quadrupole QU3B Interface Section

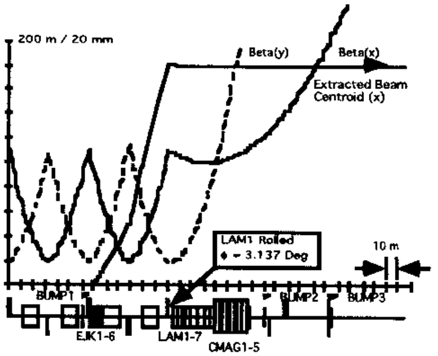

Figure 6. HEB Kicker Extraction Scheme

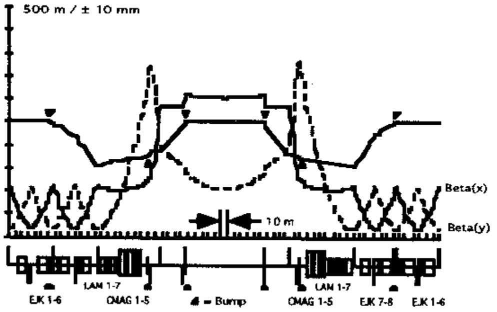

Figure 7. HEB Local Bump Scheme for Extraction

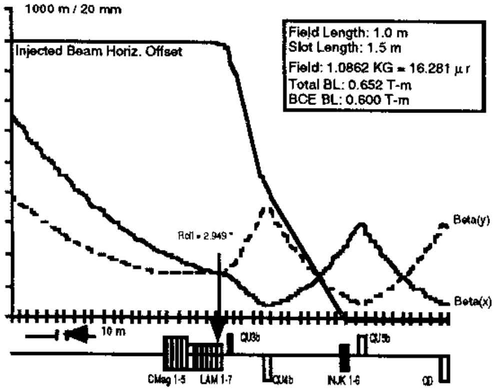

Figure 8. Collider Kicker Injection Scheme

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

[1] F. Wang, R. Schailey "HEB to Superconducting Super Collier Transfer Lines" IEEE Particle Accelerator Conference 91CH3038-7 p.985 1991.

[2] F. wang, K. Brown, J. McGill, D. Johnson "Lattice design Study for the HEB to Collider Transfer Lines" SSCL numbered publications (to be published) May 1993.

[3] R. Soundranayagam *et al.* "Consequences of Kicker Failure During HEB to Collider Injection and Possible Mitigation", these proceedings.