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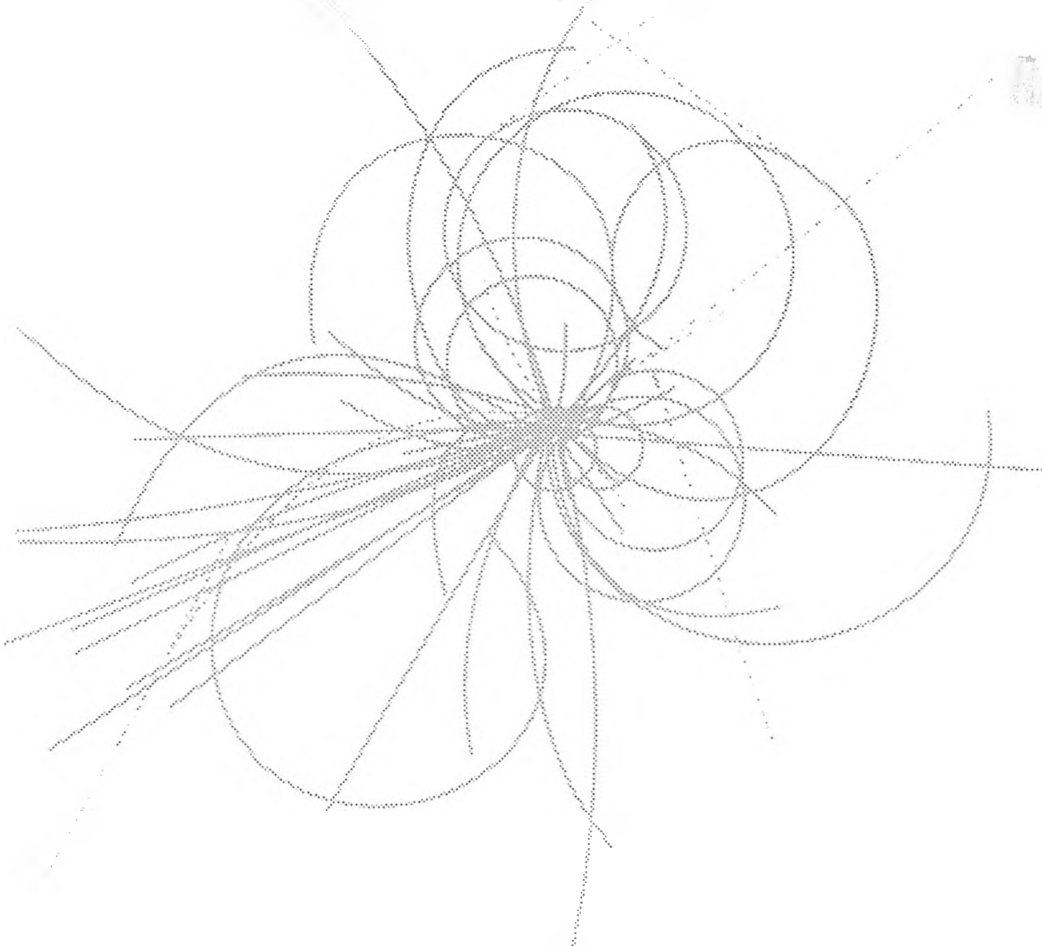

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The Medium Energy Booster at the SSC Laboratory

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Abstract

The Medium Energy Booster (MEB) is a synchrotron using conventional (non-superconducting) magnets. It has a momentum range from 12 GeV/c to 200 GeV/c. There are two modes of operation: slow spill for test beams, and collider injection operation. Two design issues that make the MEB unique at the Superconducting Super Collider (SSC) are that it goes through transition and it utilizes slow extraction for test beams.

I. INTRODUCTION

The MEB will be the third accelerator in the injector sequence to the Collider. Its circumference of 3960 m consists of resistive magnets and eight straight sections. Two of the straights are used for clockwise and counterclockwise injection into the High Energy Booster (HEB), and a third is for slow extraction (Figure 1). The following discussion will outline the present design of the MEB, including lattice, magnet design, results of transverse studies, longitudinal dynamics and transition crossing, and slow extraction.

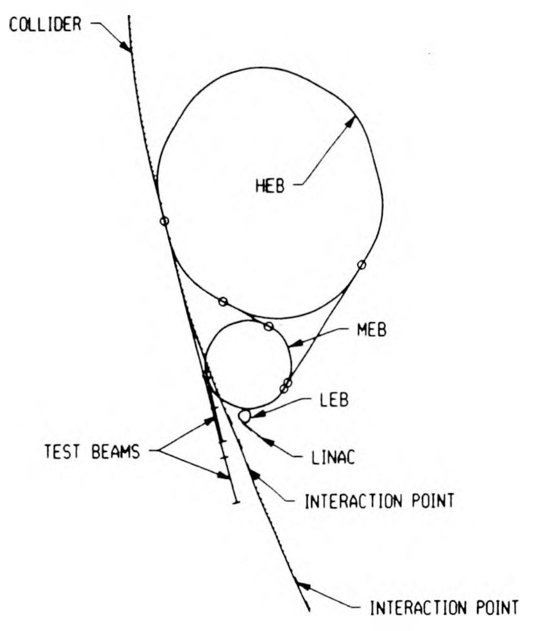

Figure 1. Placement of MEB in injector scheme with vextraction and injection sites shown.

*Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC02-89ER40486.

II. MACHINE DESIGN

A. Lattice Design

There are three types of modules in the MEB lattice: the standard cell, the injection insertion, and the long straight insertion. The MEB comprises 72 standard FODO cells. The injection insertion consists of five standard FODO cells with space for injection made by removing dipoles. Other dipoles, 180° apart, are removed for dispersion matching. The long straight insertions (Figure 2) consist of 25-m-long, dispersion free straight sections and are intended for high energy transfers and RF acceleration cavities. To achieve zero dispersion, one dipole was removed from two half cells on either side of the long straight. It was also necessary to use slightly shorter dipoles to fine tune the dispersion suppression. The long straights possess optical symmetry.

In addition to the standard cell quadrupoles, two additional quadrupole lengths are used in the long straight section design. All quadrupoles are on two separate power buses, distinct from the dipole bus.

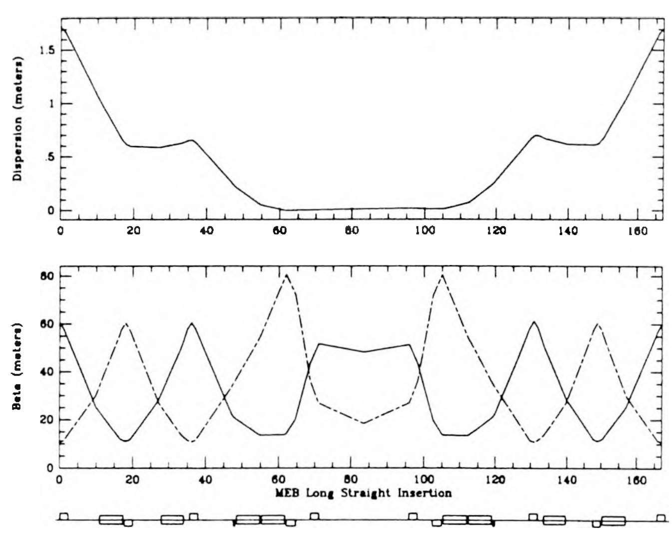

Figure 2. MEB long straight section and lattice functions.

The tune of the MEB is $\nu_{x,y} = 26.4$. Transition occurs at $\gamma_t = 24.0$. The transition gamma was increased from 15 to 24 by changing the phase advance between focusing quadrupoles in the standard cells from 60° to 90° The previous value was that used in the MEB conceptual design for the Site Specific Conceptual Design Report (SCDR).[1] Relevant machine parameters are given in Table 1.

Table 1
MEB Machine Parameters

Injection Momentum	12	GeV/c
Extraction Momentum	200	GeV/c
Circumference	3960	m
Bunch Spacing	5	m
Harmonic Number	792	
Insertions	6 long, 2 inj.	
Half Cell Length	18.04	m
Cell Phase Advance (h,v)	87.3, 88.9	
Bend Angle/Half Cell	34.6	mrad
Dipole Field @ 200 GeV/c	1.752	T
Dipole Length	6.591	m
	6.065	m
Quadrupole @ 200 GeV/c	23.61	T/m
Quadrupole Length	2.286	m
	2.623	m
	0.491	m
Tune (h,v)	26.4, 26.4	
Transition Gamma	24.0	
Emittance (normalized x,y rms)		
Collider-inj,ext.	0.6π, 0.7π	mm-mrad
Test Beam	4π	mm-mrad
Natural Chromaticity (h,v)	–32.8, –33.8	
$\eta_{max,min}$	1.75	m
	0.86	m
$\beta_{max,min}$ (cells)	60.0	m
	11.1	m

B. Magnet Design

Several different designs for the MEB dipole are being considered. One design, present in the SCDR, is based on the Fermilab Main Injector dipole design. This design contains a relatively large amount of copper and has no conductor present in the mid-plane. This magnet design is relatively easy to build due to a pancake coil construction. It does suffer from a large saturation sextupole component at the maximum field of 1.75 T (-10×10^{-4} @ 1 in.). If this design is chosen, it will be modified to have 9 turns/half core instead of 4 (Figure 3). Other magnet designs which have copper present in the mid plane and, consequently, better high field characteristics are also being considered.

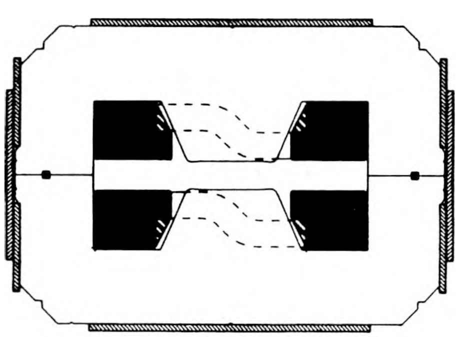

Figure 3. MEB Dipole Design Cross Section.

C. Transverse Dynamics

The dynamic aperture of the MEB is estimated to be greater than 40π mm-mrad. This number is based on expectations of future upgrades to the facility which would utilize larger emittance beams. Actual tracking studies on the MEB have not been done, but studies on the Fermilab Main Injector with similar lattice functions and magnet errors indicate that this aperture can be achieved with the present design.

D. Longitudinal Dynamics

Longitudinal studies are concentrating on the transition crossing problem. Simulations are done using the longitudinal tracking code ESME.[2] The code is running on a SUN workstation.

Transition occurs well away from injection at 22.5 GeV/c. The problems of transition crossing are many. During collider mode operation of the MEB, the principle worry is transverse emittance growth. The transverse emittance may be increased while the crossing transition due to particle bunching (high momentum spread), leads to an increase in the space charge tune shift. Very near transition, the particles require no external phase focussing force because nearly all the particles in the bunch have the same rotational frequency and do not tend to debunch (slip factor is approaching zero). The bunch requires only accelerating voltage and no RF phase-focussing-force. Any voltage differential present will cause phase space distortion and an increase in the momentum spread of the bunch. A factor that contributes to this problem, in the MEB, is the small bunch size: the longitudinal emittance at injection is 0.038 eV-s (95% bunch area). This increases the space charge forces, and hence exacerbates the transverse growth problem. The condition is alleviated by increasing γ_t.

We are studying the use of a nonfocussing transition-crossing technique[3] to avoid the tight bunching. This scheme requires the addition of a higher harmonic to the RF wave during the transition period. The higher harmonic causes the RF wave to become a flat-top (Figure 4). All the particles in the bunch then see the same voltage, and hence all get the same kick going through transition. There is no increase in bunching factor, and space charge forces are minimized. Once through transition the RF focussing is turned back on to match the bunch, and the phase is shifted to the opposite side of the RF wave.

This nonfocussing scheme has been simulated but not demonstrated. If it proves ineffective for the MEB design, another method of transition crossing, the γ_t-jump scheme, has been considered. The jump scheme decreases the time spent crossing γ_t by manipulating the dispersive properties of the machine. Through use of air-core pulsed quadrupoles, the time of γ_t is shifted. This method has been utilized elsewhere (CERN PS), and space is available in the MEB lattice for the necessary air-core quadrupoles.

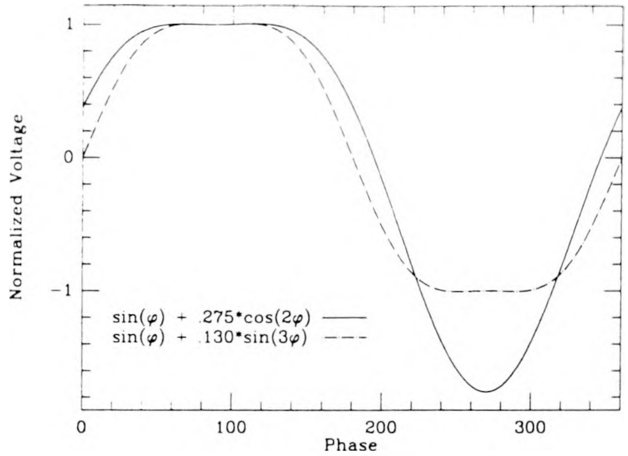

Figure 4. RF waveform with higher harmonics added to fundamental.

Figures 5 and 6 show the RF curves for the MEB. A voltage ramp, consisting of injection at 170 kV, a peak voltage of 2.1 MV, and extraction at 860 kV, has been chosen. The ramp allows for the avoidance of resonance-inducing synchrotron frequencies that are multiples of power-supply frequencies of 60 Hz. The injection voltage provides for matching to the LEB transfer.

Presently, 12 RF cavities, with the ability to run with 10, are required by the MEB. At a peak voltage of 2.1 MV, each cavity is required to run at 175 to 210 kV. They will be placed in one of the long straights (Figure 2). The cost and feasibility of having a cavity with a second harmonic for the nonfocussing scheme are being investigated.

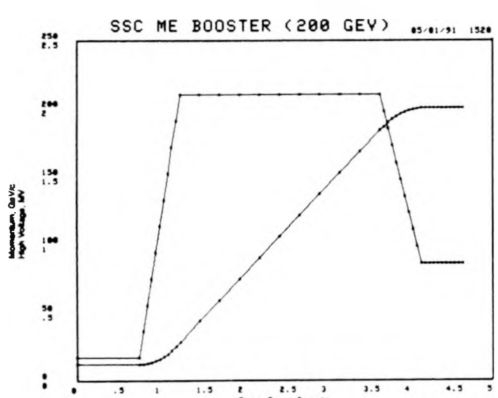

Figure 5. Momentum and Voltage Curve for MEB.

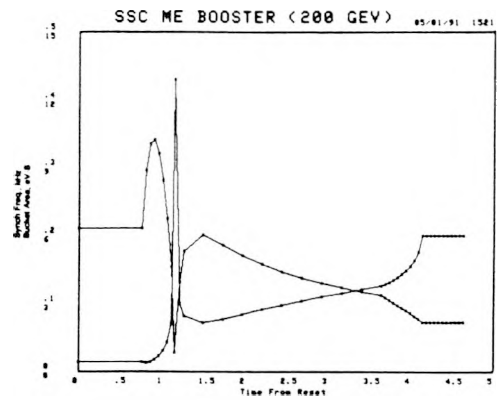

Figure 6. Synchrotron Frequency and Bucket Area.

E. Slow Extraction

The MEB will be providing external beams for the testing and calibration of collider detectors. The requirements are for primary protons in the range of 150 GeV/c to 200 GeV/c to be extracted during a 1 sec flat-top. To accomplish this, slow resonant extraction utilizing the half-integer resonance will be employed.[4] The concern with the MEB slow extraction process is the large saturation sextupole present in the dipoles at 200 GeV/c. Simulations have shown that efficiencies better than 98% can be obtained at top momentum, even in the presence of this sextupole field.

The MEB slow extraction system consists of quadrupoles, octupoles, and an electrostatic septum located 90° upstream of the extraction channel.

III. REFERENCES

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