Specifications for the Main Injector
Horizontal Correction Elements

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DEJ

The following is a summary of the correction element meeting on Sept. 1 in which we tried to specify the parameters for the normal MI horizontal correctors and those correctors around the straight sections for orbit manipulations (i.e. high field correctors). This does not specify requirements or parameters for vertical correctors.

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A summary of design parameters is given at the end.

I. Correction requirements:

Closed orbit correction contributions:

1. Tracking studies at 8.9 and 120 GeV/c shows that a +/-50 ur envelope in corrector strength will provide enough correction at all energies to correct the modeled alignment and field errors. This corresponds to a rms corrector strength of approx. 35 ur.
2. We provide a safety factor of about 3.4 for correction at high field to allow for unexpected field errors and future orbit control requirements.
3. The effect of turning off all dipole correctors was investigated at 120 Gev/c for normal and extraction tunes. All alignment and multipole errors were including in the tracking. The orbit was not corrected. A peak orbit distortion of approx +/-12 mm was found. This distortion did not reduce the dynamic aperture at the extraction tune, but did reduce the dynamic aperture by ~4 mm at normal operating (H,V) tunes of 26.425,25.415.

Aperture scans:

1. We want to provide injection energy aperture scan capability. Full aperture (at 8.9 GeV/c) steering requires 66 mm/60m, or approx. 1 mr corrector strength at injection. This is about half of the available strength at injection.

Orbit control at straight sections:

1. We attempt to minimize corrector strength required for normal high field extraction (120 slow, 120 GeV and 150 GeV extraction cycles).
2. No corrector steering is required for 120/150 GeV extraction for pbar production or Tev injection. Quads in the region have been misaligned to establish the proper extraction trajectory.
3. Approximately +/- 100 ur are needed for 120 GeV slow spill cycles.
4. Approximately +/- 150 ur should be provided in correctors around the straight sections for orbit control (tuning) of the high field orbit.
5. Approximately 130 to 380 ur are needed to control the 8 GeV orbit around the lambertsons.
6. Approximately 400 to 850 ur are needed to establish the 8 Gev pbar injection orbit.

II. Geometry constraints:

MI free space:

1. The normal dipole correctors are located in the upstream end of each quad.
2. Free space in upstream slot of the 100" and 116" quads is 17.89".
   { 20.464" - 0.825"[flange] - 1.65"[coil] - 0.19"[beam pipe] }
3. We allow .89" total free space in this slot for installation. This implys the corrector may have a TOTAL length up to 17". This length should be used as the baseline for design.
4. Free space upstream of 84" quads is 37.673". This houses a dipole corrector and up to 2 skew quads which are 8.5". So, 17" also works here.
5. Two correctors may be installed, if needed, at locations in straight sections just upstream of the first lambertson.

Magnet gap: 2.00"

The beam pipe under vacuum is less than 2.0" and it can easily be compressed during installation, if necessary.

III. Field Requirements:

Normal correctors:

Peak Integrated field:	0.060 T-m ==> 120 ur @ 150 GeV
Peak current:	10 Amps
RMS field (0.7*Peak):	0.042 T-m
RMS current :	7 Amps

High Field correctors:

Peak Integrated field:	0.090 T-m ==> 180 ur @ 150 GeV
Peak current:	12 Amps for 180 ur @ 120 GeV 15 Amps for 180 ur @ 150 GeV
RMS field (0.7*Peak):	0.063 T-m
RMS current :	8.4 Amps for 120 GeV 10.5 Amps for 150 GeV (see note (*) section V.)

IV. Field Quality:

Specification: Better than 5% at 1"

We take as an initial specification that the sum of all the correctors running at full strength should contribute less than 1% of the sextupole field that the main dipoles contribute. At full field, the integrated strength of the main dipoles is about 1.7 T * 6 m * 300, or about 3000 T-m. The trim dipoles contribute 0.06 T-m * 100, or 6 T-m. The field quality on the trims can thus be about 500 times worse than that of the main dipoles. The main dipoles are specified as 1 part in 10,000, thus we could allow the trims to vary by 500 parts in 10,000 or 5%. This should easily be exceeded.

V. Temperature rise requirements:

External steel maximum temperature:	120 deg F (~50 deg. C)
Interior coil temperature:	265 deg F (~130 deg. C)

Delta T (internal coil-outside steel): ~80 deg C

We agree to limit the temperature on the outside surface of the steel to 120 deg F (~50 deg C). This is based primarily of safety concerns about human contact with a hot object. The power requirements will dictate how hard we have to work to get rid of the power and and maintain that temperature.

We agree to limit the temperature in the interior of the coil to 265 deg F (130 deg C). This is based on prejudices about the temperature an epoxy can be happy in for long periods of time.

The most demanding ramp scenario (*) will be the 2.9 sec 120 GeV slow spill ramp with a 1 sec. flattop. This ramp could potentially be repeated in the super cycle with a duty cycle of close to unity. Since this ramp has a ratio of RMS/PEAK current, in the main dipole bus, of 0.7, this factor should be applied to the Operating current of the correctors for normal and high field operation. This yields:

Normal corrector: 7 Amps RMS
High field corrector: 8.4 Amps RMS

(*) NOTE: The 150 GeV collider injection ramp also has a RMS/PEAK current ratio of about 0.7 but its duty cycle in the super cycle is only 10%, therefore it should not be used for temperature calculations.

VI. Power supply considerations:

Normal corrector:

Peak current:	+/- 12 Amps
Op. current:	+/- 10 Amps
RMS current:	7 Amps (**)(***)
Peak Voltage:	+/- 80 volts single channel +/- 160 volts dual channel
dI/dT:	40 Amps/sec (based on Op. current)
T(0-Peak)	0.25 sec.

High field corrector:

Peak current:	+/- 18 Amps
Op. current:	+/- 15 Amps @150 & +/- 12 Amps @120
RMS current:	8.4 Amps @ 120 (*)(***)
Peak Voltage:	+/- ??? volts
dI/dT:	60 Amps/sec (based on Op. current)
T(0-Peak)	0.25 sec.

Cable resistance: Assume 1 ohm
Cable for dipole correctors specified as #10 with a resistance of ~1 ohm/1000 ft. Assume 1000' cable.

(**) NOTE: This rms current is based upon upon 70% of the Operating current. The Operating current should be roughly 80% of the peak power supply current. The present Main Ring correction element power supply was designed to have a peak current of +/-12 A and is limited to 6 Amps RMS over 1 minute.

(***) NOTE: According to Steve Hays, the specification to increase the rms current would require a design change. He says they have other reasons to change the design so a request to increase the RMS current would be another reason. The cost of this change is not known.

Each channel of the standard power supplies will generate +/- 80 Volts. The sum of the resistive and inductive loads must be compared with this. If a few magnets must run over the limit, then two channels may be configured in a push-pull mode.

VI. Magnet properties:

Resiatance / Inductance:

The inductance is determined by the volume of the magnetic field and the number of turns. The only adjustable parameter available to reduce the inductance is the width of the pole. If necessary, we can explore reducing the pole face from 6" to 5.5" or 5.0". Also, increasing the steel length decreases the number of turns required while increasing the volume. The net effect is a linear reduction in the inductance.

VII. Fabrication considerations:

We believe that it will be easier to fabricate a magnet where the cooling path from the coil to the core is through the top or bottom of the coil. (This has implications on coil aspect ratio.) If additional cooling in required for the coil during high field operation, a water-cooled copper plate could be added to the bottom of the coil only.

VIII. Installation/alignment considerations:

The magnet will be assembled (bolted together) around the beam pipe. It will be heavy enough (>280 lbs) that it will require a special installation fixture. As a baseline for weight assume following dimensions for the corrector:

gap 2", pole face 5", yoke 1.5", coil 2"x1.5"
lamination: 12" wide by 8" high by 12" long
thickness 0.060" @.018 lbs/sq.in.
12"*8" = 96 sq"- 30 sq"(for gap&coil) = 66sq"
66 sq"*(0.018 lb/sq")*200 laminations = [240 lbs.]
copper: 3 sq"cross section* 42"length = 126 cu"
126 cu"*(0.323 lbs/cu") = [40lbs]

The transverse alignment is not critical, only the roll as not to introduce a vertical component into the field.

IX. Summary:

Low field requirements:

Max. slot length:	17"
Gap:	2.0"
Peak field:	0.060 T-m
Operating current:	10 amps
RMS current	7 amps
Field quality:	5%
External temperature:	120 deg F
Max coil temperature:	265 deg F
dI/dT:	40 Amps/sec.
T (0-100%)	1/4 sec.

High field requirements:

Peak field:	0.090 T-m
RMS current:	8.4 amps
dI/dT:	60 Amps/sec.
T (0-100%)	1/4 sec.

Same geometry, field quality, and temperature rise as low field correctors.

Use low field requirements and find the minimal design that will meet the needs with no water cooling. The high field needs should then be addressed through increases in copper size an then through a single cooling plate adjacent to the gap.

X. Existing magnets:

The "stronger" MR horizontal trim has a measured strength of BL = 0.05858 kG-m/Amp or for a 10 Amp excitation this corresponds to BL = 0.05858 T-m. This is approximately the value requested for the normal trims. These have the following dimensions:

steel length:	8"	.2032 m
gap:	2.25"	.05715m
yoke:	1"	
mag. width:	10.092"	.256 m
mag. height:	9.25"	.235 m
#turns	544 per coil	14 guage sq.
coil XC (WxH):	1.125" X 2.375"	including insulation(?)

Drawings:

lamination:	0427.12-MC-85030
half core:	0427.12-ME-85032
assembly:	0427.12-ME-85033
coil:	0427.12-ME-85036 (2 sheets)

Using these numbers:
B = (1088)(10)(4*pi*1E-7)/0.05715
= 0.23923 T at 10 Amps
BL = 0.0486 T-m at 10 Amps

Measured BL:
BL = 0.05858 kG-m/Amp
= 0.05858 T-m at 10 Amps

This is about a 20 % descrepancy ???