SSC-N-183
May 27, 1986

Requirements for Dipole Field Uniformity and Beam Tube Correction Windings

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Based on aperture and practical engineering considerations we give a set of self consistent requirements for the multipole coefficients of the SSC dipole field and for the additional beam tube windings to be used for fine correction.

Table 1

Dipole Magnet Field Uniformity Requirements at 1 cm

Multipole	Variances ($\times 10^4$)	Average ($\times 10^4$)
a_1	0.7	0.2
a_2	0.6	0.1
a_3	0.7	0.2
a_4	0.2	0.2
a_5	0.2	--
a_6	0.1	--
a_7	0.2	--
a_8	0.1	--
b_1	0.7	0.2
b_2	2.0	1.0
b_3	0.3	0.1
b_4	0.7	0.2
b_5	0.1	0.02
b_6	0.2	0.04
b_7	0.2	0.06
b_8	0.1	0.1

Beam Tube Correction Winding Requirements

$b_2 \geqq 4$ units

$b_3 \geqq 0.4$ unit   Full length equivalent at 6.6T

$b_4 \geqq 0.4$ unit

$L_{winding}$ for b_2 = 8.3 m

The physical aperture of the dipoles was set using the "smear" component, of the linear aperture as a criterion.[1] The smear vs amplitude function is set by the lattice, i.e., cell length and phase shift per cell, and by the variances of the dipole multipole coefficients. The variances are in turn set by the techniques of magnet manufacture and the radius of the coil. In setting the physical aperture, the "technique" factor was determined from measurements of the Tevatron and CBA dipoles. The radius factor was determined semi-empirically,[2] based on theoretical considerations, and a table of expected variances was generated. The result, discussed in the CDR (ref. 1, Ch. 4) is that a physical aperture (inner coil inner diameter) of 4 cm is deemed adequate. The numerical values of the variances shown in Table 1 are basically Table 4.3-1 of the CDR but slightly modified to reflect the present thoughts.[9] Subsequent measurements of six 4.5 meter models at BNL[3] showed that the variances assumed in the aperture selection are achievable. We therefore suggest that the variances of Table 1 be now taken as requirements, as their achievement, and better, is shown to be practical. If necessary, some trade-offs among the higher multipole variances could be made.

In addition to the smear controlled largely by the variances, the tune shift component of the linear aperture criterion, controlled largely by systematic multipole errors, must also be taken into account. The derivation and resulting requirements are given in ref. 1. The tolerances of the systematic skew multipoles are obtained in ref. 4. [Note that the skew multipole tolerances are obtained assuming the horizontal and vertical tunes are split by an integer.] For the normal multipoles (b_n) with $n \leqq 4$ it appears impractical to achieve the needed tolerances for the systematic component solely through manufacturing control. This is particularly so when taking the persistent current contribution to the multipoles into account since they are large at injection and very small at full field. The tolerances listed in Table 1 for the systematic b_n with $n \leqq 4$ assume the existence of quadrupole correctors in the primary correction packages and b_2, b_3 and b_4 trim windings on the beam tube. For normal multipoles $n \geqq 5$ and skew multipoles $n \geqq 1$ it appears that the requirements can be met through manufacturing tolerance control. [Note that in assessing the achievable average or systematic values we assume that it will be practical to measure magnets in batches of 25 so that control of the average value to one-fifth of the variance is practical.]

The additional correction measure selected for a_1, b_1 is the shimming of the position of the collared coil package within the iron yoke. While this will not bring the magnets completely within tolerance we note that lumped a_1 and b_1 correctors will be present in any event to minimize coupling and cancel beta disturbances so they can be used for the final correction.

The correction measure for b_2, b_3, b_4 most appropriate seems to be beam tube correction windings. The large b_2 due to persistent currents demands truly local correction[5,6,7] although symmetry makes it possible to achieve adequate cancellation if the correction winding starts at either end of a dipole and extends only to the center. The strength of this correction at injection field must be the equivalent of about 10 units of b_2 over the full dipole. At full field the saturation contribution to b_2 requires a capability of about 4 units which dominates the strength requirement for this corrector. The strength requirement for b_3 is derived by extrapolating from the measured values in Tevatron magnets.[8] A conservative choice is that the b_3 *corrector strength be such as to be equivalent to 0.4 units throughout* the dipole. The strength requirements for b_4 are dominated by the geometric effects[2,8] although at injection the persistent current effect dominates and at full field there is some contribution from saturation. Accordingly a conservative requirement for the b_4 corrector strength is that it be capable of the equivalent of 0.4 units over the full dipole length at full field. The lengths of the b_3 and b_4 correctors can be determined by the convenience of winding design.

These requirements are summarized in Table 1. Note that the geometric requirements for those multipoles having beam tube windings have been relaxed compared to the one-fifth criterion to relieve manufacturing tolerances for cost optimization.

References

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