More on Multipole Errors of the IR Triplets

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A previous report, SSC-109, addressed various issues concerning the tolerances and correction of the multipoles in the IR triplets. This note is to supplement SSC-109 by a few additional tracking studies, as well as suggesting a possible set of parameters for the purpose of eventually leading to the multipole tolerance specifications for the IR triplets. It is envisioned that this set of parameters will evolve as more study results on magnet design, magnet measurement and beam dynamics become avaliable.

Table 1 gives the rms random multipole coeffcients for several cases. The values of the lower multipoles (a_n and b_n with $n \leq 5$) are those after correction using the assumed multipole windings on the beam tube, and thus represent the measurement and corrector setting errors on these multipoles. Higher multipoles ($n \geq 5$) are assumed uncorrected. Case 1 is the "nominal" case adopted in SSC-109. The rms of the higher multipoles in this case are obtained by scaling the Tevatron quadrupole data (Fisk and Peterson) to the SSC design. Linear distortions due to a_1 and b_1 are ignored in this study. In all cases, random multipoles in the arc dipoles are included, although their effect on the dynamic aperture for the colliding beam optics is negligible.

Before discussing the various cases of Table 1, it is useful to have a rough - even simplistic - idea of how much dynamic aperture is needed for colliding beam operation. The CDR (2 IRs with low β^*=0.5m and two IRs with intermediate β^*=10m) has a dynamic aperture of 13.6 mm in each dimension at a point of maximum β=8000m in the triplet. This aperture of 13.6 mm is to be used for beam size, orbit distortion, beam displacement due to finite crossing anlge, and other operational needs. In this note, we consider a slight reduction in the dynamic aperture requirement, from 13.6 mm to 11.9 mm. If there is no additional need for operational reasons, this 11.9 mm may perhaps be distributed in the following way:

- In the colliding beam operation, a non-gaussian beam tail often develops. To avoid beam losses and producing noise in the detector, the dynamic aperture needs to be 10 times the sigma of the beam. Assuming an emittance of 1.33 mm-mrad (corresponding to either a 1/3 larger emittance than assumed in CDR, or the same emittance but operating colliding beams at 15 TeV), the beam size need is 7.3 mm. The beam size need with the nominal 1 mm-mrad emittance would be 6.3 mm.

- A maximum orbit distortion of 1.2 mm in the triplets at β=8000m. This requires a good orbit control in the IR quad region.

- Beam displacement is 3.4 mm assuming a crossing angle of ±50 μrad. Note that the nominal crossing angle is ±37.5 μrad, while the maximum allowed crossing anlge is ±75 μrad.

The total need in this scenario is then 7.3 + 1.2 + 3.4 = 11.9 mm. Other scenarios of distributing the aperture are of course possible.

Dynamic apertures for three fixed random number seeds are given in the bottom three rows for each case of Table 1. The resolution of the dynamic aperture in these tracking runs is ±2.5%. It was found in SSC-109 that relaxing the lower multipoles (a_n and b_n with $n \leq 5$) from 0.05 to 0.1 units (1 unit is 10^{-4} of field at 1 cm) does not affect the dynamic aperture much, as Case 2 again shows.

Cases 3 and 4 are basically the same as Case 2 except that a systematic b_9 multipole has been included. The systematic b_5 is not included because it is presumably handled by the bore tube corrector. It is found that 0.1 unit of systematic b_9 cuts into the dynamic aperture noticeably while 0.02 unit does not.

Cases 5 to 9 correspond to various values for the higher multipoles. If 11.9 mm dynamic aperture is the specified need, case 9 will be one possible set of specifications for the multipole error tolerances of the IR triplets. Trade-offs of the tolerance specification among the higher multipoles are possible. Note that the exact value of the calculated dynamic aperture depends on the random number seed. The statistical fluctuation due to random number seed is about ±a few%. This is not included in the aperture need in the above estimate.

TABLE 1. Dynamic aperture for various cases of multipole errors in the IR triplets. Bore tube corrections are assumed for the lower multipoles a_n and b_n with $n \leq 5$. The multipole coefficients ar in units of 10^{-4} at 1 cm. Case 9 is a possible set of specifications given the present considerations.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
a_2	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
a_3	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.	0.1
a_4	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
a_5	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
a_6	0.058	0.058	0.058	0.058	0.1	0.06	0.06	0.06	0.06
a_7	0.00	0.00	0.00	0.00	0.1	0.06	0.03	0.04	0.05
a_8	0.021	0.021	0.021	0.021	0.1	0.06	0.03	0.04	0.05
a_9	0.019	0.019	0.019	0.019	0.1	0.06	0.03	0.04	0.04
b_2	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
b_3	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
b_4	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
b_5	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
b_6	0.056	0.056	0.056	0.056	0.1	0.06	0.06	0.06	0.06
b_7	0.00	0.00	0.00	0.00	0.1	0.06	0.03	0.04	0.05
b_8	0.025	0.025	0.025	0.025	0.1	0.06	0.03	0.04	0.05
b_9	0.021	0.021	0.021	0.021	0.1	0.06	0.03	0.04	0.04
syst. b_9	0.0	0.0	0.1	0.02	0.05	0.03	0.03	0.04	0.04
dynamic aperture (mm)									
seed # 1	13.2	13.7	11.5	13.9	10.9	11.5	13.2	12.6	12.6
seed # 2	13.9	13.7	11.9	13.2	10.4	11.0	12.0	11.5	11.0
seed # 3	14.5	13.7	12.6	13.2	11.4	12.1	12.6	13.2	12.0
average ± rms	13.6 ± 0.6	13.7 ± 0.2	11.7 ± 0.8	13.4 ± 0.4	10.9 ± 0.5	11.5 ± 0.5	12.6 ±0.6	12.5 ±0.9	11.9 ±0.8