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Abstract

This report summarizes the estimates on the effects and corrections needed for the triplet magnet misalignments. Due to the large beam size (high β) at the triplet during low-β^* storage, it is essential to limit the offset and roll of each individual triplet dipole, quadrupole, and correctors to be as small as reasonably achievable, i.e., definitely less than 0.5 mm and 0.5 mrad for dipole and quadrupole offsets and rolls, respectively, and definitely less than 1 mm and 5 mrad for corrector offsets and rolls, respectively. It is also important to put more emphasis upon Q2 and Q3 quadrupoles during the assembling process.

The triplet cryostat contains two 10 cm dipoles (D0) and six 13 cm quadrupoles (Q1, Q2, and Q3) of the clockwise and counter-clockwise rings, with 13 cm corrector packages C1 attached to the return end of Q2 magnet, and C2 and C3 attached to the lead and return ends of Q3 magnet, respectively. Similar to the requirements on magnetic field quality, the requirements on magnet misalignment become stringent during low-β^* storage (especially during $\beta^* = 1$ m operation) when the beam size at the triplet is large.

The alignment procedure for the triplet assembly consists of several complicated steps including aligning the various corrector layers, the corrector with respect to the quadrupole (C1 w.r.t. Q2, C2 and C3 w.r.t. Q3), the eight elements (D0, Q1, Q2-C1, and Q3-C2-C3 for each ring) with respect to each other, and the entire assembly as a rigid body. Because of the high β function and their longer length, as shown in Table 1, quadrupoles Q2 and Q3 are[1]–[3] most sensitive to the misalignments. It is therefore important to put more emphasis upon these elements. For example, when installing the assembled quadrupole-corrector packages into the cryostat, it is advantageous to align the packages so that the quadrupole centers are on the design beam trajectories; after all the elements are assembled into the cryostat, it is also advantageous to align the entire assembly as a rigid body so that the magnetic centers of the two Q2 magnets and the average position of the two Q3 magnets are in the plane of the design beam trajectory, and that the average position of the two Q2 magnets and that of the two Q3 magnets are along the design longitudinal symmetry axis. Such measures will minimize the undesired effects if the misalignment of individual magnets are of the same order of magnitude.

Using a similar method as in Ref. [4], we estimate in Table 2 the effects of given transverse offsets of the magnet centers, and the amount of correction needed if it is available. Because of the high β at the triplet locations, an offset in the quadrupole can produce a large closed orbit error. The closed orbit also shifts significantly during the last step of low-β^* squeeze when β^* is decreased to 1 m. Therefore, effective closed-orbit correction using the triplet dipole correctors, which are highly effective

Table 1: Design maximum operating current, integral magnetic field, and the design maximum β function of the magnets in the triplet assembly.

Magnet	Harmonics	Maximum[a] current (kA)	Integral magnetic[b] field (T·m)	Design[c] maximum β (m) ($\beta^* = 1$ m)
D0	b_0	5	12.6	660
Q1	b_1	5	2.8	820
Q2	b_1	5	6.5	1360
Q3	b_1	5	4.0	1350
C1	a_0/b_0	0.05	0.285	1170
C3	a_0/b_0	0.05	0.285	1308
C2	a_1	0.05	45×10^{-3}	1000
C2	a_2	0.05	21×10^{-3}	1000
C3	b_2	0.05	21×10^{-3}	1308
C2	a_3	0.05	8.6×10^{-3}	1000
C1	b_3	0.05	8.6×10^{-3}	1170
C3	b_3	0.05	8.6×10^{-3}	1308
C1	b_4	0.05	5.2×10^{-3}	1070
C2	a_5	0.05	4.1×10^{-3}	1000
C1	b_5	0.05	4.1×10^{-3}	1170
C3	b_5	0.05	4.1×10^{-3}	1308

a) For $\beta^* = 1$ m operation at storage.

b) Measured at the reference radius of 40 mm with the design maximum current.

c) The maximum of β_x and β_y at the locations along the magnet body[3].

Table 2: Effects of a transverse offset of the magnet center in the triplet assembly from its design beam trajectory. When not specified, it is assumed that $\beta^* = 1$ m at storage, the quadrupoles Q1, Q2, and Q3 are operating at 5 kA, and the various layers of the correctors C1, C2, and C3 are operating at 50 A.

Magnet	Offset (mm)	Effects for $\beta^* = 1$ m operation (for $\beta^* = 2$ m operation)	Correction needed (if available)
D0	0.5	aperture reduction of 8% rms beam radius (11% rms beam radius at $\beta^* = 2$ m)	
Q1	0.5	closed orbit offset of 7 mm at arc[a] (5 mm if $\beta^* = 2$ m)	a_0/b_0 corrector at 5 A
Q2	0.5	closed orbit offset of 23 mm at arc[a] (16 mm if $\beta^* = 2$ m)	a_0/b_0 corrector at 13 A
Q3	0.5	closed orbit offset of 14 mm at arc[a] (10 mm if $\beta^* = 2$ m)	a_0/b_0 corrector at 8 A
C2 (a_1)	1	equivalent to 4×10^{-3} I_{max} in a_0/b_0 [b] layer	
C2, C3 (a_2/b_2)	1	equivalent to 20×10^{-3} I_{max} in a_1/b_1 [b] layer	
C1, C2, C3 (a_3/b_3)	1	equivalent to 30×10^{-3} I_{max} in a_2/b_2 [b] layer	
C1 (b_4)	1	equivalent to 60×10^{-3} I_{max} in a_3/b_3 [b] layer	
C1, C3 (a_5/b_5)	1	equivalent to 100×10^{-3} I_{max} in a_4/b_4 [b] layer	

a) At arc section with $\beta = 50$ m.

b) The amount of feed-down produced is expressed relative to the maximum current I_{max} (Table 1) of the specified 13 cm corrector layer.

due to their high β locations, is essential to the successful operation during storage. Fortunately, since the betatron phase advance is small through the triplet region, it is possible to use the normal and skew dipole corrector (one for each type in each triplet) to correct the closed orbit error produced by the misalignment of D0, Q1, Q2, and Q3 magnets in the triplet. On the other hand, since a given undesired beam observable may have many origins, correcting for the misalignments will be complex in the case of closed orbit errors, especially when the entire triplet is corrected for each transverse direction by only one corrector whose maximum current is 50 A. It is therefore essential to limit the offset of each individual triplet dipole and quadrupole to be as small as reasonably achievable, i.e., definitely less than 0.5 mm.

An offset in the corrector center from its design beam trajectory produces a feed-down multipole component. Due to the complexity of higher-order multipole corrections and the strong dependence of the higher-order corrections[3] on the β value, presently we are only using the "dead reckoning" method[2] to correct individually measured multipole errors. Higher-order feed-down effects need to be small enough so that they can be left un-corrected. Therefore, it is again essential to limit the offset of each corrector center to be as small as reasonably achievable, i.e., definitely less than 1 mm.

Similarly to Table 2, Table 3 shows the effects of given rolls of the triplet magnets along the beam axis in the triplet assembly, and the amount of correction need if it is available. Because of the relatively high β at the D0 dipole locations, a roll in the D0 dipole can produce a significant closed orbit error which requires effective correction. A roll in the quadrupoles produces skew quadrupole component which will cause the linear coupling (measured by the minimum tune split ΔQ_{min} as specified[5] in Table 3). Due to their high β locations, this coupling can only be effectively corrected by the triplet a_1 corrector. Therefore, it is again essential to limit the roll of each individual triplet dipole and quadrupole to be as small as reasonably achievable, i.e., definitely less than 0.5 mrad. For the correctors, the roll of each individual layer should be definitely less than 5 mrad.

Table 3: Effects of a roll of the magnet along the beam trajectory in the triplet assembly. It is assumed that D0, Q1, Q2, and Q3 are operating at 5 kA, and the various layers of C1, C2, and C3 are operating at 50 A.

Magnet	Roll (mrad)	Effects for $\beta^* = 1$ m operation (for $\beta^* = 2$ m operation)	Correction needed (if available)
D0	0.5	closed orbit offset of 1.3 mm at arc (0.9 mm at $\beta^* = 2$ m)	a_0/b_0 corrector at 1 A
Q1	0.5	equivalent to $\Delta Q_{min} = 0.006$ [a] ($\Delta Q_{min} = 0.003$ at $\beta^* = 2$ m)	a_1 corrector at 3 A
Q2	0.5	equivalent to $\Delta Q_{min} = 0.026$ [a] ($\Delta Q_{min} = 0.013$ at $\beta^* = 2$ m)	a_1 corrector at 7 A
Q3	0.5	equivalent to $\Delta Q_{min} = 0.016$ [a] ($\Delta Q_{min} = 0.008$ at $\beta^* = 2$ m)	a_1 corrector at 5 A
C1, C3 (a_0/b_0)	5	equivalent to 5×10^{-3} I_{max} in b_0/a_0 [b] layer	
C2 (a_1)	5	equivalent to 10×10^{-3} I_{max} in b_1/a_1 [b] layer	
C2, C3 (a_2/b_2)	5	equivalent to 15×10^{-3} I_{max} in b_2/a_2 [b] layer	
C1, C2, C3 (a_3/b_3)	5	equivalent to 20×10^{-3} I_{max} in b_3/a_3 [b] layer	
C1 (b_4)	5	equivalent to 25×10^{-3} I_{max} in a_4 [b] layer	
C1, C3 (a_5/b_5)	5	equivalent to 30×10^{-3} I_{max} in b_5/a_5 [b] layer	

a) Minimum tune split due to linear coupling.

b) Relative to the maximum-current strength of the specified 13 cm corrector layer.

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References

[1] J. Wei and M. Harrison, *Tune Shift Due to Magnetic Multipoles in RHIC*, XV Intern. Conf. High Energy Accel. (Hamburg), p.1031 (1992).

[2] J. Wei, R. Gupta, and S. Peggs, *Magnetic Correction of RHIC Triplets*, Proc. 1993 Particle Accelerator Conferences, Washington, D.C., p. 258 (1993).

[3] J. Wei and S. Peggs, *Requested Systematic Body b_5 Multipoles in RHIC Triplet Quadrupoles*, Note RHIC/AP/18 (1993).

[4] J. Wei, S. Peggs, S. Tepikian, P.A. Thompson, and D. Trbojevic, *Effects of CQS and Dipole Misalignments in RHIC*, Note RHIC/AP/71 (1995).

[5] F. Pilat, private communications (1995).