### vii. Standard Aperture Corrector Magnets

Corrector/trim magnets will be provided at each quadrupole in the arcs, as well as in the insertions (except at Q1 whose corrector is attached to Q2) to compensate for systematic and random errors of the magnets and to control various beam dynamic properties as discussed in the Lattice and Beam Dynamics section.

The correctors have the same aperture as their quadrupoles implying the count of 420 standard-aperture (i.e. 8 cm) correctors and 72 large aperture (i.e. 13 cm) correctors.

**Standard Aperture Correctors**

The 8 cm correctors are nominally 0.5 m in effective length and are an integral part of the CQS package. They contain either four multipole elements (132 per ring) or a lone dipole element (78 per ring). The following 8 cm quadrupole-corrector combinations are required for the two rings

- $b_0$, $b_1$, $b_3$, $b_4$ @ 96 QF
- $b_0$, $a_1$, $b_3$, $b_4$ @ 36 QF
- $a_0$, $a_1$, $b_3$, $b_4$ @ 132 QD
- $b_0$ @ 78 QF
- $a_0$ @ 78 QD

The dipole correctors correct the closed orbit error resulting primarily from random dipole rotational errors and quadrupole misalignments around the ring, necessitating individual current control in each corrector. For this reason, a design using relatively low current has been adopted; this reduces the size of the electrical bus work, power supplies and heat leaks in cryogenic current leads. The normal quadrupoles are used for the gamma-transition jump. The skew quadrupole correctors correct: 1) the effect of random skew quadrupole errors in the dipole, an effect which can be reduced and perhaps eliminated by a shuffling/sorting procedure, and 2) random installation errors in the quadrupoles. The decapole correctors compensate for dipole iron saturation effects. The octupole correctors are used for the correction of second order chromaticity effects; $b_4$ will remain initially without power supplies.

Figure 7-1 shows a cross-section of the four-element arc corrector magnet (the "cold mass"), and Fig. 7-2 shows the cross-section in greater detail. The magnet utilizes a cold stainless steel beam tube of ~69 mm inner diameter common to the CQS assembly. In radially increasing order, the coil structures are decapole, octupole, quadrupole, and dipole coils, respectively. Each of the inner three structures consists of a double layer of racetrack coils wound with superconducting wire, with one coil per pole. The outermost winding, the dipole, has three double layers of superconducting wire arranged to minimize field harmonics. Each double layer is wound on a flat, flexible substrate using the specially developed technology which incorporates the MULTIWIRE process. Subsequently,

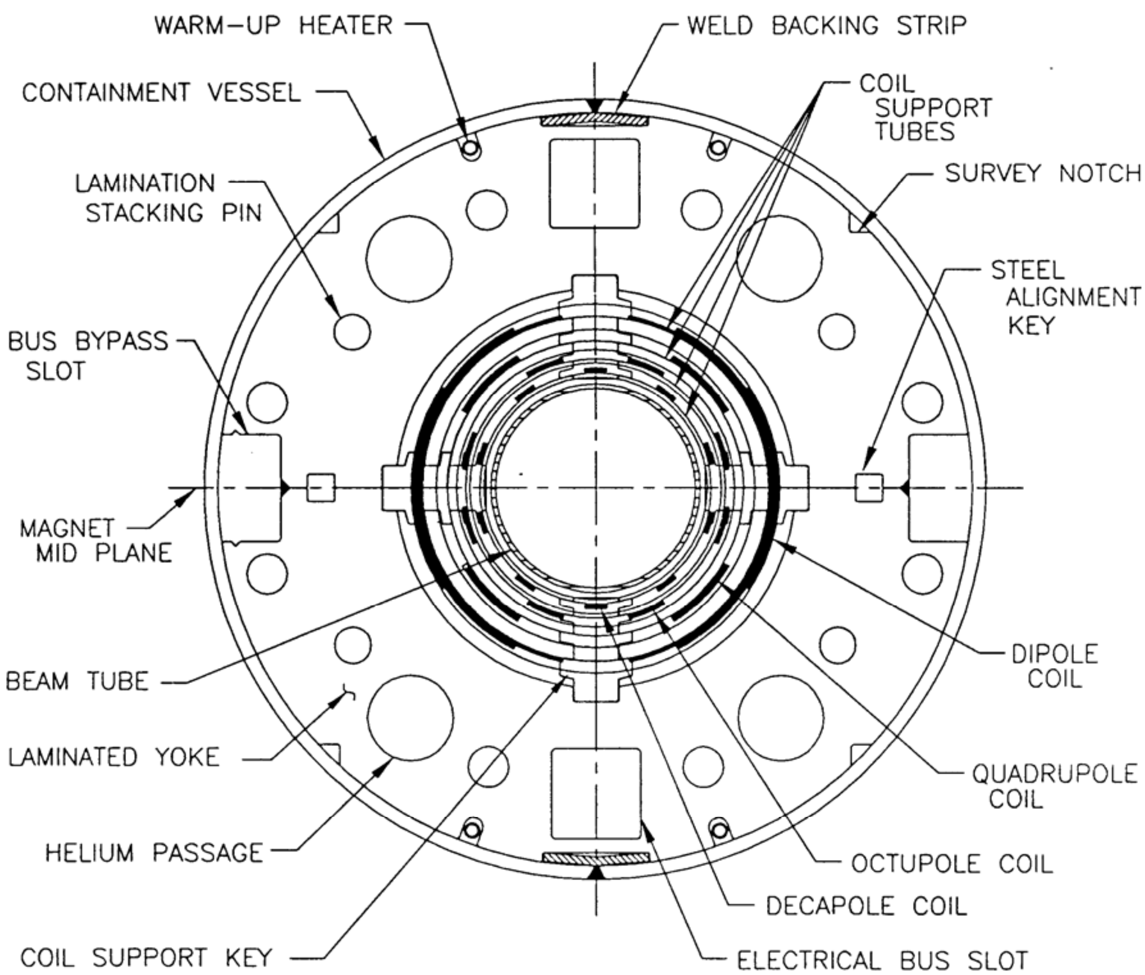


**Fig. 7-1.** Arc corrector cross-section (beam tube i.d. = 69 mm).

the substrate is epoxy-bonded to a stainless steel support tube which is previously wrapped with Kapton and fitted with aluminum locating pins. The wire is a multifilamentary NbTi composite wire, the parameters of which are given in Table 2-5.

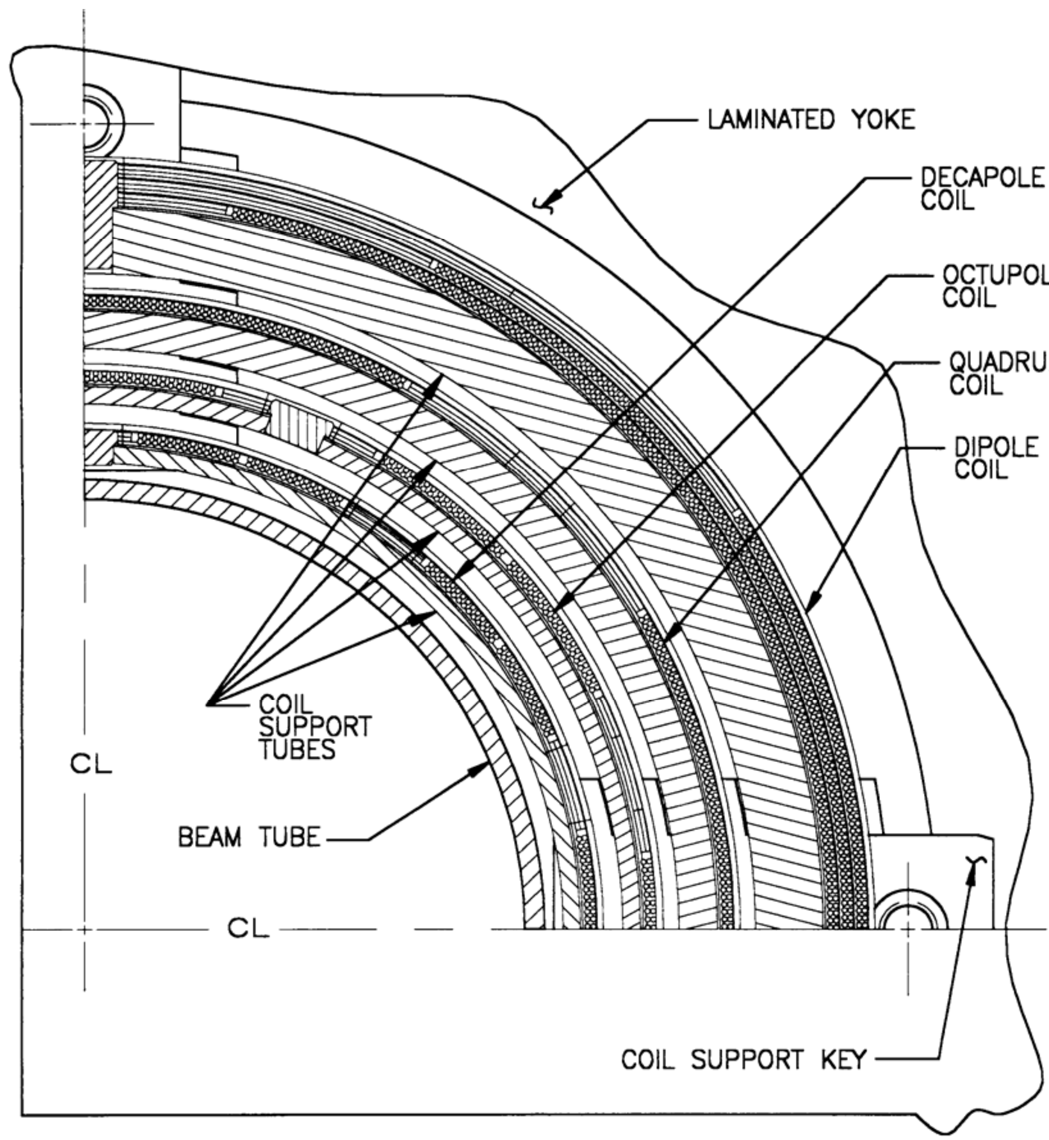


**Fig. 7-2.** Arc corrector coil cross-section (beam tube i.d. = 69 mm).

**Table 7-1.** Standard-Aperture Corrector Magnets

| | | |
|---|---|---|
| Number of correctors, arc and Q9 | 300 | |
| Number of insertion correctors | 120 | |
| Effective length, nominal* | ~0.5 | m |
| Coil length, nominal* | (~23 in.) ~580 | mm |
| Wire diameter | (0.013 in.) 0.33 | mm |
| Length, lamination | (26.50 in.) 0.673 | m |
| Outer diameter | (10.50 in.) 266.7 | m |
| Weight of steel | (430 lb) 195 | kg |
| Lamination thickness | (0.0598 in.) 1.519 | mm |
| Number of cooling channels | 4 | |
| Diameter of cooling channels | (1.187 in.) 30.15 | mm |
| Bus cavity width, height | (1.25 in.) 31.75 | mm |

*For exact values see Tables 7-2 and 7-3.

The beam tube fits loosely within the bore of the decapole coil support tube. It is actually the end portion of a continuous beam tube for the corrector-sextupole-quadrupole (CQS) package. It is fixed at one end to a beam position monitor located near the far end of the sextupole magnet; the other end of the beam tube is secured outside the end of the corrector magnet.

The major standard-aperture corrector design parameters are given in Table 7-1. The physical length of the various coils is nominally 0.58 m, a length short enough that the stainless steel support tubes can be supported solely at their ends. The tube diameters were selected from commercially available standard size to minimize machining. The dipole and quadrupole support tube thicknesses were chosen to give acceptable distortions due to the predicted magnetic forces, and the octupole and decapole support tube thicknesses were determined by machining requirements. The end support is provided by separators, four at each end, which serve to position the tubes radially, azimuthally, and axially, and which tie into the overall corrector/quadrupole/sextupole support and alignment structures.

**Table 7-2.** Mechanical Parameters of Arc Correctors coils. All coils are double layers.

| Multipole | Support tube o.d. ((in.)/mm) | Turns/Pole | Overall length ((in.)/m) | Wire length (m) |
|---|---|---|---|---|
| Decapole | (3.231) 82.1 | 28 | (22.980) 0.584 | 306 |
| Octupole | (3.624) 92.0 | 38 | (22.962) 0.583 | 359 |
| Quadrupole | (4.126) 104.8 | 90 | (23.016) 0.585 | 426 |
| Dipole/1 | (4.824) 122.5 | 278 | (22.850) 0.580 | 660 |
| Dipole/2 | | 226 | | 544 |
| Dipole/3 | | 122 | | 307 |

The yoke laminations are stamped from 1.5 mm thick low-carbon steel sheet. They have the same external configuration as the quadrupole laminations. Assembly and alignment is as described for the arc quadrupole, with which the sextupole and corrector share a common support structure and helium containment vessel.

A summary of the arc corrector coil parameters required for each multipole is given in Table 7-2, and Table 7-3 gives the operating parameters of the corrector magnets. In general, all the correctors are designed to operate conservatively at ~25-33% of their quench limit.

All correctors were quench tested because the conductor consists of a single strand, increasing the consequences of damage to a strand at any stage of production. In particular, careful study indicated that it would be difficult to detect damage during the automated coil winding process. Therefore, all corrector layers except for the dipole were tested to ± 100 A, twice the maximum operating current. Dipoles were tested to ± 70 A, since quenches at higher current could damage the magnet. Correctors other than the dipole were tested in self field and in the background field of the dipole at 70 A. In all, 1229 layers were tested [MU97]. About 2/3 of the layers reached the maximum current without quenching. Seven layers failed during quench test and were replaced.

**Table 7-3.** Operating Parameters of Arc Correctors

| Multipole | Inductance (mH) | $I_{op}$ (A) | $B$ @ 2.5 cm (T) | $L_{eff}$ (m) | $I_Q$ (A) |
|---|---|---|---|---|---|
| Decapole | 5.0 | 59.0 | 0.016 | 0.575 | 202 |
| Octupole | 8.0 | 50.6 | 0.017 | 0.571 | 198 |
| Quadrupole | 29.0 | 49.8 | 0.067 | 0.555 | 190 |
| Dipole | 840 | 52.2 | 0.596 | 0.508 | 160 |

**Table 7-4.** Integral field quality measured in the 80 mm corrector coils.

| Layer Type | Transfer Function, T.m/kA @25 mm (warm) | Std. Dev. in T.F. | Change in T.F. on Cooldown | Harmonics as Fraction of the Fundamental Field |
|---|---|---|---|---|
| $b_0/a_0$ | 5.5549 | 0.16% | +1.0% | <0.3% |
| $b_1$ | 0.7627 | 0.18% | +0.7% | <0.6% |
| $a_1$ | 0.7570 | 0.09% | +0.7% | <0.6% |
| $b_3$ | 0.1920 | 0.53% | +0.9% | <2% |
| $b_4$ | 0.1494 | 0.48% | +1.2% | <2% |

The correlation between warm and cold field quality measurements was good enough that the only ~20% were measured cold. The data for all the 80 mm correctors are summarized in Table 7-4. The reproducibility of the integral transfer function is typically 0.2%, and the harmonics are at the level expected for a corrector, ~ 1% of the fundamental. The standard deviation of the warm-cold difference in the integral transfer functions is less than 0.1% of the transfer function for the dipole and quadrupole coils and ~ 0.3% for the octupole and decapole coils.