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Overview of the New AGS Octupole System

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Technical Note

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Introduction

Twelve normal octupoles are scheduled to be put in the AGS. The vector potential of a normal octupole varies as $Re[(x+iy)^4]$ and is given by

$$\mathbf{A} = \hat{z} B_{tip}(6x^2y^2 - x^4 - y^4)/4R, \tag{1}$$

where B_{tip} is the pole tip field and R is the inner radius or half the distance between opposite pole tips. For a skew octupole

$$\mathbf{A} = \hat{z} B_{tip} xy(y^2 - x^2)/R. \tag{2}$$

As with sextupoles,quadrupoles and dipoles the normal octupole has no pole in the horizontal plane while the skew octupole has two poles centered in the horizontal plane. For $\hat{z}$ pointing downstream, and $\hat{y}$ pointing up both octupoles would be in A polarity for $B_{tip} \geq 0$[1].

The Hardware

Table 1 lists the magnetic parameters of the octupoles.

Table 1: AGS Octupole Parameters

quantity	symbol	value
pole tip field	B_{tip}	196 G/A
radius of magnet	R	3.95"
length of magnet	ℓ	6"
turns per pole	N_t	395

The octupoles will be driven by the same bipolar type power supplies as the new AGS horizontal and vertical correction dipoles. These supplies are rated at a DC value of 15A and a pulsed value of 25A. The planned locations for these magnets are in the straight sections:
A6,A9,A19, D6,D9,D19, G6,G9,G19, J6,J9,J19.

Utility

The octupole locations are 90° apart in 35θ phase and will allow simultaneous correction of the 3 normal octupole resonance lines crossing through $Q_x = Q_y = 8.75$. By powering octupoles on opposite sides of the ring (*eg.* A6 and G6), with opposite currents, the 35θ components will add in phase and the 26θ components will cancel. Such an excitation configuration will allow for correction of the octupole lines without creating momentum dependent (via dispersion) sextupole stopbands.

Also, these magnets will allow for a small amplitude dependent betatron tune shift. By powering magnets 90° apart with the same current (*eg.* A6, D6, G6, J6) the 35θ and 26θ lines will be unaffected but a 0θ component will be created. For one dimensional motion the octupole induced tune shift is given by [2]

$$\frac{d\nu}{d\epsilon} = \frac{1}{32\pi} \oint \frac{\beta^2 B'''}{(B\rho)} ds, \tag{3}$$

where $B''' = 6B_{tip}/R^3$ is the third derivative of the octupole field with respect to x and $\epsilon = a^2/\beta$. A real particle will have nonzero emittance in both planes. From eq(1), an octupole that is confining for a pure x or y offset will be deconfining when $x = y$. Luckily, the modulation in the β function can be exploited so that the average x and y tune shifts, for all combinations of x and y emittances, will have the same sign. Detailed calculations are still underway, but assuming a factor of 2 reduction so that the smooth Hamiltonian is confining for all offsets gives

$$\frac{d\nu}{d\epsilon} = \frac{6}{32\pi} \frac{\bar{\beta}^2 B''' \ell}{(B\rho)}. \tag{4}$$

For 15 amps and a rigidity of 8 T-m (protons at injection)

$$\frac{d\nu}{d\epsilon} = 4.3 \times 10^{-4}/(mm - mrad).$$

For an average beam radius of 2 cm this gives $\Delta\nu = 0.01$ which is comparable to the tune spread induced by chromaticity.

Placement Tolerances

If the octupoles are not centered on the closed orbit the beam will see effective sextupole and quadrupole fields which could open stopbands. These stopbands could limit the beam current since the space charge tune shift depends on the beam current. It is therefore necessary to estimate the placement tolerances needed.

The simplest estimate is to assume a transverse offset in an octupole, calculate the effective sextupole and quadrupole fields associated with the offset, and make sure the sextupole and quadrupole correction strings are strong enough to cope with the error. Consider the induced sextupole field.

For an offset x_0 in an octupole, the integrated sextupole strength through the octupole is

$$S_{oct} = 3B_{tip}\ell x_0/R^3. \tag{5}$$

There are 16 sextupoles with auxiliary (floating) power supplies. These can supply a current of 3 amps and the integrated strength of a sextupole is $S_{sext} = 17I\,\mathrm{Gin}^{-1}\mathrm{A}^{-1}$. Assume 10 A in the octupole and

1 A in the sextupole. Also assume that the octupole contribution to the stopband is random while the sextupole correction is coherent. Equating the sextupole strengths gives $\sqrt{12}S_{oct} = 16S_{sext}$ and $x_0 = 0.069'' = 1.7\text{mm}$.

An analogous calculation for the half integer stopband gives $x_0 = 6.7\text{mm}$. So a placement tolerance of 2mm should be acceptable.

References

[1] E. Bleser, Booster Tech Note 180, 1990.

[2] D.A. Edwards and M.J. Syphers, *An Introduction to the Physics of High Energy Accelerators*, Wiley, 1993, page 142.