MI-0004

Main Injector Dipole: Conductor Optimization

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Magnet Resistance

$$R_M = \frac{2 L N_T \rho_{Cu}}{A}$$

L = Magnet length
N_T = # turns
A = Conductor Area
$\rho_{Cu} = 1.7 \times 10^{-8}\ \Omega\text{-m}$

Magnet Current

$$I = \frac{Bg}{\mu_0 N_T}$$

B = Magnetic field
g = gap
$\mu_0 = 4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}$

$$B = \frac{2\pi (B\rho)}{N_M L}$$

N_M = # magnets
$(B\rho)$ = Magnetic Rigidity
$= \frac{E}{.03\ \text{GeV/kG}\cdot\text{m}}$

Power

From $P = N_M I^2 R_M$:

$$P = \frac{8\pi^2 (B\rho)^2 \rho_{cu} g^2}{N_M L \mu_0^2 N_T A}$$

For slow spill $P_{av} = \frac{1}{2} P$

$$P_{av} = \frac{4\pi^2 (B\rho)^2 \rho_{cu} g^2}{\ }$$

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For Main Injector: $B\rho = \frac{120 \text{ GeV}}{.03} = 4000 \text{ kG-m}$

$N_M = 300$, $L = 6.07 \text{ m}$, $g = .05 \text{ m}$

$$\Rightarrow \boxed{P_{av} = \frac{9.3 \times 10^4 \text{ Watts} \cdot \text{m}^2}{N_T A}}$$

(Note: For B_2 $N_T A = 16(.00049 \text{ m}^2) = 7.8 \times 10^{-3} \text{ m}^2$
$\Rightarrow P_{av} = 11.9 \text{ MW}$)

Magnet Cost

$\# Cu = 2 L A N_T \rho N_M$

$$\boxed{\# Cu = (6.4 \times 10^7 \text{ lbs/m}^2)\, N_T A}$$

Cost = $2.60/lb × 2 for extra steel, handling, etc
= $5.20/lb.

Incremental Magnet Cost:

$$\boxed{\$Mag = \$334M \left(\frac{N_T A}{m^2}\right)}$$

Operating Cost

Assume $.05/kW-hr, 67% DF

$$\$Op = \frac{\$2.7 \times 10^4 / \text{year}}{(N_T A / m^2)}$$

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Optimize

$ Mag + 5 year × $ Op

$$\$ = 334\,(N_T A) + \frac{0.14}{N_T A}$$

$$\frac{d\$}{d(N_T A)} = 0 = 334 - \frac{0.14}{(N_T A)^2}$$

$$\Rightarrow (N_T A)_{opt} = \sqrt{\frac{.14}{334}} = .02\ m^2$$

$$\boxed{(N_T A)_{opt} = 32\ in^2}$$

Turns

N_T	I_{max}	$N_{P.S.}$ (@ 1 KV)	$ P.S.
16	4700 A	24	5.9 M
8	9400 A	12	4.5 M
4	18800 A	6	4.0 M

$$\boxed{N_T = 8 \; : \; A = 4\ in^2}$$