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Injection For RHIC

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Injection for RHIC.

We assume an injection septum magnet in one of the L_{670} driftspaces with its exit 1 m upstream of Q_{70}, followed by an injection kicker (full aperture) in the adjoining L_{780} drift space, 2 m long and its exit 1 m upstream of Q_{80}, thus with its center 2 m upstream of that magnet.
We calculate for the betatron parameters at the septum magnet exit and the kicker center in the present $\beta^*_x * \beta^*_y = 17 \times 3\ m^2$ lattice:

	Horizontally		Vertically	
	β_H (m)	$\psi_H/2\pi$	β_V (m)	$\psi_V/2\pi$
Septum magn.	16.98012	1.92844	22.73199	1.8784
Kicker	37.81594	1.98960	11.04818	1.94608

The leverage arm length between kicker and septum magnet is then:

	Horizontally	Vertically
$\sqrt{\beta_s \beta_k}\ \sin \Delta\psi$ (m)	9.50	6.53

The circulating beam requires (after two hours) an aperture of

	Horizontally		Vertically
Septum magnet $(mm)^2$	$2 * 18$	$\times$	$2 * 18$
Kicker $(mm)^2$	$2 * 27$	$\times$	$2 * 13$

based on 6σ for an emittance $\varepsilon\gamma = 30/6 * 10^{-6}$ rad-m and a momentum spread of $\frac{\Delta p}{p} = 2 * 0.003$, and local values for β and x_p (dispersion)

The beam to be injected has cross sectional dimensions in the ~~XXXX~~ septum magnet's exit of

$H \times V = 2 * 4.7 \times 2 * 4.3$ (mm x mm)

assuming that that beam has $\frac{\Delta p}{p} = 2 * 0.0013$ and taking the $\sigma\sqrt{6}$ values for an emittance of $\gamma\varepsilon = 10/6 \times 10^{-6}$ rad-m.

We also assume that the effective septum thickness will be ≤ 5 mm. It follows that the kicker must provide a deflection $\Delta x' \geq (18+5+4.7)/9.5 = 3$ mrad if it deflects horizontally and

$$\Delta y' \geq (18+5+4.3)/6.53 = 4.2 \text{ mrad}$$

if it deflects vertically.

Evidently horizontal deflection requires less kicker strength.

The $B\rho$ value of the incoming beam is 98.22 Tm, thus for a horizontally deflecting kicker requires at least

$$B\ell = \alpha B\rho = 3 \times 98 \times 10^{-3} = 0.3 \text{ Tm}.$$

We choose it to have a length of 2 m, thus $B = 1.5$ kG, quite manageable for conventional ferrites.

Using this value we find for the stored energy, the excitation current and the self inductance:

$$E = \frac{1}{2\mu_0} B^2 \times \text{Volume} \geq \frac{0.15^2 \times 2 \times 54 \times 26 \times 10^{-6}}{2 \times 4\pi \times 10^{-7}}$$

$$\geq 25 \text{ Joule}$$

$$I = \frac{Bg}{\mu_0} = \frac{0.15 \times 26 \times 10^{-3}}{4\pi \times 10^{-7}} = 3100 \text{ A}$$

$$L = \mu_0 \frac{L \times w}{g} = 4\pi \times 10^{-7} \times 2 \times \frac{54}{26} = 5.2\ \mu H$$

A linear rise from no excitation to full excitation in 150 nsec (bunch centers are 220 nsec apart) requires a voltage of $V_k = L\frac{di}{dt} = 5.2 \times \frac{3100}{0.15} = 108$ KV and an instantaneous power of 166 MW.

Aperture in Q_{70}

The path of the injected beam is displaced by 3(mrad) * 6 m = 18 mm from the reference orbit in this quad. The beam's half width at that point is $hw = x_p \frac{\Delta p}{p} + \sqrt{\frac{\varepsilon \beta}{\gamma}}$

$$= 0.714324 * 1.3 + \sqrt{\frac{10 \times 15.2995}{12.5}}$$

$$= 4.427 \text{ mm}.$$

Q_{70} must provide a physical aperture of at least $\rho = 18 + 4.427 =$ 23 mm for that reason, slightly larger than the 20 mm required vertically by the circulating beam after 2 hours.

Beam direction at ~~a~~ septum magnet exit.

The injected beam leaves the septum magnet with an angle

$$x' = -(1 + \ell q_7) x'_k = -(1 + 6 \times 0.129)\, 3 = 4.77 \text{ mrad}.$$

relative to the reference orbit.

Kicker considerations.

We estimated kickers of 2, 3, 4, 5 m length, all ending 1 m upstream of Q80, and all with sufficient aperture to contain the circulating beam after two hours ($\varepsilon\gamma = 6 \times 30 \times 10^{-6}$; $\Delta p/p = \pm 0.003$). We tabulate the results below:

Length	Deflection Angle	Field	Aperture	Stored Energy	Current	Inductance
L (m)	$\Theta = \Delta x'$ (mrad)	B (T)	$H \times V$ (mm × mm)	E (Joule)	I (A)	L (μH)
2	2.915	0.142	58 × 27	25.1	3051	5.4
3	3.123	0.102	30	21.6	2435	7.3
4	3.362	0.0824	33	20.7	2164	8.8
5	3.640	0.0713	35	20.5	1986	10.4

The longest kicker seems to be the best one because it stores least energy and can easily be subdivided into a number of modules in order to reduce the requirements on the switch thyratron.

Errors.

The deflection angle produced by the kicker are uncertain for a number of reasons, primarily variations in pulse height and reflections on imperfect terminations. If I assume that the deflecting field can be kept within 1%,

i.e. $\left|\Delta B/B\right| \leq 0.01$

I obtain for the deflection angle

$$\left|\frac{\Delta\theta}{\theta}\right| = \left|\frac{\Delta B}{B}\right| \leq 0.01$$

Thus $\Delta\theta \sim 30\ \mu rad$.

The angular spread in the incoming beam is of the order of $\sqrt{\frac{\varepsilon}{\beta}} = \sqrt{\frac{10}{30\gamma}} = \frac{166}{577}\ \mu rad$; the kicker error is negligeable compared to this at 1% stability.

It may be advantageous to inject intentionally with a coherent betatron error in both horizontal and vertical planes, because this leads quickly (via filamentation) to a circulating beam of large and controlable emittance and of somewhat controlable density distribution. It may be worth while to enhance the filamentation process with the aid of some octupoles.