

## Injection For RHIC

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19 March '84

Injection for RHIC.

We assume an injection septum magnet in one of the L670 drift spaces with its exit 1 m upstream of Q70, followed by an injection kicker (full aperture) in the adjoining L780 drift space, 2 m long and its exit 1 m upstream of Q80, thus with its center 2 m upstream of third magnet.

We calculate for the Betatron parameters at the septum magnet exit and the kicker center in the present

$\beta_x^* * \beta_y^* = 17 * 3 \text{ m}^2$  lattice:

	Horizontally		Vertically	
	$\beta_H$ (m)	$\psi_H/2\pi$	$\beta_V$ (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) <sup>2</sup>	2 * 18	2 * 18
Kicker (mm) <sup>2</sup>	2 * 27	2 * 13

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

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

$$H \times V = 2 \times 4.7 \times 2 \times 4.3 \text{ (mm} \times \text{mm)}$$

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

We also assume that the effective septum thickness will be  $\lesssim 5 \text{ mm}$ . It follows that the kicker must provide a deflection  $\Delta x' \geq (18 + 5 + 4.7)/9.5 = 3 \text{ mrad}$  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

### 3. Length

The  $B_p$  value of the incoming beams is  $98.22 \text{ Tm}$ , therefore for a horizontally deflecting kicker requires at least

$$Bl = \alpha B_p = 3 \times 98 \times 10^{-3} = 0.3 \text{ Tm}$$

We choose it to have a length of  $2 \text{ m}$ , thus  $B = 1.5 \text{ kg}$ , quite manageable for conventional ferrites.

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

$$E = \frac{1}{2\mu_0} B^2 \times \text{Volume} \geq \frac{0.15^2 \times 2 \times 54 \times 26 \times 10^{-6}}{2 \times 4\pi \times 10^{-7}} \geq 2.5 \text{ Joule}$$

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

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

A linear rise from no excitation to full excitation in  $150 \text{ nsec}$  (bunch centers are  $220 \text{ nsec}$  apart)

requires a voltage of  $V_k = L \frac{di}{dt} = 5.2 \times \frac{3100}{0.15} = 108 \text{ KV}$  and an instantaneous power of  $166 \text{ MW}$ .

Aperture in  $\psi_70$

The path of the injected beam is displaced by  $3(\text{mrad}) \times 6\text{m} = 18\text{mm}$  from the reference orbit in this quad. The beam's half width at that point is

$$\begin{aligned}hw &= x_p \frac{\Delta p}{p} + \sqrt{\frac{\epsilon \beta}{\gamma}} \\ &= 0.714324 \times 1.3 + \sqrt{\frac{10 \times 15.2995}{12.5}} \\ &= 4.427\text{mm}.\end{aligned}$$

$\psi_70$  must provide a physical aperture of at least  $p = 18 + 4.427 = 23\text{mm}$  for that reason, slightly larger than the  $20\text{mm}$  required vertically by the circulating beam after 2 hours.

Beam direction at septum magnet exit.

The injected beam leaves the septum magnet with an angle

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

relative to the reference orbit.

Kicker considerations.

We estimated kickers of 2, 3, 4, 5 m length, all ending 1 m upstream of  $\psi_80$ , and all with sufficient aperture to contain the circulating beam after two hours ( $\epsilon \gamma = 6 \times 30 \times 10^{-6}$ ,  $\Delta p/p = \pm 0.003$ ). We tabulate the results below:

Length (m)	Deflection Angle (mrad)	Field (T)	Aperture (mm x mm)	Stored Energy (Joule)	Current (A)	Inductance ( $\mu\text{H}$ )
2	2.915	0.142	58 x 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 thyatron.

## 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. I/s assume that the deflecting field can be kept within 1%,

$$\text{i.e. } |\Delta B/B| \leq 0.01$$

or  $\Delta B$  obtain for the deflection angle

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

Thus  $\Delta \theta \sim 30 \mu\text{rad}$ .

The angular spread in the incoming beam is of the order of  $\sqrt{\frac{2}{10}} = \sqrt{\frac{10}{30}} = \frac{166}{577} \mu\text{rad}$ , the kicker error is negligible compared to this at 100% 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 controllable emittance and of somewhat controllable density distribution. It may be worth while to enhance the filamentation process with the aid of some octupoles.