Subject: KICKER REQUIREMENTS FOR PHASE-PLANE INTERCHANGE INJECTION INTO NAL STORAGE RINGS

We assume that the extracted beam at 100 GeV is rotated in real space so that vertical and horizontal phase planes are interchanged, as discussed in a note by Keil*. The beam emittances immediately before injection into the storage rings are then estimated to be

$$\left.\begin{aligned} A_h &= 2.2\ \pi \times 10^{-6}\ \text{rad m}\ , \\ A_v &= 1.0\ \pi \times 10^{-6}\ \text{rad m}\ . \end{aligned}\right\} \tag{1}$$

Injection of 3 turns on a 1/3 integer resonance in the horizontal plane can be achieved by two kickers spaced one half-wavelength, with a septum magnet located at or near the maximum of the displaced closed orbit. We use suffixes k and s to indicate the azimuths of kickers and septum respectively.

1. Screened, limited-aperture kicker magnet

The closed-orbit displacement at the septum that must be provided by the kickers is

$$\Delta x_s = 2\sqrt{\frac{\beta_s A_h}{\pi}} + t\ , \tag{2}$$

where t is the effective septum thickness.

The bending angle θ_k of each kicker is

*E. Keil, "Aperture Requirements at Injection Into the NAL Storage Ring," National Accelerator Laboratory Internal Report FN-169, August 27, 1968.

$$\theta_k = \frac{\Delta x_s}{\sqrt{\beta_k \beta_s}} = 2 \sqrt{\frac{A_h}{\beta_k \pi}} + \frac{t}{\sqrt{\beta_k \beta_s}} \qquad (3)$$

If B = flux density

ℓ = effective length

N = no. of sections

V = charging voltage

τ = rise time

w = effective width of aperture

of each kicker,

$$B\ell = \frac{NV\tau}{2w} \quad , \qquad (4)$$

also,

$$\theta_k = \frac{0.3B\ell}{p} , \qquad (5)$$

where p is the momentum in GeV/c.

Then,

$$\begin{aligned} \frac{NV\tau}{2w} &= \frac{p}{0.3} \theta_k \\ &= \frac{p}{0.3} \left[2 \sqrt{\frac{A_h}{\beta_k \pi}} + \frac{t}{\sqrt{\beta_k \beta_s}} \right] \end{aligned} \qquad (6)$$

The aperture width w can be expressed as:

$$w = 2f \sqrt{\frac{\beta_k A_h}{\pi}}$$

where f is a fringing-field factor (> 1).

Hence:

$$\frac{NV\tau}{f} = \frac{4p}{0.3}\left[\frac{2}{\pi} A_h + t\sqrt{\frac{A_h}{\beta_s \pi}}\right] \qquad (7)$$

Assuming a septum thickness t of 10^{-3} m,

β_s = 10 m and A_h = $2.2\pi \times 10^{-6}$ rad m,

$$\frac{NV\tau}{f} = \frac{4p}{0.3}\left[4.4 + 0.47\right] \times 10^{-6} \text{ V sec.}$$

One sees that the total kicker flux is not very sensitive to t and β_s in this range and is almost momentum-independent, since A_h scales as p^{-1}.

The kickers have to be turned off in about 50 nanosecond; without a "tail-clipper" the rise time should be about half this figure. Putting $\tau = 25 \times 10^{-9}$ sec, p = 100 GeV/c, and f = 1.54, we have

$$NV = 4 \times 10^5 \text{ V} .$$

For a 6-section kicker,the required charging voltage would be about 67 kV.

Also:

$$B\ell = \frac{NV\tau}{2w} = \frac{NV\tau}{4f}\sqrt{\frac{\pi}{\beta_k A_h}} , \qquad (8)$$

and, if we assume β_k = 50 m,

$$B\ell = 0.155 \text{ T m.}$$

A kicker effective length of 1.55 m leads to a field of 0.1 T.

If h is the height of the kicker gap, Z the characteristic impedance, β_{kv} the vertical betatron function at the kicker and f' (> 1) a vertical filling factor,

$$Z = \frac{\mu_0 w \ell}{h N \tau} \tag{9a}$$

$$= \frac{\mu_0 \ell}{N \tau} \frac{f}{f'} \sqrt{\frac{\beta_k A_h}{\beta_{kv} A_v}} . \tag{9b}$$

Assuming $f' = 1.3$, $\beta_{kv} = 25$ m and $A_v = 1.0\pi \times 10^{-6}$ rad m,

$$Z = 32.2\,\Omega$$

The current I is then

$$I = \frac{V}{2Z} = 1035 \text{ A}.$$

The inductance and capacitance per section are given respectively by

$$L = Z\tau = 0.805 \times 10^{-6} \text{ H} ,$$

and

$$C = \frac{\tau}{Z} = 0.78 \times 10^{-9} \text{ F}.$$

2. Full-aperture kicker magnet

In this case we can assume a picture-frame yoke with no fringing-field factor. The full radial aperture required is shown in FN-169 to be 0.045 m. Using this value for w in Eq. (6), with the same values as before for the other parameters, we arrive at:

$$NV = 5.38 \times 10^5 \text{ V}.$$

For an 8-section kicker, the required charging voltage would be about 67 kV. Also, from Eq. (8),

$$B\ell = 0.15 \text{ T m} ,$$

or 0.1T in a 1.5 m kicker magnet.

Again assuming $\beta_{kv} = 25$ m, $A_v = 1.0\ \pi \times 10^{-6}$ rad m, the vertical beam diameter is

$$2\sqrt{\frac{\beta_{kv} A_v}{\pi}} = 0.01 \text{ m}.$$

for the full-aperture kicker we allow a somewhat larger safety factor of 1.5 in the vertical aperture, to take care of a possible variation of vertical closed orbit with radial position. The kicker gap height is then 0.015 m, and from Eq. (9a)

$$Z = 28.2\,\Omega\ ,$$

leading to:

$$I = 1190 \text{ A}\ ,$$

$$L = 0.705 \times 10^{-6} \text{ H}\ ,$$

$$C = 0.886 \times 10^{-9} \text{ F}\ .$$

From the above examples it can be concluded that the design of kicker magnets for injection into storage rings at 100 GeV presents no special problems over and above those normally present at lower energies. In fact, the screened kicker turns out to be very similar to the original one proposed for the CERN ISR,* apart from the shorter rise time and consequently higher voltage. For this type

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*CERN Report "Design Study of Intersecting Storage Rings for the CPS" AR/Int. SG/64-9, 1964.

of injection scheme, tolerances will also be similar.

A full-aperture kicker magnet is only slightly bigger, but an investigation should be made into the tolerances that will be imposed by kicking the stacked beam.