BNL-101952-2014-TECH

AD/RHIC/40;BNL-101952-2013-IR

Resonant Excitation for RHIC Injection Kicker

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June 1988

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AD/RHIC-40

RHIC TECHNICAL NOTE NO. 40

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New modes for operating RHIC have been proposed recently. There is the desire to fill every third, rather than every sixth bucket of the 342 that are available in each ring, and there is the likelyhood that the AGS will accelerate three ion bunches, rather than one, per pulse, at least initially. Instead of trying to design a transfer system with the capability to match all possible configurations it may be easier to transfer the bunches from AGS to RHIC always one at a time. The AGS functions as a storage ring in which the bunches circulate until they can be moved to RHIC. One advantage of doing this is that the extraction and injection kickers will always be excited with the same waveforms. The distance in time between successive transfer operations, about 2.3msec or longer, is restricted in two ways. As the ratio of the circumferences of RHIC and the AGS is 19/4, the same situation occurs only every 4 RHIC revolutions and every 19 AGS revolutions, thus with a period of about 50μsec; successive bunch transfers will have to be separated by that period or a multiple thereof. Filling every third bucket in RHIC implies that the distance between successive bunches is half of what it is in the AGS. Therefore, after a bunch has been transfered, the remaining bunches in the AGS will have to be shifted in phase, relative to the bunch train in RHIC, by π AGS rf radians, equivalent to three bucket lengths in RHIC. The fastest way to do this is by means of a forced half synchrotron oscillation with a phase amplitude of $\pi/2$ radians, which takes about 2.3 msec. The kicker excitation may last of the order of 200nsec or less and beam is deflected during 20nsec. Under these conditions it may be acceptable and simpler to drive the kickers with resonant powersupplies than with PFNs (pulse forming networks). We therefore consider some of the implications of doing so.

Pertinent numbers:
Distance between bucket centers: $\tau = 1/(h\nu) = 1/(342\times78.196\cdot10^3) = 37.39$nsec.
Matched bunchlength for bunch area of 0.3eVsec: 17nsec.
Fill every third bucket, i.e. a bunch every $3\times37.39 = 112.2$nsec.
Then maximum length of quarter wave of (half sinusoidal) kicker excitation:
$112.3-17/2 = 103.68\text{nsec} \approx 100\text{nsec}$, thus:
$\tau_k = 4\times100 = 400$nsec, $\nu_k = 1/400\text{e-}9 = 2.5$MHz, $\omega_k = 15.7\cdot10^6$rad/sec

The deflection is proportional to the excitation: $\Theta(t) = \Theta_{max}\cos(\omega_k t)$, $|t| \leq 17/2 = 8.5$nsec, thus $\Theta_{min} = \Theta_{max}\cos(15.7\cdot10^6\times8.5\cdot10^{-9}) = 0.9911\Theta_{max}$. The variation in the deflection angle is thus $\Delta\Theta = (1-0.9911)\Theta_{max} = 0.0089\Theta_{max}$. The nominal deflection angle is 1.3mrad, the change in beam direction during the pulse, due to the sinusoidal excitation, is thus $\Delta\Theta = 11.57\mu$rad $\approx 12\mu$rad total, $\pm6\mu$rad relative to the average. This variation of direction causes a blow up in vertical emittance according to $\bar{\varepsilon}/\varepsilon = [1+(\beta\cdot\Delta\Theta^2/\varepsilon)^{1/2}]^2$, with ε the nominal emittance and $\bar{\varepsilon}$ the emittance after the blowup has occurred, and β the amplitude function at the kicker location. The effect is worst for the bunches with the smallest emittance. Protons are expected to have the smallest emittance: $\varepsilon = 0.6\pi\cdot10^{-6}$rad-m, while $\beta \approx 50$m. Using $\Delta\Theta = 6\mu$rad, I find $\bar{\varepsilon}/\varepsilon = 1.1125$, thus a blowup of 11% . This may be acceptable in view of the fact that the blowup increases with the fourth power of the distance to the center of the bunch: only a limited number of particles at the head and the tail of the bunch is seriously affected. Some flattening of the top of the current waveform by means of clever circuitry will help to minimize this effect. It is also clear that the crest of the current waveform must occur at the instant that the bunch center passes through the kicker within a few nsec, evidently this tolerance increases with increasing flatness of the top of the waveform.

I assume, that the kicker will have to deflect the incident beam, which has a rigidity of $B\rho$=100Tm, over 1.3mrad. It may have a gap g=25mm, a width w=45mm and a length ℓ=3.25m. The choice of length is somewhat arbitrary, any length up to 13m is acceptable; larger lengths require proportionally lower fields and smaller charging capacitors, but tend to require somewhat more ferrite. The Z/n increases also with increasing length. For the dimensions given, the kicker will have to provide a B_k=0.04T, which requires a current $i_k = B_k g/\mu_o$=800A. The inductance L is $L=\mu_o \ell w/g$=7.35μH. I assume that the lead inductance will increase this number to L_{eff}=8μH. This inductance requires a capacitance $C=1/(\omega_k^2 L)$ to resonate at frequency ω_k, numerically: $C=1/[(15.7\cdot10^6)^2\cdot8\cdot10^{-6}]$=507pF. Neglecting resistive losses, one has for the relation between the amplitudes of voltage and current: $V_c=\omega L i_k$; this yields for the charging voltage of the capacitor: $V_c=15.7\cdot10^6\cdot8\cdot10^{-6}\cdot800$=100.5kV. Subdivision yields larger capacitors and lower voltages. Some examples are tabulated below.

Number of sections	1	2	3	4
Length/section [m]	3.25	1.63	1.08	0.81
Inductance/section [μH]	8	4.3	3.1	2.5
Capacitance/section [pF]	507	940	1308	1623
Charging Voltage [kV]	101	54	39	32
Current [A]	800	800	800	800
Field [T]	0.04	0.04	0.04	0.04
Frequency [MHZ]	2.5	2.5	2.5	2.5