# SYNCHRONIZATION AND TOLERANCES FOR TRANSFER OF BEAM FROM AGS TO ISA

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The detailed procedure for matching during the transfer of beam from AGS to ISA has not yet been formulated. We shall assume here that both AGS and ISA are flat-topped for beam transfer and the rf voltages are properly adjusted to match beam-bunch shape. Specifically we shall take the AGS rf voltage to be 36 kV. This scheme may have to be modified when instability considerations are taken into account but will nevertheless serve to illustrate to first order the synchronization procedure required.

## A. Beam-bunch dimensions in AGS

On the flat top $\phi_s = \pi$ and for the maximum dimensions of the bunch we have (for $\beta \simeq 1$)

$$\widehat{\frac{\Delta p}{p}} = \frac{A}{\gamma\eta}^{\frac{1}{2}} \qquad \widehat{\Delta\phi} = \left(\frac{A}{\frac{1}{2\pi h}\frac{eV}{mc^2}}\right)$$

where

$$A = \left(\frac{2}{\pi h}\frac{eV}{mc^2}\frac{\eta}{\gamma}\right)^{\frac{1}{2}} \frac{f\epsilon}{mc^2}$$

with

$\epsilon$ = longitudinal emittance = 0.36 eV sec

f = rf frequency of AGS or ISA = 4.45 MHz

V = rf voltage = 36 kV

$\eta = 1/\gamma_t^2 - 1/\gamma^2 = 0.0095$; ($\gamma = 31.4$, $\gamma_t = 9.75$)

h = harmonic number = 12

we get

$$A = 4.24 \times 10^{-8}$$

$$\widehat{\frac{\Delta p}{p}} = 3.8 \times 10^{-4}, \qquad \widehat{\Delta\phi} = 0.29 = 17^{\circ}$$

Thus, the full monentum and phase tolerances during transfer should be, say,

$$\frac{\delta p}{p} \cong 7 \times 10^{-5}, \qquad \delta\phi \cong 0.05 \cong 3^{\circ} .$$

B. Bunch-shape matching

With ISA also on flat top, beam-bunch shape is matched if

$$\left(\frac{V}{h\eta}\right)_{ISA} = \left(\frac{V}{h\eta}\right)_{AGS}$$

with

$$\frac{h_{ISA}}{h_{AGS}} = \frac{11}{3} \qquad \text{and}$$

$$\eta_{ISA} = 0.00113 \quad (\gamma_t = 21.6)$$

we get

$$V_{ISA} = 0.436 \quad V_{AGS} = 15.7 \text{ kV}$$

A 1% tolerance on the rf voltage is good enough and should be rather easy to meet.

C. Momentum matching

Of the 3 quantities: magnetic field B, beam radial position x, and rf requency f, any two will fix the momentum. However, to get the same momentum definition, the accuracy requirements are

different for different sets of defining parameters.

1. B and f

In this case we have

$$\frac{\delta f}{f} = \frac{\delta \beta}{\beta} - \frac{\delta R}{R} = \frac{1}{\gamma^2}\frac{\delta p}{p} - \frac{1}{\gamma_t^2}\left(\frac{\delta p}{p} - \frac{\delta B}{B}\right) = -\eta\frac{\delta p}{p} + \frac{1}{\gamma_t^2}\frac{\delta B}{B}$$

or

$$\frac{\delta p}{p} = -\frac{1}{\eta}\frac{\delta f}{f} + \frac{1}{\eta\gamma^2}\frac{\delta B}{B} = -105\frac{\delta f}{f} + 1.11\frac{\delta B}{B}$$

If each term on the right-hand side has to be accurate to, say, $5 \times 10^{-5}$ we get

$$\frac{\delta f}{f} \sim 4.8 \times 10^{-7} \qquad \frac{\delta B}{B} \sim 4.5 \times 10^{-5}$$

This accuracy in frequency is rather difficult to achieve in the AGS acceleration cycle.

2. B and x

$$\delta x = x_p\left(\frac{\delta p}{p} - \frac{\delta B}{B}\right)$$

or

$$\frac{\delta p}{p} = \frac{\delta x}{x_p} + \frac{\delta B}{B}$$

This same criterion gives

$$\frac{\delta x}{x_p} \sim 5 \times 10^{-5} \qquad \text{or} \qquad \delta x \sim 0.1 \text{ mm at } x_p = 2 \text{ m}$$

$$\frac{\delta B}{B} \sim 5 \times 10^{-5}$$

This, although difficult, is achievable. Of the 3 different

combinations this is the best. Also, momentum is defined by B and x more directly than by other combinations involving f. In principle, f defines only the synchronous momentum and any coherent phase oscillation will weaken the utility of f.

3. f and x

$$\frac{\delta f}{f} = \frac{1}{\gamma^2}\frac{\delta p}{p} - \frac{1}{\gamma_t^2}\frac{\delta p}{p} - \frac{\delta B}{B} = \frac{1}{\gamma^2}\frac{\delta p}{p} - \frac{1}{\gamma_t^2}\frac{\delta x}{x_p}$$

or

$$\frac{\delta p}{p} = \gamma^2 \frac{\delta f}{f} + \frac{\gamma^2}{\gamma_t^2}\frac{\delta x}{x_p} = 984\,\frac{\delta f}{f} + 10.4\,\frac{\delta x}{x_p}$$

The criterion leads to

$$\frac{\delta f}{f} \sim 5.1 \times 10^{-8} \qquad \frac{\delta x}{x_p} \sim 4.8 \times 10^{-6}$$

which is very much worse than either of the other two cases.

In summary, at 28.5 GeV the AGS should be flat topped (to give $\phi_s = \pi$) at a field strength accurate to $\delta B/B \sim 5 \times 10^{-5}$ and the rf should be adjusted so that the radial position of the beam is accurate to $\delta x \sim 0.1$ mm (at $x_p \sim 2$ m). The momentum of the beam is, then, accurate to $\delta p/p \sim 7 \times 10^{-5}$. The rf voltage is then reduced adiabatically to 36 kV. Both the momentum and the shape of the beam bunches are now properly matched and the injection sequence can start anytime. In practice the momentum defining tolerances $\delta B/B$ and $\delta x/x_p$ may be relaxed. Any excessive momentum error may be corrected in the ISA after injection (see Section E below).

D. Injection sequence

The firing sequence of the AGS extraction kicker, and the ISA injection kicker and septa is shown in Fig. 1. The first event in

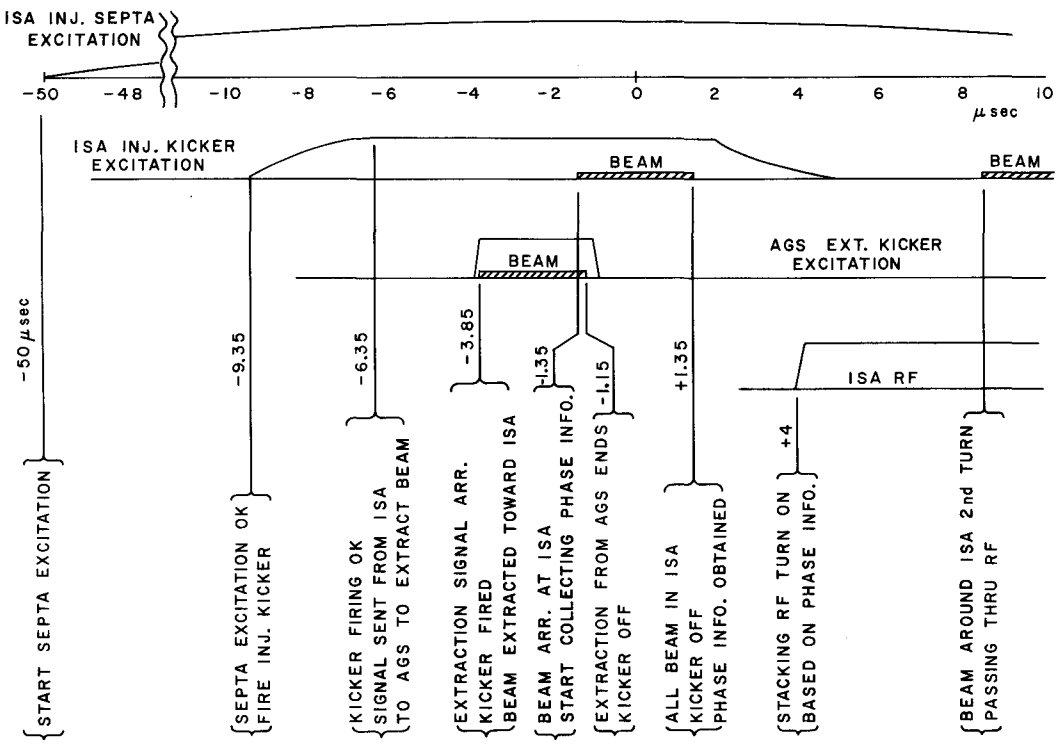


Fig. 1. Injection sequence. Assumed times - 1. ISA injection septa excitation - half sinewave half-period = 100 μsec. 2. ISA injection kicker rise and fall time = 3 μsec. (Can also be as long as 6 μsec.) 3. Transit time for beam or signal between AGS and ISA = 2.5 μsec. 5. AGS extraction kicker rise and fall time - negligible. 6. ISA stacking rf turn-on time = small. (Can be as long as 6 μsec.) 7. Beam revolution time in ISA = 10 μsec.

the sequence is the excitation of the injection septa shown at -50 μsec. The tolerances of the various times are rather loose and easy to attain, so that no special consideration of the timing tolerances is necessary.

The excitation of the pulsed injection magnets (two septa and a kicker) must be reproducible, pulse-to-pulse, and flat over the 2.7 μsec period of the 11-bunch train of beam bunches from the AGS. In order that the transverse phase space of the trapped beam not be diluted by more than 20%, the reproducibility and flatness must be good to ± 0.3% for the first septum magnet (KSV2), ± 0.6% for the second septum, and ± 1% for the kicker.

E. Synchronous capture by the ISA stacking rf system

After injection the beam-bunch phase in the ISA is picked up by a phase sensor during the first turn. The ISA rf is then turned on to a voltage of 15.7 kV and at the proper phase to synchronously capture the beam bunches on the second turn around. The phase oscillation frequency is ~ 6.5 Hz, fast enough for correcting any excessive momentum error in a small fraction of a second. For example, a momentum error will turn into a phase error in ¼ of a phase oscillation (38.5 msec). The rf phase can then be shifted to center on the beam bunches. The time required for shifting depends on the magnitude of the shift, but should be no more than a few revolutions even in the extreme case of a 180° shift. However, if the required accuracy in B and x is attained, there should be no need for correction in the ISA.