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INJECTION INTO THE ISA: ENERGY STACKING

M. Month

December 5, 1972

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INTERSECTING STORAGE ACCELERATOR NOTES

INJECTION INTO THE ISA: ENERGY STACKING*

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ABSTRACT

Details of a scheme for injection into the ISA are given. The basic idea, as proposed for the ISA by Keil and Sessler, is one which is presently used to stack the ISR at CERN. A stack is built by injecting a pulse, moving the injected beam by rf acceleration across a septum into an area for the parked stack and storing the beam here. The septum protects the stack from the injection kick. The stacked beam is then rebunched and accelerated to 200 GeV.

The method proposed here involves the following steps:

- 1) With an ISA circumference three times the AGS circumference, three AGS pulses are injected into the ISA by direct transfer. The AGS bunches are modified and matched into a stationary bucket in the ISA.
- 2) The 36 bunches in the ISA are accelerated to the stacking orbit. Since all 36 buckets are utilized, the technique of suppressed buckets is not needed. The voltage and stable phase are conceived as programmed so as to optimize the stacking procedure, which means for the most part to minimize the dilution of longitudinal phase space. At this stage, the implications of longitudinal instabilities in a coasting beam are discussed.
- 3) The stack is rebunched and accelerated from its initial 30 GeV to its final 200 GeV. The capture procedure and final beam characteristics are discussed.

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The implications for acceleration times, voltage requirements, aperture and energy spread are also considered. The significant conclusions are:

- a) No problems with longitudinal instabilities in the AGS. b) Thirty stacking cycles (90 AGS pulses) are employed. This requires that the AGS produce 8.3×10^{12} protons per pulse and leads to 15 Amps in the ISA. The stacking time is about 3 seconds per cycle. The impedance tolerance for longitudinal instabilities in the full coasting stack is 10 ohms and may be attainable.
- c) The aperture required in the normal lattice segments is 22 mm. d) The accelerating voltage required is about 60 kV/turn. Acceleration, if done with energy increments of 10.4 keV/turn takes about 128 seconds to get to 200 GeV and produces a bunched beam of momentum spread, $\frac{\Delta p}{p} = \pm 8.2 \times 10^{-4}$, which by adiabatic debunching could be reduced to $\frac{\Delta p}{p} = \pm 4.7 \times 10^{-4}$.

I. Introduction

We present here a scheme designed to inject 15 Amps current into the ISA.¹ It is based on a method used at present to stack the ISR at CERN.² Originally, the idea to use this technique for the ISA was suggested by Keil and Sessler.³ Basically, the method consists of building a stack by 1) injecting into the ISA three pulses from the AGS ($R_{ISA} \approx 3 R_{AGS}$), and 2) moving the injected beam by rf acceleration across a septum (which protects the stacked beam from the injection kick) into an area within the chamber designated for the parked stack. Then the stacked beam is rebunched and accelerated from its 30 GeV injection energy to its final energy of 200 GeV.

The procedure can be divided into three steps. The first is beam preparation in the AGS and matching into ISA buckets. Secondly, there is the stacking process. Here we deal with the problems of 1) longitudinal phase space dilution and energy spread, 2) ISA current and AGS intensity, 3) ISA aperture requirements, 4) time constraints, and 5) longitudinal instabilities in a coasting beam. The final step consists of rebunching and accelerating the stack. Here we must consider 1) the losses in the rebunching operation, 2) the added aperture requirements from increased energy spread on rebunching, 3) the voltage needs and 4) the final beam characteristics.

The details involved in these three steps will be described in the following sections. At this point let us, however, state the conclusions.

- A) The beam preparation in the AGS for matching into ISA buckets involves an adiabatic voltage reduction from 384 kV to 3 kV. This increases the rf phase width from $\pm 10^\circ$ to 34° . At the same time, the energy spread is reduced to ± 5.3 MeV with $\frac{\Delta p}{p} = \pm 1.9 \times 10^{-4}$. This should not be problematic with respect to longitudinal instabilities. In any case, the partial debunching need not be taken this far.
- B) Each stacking cycle involves 3 AGS pulses. If we stack 30 cycles (90 AGS pulses), then to obtain 15 Amps in the ISA requires that the AGS produce $N_{\text{AGS}} = 8.3 \times 10^{12}$ protons per pulse. Since $R_{\text{ISA}} = 3 R_{\text{AGS}}$ and $h_{\text{ISA}} = 3 h_{\text{AGS}}$, all 36 circulating buckets in the ISA will be utilized. Thus the difficulties involved with the technique of suppressed buckets is avoided. With an initial ISA voltage of 1.3 kV, the stacking time is about 3 seconds per cycle leading to a stacking time on the order of a few minutes. The energy spread, assuming a 50% efficiency in the stacking process, is ± 46.8 MeV, with $\frac{\Delta p}{p} = \pm 1.7 \times 10^{-3}$. With such an energy spread, the impedance tolerance for the onset of longitudinal instabilities becomes $\left| \frac{Z_k}{k} \right| \leq 10.4$ ohms, (k is the mode number with respect to the azimuth), which appears attainable. For the bunched beam being accelerated to the stack, the tolerance is a little lower, $\left| \frac{Z_k}{k} \right| \leq 4$ ohms, but may also be possible to achieve. Actually, by increasing the voltage somewhat for the stacking process, this tolerance could be improved.
- As a point of reference, we note that the shunt impedance normally responsible for the negative mass instability has a value in the ISA at injection given by $\left| \frac{Z_h}{h} \right| = 0.5$ ohms which is far below the threshold indicated above. The aperture needed in the normal part of the lattice to accommodate this injection procedure is found to be 22 mm.
- C) With adiabatic capture in the rebunching process, we can ideally assume minimal losses. With this assumption, a voltage of 60 kV provides a bunched beam at full energy (200 GeV) with an energy spread $\Delta E = \pm 153.5$ MeV, that is $\frac{\Delta p}{p} = \pm 8.2 \times 10^{-4}$. This could, of course, be reduced by adiabatic

debunching to about $\frac{\Delta p}{p} = \pm 4.7 \times 10^{-4}$. The rebunching process increases the energy spread at injection from $\frac{\Delta p}{p} = \pm 1.7 \times 10^{-3}$ to

$\frac{\Delta p}{p} = \pm 3.8 \times 10^{-3}$. This increases the stack size due to momentum

spread from 5.8 mm to 12.9 mm. However, at the time of rebunching there is available aperture (~ 8 mm) from the "injected orbit" allowance and thus by suitably moving the beam, this effect does not require any additional aperture. With a stable phase angle of 170° , the acceleration process will involve an energy gain of 10.4 keV/turn and will take about 128 seconds.

2. Beam Preparation in the AGS and Matching into ISA Buckets

The AGS bunches at 30 GeV are elliptical. Their energy and rf phase half widths are given by

$$\Delta E = \sqrt{\frac{AEB^2}{\pi} \left(\frac{\Omega}{|\eta|} \right)} \quad (2.1)$$

$$\Delta \phi = \left(\frac{|\eta|}{\Omega} \right) \left(\frac{h}{R} \right) \frac{c}{\beta} \frac{\Delta E}{E} \quad (2.2)$$

where the final energy, $E = 28.14$ GeV,

the harmonic number $h = 12$,

$$\eta = \frac{1}{\gamma_{tr}^2} - \frac{1}{\gamma^2} = -.0137 \quad ,$$

the AGS radius, $R = 128.5$ m ,

$\beta = 0.9995$,

$$\text{the invariant area, } A = \pi \frac{\Delta E}{\beta} \left(\frac{R}{h} \right) \Delta \phi = 0.35 \text{ eV sec,} \quad (2.3)$$

the synchrotron angular frequency,

$$\Omega = 2\pi f_\omega \left(h |\tau| \text{eV} |\cos \phi_s| / 2\pi E \right)^{\frac{1}{2}} \quad (2.4)$$

$$f_\omega = \frac{c}{2\pi R} = 371.57 \text{ kHz} ,$$

and the peak voltage per turn is V .

The voltage is reduced adiabatically from 384 kV to 3 kV with the bunch maintained in a stationary bucket ($\phi_s \rightarrow 0$). The bunch characteristics before and after this voltage reduction are:

$$\begin{aligned} \text{Bunch Before:} \quad \Delta E &= \pm 17.86 \text{ MeV}, \quad \frac{\Delta p}{p} = \pm 6.3 \times 10^{-4} \\ \Delta \phi &= \pm 10.0^\circ \end{aligned} \quad (2.5)$$

$$\begin{aligned} \text{Bunch After:} \quad \Delta E &= \pm 5.31 \text{ MeV}, \quad \frac{\Delta p}{p} = \pm 1.9 \times 10^{-4} \\ \Delta \phi &= \pm 33.7^\circ \end{aligned} \quad (2.6)$$

To match this bunch into an identical ISA bunch in an equivalent stationary bucket requires

$$\frac{\Omega_{\text{AGS}}}{|\eta|_{\text{AGS}}} = \frac{\Omega_{\text{ISA}}}{|\eta|_{\text{ISA}}} \quad (2.7)$$

This follows from Eqs. (2.1 and 2.2) and the fact that the harmonic numbers and radii are chosen so that

$$\frac{R_{\text{AGS}}}{h_{\text{AGS}}} = \frac{R_{\text{ISA}}}{h_{\text{ISA}}} \quad (2.8)$$

Equation (2.7) gives us the required ISA voltage:

$$V_{\text{ISA}} = V_{\text{AGS}} \left(\frac{h_{\text{ISA}}}{h_{\text{AGS}}} \right) \left(\frac{|\eta|_{\text{ISA}}}{|\eta|_{\text{AGS}}} \right) \quad (2.9)$$

Assuming a transition energy in the ISA corresponding to $\gamma_{\text{tr}}^{\text{ISA}} = 18$, we have $V_{\text{ISA}} = 1.3 \text{ kV}$, where we have used $|\eta|_{\text{ISA}} = -.002$ and $h_{\text{ISA}} = 36$, which implies $R_{\text{ISA}} = 385.5 \text{ m}$.

Thus after the direct transfer of 3 AGS pulses into the ISA, we have circulating in the ISA 36 bunches. The stationary buckets are characterized by a voltage of 1.3 kV. The bunches are elliptical with characteristics:

$$\begin{aligned} \Delta E &= \pm 5.31 \text{ MeV}, \quad \frac{\Delta p}{p} = \pm 1.9 \times 10^{-4} \\ \Delta \phi &= \pm 33.7^\circ \end{aligned}$$

as given in Eq. (2.6). Since the AGS circumference is precisely 1/3 of the ISA circumference, each of the 36 buckets will be utilized and there is no need for bucket suppression.

3. Beam Stacking in Energy by RF Acceleration

The 36 bunches are now moved from their injection orbit to the stack by frequency modulation. The stable phase angle is slowly changed to 150° . With a peak voltage of 1.3 kV, this provides an energy gain of 0.65 keV/turn. As the bunches approach the parking orbit, the frequency modulation is again reduced and the voltage is also reduced. Ideally, this results in the injected bunches being deposited in the stack debunched and with no phase space dilution. There is however the effect of the accelerating bucket moving into the stack to consider. To minimize the dilution in practice, a programmed system for frequency modulation and voltage changes will be required. Here we use a simplified conceptualization of the rf parameter changes, shown schematically in Fig. 1, and we simply assume some dilution factor, say a factor of 2, or 50% efficiency.

Fig. 1 RF PARAMETER CHANGES

There are five subjects which we will treat:

- a) Energy spread,
 - b) ISA current and AGS intensity required,
 - c) Time for the acceleration cycle,
 - d) Longitudinal instability in the coasting stack,
- and e) Aperture requirements.
- a) Energy Spread. Each bunch is accelerated, debunched and deposited in the stack. With our assumption of ideal debunching, the energy half-width is given by

$$\Delta E = \frac{A}{4\pi} \frac{h}{R} \beta c \quad (3.1)$$

Using $A = 0.35$ eV-sec, $h = 36$, $R = 385.5$ m,

$$\Delta E = \pm 0.78 \text{ MeV}, \quad \frac{\Delta p}{p} = \pm 0.28 \times 10^{-4}.$$

To compute the final energy spread in the stack, let u be the number of stacking cycles and let t be the energy spread efficiency. Then,

$$\left(\frac{\Delta p}{p}\right)_{\text{stack}} = \frac{u}{t} \left(\frac{\Delta p}{p}\right)_{\text{cycle}}. \quad (3.2)$$

For $u = 30$ cycles and a stacking efficiency of 50%, we have

$$\Delta E = \pm 46.8 \text{ MeV, and}$$

$$\frac{\Delta p}{p} = \pm 1.7 \times 10^{-3}.$$

- b) ISA Current and AGS Intensity. The circulating ISA current, I_0 , is related to the number of protons per AGS pulse, N_{AGS} , by

$$I_0 = 3 e u N_{\text{AGS}} f_{\infty}^{\text{ISA}} \beta, \quad (3.3)$$

where

$$f_{\infty}^{\text{ISA}} = \frac{c}{2\pi R_{\text{ISA}}} = 123.9 \text{ kHz}.$$

If we assume $I_0 = 15$ Amps, then

$$u N_{\text{AGS}} = 2.5 \times 10^{14}.$$

Thus we obtain the following requirements on AGS intensity:

- For 10 cycles (30 AGS pulses) $\rightarrow N_{\text{AGS}} = 2.5 \times 10^{13}$ ppp
 For 20 cycles (60 AGS pulses) $\rightarrow N_{\text{AGS}} = 1.2 \times 10^{13}$ ppp
 For 30 cycles (90 AGS pulses) $\rightarrow N_{\text{AGS}} = 8.3 \times 10^{12}$ ppp.

- c) Time for Acceleration in Stacking Cycle. The time of each stacking cycle is governed by four factors: (1) practical considerations in manipulating the septum of the kicker magnet; (2) the AGS cycle time; (3) the time required for adiabatically changing the voltage and modulating the

frequency during the stacking cycles; and (4) the acceleration time itself. We will not be concerned with the first two. The third contribution to the stacking cycle time depends on the specific details of the acceleration procedure. However, we will not go into much detail here, but rather we will be satisfied with an order of magnitude result. Thus, neglecting the third contribution to stacking time, we consider an idealized process with a specified voltage, V , and stable phase, ϕ_s .

Since the acceleration is governed by the equation

$$\frac{\dot{p}}{p} = eV \sin \phi_s \frac{1}{E\beta} \frac{1}{f_{\omega}^{ISA}}, \quad (3.4)$$

we can estimate the time, δt , to accelerate an amount of momentum, δp :

$$\delta t = \frac{E\beta}{f_{\omega}^{ISA}} \frac{1}{eV \sin \phi_s} \left(\frac{\delta p}{p} \right). \quad (3.5)$$

If the orbit at the injection kicker point is to be moved a distance δR , then

$$\delta R = \gamma_I \frac{\delta p}{p}, \quad (3.6)$$

where γ_I is the momentum compaction function at the injection point. Substituting this equation into Eq. (3.5) and using the value $\gamma_I = 4.5$,⁴ we obtain

$$\delta t \text{ (sec)} = 0.078 \delta R \text{ (mm)}. \quad (3.7)$$

We will show in the next section that the orbit is required to move about 3.5 cm. This gives then for the stacking cycle time

$$\delta t = 2.7 \text{ sec.}$$

For 30 cycles, $\delta t = 81 \text{ sec.}$ Thus, assuming that the adiabatic changes in voltage and frequency require roughly the same time as the acceleration itself, we can estimate that the stacking time can be made as low as a few minutes.

- d) Longitudinal Instability in the Coasting Stack. The possibility of a collective longitudinal instability exists for the coasting stack. This effect is stabilized by the energy spread of the stack. The tolerable coupling impedance is related to the square of the energy spread

through the relation

$$\left| \frac{Z_k}{k} \right| \leq \frac{\tau}{I_0 E} (\Delta p)^2, \quad (3.8)$$

where I_0 is the current in amps and we have neglected a form factor which depends on the momentum distribution and is of the order of unity.⁵ As implied, all modes k (related to the azimuth) will be effectively stabilized by a sufficient momentum spread, Δp . For the stack we have been considering $\Delta p = 46.8$ MeV/c, $I_0 = 15$ Amps, $E = 28.14$ GeV, $\tau = -.002$; thus,

$$\left| \frac{Z_k}{k} \right| \leq 10.4 \text{ ohms, which may be attainable at present.}$$

As a point of reference, we compute the coupling impedance for the negative mass instability:

$$\left| \frac{Z_k}{k} \right| = \frac{1}{2\epsilon_0 \beta c \gamma^2} [1 + 2 \ln \frac{b}{a}]. \quad (3.9)$$

With $\epsilon_0 = \frac{1}{36\pi} \times 10^{-9}$ (Coul./m-Volt), $\gamma = 30$, and assuming that the ratio, (chamber radius/beam radius) = $b/a = 2$, we obtain,

$$\left| \frac{Z_k}{k} \right|_{\text{negative mass}} = 0.5 \text{ ohms,}$$

which is a factor of 20 less than the tolerable impedance. However, in addition to stipulating the coupling impedance tolerance for the completed stack, we must also consider the situation for the partial stack. For example, take the first cycle. In the case of a 30 cycle stack, we have that after the first cycle, there will be 0.5 Amps in the partial stack. We can then compute the impedance limit. Since $\Delta p = 0.15$ MeV (using a dilution of Δp of a factor of 2), $I_0 = 0.5$ Amps,

$$\left| \frac{Z_k}{k} \right| \leq 0.35 \text{ ohms.}$$

Note that we must here consider the debunched partial stack. Now, as more cycles are stacked, this tolerance value keeps increasing since it depends on the square of Δp , while only linearly on I_0 , which is also increasing. Thus, only the first few cycles are problematic. We can overcome this difficulty by simply artificially increasing the energy spread for the first few cycles. (In fact, if we don't, the instability will probably do it for us.) Thus, if the ISA cannot

be built to satisfy this low coupling impedance, then a minor increase in momentum spread will be the result.

Another point which must be considered is the presence of the bunches in the buckets being accelerated to the coasting stack.

If we simply assume a decoupling from the stacked beam, we can estimate a tolerable coupling impedance for these bunches.

Taking the momentum spread from Eq. (2.6) and using it in Eq. (3.8), we obtain $\left| \frac{Z_k}{k} \right| < 3.8$ ohms. This tolerance may be possible to achieve. However, here there is another way out. By increasing the matching voltage in the AGS, there results a higher momentum spread in the bunches being matched into the ISA. Thus the shunt impedance tolerance will be increased from the value of about 4 ohms. For example, a doubling of the momentum spread will mean an increase of the tolerable $\left| \frac{Z_k}{k} \right|$ by a factor of 4 to about 16 ohms.

e) Aperture Requirements

The aperture requirements related to the injection procedure is schematically depicted in Figs. 2a and 2b.

Fig. 2a APERTURE UTILIZATION AT INJECTION POINT

Fig. 2b APERTURE UTILIZATION IN NORMAL LATTICE CELL

At the injected point the injected beam must be moved across the kicker septum used to shield the stacked beam from the injection kick. The total distance the beam is moved via rf acceleration is δR , which, as can be seen from Fig. 2a, is given by

$$\delta R = 2 \sqrt{\beta_I \epsilon} + c + \gamma_I \delta_s, \quad (3.10)$$

where β_I is the value of the horizontal β -function at the injection point, γ_I is the value of the momentum compaction function, ϵ is the horizontal emittance, $\delta_s = \left(\frac{\Delta p}{p}\right)_{\text{stack}}$, and c is the space allotted for the kicker septum shield. With the values $\beta_I = 10$ m, $\gamma_I = 4.5$ m (see ref. 4), $\epsilon = 0.4 \times 10^{-6}$ radian-m., $\delta_s = 3.3 \times 10^{-3}$ and $c = 15$ mm, we find

$$\delta R = 4 + 15 + 15 = 34 \text{ mm.}$$

From Figs. 2a and 2b we can see that the aperture requirement for the normal lattice cell is

$$a_N = \gamma_N \delta_B + \frac{\gamma_N}{\gamma_I} \delta R + 2 \sqrt{\beta_N \epsilon}, \quad (3.11)$$

where $\delta_B = \left(\frac{\Delta p}{p}\right)_{\text{Injected Beam}}$, and β_N and γ_N are values of β and the momentum compaction function in the normal lattice cell. If we use the values $\beta_N = 40$ m, $\gamma_N = 1.76$ m, $\delta_B = 3.8 \times 10^{-4}$, we obtain

$$a_N = 0.7 + 13.3 + 8.0 = 22.0 \text{ mm.}$$

The situation for the normal cell of the ISA lattice is shown in Fig. 3. From the figure, we see that after formation of the stack, about 8 mm of aperture, that used by the injected beam is not utilized. However, we will see in a later section that when the stack is re-bunched for acceleration to 200 GeV, the momentum spread is significantly increased. By properly manipulating the beam, the aperture set aside for the injected beam can be utilized for this purpose. Since the needed extra aperture is about 7 mm, the "unused" aperture for the "injected beam", which is 8 mm, is sufficient.

Fig. 3 APERTURE UTILIZATION OF NORMAL ISA LATTICE CELL

4. Rebunching and Accelerating the Stack to 200 GeV

The coasting stack must be rebunched for acceleration to 200 GeV. If one bunches adiabatically then the particle losses can in principle be minimized to a small amount that escape through the unstable fixed point of the bucket (i.e. the separatrix). Similarly the dilution of the longitudinal phase space can be kept to an insignificant amount. Here, we will simply assume ideal circumstances - no losses, no dilution of phase space area.

To bunch a fully debunched beam of full energy spread, ΔE , requires a voltage given by

$$eV = \frac{\pi^3}{88^2 \alpha^2(\phi_s)} \frac{h|\eta|}{E} (\Delta E)^2, \quad (4.1)$$

where $\alpha(\phi_s)$ is the moving bucket factor.⁶ With the values $h = 36$, $\eta = -.002$, $\alpha = .696$ (which corresponds to a moving bucket with stable phase $\phi_s = 170^\circ$, which means $\sin \phi_s = 0.174$), $E = 28.14$ GeV, and $\Delta E = \pm 46.8$ MeV, we obtain the required peak voltage per turn,

$$V = 45.0 \text{ kV/turn.}$$

In practice, a somewhat larger voltage is desirable, so that a bucket is produced which is not too close to the particles in the bunch. Under these circumstances, i.e. $V \gtrsim 50$ kV/turn, the energy half-width of each bunch is given by

$$\Delta E = \left[A f_{\infty} \beta^2 \right]^{\frac{1}{2}} \left[\frac{2h}{\pi |T|} \text{ eV} |\cos \phi_s| E \right]^{\frac{1}{2}}, \quad (4.2)$$

where A is the invariant area in units of eV-sec. At 28 GeV, using $A = 21.03 \text{ eV-sec}$, $f_{\infty} = 123.9 \text{ kHz}$, we obtain for $V = 60 \text{ kV/turn}$,

$$\Delta E = \pm 107 \text{ MeV}, \quad \frac{\Delta p}{p} = \pm 3.8 \times 10^{-3}.$$

We have previously seen (see Fig. 3) that 5.8 mm of aperture are set aside for the stack momentum spread. This corresponds to a momentum spread $\frac{\Delta p}{p} = \pm 1.7 \times 10^{-3}$. With this rebunching at a voltage of 60 kV/turn, the required aperture becomes 12.9 mm. As pointed out in an earlier section, aperture allotted for the "injected beam" can be utilized for this purpose. Thus no extra aperture need be assigned.

At full energy, $\gamma = 200$, $T = -.003$, and for $V = 60 \text{ kV/turn}$, there results for a bunched beam

$$\Delta E = \pm 153.5 \text{ MeV}, \quad \frac{\Delta p}{p} = \pm 8.2 \times 10^{-4}.$$

If one debunches by non-adiabatically turning off the rf voltage, the final momentum spread will remain at this value. If, however, one reduces the voltage adiabatically, the momentum spread can be reduced to as low as

$$\frac{\Delta p}{p} = \pm 4.7 \times 10^{-4},$$

for an ideally debunched beam.

Finally, we compute the acceleration time. For a peak voltage of 60 kV/turn and a stable phase given by $\sin \phi_s = 0.174$, the energy gain per turn is

$$\delta E = 10.4 \text{ keV/turn}.$$

Thus, the number of turns required to accelerate the beam from 30 to 200 GeV is

$$n \approx 16 \times 10^6 \text{ turns}.$$

The time is very nearly given by

$$t_{\text{acc}} \approx \frac{n}{f_{\infty}} = 128 \text{ seconds}.$$

5. Conclusions

We have described a scheme for injection into the ISA which stacks the beam in energy by using rf acceleration to move the injected beam from the injection orbit to the parking orbit. Concerning the circulating current, we conclude that

15 Amps circulating current in the ISA requires 30 stacking cycles of 90 AGS pulses and an AGS intensity of $N_{\text{AGS}} = 8.3 \times 10^{12}$ protons per pulse.

Secondly, with respect to energy spread, we find that given an initial momentum spread of $\frac{\Delta p}{p} = \pm 6.3 \times 10^{-4}$ in the original bunched AGS beam, and assuming an energy spread efficiency factor of 50% in the stacking process, then the momentum spread of the coasting stack is $\frac{\Delta p}{p} = \pm 1.7 \times 10^{-3}$.

Thirdly, assuming adiabatic rebunching, then after acceleration to 200 GeV, there results a bunched beam with $\frac{\Delta p}{p} = \pm 8.2 \times 10^{-4}$, which, with adiabatic debunching, could be reduced to as low as $\Delta p/p = \pm 4.7 \times 10^{-4}$.

We have not discussed various timing requirements; for example, regarding the means of getting 3 AGS pulses in sequence within the ISA circumference. Nor have we discussed the times required for adiabatic processes. With these limitations, we have made the following time estimates:

The acceleration time per stacking cycle is about 3 seconds. For 30 cycles, we obtain a stacking time of about 1 1/2 minutes. Other factors, such as adiabatic processes, could double this to about 3-4 minutes.

Acceleration of the stack to 200 GeV is estimated at about 128 seconds.

As far as concerns the problem of longitudinal instabilities in a coasting beam, we find that

for the momentum spread of $\frac{\Delta p}{p} = \pm 1.7 \times 10^{-3}$ and a circulating current of 15 Amps in the coasting stack, the coupling impedance tolerance for longitudinal instability is $\left| \frac{Z_k}{k} \right| < 10.4$ ohms, which may be feasible to attain in practice.

The voltage requirements are threefold:

First, the voltage in the AGS must be reduced adiabatically from 384 kV to 3 kV.

Secondly, the matching voltage in the ISA corresponding to 3 kV in the AGS is 1.3 kV. This same voltage can be used to accelerate the injected beam into the stack. With a stable phase given by $\sin \phi_s = 1/2$, the energy gain per turn is 0.65 keV/turn.

Thirdly, the voltage required to rebunch the stacked beam (with an accelerating phase given by $\sin \phi_s = 0.174$) is 45.0 kV/turn. This produces a tightly fitting bucket. For 60 kV/turn, the acceleration time is 128 seconds, with an energy gain of 10.4 keV/turn.

Finally, we have concluded that with an injection kicker point in the lattice which has the characteristics of high momentum compaction value, low β , then the total required aperture in the normal lattice for this injection process is 22 mm.

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