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A NEW METHOD FOR INJECTION INTO THE ISA

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Abstract

A new method is proposed for injection into ISABELLE. The method involves successive extraction of single bunches from the AGS and compaction of the bunch sequence in the ISA. Very low final energy spread ($\pm 0.7 \times 10^{-4}$) is achieved at 200 GeV in the ISA.

Introduction

The method of injection proposed for the ISA by J.P. Blewett in AADD-169 (CRISP 71-6), analyzed and modified by E.D. Courant in CRISP 71-5, and incorporated in the Preliminary Design Study (BNL 16716) has been shown to require reduction of the energy spread in the AGS to the point where there is danger of instability (cf. Keil and Sessler, CRISP 72-74). It has been shown also that this injection procedure results in more phase-space dilution than is involved in the injection procedure used at the CERN ISR. It is the purpose of this note to describe a new procedure which does not seem to have these disadvantages, and which gives a very low energy spread in the final ISA beams.

The new method involves no rebunching in the AGS and is based on the fact that, with existing apparatus, it is possible to extract single bunches from the AGS. The process involves transfer of a bunch from the AGS into the ISA; then, as soon as the kickers in the AGS and the ISA recover, another bunch is extracted from the AGS and deposited in the ISA as close as possible to the previous bunch. By application of the moving bucket techniques described by J.G. Cottingham in BNL 16945 (CRISP 72-26), the second bunch is moved as close as is desired to the first bunch. The process is continued until all twelve bunches have been transferred; they will be held in a close sequence in the ISA by the ISA's rf system which is to generate a train of waves of the same length as the sequence of stacked bunches. The procedure is repeated on subsequent AGS pulses until both ISA rings are filled except for a short vacant portion after the last bunch; this unfilled region corresponds to the rise and fall times of the ISA kicker. Its length will be less than 3% of the circumference of the ISA.

In this report we shall concentrate on the procedure for compressing the string of pulses in the AGS into one-tenth of the circumference of the AGS. This procedure, in a ring having three times the circumference of the AGS, and assuming an AGS intensity of 2×10^{13} protons per pulse, will lead to a total circulating charge in the ISA of 6×10^{14} protons and an average circulating current of 12 A.

Specifications

In the AGS the bunch characteristics are as follows:

Bunch length	19.6° at 4.5 MHz 3.66 m 12.2 nsec
Bunch separation (center to center)	67.26 m 224.5 nsec
Momentum spread $\Delta p/p$	$\pm 6 \times 10^{-4}$

The configuration desired in the ISA after the injection procedure is completed includes:

Bunch length and momentum spread	Matched to ISA buckets
Bunch separation	6.73 m 22.4 nsec

Kicker Capabilities

In principle, fast kickers could be used to deposit the bunches in the ISA with the final bunch separation. But since the clear space between bunches will correspond to elapsed times of only about 10 nsec, either the rise time or the fall time of the kicker must be less than 10 nsec.

The problems encountered in the design and pulsing of kickers are discussed in the paper by E.B. Forsyth and M. Fruitman [Particle Accelerators 1, 27 (1970)]. There it is shown that the power required to energize a magnetic kicker is

$$W = \frac{(B\rho\theta)^2 A}{4\pi Lt} \times 10^7 \text{ volt-amperes ,}$$

where $B\rho$ is the magnetic rigidity of the protons = 103 T·m at 30 GeV,
 θ is the deflection angle in the kicker (we assume 1 mrad),
 A is the kicker aperture in m^2 (we assume $A = 0.05 \times 0.05 m^2$),
 L is the length of the kicker along the beam,
 t is the rise time of the kicker field.

Because the previous bunch must have left the kicker before the field begins to rise and because the kicker must be at full field when the entering bunch arrives, L and t are connected by the relation

$$t + L/c = \text{time between bunches} = 10 \text{ nsec.}$$

The power required will be a minimum when $t = L/c = 5 \text{ nsec.}$ With these parameters we find

$$W = 2800 \text{ MVA}$$

$$L = 1.5 \text{ m}$$

$$B = \text{about } 0.07 \text{ T (700 G)} .$$

This power level is uncomfortably high and the time scale is uncomfortably short.

Proposed Injection Procedure

To reduce the demands on the kicker to more reasonable levels we shall inject each bunch 100 nsec behind the final location of the previous bunch. This will reduce the kicker power to levels already in use at Brookhaven and CERN.

The ISA bucket into which the AGS bunch will be captured is 6.73 m long whereas the bunch from the AGS is 3.66 m long. To avoid dilution of phase space, it will be necessary to make a phase-space transformation in the AGS by adiabatic reduction of acceleration voltage. By a reduction of AGS rf volts from about 400 kV to about 40 kV, the bunch length will increase from 3.66 m to about 6.7 m, a perfect match to the ISA bucket. The same debunching process will reduce the energy spread in the AGS bunches to about $\pm 3.2 \times 10^{-4}$.

The procedure for bringing the bunch separation down to 22.4 nsec will include injection at a slightly lower energy than that of the bunches ahead. The latest injected bunch will then travel on an orbit of slightly smaller radius and will gradually catch up to the bunches ahead. At the same time the bunch is accelerated in a moving bucket so that, when it has reached a point centered 22.4 nsec behind the previous bunch, it will have the same mean energy as the other, previously injected, bunches. The process is indicated in Fig. 1.

Figure 1

The parameters required are easily evaluated. If the momentum of the newly injected bunch is given by

$$p = (1 - x)p_0,$$

where p_0 is the energy of the bunches already injected and located in orbit, its circulation time in the ISA will be less than that of the other bunches by a fraction $x\eta$, where $\eta = 1/v^2 - 1/\gamma^2$. Here v , the tune of the ISA, is assumed to be about 19. Hence for γ corresponding to protons at 30 GeV, $\eta \cong 0.0017$.

For a machine with 2400 m circumference the separation of the bunches will decrease by $2400 \times \eta$ meters per revolution. Hence the number of revolutions needed to close the 30 m (100 nsec) separation will be

$$30/(2400 \times \eta) = 7.35/x$$

and the time required to catch up will be $59/x$ μ sec. But continuous acceleration is taking place so the average amount gained per revolution will be only half of the amount given above, and the time required becomes $118/x$ μ sec.

At this point we arbitrarily assume that we wish to inject the 12 bunches during a period of one second and conclude that the catch-up time is to be 80 msec (10^4 revolutions). This fixes the value of x at 1.5×10^{-3} . The injection orbit radius will differ from the final radius by only about 2 mm; only this much extra aperture is required for the injection process.

The energy difference between injected and compacted bunches is 45 MeV; hence the necessary energy gain per revolution is 4500 eV. A higher peak voltage will be required to contain the momentum spread. A satisfactory rf bucket is provided by a peak voltage of about 10,000 V, and a stable phase angle for acceleration of $\sim 30^\circ$.

For a conservative design allowing for phase and momentum errors we assume a peak rf voltage of 12,000 V.

Rf System

The pulse excited accelerating cavity described by Cottingham in CRISP 71-26 will serve satisfactorily in this service. Its lumped constant equivalent is shown in Fig. 2. The driver is a pair of Machlett 4CX15000A tetrodes. Five such cavities will be required to supply approximately 12 kV peak.

Figure 2

The discontinuous 360° sine wave is produced when the tetrode grid is driven positive with a square pulse. A similar discontinuous start of the holding wave train can be achieved by the same procedure.

Another system, rather similar in concept, for producing discontinuous sine waves has been proposed by Schnell [Proc. Sixth Conf. on High Energy Accelerators, Cambridge, Mass. 1967 (CEAL-2000), p. 85].

Acceleration

The stacked bunches in the ISA occupy the full 360° of the accelerating wave. Hence the stable phase angle must initially be kept low. The average energy gain per turn for acceleration from 30 to 200 GeV in 120 seconds is 11.3 kV. With the pulse excitation deactivated, the holding cavities can be excited to the higher level needed for this amount of acceleration.

During acceleration the bunch length will damp in proportion to

$$((1/v^2 - 1/v'^2)/E)^{\frac{1}{2}}$$

which gives a decrease in bunch length by a factor of 0.69 between 30 GeV and 200 GeV. The momentum spread damps in proportion to

$$((1/v^2 - 1/v'^2)E^3)^{-\frac{1}{2}}$$

which yields a factor of 0.215 and a final momentum spread of $\pm 0.7 \times 10^{-4}$.

Comparison of Injection Systems

Three possible injection systems have been proposed. These are: the original ISA system as presented in the grey book (BNL 16716), the CERN ISR system modified by Keil and Sessler (CRISP 72-74), and the system described above. The writers are indebted to R. Chasman who has modified the Keil-Sessler system taking into consideration the increase of the ISA circumference to three times that of the AGS.

	<u>Grey Book</u>	<u>Keil- Sessler- Chasman</u>	<u>Blewett- Cottingham</u>
$\delta p/p$ in AGS after acceleration to 30 GeV	$\pm 6 \times 10^{-4}$	$\pm 6 \times 10^{-4}$	$\pm 6 \times 10^{-4}$
$\delta p/p$ in AGS after debunching	$\pm 5 \times 10^{-5}$	$\pm 1.4 \times 10^{-4}$	$\pm 3.2 \times 10^{-4}$
$\delta p/p$ in AGS at time of beam extraction	$\pm 2.5 \times 10^{-3}$	$\pm 1.4 \times 10^{-4}$	$\pm 3.2 \times 10^{-4}$
Stacking time (minutes)	~ 1	~ 1	~ 1
ISA rf frequency (MHz)	4.45	4.45	44.5
ISA peak rf volts (kV)	40	24	12
$\delta p/p$ in ISA after rebunching	-	$\pm 2.5 \times 10^{-3}$	-
$\delta p/p$ in ISA after acceleration	$\pm 5.4 \times 10^{-4}$	$\pm 5 \times 10^{-4}$	$\pm 0.7 \times 10^{-4}$

The following comments seem pertinent:

- If it is desired, all three systems can be given reduced energy spread by debunching at 200 GeV.
- The system proposed in this report seems to have the least dilution of phase space of the three systems. The rebunching procedures in the grey book system result in some loss of phase space. The debunching and rebunching process in the Keil-Sessler-Chasman system involves a fairly large phase-space loss. In the Blewett-Cottingham system, however, it appears in principle to accomplish all processes without appreciable phase-space dilution.
- The Keil-Sessler-Chasman system is a proven system. It has the advantage that it can be used to give peak ISA performance even when AGS performance is not at its peak, or can be used to give increased ISA intensity to the limit of acceptance of the ISA aperture.
- A possible variation of the Blewett-Cottingham system is possible; with no AGS debunching and an ISA radiofrequency of about 81 MHz the ISA charge can be approximately doubled over the 6×10^{14} protons expected, with a corresponding increase of luminosity by a factor of about four.

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