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INTERSECTING STORAGE ACCELERATOR NOTES

RF Stacking in ISABELLE

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RF Stacking in ISABELLE

1. Introduction

The proton accumulation scheme proposed for ISABELLE involves, among other things, considerable beam gymnastics in the AGS. In particular, the proposed scheme involves *adiabatic debunching* of the AGS beam which would result in a momentum spread requiring very small coupling impedances in the AGS in order to be longitudinally safe. This difficulty can be avoided with a stacking scheme similar to that employed in the ISR. The present note outlines such a scheme.

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2. Description of energy stacking

The 12 bunches circulating in the AGS are transferred into ISA by a fast ejection-injection scheme. They are captured in RF buckets and accelerated in energy to a stacking orbit and deposited there with suppressed buckets, by non-adiabatically turning off the RF voltage. The process is repeated about 50 times resulting in 6×10^{14} protons stored in an energy spread of about 40 MeV. Subsequently, the coasting stack is bunched and accelerated by a system similar to that presently contemplated for ISA.

In the injection insertion, this scheme requires the injected beam orbit to be physically separated from the stacking orbits. There are no additional aperture requirements in the normal ISA lattice, if this injection insertion can be designed with $X_p \approx 4$ m and θ_H somewhat smaller than in the normal lattice.

3. Details of the scheme

3.1. Longitudinal phase space areas

One AGS bunch has an area

$$\Delta E \Delta t = 0.35 \text{ eVs} \quad (1)$$

The energy spread of a perfectly debunched bunch of this area is, in the ISA:

$$\Delta E = 0.52 \times 10^5 \text{ eV} \quad (2)$$

RF stacking allows the accumulation of protons such that the energy spread of the stack is just (2) multiplied by the number of bunches stacked, and by an efficiency factor. We find for 30 pulses = 360 bunches, and 50% efficiency:

$$\Delta E = 38 \text{ MeV} \quad (3)$$

At 30 GeV, this corresponds to a relative energy spread

$$\frac{\Delta E}{E} = 1.24 \times 10^{-3} \quad (4)$$

The above calculation assumes that the stacking process is performed with only 12 buckets circulating in a machine with harmonic number 30, i.e. 18 buckets have to be suppressed. Bucket suppression has been shown to work in the ISR for RF voltages below 500V.

In order to have reasonably efficient RF stacking it is necessary to have the stacking buckets fit tightly around the bunches. A certain amount of spill-out is unavoidable, and perhaps even desirable, in this operation. Beam scrapers are required to control the loss of protons which are not suitably stacked.

3.2. Aperture requirements

We assume, as in the preliminary proposals phase space interchange in the transfer line to ISA and get a horizontal emittance

$$\epsilon_H = 0.4\pi \cdot 10^{-6} \text{ rad m} \quad (5)$$

We also assume that in the injection insertion X_p can be increased to 4 m, and β_H reduced to 10m. Using the emittance (5), the incoming beam has a full width of 4 mm. The stack has a width of 4 mm for betatron oscillations and 5 mm for the momentum spread given by (4).

Injected beam and stack have to be separated by a free space which allows the stack to be shielded from the stray field of the injection magnet. In the ISR, this space is 15 mm, and we adopt the same value. A cross-section of the vacuum chamber in the injection region is shown in Fig. 1.

In the normal lattice, the maximum values are $\beta_H = 38.3 \text{ m}$ and $X_p = 1.45 \text{ m}$. This results in the cross-section of the vacuum chamber shown in Fig. 2. Notice in Fig. 2 that the injected beam and the stack overlap and together

require no more aperture than in an ISA as presently conceived.*)

3.3. RF parameters

The transfer of the bunched AGS beam into ISA requires matching of the bunch shape to the RF system in the two machines. There are two possibilities for the matching, it can be done in the AGS, or in ISA.

Matching in the AGS can be done by adiabatically lowering the RF voltage. Matching in ISA can be done by the voltage jump method or by jumping to the unstable fixed point. Both methods have been used in the ISR. The voltage required to create buckets with the area given in (1) is

$$eV = \frac{E_o^2 A^2 \pi h \eta}{128 E \alpha^2} \quad (6)$$

where $A = 0.0104$ is bunch area in units of $\Delta p/m_o c$, Δp , and $\alpha = 0.33$ is the area ratio of moving and stationary buckets with the same voltage. Inserting $\eta = 2 \times 10^{-3}$, $h = 30$ we find $eV = 49$ V.

This voltage is small enough that suppressing buckets is easy.

The bucket area also determines the rate of energy change during acceleration

$$\frac{\dot{p}}{p} = \frac{A^2 \Gamma h \eta c}{256 \gamma^2 \alpha^2 B R} = 1.3 \times 10^{-4} \quad (7)$$

The momentum width of the stack is given by (4); therefore it takes $\tau = 9.5$ secs to traverse the stack with tightly fitting buckets.

The momentum change outside the stack, from injection orbit to the bottom of the stack, is even bigger, $\Delta p/p = 5.10^{-3}$. Moving across this width with the same buckets would take 39 secs. Consequently, the whole

*) This result depends critically on the assumed parameters in the injection insertion. If X_p and θ_H are those of the normal lattice the required full radial aperture becomes 57.0 mm (which includes the contribution from sagitta, closed orbit distortions and alignment as assumed in the preliminary proposal).

stacking process would take 40 min assuming that 50 pulses are stacked. However, it is not necessary to accelerate the injected beam with tightly fitting buckets. If we increase the voltage by a factor of 10, the total stacking time is reduced to 11 min. Matching the AGS bunches into this bucket requires a reduction of the RF voltage to 2.6 kV.

4. Discussion

4.1. Coupling impedance

As remarked in the introduction, the primary motivation for stacking in energy is to reduce the likelihood of longitudinal instability by avoiding the debunching of the beam in the AGS.

The tolerable coupling impedance for a coasting beam is given by

$$\left| \frac{Z}{n} \right| \leq \frac{E_0}{e} \frac{\eta}{I_0 \gamma} \left(\frac{\Delta p}{m_0 c} \right)^2 \quad (8)$$

For the AGS, using $\eta = 0.013$, $I_0 = 1.2$ A, $\gamma = 30$, and $\Delta p/m_0 c = 1.75 \times 10^{-3}$ we find

$$\left| Z/n \right| \leq 0.9 \, \Omega \quad (9)$$

This figure should be compared to coupling impedances which actually exist in machines like the AGS, CPB or ISR which are all in the region of several ohms, mainly due to the resistivity of the vacuum chamber.

In ISA, we find, using $\eta = 2 \times 10^{-3}$, $I_0 = 15$ A, $\Delta p/m_0 c = 3.7 \times 10^{-2}$:

$$\left| Z/n \right| \leq 5.6 \, \Omega \quad (10)$$

This is much higher than (9), and might be technically feasible in a new machine with a vacuum chamber at 4.2°K.

For the first pulse arriving in ISA, the tolerable coupling impedance is $Z/n = 0.6 \, \Omega$, assuming $I_0 = 0.5$ A, $\Delta p/m_0 c = 2/25 \times 10^{-3}$ corresponding to full moving buckets at $\Gamma = 0.5$. It might be possible to design ISA with this low coupling impedance. Should this not be possible, there is avail-

able the option of stacking with higher Γ (this would result in a higher momentum spread and, consequently Z/n) at the expense of a lower stacking efficiency at the beginning of the stacking process, but negligible degradation of final beam quality.

4.2. Magnet lattice

An injection insertion with a high value of X_p is of vital importance for the feasibility of energy stacking, the bigger the value of X_p , the less aperture is required in the normal lattice for stacking. X_p is more important than θ_H .

The tolerable coupling impedances in ISA could be increased by having a larger value of η , i.e. a lower value of the transition energy.

4.3. Rebunching

At the end of the stacking process, the coasting beam has to be rebunched before acceleration to 200 GeV. This operation requires 60^2 times the RF voltage for tightly fitting bunches, i.e. 176 kV if it is done at harmonic number 30. Lower harmonic numbers require proportionally lower RF voltages. When the beam is bunched its momentum spread increases and hence more aperture is required. However, this corresponds to only a few millimeters.

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Fig. 1

Fig. 2