Conf-8304105--1

BNL-33218

# Possible Use of Synchrotrons as Post-acceleration Boosters for Tandems

P. Thieberger
Department of Physics, Brookhaven National Laboratory
Upton, New York 11973 U.S.A.

BNL--33218

DE83 014443

## Abstract

The recent development of a high-intensity negative-ion source and the demonstration that intense heavy-ion-beam bursts can be accelerated by a large tandem make synchrotrons a possibly attractive alternative when considering different types of tandem-injected heavy-ion-booster accelerators.

Injection of tandem beams into the AGS (the 30 GeV Brookhaven proton synchrotron) was proposed years ago as a possibility for producing relativistic heavy ions.[1) More recently, this possibility was investigated in greater detail[2,3,4) and the use of a proposed Accumulator Booster for the AGS as a heavy ion booster has also been suggested.[5) The development of smaller, dedicated synchrotrons as possible heavy ion post acceleration boosters for tandems was recently mentioned by Wegner,[6) but had not been widely considered in the past. The obvious reason is that synchrotrons only accept injected beam during a very small fraction of the acceleration cycle and the final beam intensities would then be orders of magnitude lower than intensities normally available from tandems. Such low intensities would be insufficient for most experimental programs. This situation may now have changed through the development by Roy Middleton (University of Pennsylvania) of his Mark VII sputter ion source[7) which delivers many negative ion beams at intensities two orders of

MASTER

magnitude larger than previously available and through the demonstration[4,8) at Brookhaven that, when pulsed, such intense beams can indeed be accelerated in large tandems.

Compared to cyclotrons, synchrotrons have certain advantages. Isochronization and related focussing problems do not arise. Those problems impose upper limits for the energy of relativistic beams in cyclotrons. The magnetic field volume is much smaller and scales roughly as the maximum momentum of the accelerated particles rather than the square of the momentum or faster as is the case for cyclotrons. Finally, the accelerating electrodes or cavities have much smaller capacitances and losses and much less r.f. power is required.

Disadvantages of synchrotrons are the macroscopically discontinuous nature of the accelerated beam, the greater difficulty and cost of generating rapidly changing oscillator frequencies and magnetic fields, more stringent vacuum requirements, and possible beam quality deterioration. (To what extent the tandem beam quality can be preserved depends on a detailed study of the beam capture and bunching, which is beyond the scope of this note.)

Possible basic parameters for a 15 m diameter rapid cycling heavy ion synchrotron booster have been estimated as an illustration and are given in table 1. A repetition rate of 20 Hz was chosen with 12 msec acceleration time, 25 msec extraction or spill time, and 12 msec for returning the magnetic field and the oscillator frequency to their lower values. A 50% duty cycle should be acceptable for most nuclear physics experiments. The horizontal acceptance was assumed to be 120

$\pi$ mm mrad (the same as the AGS acceptance) and the number of injected turns was simply assumed to be the ratio of the horizontal acceptance to the horizontal beam emittance based on a value of 15 $\pi$ mm mrad MeV$^{1/2}$ for the tandem beams.$^{8)}$ Whether this number of turns can be injected in practice must be decided by detailed injection studies which are beyond the scope of this note. Also, any significant increase in the tandem beam emittance (e.g., by the stripper preceding the synchrotron) will reduce the maximum number of injected turns and, therefore, the final intensities. The maximum magnetic field averaged around the ring was chosen to be 7 kGauss, which for instance could mean 14 kGauss in the magnets if they occupy 50% of the circumference. A linear magnetic field ramp ($\dot{B}$=const) was assumed for simplicity but this may not be optimum or practical.

Parameters for several beams from such an hypothetical accelerator are given in table II. The beam intensities shown are obtained by assuming 200 μA of pulsed negative ion source output. No losses other than the ones due to stripping efficiencies and duty factor are included in these numbers and real intensities will therefore be lower. There are, however, several accelerator parameters which could be varied if higher intensities are required. For instance a higher repetition frequency could be chosen, the acceptance could be made larger and the radius of the ring could be increased without changing the number or size of the magnets.

The accelerator parameter which is most difficult to estimate is the vacuum required to avoid excessive beam losses due to charge exchange collisions with residual gas molecules. Experimental values of electron pickup and loss cross sections do not exist over large portions of the energy range of interest. A method was used to estimate the vacuum requirements which is based on extrapolation of semiempirical average charge and electron capture cross section expressions.[9,10] There are large uncertainties associated with these extrapolations. The value obtained for the worst case considered which is the charge 27 uranium beam (see table II) is $10^{-10}$ torr for a 10% beam loss during acceleration plus another 5% loss during the extraction time. The total charge exchange cross section starts at a high value of $2.2\times10^{-14}$ $cm^2$ at the injection energy and then falls very sharply as the energy is increased. If the 80 turns (see table II) could be injected in 80 consecutive beam revolution periods, then the injection time is sufficiently short to only produce an additional 2% beam loss inspite of the large cross section. However, much larger injection times or the necessity of spending considerable time for capturing and bunching the beam before acceleration would increase the losses to the point where an even better vacuum would be required. Normally, the minimum acceptable capture and bunching time is given by the maximum acceptable longitudinal emittance. However, as was recently pointed out by Chasman[11], it seems that the need for considerable capture times in the synchrotron could be reduced or even eliminated by prebunching the tandem beam which can be done, introducing a relatively small energy dispersion.

Large synchrotrons are at present the only viable circular accelerators for the production of highly relativistic heavy ions. According to the above considerations it seems possible that smaller synchrotrons may become competitive with existing or proposed heavy ion post-acceleration tandem boosters. Whether and for what size machine this will occur, can only be decided by detailed design studies.

I am grateful to C. Chasman, M. Barton and H. Wegner for stimulating and instructive discussions.

This work was supported by the U.S. Department of Energy under Contract No. DE-AC02-76CH00016.

## REFERENCES

1. K. Prelec and A. van Steenbergen. Informal Report, BNL-19407 (1974).
2. Proposal for a 15 A·GeV Heavy Ion Facility at Brookhaven. Informal Report, BNL-32250 (1983).
3. M.Q. Barton. Proc. 1983 Particle Accelerator Conference, IEEE Trans. on Nucl. Sci. (to be published).
4. P. Thieberger. Proc. of present conference, Nucl. Inst. and Methods (to be published).
5. Y.Y. Lee and L.W. Smith. Brookhaven National Laboratory, AGS Division, Technical Note No. 187 (1983).
6. H. Wegner, private communication.
7. R. Middleton. Nucl. Instr. and Methods (to be published).
8. P. Thieberger, M. McKeown and H.E. Wegner. Proc., 1983 Particle Accelerator Conference, IEEE Trans. on Nucl. Sci. (to be published).
9. H.D. Betz and Ch. Schmelzer. UNILAC Bericht 1-67, Heidelberg (1967).
10. K. Prelec. PPA Technical Note A-507 (1969).
11. C. Chasman, private communication.

## TABLE I

### Main Characteristics of an Hypothetical Tandem-Synchrotron System Used as an Example in the Text

| | |
|---|---|
| Negative ion intensity | 200 μA (pulsed) |
| Tandem terminal voltage | 15 MV |
| Tandem beam emittance | $15\pi$mm mrad MeV$^{1/2}$ |
| Ring diameter | 15 m |
| Acceptance | $120\pi$mm mrad |
| Maximum field average | 7 kGauss |
| Minimum field average | 0.9 kGauss |
| Acceleration time | 12 msec |
| Extraction time | 25 msec |
| Reset time | 12 msec |
| Maximum total acceleration voltage per turn | 18 kV |
| Vacuum | $10^{-10}$ torr |

# TABLE II

## Properties of Beams that could be obtained with the System Described in Table I and in the Text

| Ion | Tandem Stripper | Tandem Beam Energy | Injected Charge State | Maximum Number of Injected Turns | Minimum Orbit Frequency | Maximum Orbit Frequency | Final Energy | Maximum Average Intensity * |
|---|---|---|---|---|---|---|---|---|
| | | MeV | | | MHz | MHz | MeV/AMU | pnA |
| $^{16}$O | foil | 120 | 8 | 92 | 0.80 | 4.1 | 287 | 198 |
| $^{36}$S | foil | 165 | 14 | 100 | 0.66 | 3.8 | 225 | 54 |
| $^{32}$S | gas | 120 | 13 | 86 | 0.57 | 3.6 | 197 | 64 |
| I | foil | 210 | 31 | 120 | 0.38 | 2.4 | 76 | 50 |
| $^{127}$I | gas | 105 | 25 | 80 | 0.27 | 1.9 | 50 | 48 |
| $^{238}$U | foil | 210 | 35 | 120 | 0.27 | 1.5 | 28 | 40 |
| $^{238}$U | gas | 105 | 27 | 80 | 0.20 | 1.1 | 17 | 36 |

---

[*] These intensities are based on 200 μA injected negative beams. Only losses due to the duty factor and to stripping efficiencies were considered (see text).