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The ADRIA Project

A. Dainelli, A. Lombardi, A. Ratti*, A. G. Ruggiero*
INFN-LNL, Via Romea 4, Legnaro (PD) I-35020, Italy

Abstract

A proposal of accelerator complex for the Laboratori Nazionali di Legnaro is described. The main components are a Heavy Ion injection system, two rings, a Fast Synchrotron and an Accumulator, both with a maximum rigidity in excess of 22 Tm connected by a Transfer Line where unstable isotopes are produced and selected. The system is designed for the acceleration of heavy ions with specific energy in the range of few GeV/u, the production of unstable isotopes and their deceleration to specific energies around the Coulomb barrier. The unstable isotopes are produced by impinging the primary beam on a production target and collecting them in the Accumulator where electron and stochastic cooling techniques are applied to reduce the large phase space volume generated in the production process and during accumulation. At the repetition rate of 10 pulses per second, primary beam currents are in excess of 10^{11} ions/s.

I. INTRODUCTION

The proposed complex of accelerators has the main goal to accelerate broad range of ion species to specific energies of few GeV/u for direct experiments in nuclear physics on fix target and for unstable isotopes production. The beam quality (transverse and longitudinal spreads) has to be adequate for precise measurements typical of nuclear structure studies.

The ensemble of the following components are referred to as the ADRIA Complex:

- a Heavy Ion Injector (XTU tandem & ALPI);
- a Fast Cycling Synchrotron (Booster);
- a Slow Cycling Synchrotron (Accumulator);
- a Transfer Line;
- an Experimental Area.

The acceleration system consists of a heavy ion injector [1] and a Booster with a maximum magnetic rigidity of 22.25 Tm; the same rigidity has been fixed for the Accumulator. The two rings, with the same shape and circumference (267 m), are located in the same building stacked one on top of the other with 2.5 m of separation between the beam axis.

After the acceleration in the Booster, the primary ion beam is extracted and travels through the Transfer Line to a target where exotic fragments are produced and selected. The secondary beam is injected into the Accumulator where the momentum spread is reduced by bunch rotation [2] and cooling techniques.

After the accumulation of 12 subsequent pulses from the fast synchrotron, the beam is cooled and then bunched for the final deceleration to specific energies adequate to study nuclear interactions around the Coulomb barrier.

The system will be capable to deliver beams with intensities in excess of 10^{11} ions/s and specific energies ranging from 1 GeV/u (Uranium) to 2.5 GeV/u (Oxygen). With the addition of a proton linac it will be also possible to accelerate intense beams of protons to 8 GeV.

II. THE SYNCHROTRON LATTICES

The two rings, with the same rigidity and shape, have similar lattices with fourfold symmetry and the basic cell has standard FODO structure (Fig. 1). Each period, which has a mirror symmetry with respect to its mid point, is made of an arc (4 subsequent cells) and two half straight sections at the ends. The two half straight sections are obtained by removing the bending magnet from the standard cell. The total number of cell is 24 each about 11 m long.

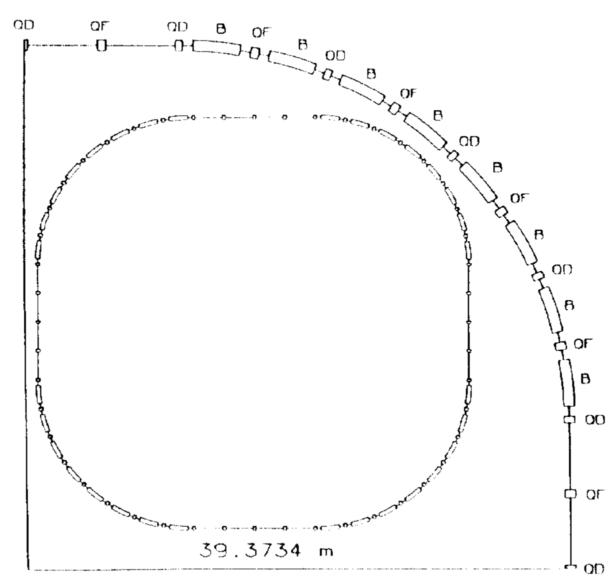

Figure 1: Booster Ring Lattice

The phase advance per cell is about 90° in the horizontal and 60° in the vertical plane; the betatron

* Brookhaven National Laboratory, Upton, N.Y. 11973, USA

tunes are 5.8 and 3.8 respectively, away from any low-order systematic resonances.

The bending is provided by 32 curved dipoles 3.46 m long and a magnetic field of 1.3 T, for a maximum field variation of 40 T/s. The magnetic gap is 10 cm, whereas the bore radius of the focusing quadrupoles is 7 cm in both rings for the betatron acceptance of 140 π mm-mrad.

The horizontal betatron phase advance in each arc is 360° which enables zero dispersion values at the extremities. The dispersion function remains zero along the full length of the straight section. The transition energy (γ_t=4.6) is well above the maximum energy reached during the heavy ion acceleration cycle and it is crossed only in the proton cycle.

To provide space (~10 m) for the electron cooling system a different quadrupole arrangements have been chosen in the long straight section of the Accumulator. The phase advances per cell and the betatron tunes of the Accumulator are the same as in the Booster.

III. THE RF SYSTEM

To cope with the large frequency swing required for the acceleration of the wide mass range involved, the Booster rf system is made of two different groups of cavities. The first (LFRF, 6 cavities) sweeps from 5 to 32 MHz while the second (HFRF, 6 cavities) covers the frequencies ranging from 30 to 51 MHz.

Both LFRF and HFRF systems are made of double-gap cavities, tuned by longitudinally biased Ni-Zn ferrites. Table 1 summarizes the rf requirements for the acceleration of different ion species. The rf frequency at injection is 5 MHz for all kind of ions and equals the frequency of the low energy buncher of the ALPI injector. Since different ions are injected with different velocities, the proper harmonic numbers are chosen for each species.

The acceleration of protons to 8 GeV (10 Hz) is within the limits of the facility, provided that an additional rf system is built to deliver a total voltage of 270 kV in a frequency range from 50 to 56 MHz.

The rf system in the Accumulator fulfills three tasks, namely the capture and subsequent rotation in the longitudinal phase space of the secondary beam bunches, the rf stacking and the deceleration.

Two cavities with a gap voltage of 700 kV, tuned at fixed frequencies ranging from 26 to 47 MHz, are used for the bunch rotation [3]. The rf stacking is performed by a second system of two similar rf cavities which displace the beam by a 1.2 % momentum variation.

The third system of rf cavities is required for the deceleration at the end of the stacking and cooling processes. The rf is turned on to adiabatically bunch and capture the coasting beam, at the same harmonic number selected in the corresponding acceleration process in the Booster. The beam is decelerated to about 4÷10 MeV/u which corresponds to the Coulomb barrier. A total of 50 kV is needed. The deceleration stops at the lowest available rf frequency of 5 MHz, where a final momentum spread of about 0.02% is expected.

TABLE 1. RF parameters for heavy ion acceleration

	S	Cu	Au	
A	32	63	197	
Q	16	27	51	
Inj. Kin. Energy	16.40	10.39	4.58	MeV/u
Extr. Kin. Energy	2.53	2.08	1.03	GeV/u
Injection β	.185	.148	.098	
Extraction β	.963	.950	.880	
Harmonic Number	24	30	45	
		LFRF System		
Peak Voltage	195	200	210	kV
Trans. Time Fact.	.98	.96	.91	
Voltage/Gap	17.8	17.4	19.2	kV
		HFRF System		
Peak Voltage	-	-	210	kV
Trans. Time Fact.	-	-	.82	
Voltage/Gap	-	-	21.4	kV

IV. THE PRODUCTION OF EXOTIC BEAMS

The beam Transfer Line between the rings is also used for the production and the separation of exotic beams to be collected and decelerated in the Accumulator. Its layout consists in one half of a ring with some modifications of the insertion regions to accommodate the production target and the degrader station, used for the energy and mass analysis.

The Transfer Line and the collection system of fragments are designed for the capture of a full momentum spread of at least 0.7%; the production angle is chosen to be 7.5 mrad corresponding to a transverse momentum spread which matches the longitudinal momentum width. The expected yield can then be as large as one part in ten thousand and typically 10^6 fragments of assigned mass number and atomic number can be collected per every Booster pulse.

The production target is located in a dispersion free insertion of the Transfer Line where a waist with transverse betatron functions of the order of 1 m are designed in both planes.

The full beam emittance of the primary beam is around 5π mm- mrad and the beam size at the target is 2.3 mm. The emittance of the secondary beam is 17 π mm-mrad. Based on these figures, the betatron acceptance of the Transfer Line and of the Accumulator is set to 40 π mm-mrad and the momentum aperture to 2%. Momentum selection of the fragments is obtained using two pairs of collimators and slits in an

8 meter drift. A horizontal waist $\beta^*=1$ m is designed in the middle of the drift section, where the degrader target is also placed.

V. THE COOLING SYSTEMS

In the Accumulator both stochastic and electron cooling are planned in order to have manageable beam dimensions during the process of accumulation, capture and deceleration of fragments. The most demanding requirements are imposed by the accumulation process, when by setting the total cooling time to 150 ms. The average momentum spread in the stack is maintained to 0.3 %.

TABLE 2. Electron and Stochastic cooling parameters

Electron Cooling		
Kinetic Energy	1	GeV/u
β	0.8	
Mass	200	
Charge State	80	
Length of the e-Beam	8	m
Beam Transv. Dimension	10	mm
e-Beam Current	15.5	A
Cooling Time	0.3	s
e-Beam Energy	0.6	MeV
e-Beam Power	7.1	MW
Stochastic Cooling		
Number of ions	1×10^7	
Bandwidth	1-2	GHz
Method	Notch Filter	
No. of Pickups	16	
No. of Kickers	32	
Schottky Power	1	kW
Thermal Power	negligible	
Amplifier Gain	160	db

A second cooling period of 0.5 s, following the stacking cycle, reduces at the same rate the total beam momentum spread to $1\cdot10^{-4}$ (Fig. 2). Electron cooling alone is adequate for the reduction of the beam emittance. Betatron cooling proceeds at twice the rate of momentum cooling; thus, over a period of 0.5 s, the betatron emittance can be reduced by at least one order of magnitude.

The power required for the electron cooling is of the order of 7 MW, which indicates the need for a very efficient energy recovery system. Stochastic cooling can be implemented with a bandwidth of the order of 2 GHz and a power of 1 kW. Table 2 summarizes the cooling parameters.

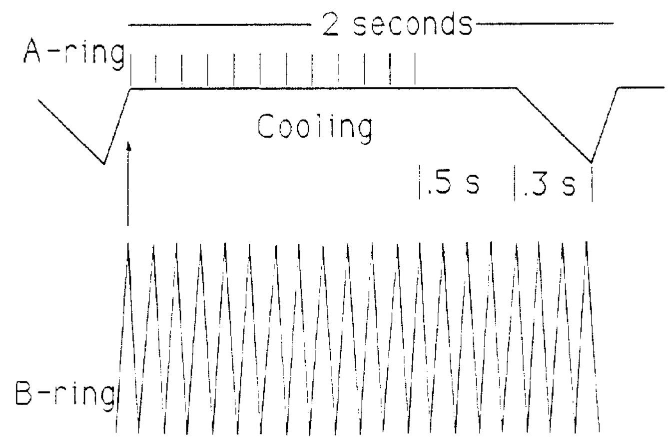

Figure 2: Magnetic cycle of the ADRIA Complex

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VII. REFERENCES

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