RAPID CYCLING SUPERCONDUCTING BOOSTER SYNCHROTRON[1]

N.N. Agapov, A.V. Butenko, D. Dinev, H.G. Khodzhibagiyan, A.D. Kovalenko, O.S. Kozlov, V.A. Mikhailov, V.A. Monchinsky, A.A. Smirnov, V.I. Volkov, JINR, Dubna, Russia

Abstract

The existing set of Nuclotron heavy ion sources: a duoplazmatron, polarized deuteron, laser and electron beam ion sources, permits to have ion beams over a wide range of masses. The main problem for us now is to gain high intensity of accelerator particles. It can be solved by means of multiturn injection of the low current beams into the booster, acceleration up to the intermediate energies, stripping and transfer into the main ring. A design study of this accelerator - the 250 MeV/Amu Nuclotron booster synchrotron at a 1 Hz repetition rate and circumference of 84 m, has been completed. The lattice dipole and quadrupole magnets have an iron yoke, coils, made of a hollow superconductor, are cooled by two-phase helium flow, as well as the Nuclotron magnets.

1 INTRODUCTION

The design of the Nuclotron accelerator complex has been done to provide prospects in the field of relativistic nuclear physics at the Laboratory of High Energies, JINR. This project includes the superconducting synchrotron Nuclotron, storage ring - booster and a new linac. The first of the three is under operation since March 1993, and the latest results concerning Nuclotron operation are presented at this conference [1]. The realization of the above mentioned program, together with the upgraded ion sources, will allow us to obtain beam intensities, limited by space charge forces, as high as $\sim 5 \cdot 10^{12}(A/q^2)$ for ions with $q/A = 0.5$ and $\sim 10^9$ for the heaviest ones.

The set of the heavy ion sources: the duoplasmatron (for protons, deuterons, and α-particles), source of polarized deuterons, laser source (for nuclei up to silicon) and electron beam ion source (EBIS, for the heaviest ions), permits to get ion beams over a wide range of masses. The existing injector (the Alvaretz type linac [2]),. accelerating ions with a charge-to-mass ratio of $0.33 \le q/A \le 0.5$ up to 5 MeV/u and protons up to 20 MeV, meets the requirement of experiments at the present stage of the accelerator facility development.

The injection into the Nuclotron by the charge exchange method allows us to store only protons and deuterons. However, the efficiency of this method is very limited because the injected beam emittance and Nuclotron lattice acceptance are equal ($\varepsilon_{x,y} \cong A_{x,y} \cong 50\pi$ mm·mrad). Therefore, we always planned to include the booster into the Nuclotron scheme for increasing the intensity of heavy ions [3]. Besides the operation together with the main ring, the booster can be used independently for scientific and applied research.

This paper describes a new concept of the rapid cycling superconducting booster. The layout of the booster, Nuclotron, injector and beam transfer lines in the Synchrophasotron building is shown in Fig. 1.

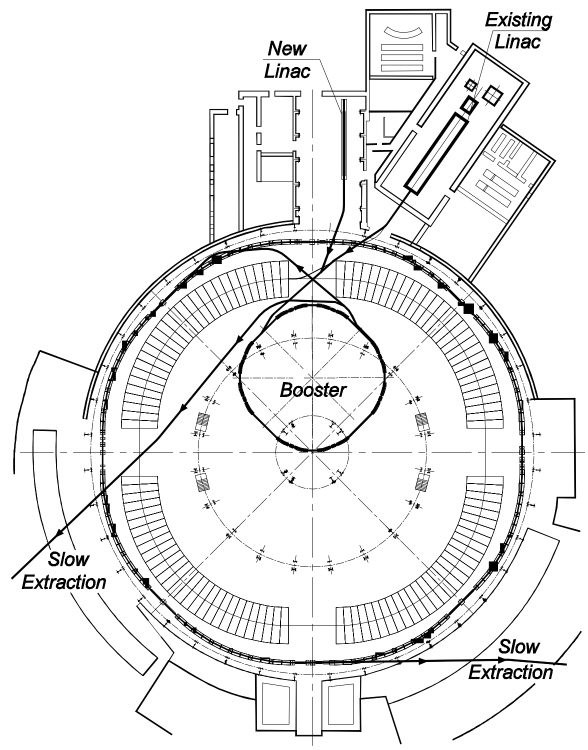

Figure 1: Layout of the accelerator facility.

2 GENERAL PARAMETERS OF THE BOOSTER

The studied method of proton synchrotron acceleration has the following features in case with the heavy ions:

- The low efficiency of interaction with external electric and magnetic fields ($\sim q/A$) and the high value - with beam self fields ($\sim q^2/A$).
- The high probability of ion charge exchange with residual gas molecules during the acceleration time t ($pt < 10^{-9}$ Torr·sec, where p is the residual gas pressure).
- The acceleration of the beam, having the spectrum of charges ($\Delta q/q$) and masses ($\Delta m/m$).
- The low phase density of the injected beams.

[1] The work supported by the Russian Foundation for Basic Research grant No 18400

The best way to reach these features is to use the rapid cycling synchrotron booster (with low acceleration time) with a large enough circumference (that means large longitudinal acceptance), large apertures of lattice magnets (that provides large transversal acceptance) and high vacuum in the ring. The using of the Nuclotron existing setups, equipment and tools are supposed to reduce the costs for superconducting magnet manufacturing and make the exploitation of the accelerator complex more efficient.

The chosen main characteristics of the Nuclotron booster are presented in the Table 1.

Table 1. General booster parameters

Maximum energy	250MeV/Amu
Injection energy	5 MeV/Amu
Circumference	84 m
Repetition rate	1 Hz
Emittance horizontal vertical	50 π·mm·mrad 32 π·mm·mrad
Vacuum	10^{-10} Torr

Here the kinetic energy is defined by the injection energy into the main ring, the booster circumference will be equal to 1/3 of the Nuclotron one. The repetition rate and acceptance are limited by characteristics of the superconducting magnets.

One can inject 5 pulses from the booster into the Nuclotron ring at the acceleration harmonic numbers of 1 and 5 in the booster and Nuclotron respectively.

3 LATTICE AND MAGNETS

We have chosen the lattice of four superperiods. Each of them consists of two regular symmetrical FDF triplets of quadrupole lenses, eight dipole magnets, four short, one middle and one long straight sections. The short 400 mm drift spaces are purposed for correcting magnets and beam position monitors, 1940 mm middle ones - for quadrupoles and sextupoles of the resonance slow extraction system. The 6500 mm long "warm" straight section is intended to place elements of the injection, acceleration, the fast and slow extraction and, maybe, electron cooling systems. The geometry of the booster superperiod and main lattice parameters are presented in Fig.2 and Table 2, respectively.

The lattice acceptance was chosen to have the extracted beam emittance of $\varepsilon_{x,y} \leq 50\pi$ mm·mrad.

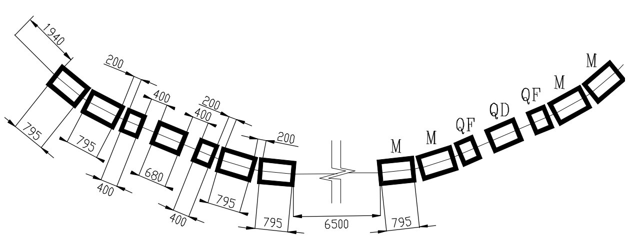

Figure 2: Geometry of the booster superperiod

Table 2. Lattice parameters

Maximum magnetic rigidity	4.86 T·m
Injection magnetic rigidity	0.646 T·m
Betatron tune $Q_{x,y}$	≈2.75
Momentum compaction factor	0.204
Acceptance horizontal Vertical	400 π·mm·mrad 225 π·mm·mrad
Dipole magnets	
Maximum magnetic field	1.2 T
Magnetic field at the injection	0.16 T
Number	32
Effective length	795 mm
Aperture (x·y)	160·100 mm^2
Sagitta	9.65 mm
Quadrupole lenses	
Maximum gradient	6.59 T/m
Gradient at the injection	0.88 T/m
Number of focusing defocusing	16 8
Effective length of focusing defocusing	400 mm 680 mm
Circle diameter between poles	130 mm

The betatron and dispersion functions of each superperiod are shown in Fig. 3.

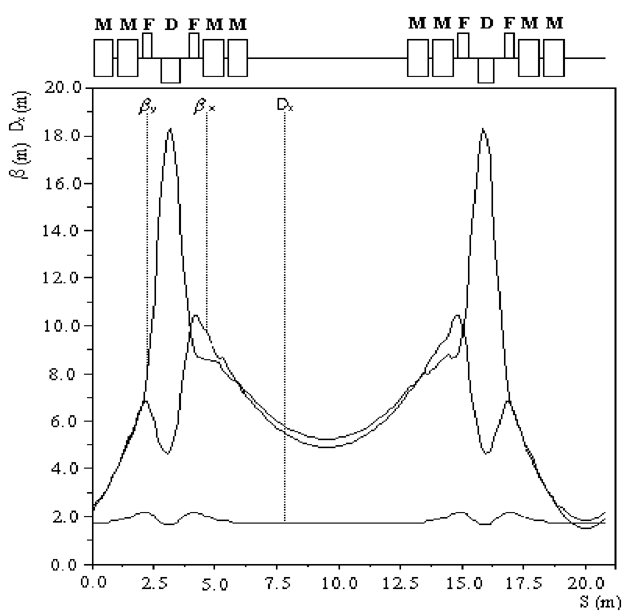

Figure 3: One superperiod lattice functions.

The quadrupole lenses and dipole windings, connected in series, are supplied with the equal current of 1 kA. The additional power supplies connected to certain groups of the lenses are used to change values of betatron tunes, to modify the lattice functions and to correct tune spreads and stopbands of betatron resonances.

The lattice dipole and quadrupole magnets have iron yokes. Like in Nuclotron, the windings made of a hollow superconductor are cooled by the two-phase helium flow. Despite of the high repetition frequency, miniature sizes of the magnets and a small number of them allow one to supply magnets with the electric current less than 1 kA. Thus, current leads can be used without helium flow cooling. The dipole and quadrupole windings are carried out from tubular cable. Superconducting wires are connected in series.

4 INJECTION AND EXTRACTION SYSTEMS

The existing linac will be used as injector at the first stage of the booster operation. We intend to carry out numerical simulations of all the multiturn injection methods. It is very promising to use the charge exchange method to store ions in the range from helium to carbon (see [4] and Fig. 4). High intensities of heavier elements can be achieved by the injection of ions with the filled K-shells and stripping at the entrance of the booster.

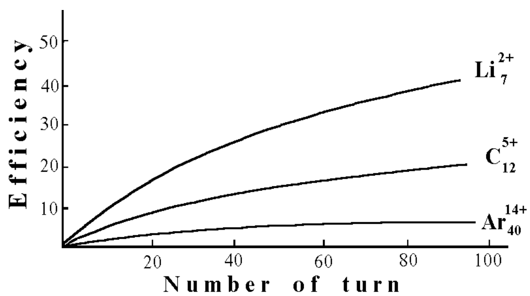

Figure 4: Efficiency of the charge exchange injection [4].

The multiturn injection scheme includes four bump magnets and septum magnet (see Fig. 5 and Table 3). The bump magnets produce the local closed orbit distortion, which decreases during injection time (several tens of turns).

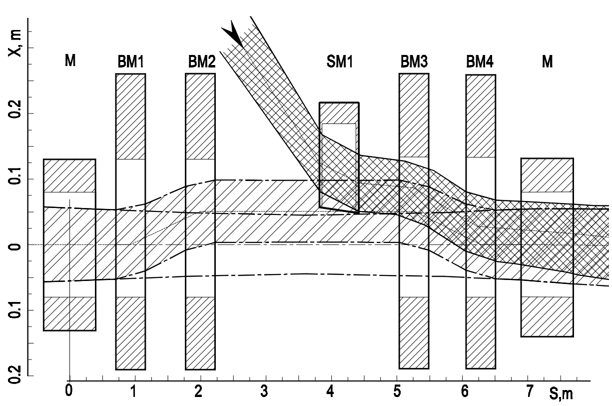

Figure 5: Multiturn injection scheme.

Fast (single turn) extraction is planned to transfer the beam into the Nuclotron and, if necessary, to the experimental hall. It consists of a kicker and a septum magnet. The scheme of the fast extraction and characteristics of the magnets are given in Fig. 5 and Table 3.

According to the chosen betatron tune $Q_{x,y} \approx 2.75$ it is worthwhile using the nearest 3rd order integer resonance $3Q_x = 8$ for slow extraction. At the extraction, the working point is shifted towards the resonance by additional currents in the lattice quadrupoles. Simultaneously, four sextupole lenses produce the 8-th azimuthal harmonic of the sextupole field. Four special quadrupole lenses, placed at equal distance, make slow crossing of the resonance band. Two septum magnets are intended to extract the beam in the horizontal plane. The extracted beam is transported to the experimental hall 2B. The directions of the slow and fast extractions coincide.

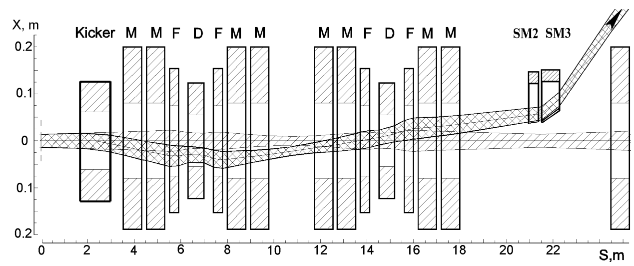

Figure 6: Fast/slow extraction scheme.

Table 3: Injection/extraction magnet parameters

	Field (T)	Length (mm)	Aperture (mm^2)
Injection septum magnet	0.12	600	120x100
Bump magnets	0.1	450	220x100
Kicker	0.035	1400	150x100
Extraction septum magnet SM2	0.05	500	100x100
SM3	0.44	800	120x100

5 CONCLUSION

The main goals of the superconducting booster construction are: to get Nuclotron beams of higher intensity (more than one order); to use lower energy booster beams for fundamental and applied researches, to develop the rapid cycling superconducting technology.

The experience of the Nuclotron manufacture and exploitation makes us believe this project would be realized.

REFERENCES

[[1] A.D.Kovalenko, «Nuclotron: Status & Future», these proceedings.

[2] A.M.Baldin et al., «Upgrades of Nuclotron Injector for Acceleration of Ions with Z/A = 0.28», Proc. XVIII Int. Linear Accelerator Conf., 1996, Geneva, v.1, p. 352.

[3] I.B.Issinsky and V.A.Mikhailov, «Conception of the 200 MeV/u Booster for the Nuclotron» Proc. of the 1991 IEEE Particle Accelerator Conf., San Francisco, v.5, p.2886.

[4] V.Anguelov et al., «Charge Exchange Injection of Heavy Ions in Synchrotrons», Proc. 4-th EPAC'94, London, vol.2. p. 1222.