

## RAPID CYCLING SUPERCONDUCTING BOOSTER SYNCHROTRON

N. N. AGAPOV, A. V. BUTENKO, H. G. KHODZHIBAGIYAN,  
A. D. KOVALENKO, O. S. KOZLOV, V. A. MIKHAILOV,  
V. A. MONCHINSKY, A. A. SMIRNOV, V. I. VOLKOV  
*Joint Institute for Nuclear Research, Dubna  
141980 Dubna, Moscow Region, Russia*

D. DINEV  
*Institute for Nuclear Research and Nuclear Energy  
72 Tzarigradsko Chaussée Blvd, 1784 Sofia, Bulgaria*

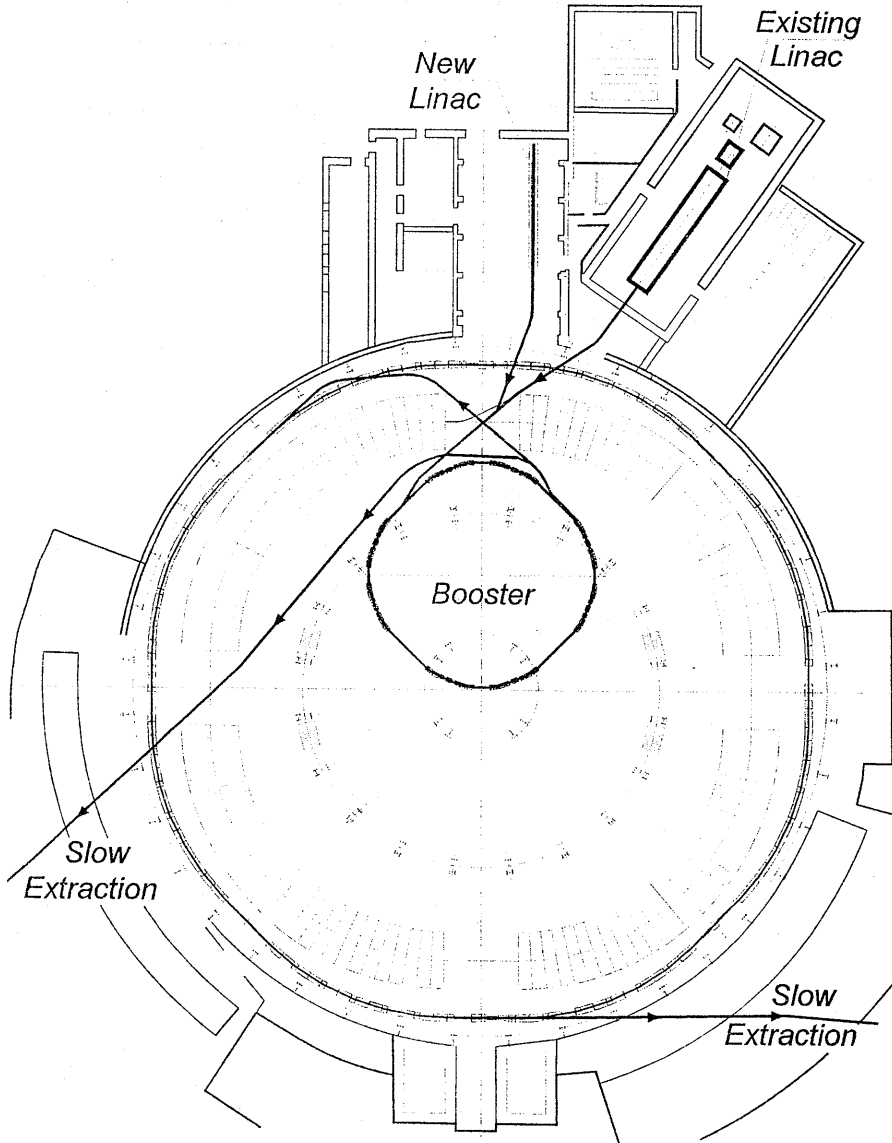
**Abstract.** The existing set of Nuclotron heavy ion sources, such as duoplazmatron, polarized deuteron, laser and electron beam ion sources permits to have ion beams over a wide range of masses. The main problem for us now is to gain high intensity of accelerator particles. It can be solved by means of multiturn injection of the low current beams into the booster, acceleration up to the intermediate energies, stripping and transferring into the main ring. A design study of this accelerator — the 250 MeV/Amu Nuclotron booster synchrotron at 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 hollow superconductor, are cooled by two-phase helium flow, as well as the Nuclotron magnets.

**PACS number:** 29.20.-c

### 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 have been reported at a 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  $\approx 5 \times 10^{12}$  ( $\text{A}/q^2$ ) for ions with  $q/A = 0.5$  and  $\approx 10^9$  for the heaviest ones.



**Fig. 1.** Layout of the accelerator facility

The set of the heavy ion sources: the duoplasmatron (for protons, deuterons,

and  $\alpha$ -particles), the 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 Alvarez type linac [2]), accelerating ions with a charge-to-mass ratio of  $0.33 \leq q/A \leq 0.5$  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 methods 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 ( $\varepsilon_{x,y} \simeq A_{x,y} \simeq 50\pi$  mm mrad). Therefore, we have 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 Synchrotron building is shown in Fig. 1.

## 2. General Parameters of the Booster

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

- low efficiency of interaction with external electric and magnetic fields ( $\sim q/A$ ) and the high value — with beam self fields ( $\sim q^2/A$ )
- 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)
- acceleration of the beam, having the spectrum of charges  $\Delta q/q$  and masses  $\Delta m/m$
- low phase density of the injected beams.

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.

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

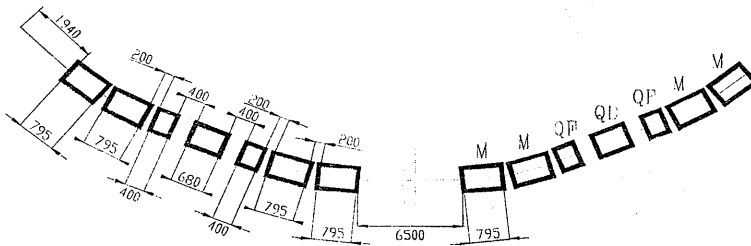
magnets. One can inject 5 pulses from the booster into the Nuclotron ring at the acceleration harmonic numbers of 1 and 5 in the booster and Nuclotron respectively.

**Table 1.** General booster parameters

Maximum energy	250 MeV/Amu
Injection energy	5 MeV/Amu
Circumference	84 m
Repetition rate	1 Hz
Emittance	horizontal 50π mm mrad
	vertical 32π mm mrad
Vacuum	10 <sup>-10</sup> Torr

### 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 possible electron cooling systems. The geometry of the booster superperiod and the main lattice parameters are presented in Fig. 2 and Table 2, respectively.



**Fig. 2.** Geometry of the booster superperiod

The lattice acceptance was chosen to have the extracted beam emittance of  $\epsilon_{x,y} \leq 50\pi$  mm mrad. The betatron and dispersion functions of each superperiod are shown in Fig. 3.

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.

Table 2. Lattice parameters

Maximum magnetic rigidity		4.86 T m
Injection magnetic rigidity		0.646 T m
Betatron tune $Q_{x,y}$		$\approx 2.75$
Momentum compaction factor		0.204
Acceptance	horizontal	$400\pi$ mm mrad
	vertical	$225\pi$ 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 ( $x \times y$ )		$160 \times 100$ mm <sup>2</sup>
Sagitta		9.65 mm
Quadrupole lenses		
Maximum gradient		6.59 T/m
Gradient at the injection		0.88 T/m
Number of	focusing	16
	defocusing	8
Effective length of	focusing	400 mm
	defocusing	680 mm
Circle diameter between poles		130 mm

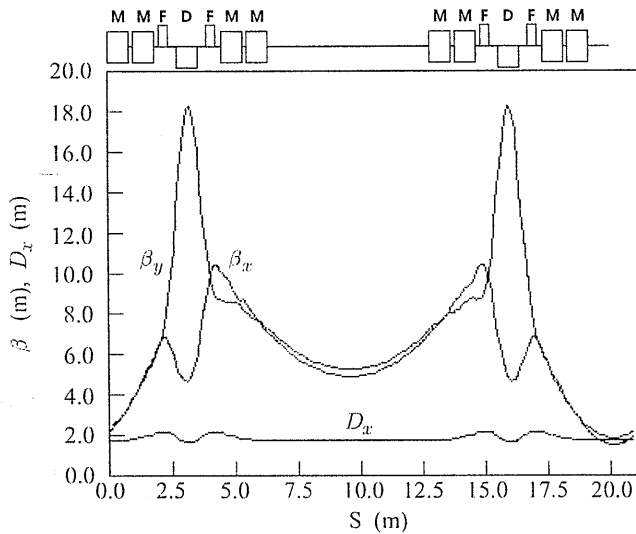


Fig. 3. One superperiod lattice functions

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 an injector at the first stage of the booster operation. We intend to carry out numerical simulations of all the multturn 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 Nuclotron.

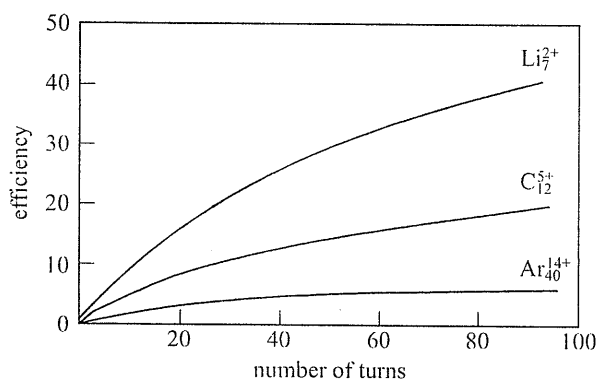
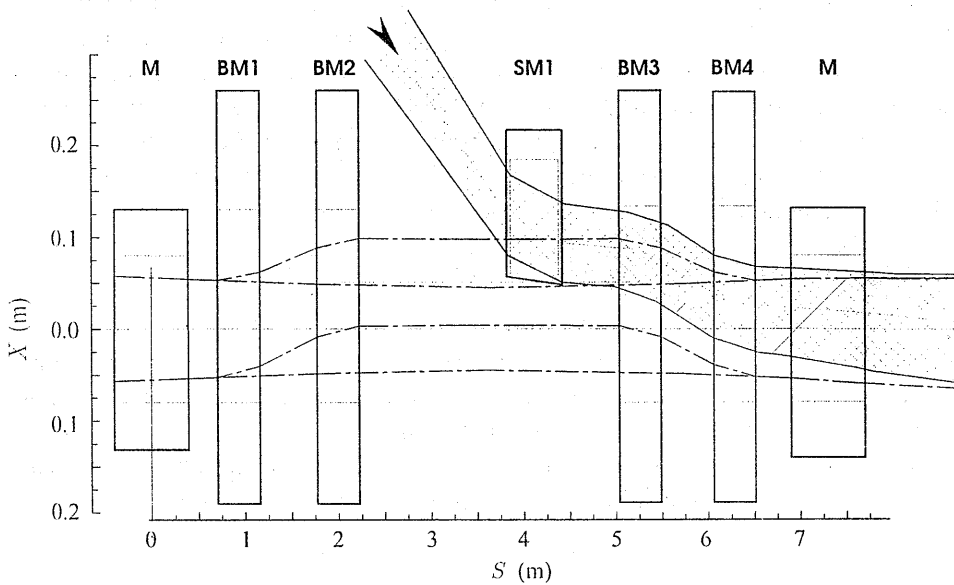


Fig. 4. Efficiency of the charge exchange injection [4]

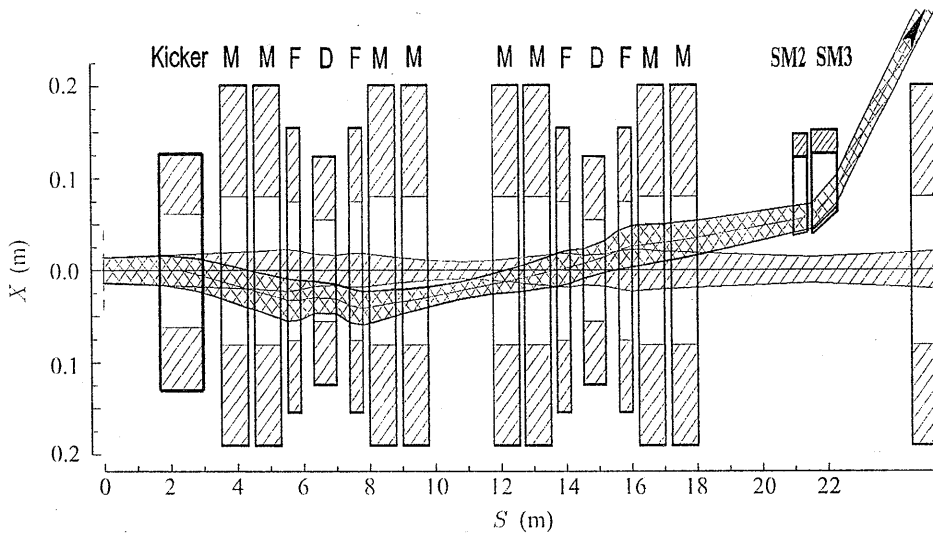
Table 3. Injection/extraction magnet parameters

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

The multturn 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).



**Fig. 5.** Multiturn injection scheme



**Fig. 6.** Fast/slow extraction 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 3<sup>rd</sup> 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<sup>th</sup> 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.

## 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

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