NUCLOTRON LATTICE

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Introduction

Deuterium nuclei were first accelerated up to relativistic energies in the Dubna Synchrophasotron, JINR as a result of a partial reconstruction of both the injector and the RF system in 1970[1]. A subsequent development of the Synchrophasotron as a heavy-ion accelerator followed different paths:
1) creation of new types of ion sources with a high ionization level and rather strong pulse currents (electron-beam and laser[2,3] sources);
2) creation of a polarized deuteron source[4];
3) broadening of the beam transfer lines[5];
4) vacuum improvement by means of cryogenic pumping out[6].

The design of the accelerator facilities named Nuclotron has been developed to provide long-term prospects in the field of relativistic nuclear physics at the Laboratory of High Energies, JINR. It includes a superconducting synchrotron[7] (under construction now), a new linac[8] and a booster synchrotron[9]. The implementation of this program in combination with the improved ion sources will allow one to attain beam intensities limited by a space charge of $5\cdot10^{12}(A/q^2)$ for light ions and 10^9 for heavy ones.

The existing linac will be used as an injector at the first stage of operation. It can accelerate ions from deuteron to xenon with the charge to mass ratio from $0.33\leqslant q/A\leqslant 0.50$ up to 5 MeV/u and protons up to 20 MeV/u.

The dipole and quadrupole magnets have an iron yoke and coils made from a hollow superconductor cooled by a two-phase helium flow. The Nuclotron lattice and its features have been mainly determined by the magnets' parameters as well as by their position in the ring tunnel inside the Synchrophasotron building and the opportunity to derive maximum benefit from the existing experimental halls and equipment.

This report gives a description of the Nuclotron lattice, the injection and slow extraction systems and general characteristics of their elements.

Lattice of the Superconducting Ring

The shape of the ring tunnel and also the existing injection and extraction directions make it possible to place the synchrotron with a 250 m circumference and the number of superperiods divisible by 4 on the ground floor of the Synchrophasotron building. A layout of the Nuclotron is shown in Fig.1.

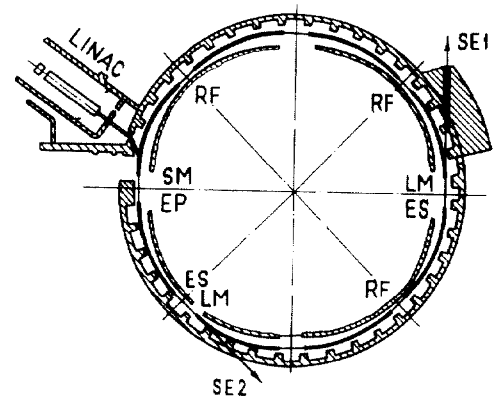

Fig.1. Nuclotron layout (SM-septum-magnet, EP - electrostatic plates, RF - radio-frequency cavity, ES - electrostatic septum, LM - Lambertson magnet).

The chosen lattice contains 8 superperiods. Each superperiod consists of 3 regular FODO cells with dipole magnets and one cell without them. One regular cell includes focusing and defocusing quadrupole lenses, 4 dipole magnets and two small drift spaces used to install correcting magnets, beam position monitors and so on. The lattice functions for one superperiod and for betatron tunes $Q_{x,z}$=6.75 are shown in Fig.2.

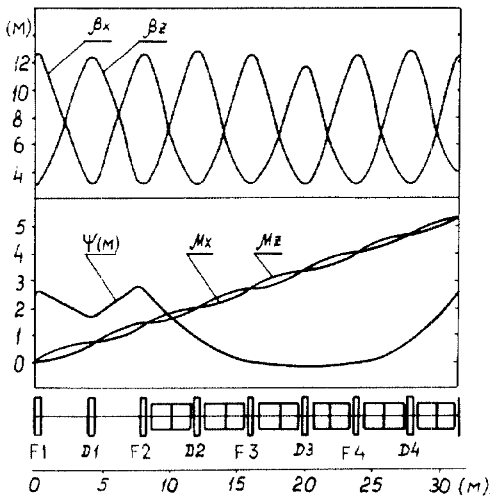

Fig.2. Lattice functions for one superperiod ($\beta_{x,z}$- betatron functions, Ψ'- dispersion function, $\mu_{x,z}$ - betatron phase).

The correcting system is composed of 32 superconducting multipole magnets and 24 beam position monitors. It performs corrections of chromaticity , octupole tune spread and the most important resonances up to the 4-th order inclusive. Each correcting magnet contains coils forming independently up to 4 different types of magnetic field out of 8 available ones: normal and skew dipole, quadrupole, sextupole and octupole.

The general parameters of Nuclotron are given in Table 1.

Table 1

General Nuclotron Parameters

Injection energy for nuclei	5 MeV/u
for protons	20 MeV
Maximum energy for nuclei (q/A=0.5)	6 GeV/u
for protons	12.8 GeV
Circumference	251.52 m
Duration of acceleration	(0.5-1.5)sec
Maximum accelerating voltage	50 kV
Transition energy	7.6 GeV
Field in the dipole magnets	
at injection	0.029 T
maximum	2.083 T
Gradient in the quadrupole lenses	
at injection	0.490 T/m
maximum	34.6 T/m
Betatron tunes Q_x, Q_z	6.75
Chromaticity $\Delta Q_x/(\Delta p/p)$	-7.9
$\Delta Q_z/(\Delta p/p)$	-8.1
Compaction factor	0.012
Maximum closed orbit (after correction)	4 mm
Acceptance horizontal	40 mm mrad
vertical	45 mm mrad
Maximum momentum spread	4.10^{-3}

Injection and Extraction Systems

At the first stage the existing linac will be used to inject a single turn of 20 MeV protons or 5 MeV/u ions with the charge to mass ratio over the range $0.33 \leqslant q/A \leqslant 0.50$.

Slow extraction will be performed at any energy in the range from 0.2 to 6.0 GeV/u in two directions SE1 and SE2 existing for the Synchrophasotron. Its duration will be up to 10 sec. Rather complex schemes for the extraction and injection systems and beam transfer lines both with horizontal and vertical beam bending were designed because the Nuclotron ring will be placed at a 3.9m level below the existing linac and the Synchrophasotron experimental equipment. The injection and extraction systems placed inside the accelerator cryostat must have a low level of gas desorption and heating to avoid additional loads on the cryogenic and vacuum systems.

Taking into account all the features of Nuclotron, the injection scheme was chosen to provide a beam bend in the vertical plane. The injection system contains a septum magnet (SM) for a preliminary beam bend and a pulse device (electrostatic deflecting plates - EP) for final fitting the beam to the reference orbit. The injected beams completely conform with the Nuclotron lattice in transverse phase space and dispersion.

The septum magnet has a rather small field (up to 0.2 T) and a large thickness (10 mm) at a 0.5 m length. This permits one to make the superconducting coil and current septum. The voltage on the electrostatic deflecting plates does not exceed 40 kV, and the level of gas desorption and heating for this pulse device is much lower than in kickers. The effective length of the deflecting plates is 1.5 m.

In accordance with the chosen betatron tunes $Q_x \cong Q_z \cong 6.75$, it is worthwhile to use the nearest third order integer resonance. $3Q_x=20$ for slow extraction. The working point is shifted to the resonance band by the lattice quadrupole lenses. Simultaneously the 20-th harmonic of the sextupole field component is created by means of 4 sextupole magnets. The slow crossing of the resonance band is produced by the 4 special quadrupole lenses placed at equal distances apart.

The beam is extracted in either directions with the aid of an electrostatic septum (ES) and a two-section Lambertson magnet (LM). The ES deflects particles in the horizontal plane. The application of the LM allows one to provide a beam by-pass around the lattice elements and its rise up to the level of the existing beam lines in the experimental halls. General parameters of the slow extraction system are given in Table 2. The phase trajectories at the entrance of the ES are shown in Fig.3. There are an ellipse surrounding the Nuclotron acceptance (A_x= 210πmm mrad) and phase portraits for the electrostatic septum and the Lambertson magnet (hatching).

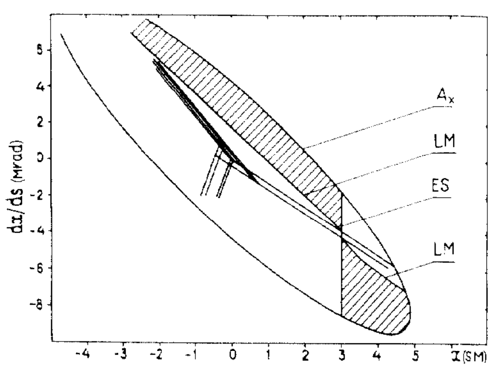

Fig.3. Phase trajectories and phase portraits of the slow extraction elements at the entrance of the electrostatic septum.

Table 2

General Characteristics of the Slow Extraction System

Parameter	Unit	Energy (GeV/u) 0.2	6
dBz/dx (quadrupoles)	T/m	0.14	0.68
d^2Bz/dx^2 (sextupoles)	T/m^2	13.3	233
Tension of the electric field in ES	NV/m	1.26	10
Field in LM	T	0.136	1.450
Effective emittance			
horizontal	mm mrad	9.5	2.5
vertical	mm mrad	20	2.0
Instantaneous momentum spread		7.10^{-4}	2.10^{-4}
Duration	sec	(1 ÷	10)
Duty factor of the extracted beam current	%	95	95
Slow extraction efficiency	%	95	96

Present Status

The state of work is the following to date. All basic lattice elements are almost ready and their electric and cryogenic tests have been performed. The measured nonlinearities of the magnetic field in the lattice dipoles and quadrupoles are less than the calculated tolerances. Complex tests of many days have been carried out for 1/8 of the Nuclotron ring.

References

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