EXPECTED CHARACTERISTICS OF THE NUCLOTRON BEAMS FOR EXPERIMENTAL SETUPS

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Abstract

The experiments are planned to perform on the external beams of the Nuclotron [1]-[2], require a knowledge of their final characteristics which are determined by the initial ones such as energy range and spread, time structure, envelopes etc., generated inside the accelerator. One of the distinctive features of the Nuclotron is the possibility to extract accelerated beams beginning with an injection energy of 5 MeV/amu up to a maximum of 6 GeV/amu.

1 ENERGY RANGE

The application of the resonance of radial betatron oscillations for extraction of the beam requires a space between its pre-resonance envelope and the septum of a deflecting device. This space is used for the growth of the betatron amplitude. After injection and at the initial stage of acceleration, the beam occupies a considerable part of the aperture. The reserve, chosen in designing in the aperture of the vacuum chamber (for possible great orbit distortions during commissioning and the use of a beam with a larger emittance from the booster in the future), permits one to perform the extraction over the full energy range of the accelerator.

Owing to diminishing the emittance and momentum spread the extraction coefficient is increased with raising the particle energy. However at a maximum beam energy narrowing the dynamic aperture of the accelerator appears, due to iron saturation for high magnetic fields above 1.9 T in the dipoles and 37 T/m in the quadrupoles. The sextupole and octupole components, arising in this case, distort the phase trajectories which enlarge the effective emittance and decrease the extraction coefficient.

Filling the aperture of the vacuum chamber in the straight section where the electrostatic septum is located, is shown in Fig. 1–2. Two cases are more typical: the picture just after the injection at a beam energy of 5 MeV/amu and at 5.5 GeV/amu. The intermediate case for an energy of 200 MeV/amu is also presented.

To avoid beam losses on the septa of the extraction devices under injection, additional currents are introduced in the nearest structure dipoles at this time to make a horizontal orbit bump and to shift the circulating beam to the inner wall of the vacuum chamber. The required additional horizontal space turns out to be enough for beam extraction at the injection energy. In this case, the extraction coefficient has the lowest value due to a larger momentum spread [3] as well as due to the limitations in the vertcal plane of the aperture. The values of the extraction coefficient for these three cases are presented in Table 1.

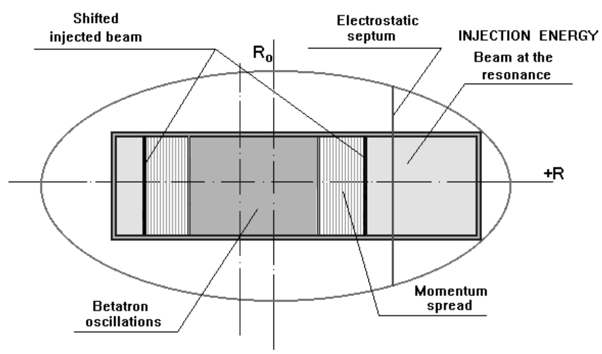

Figure 1: Filling the aperture of the Nuclotron vacuum chamber after the injection at a beam energy of 5 MeV/amu.

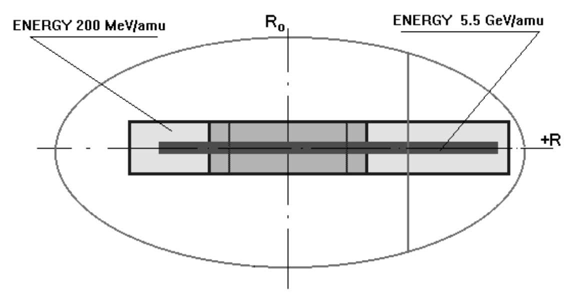

Figure 2: Filling the aperture of the vacuum chamber at a beam energy of 200 MeV/amu and 5.5 GeV/amu.

Table 1: Slow extraction efficiency.

Beam energy	5 MeV/u	200 MeV/u	5.5 GeV/u
Extr.coeff.,%	93	96	98

2 BEAM EMITTANCE

The phase diagrams of particles for the resonance $Q_x = 20/3$ in the Nuclotron for the low and high energy before the essential influence of the third and fourth components in magnetic fields are shown in Fig. 3–4. As seen the full value of the extracted beam emittance is determined by the total momentum spread in the beam and the spectrum of the radial amplitudes. The instantaneous emittance is much

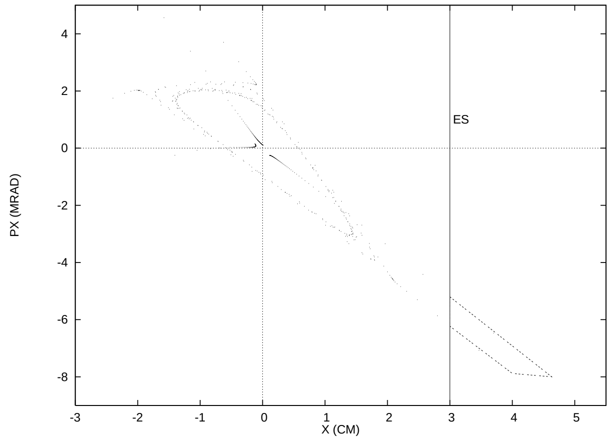

Figure 3: Horizontal phase space at ES during slow extraction at 200 MeV/amu.

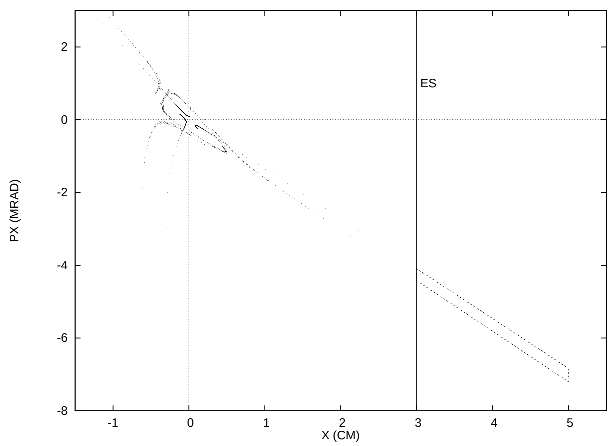

Figure 4: Horizontal phase space at ES during slow extraction at 6 GeV/amu.

smaller than this value since the particles, leaving the separatrix at every instant,have only part of the total momentum spread. The emittance of particles inside the septum gap is correlated in time with their amplitudes and momenta, and therefore it can be decreased by steering the entry or exit angle of particles during the extraction process. The first one can be done by means of bump-magnets, the latter by means of an additional magnet corrector downstream the accelerator exit. This decrease has a limitation connected with a permanent occurrence of particles with different momenta in the gap. The calculated simultaneous momentum spread of particles coming to physical setups, dp/p is equal to $\pm 7 \times 10^{-4}$ and $\pm 2 \times 10^{-4}$ for low and high energies, respectively. The emittance value of the extracted beam in the horizontal plane is $9.5\pi\ \mathrm{mm} \cdot \mathrm{mrad}$ for the low energy and $2.5\pi\ \mathrm{mm} \cdot \mathrm{mrad}$ for the high one. Its value in the vertical plane is equal to $20\pi\ \mathrm{mm} \cdot \mathrm{mrad}$ and $2.0\pi\ \mathrm{mm} \cdot \mathrm{mrad}$, respectively.

3 BEAM IN THE TRANSPORT LINES

As the values of emittance indicated above much smaller than the Synchrophasotron one, it allows one to use the existing beam lines in the Main Experimental Hall, actually without changing. Only the head part of the transfer line should be constructed. The expected envelopes of the external beam in the transport channel, obtained from the phase diagrams of Fig. 3–4, are shown in Fig. 5–6.

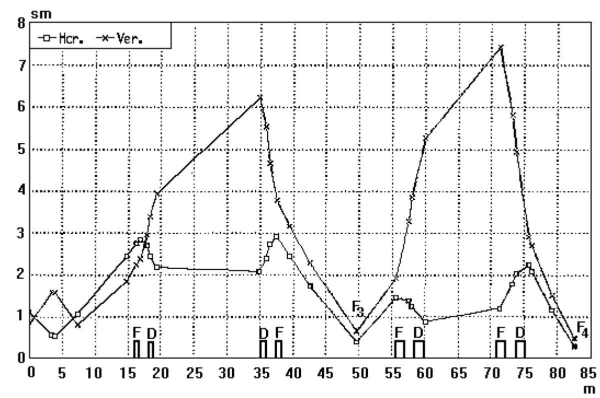

Figure 5: Envelopes of the 200 MeV/amu extracted beam.

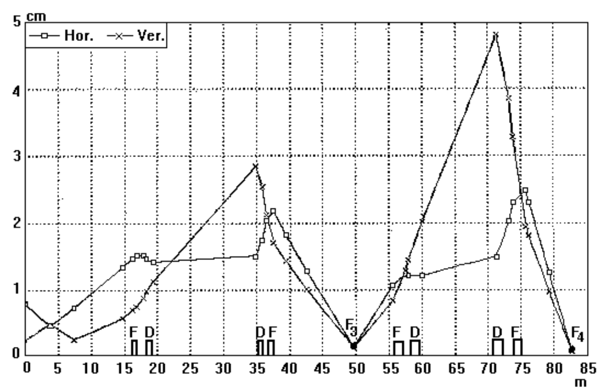

Figure 6: Envelopes of the 6 GeV/amu extracted beam.

4 BEAM TIME STRUCTURE

The main reason of beam inhomogeneity in time is due to ripples in current supplies or parasitic currents in transport cables. The band of these frequencies lies within 50 Hz and several kHz. Large difficulties in suppressing perturbations are caused by high frequencies since an instantaneous current of the extracted beam is determined by the effective derivative of the radial betatron frequency $\mathrm{Q_x}$. It is also more difficult to suppress high frequencies by means of a beam feedback system. The main specific role of this system is to control the beam time macro-structure and particle steering to the targets, since the time homogeneity must be provided with a high stability of supply currents. The evaluations of the beam time homogeneity coefficient

$$F = \left(\int_0^{T_e} \frac{dN_e}{dt} dt \right)^2 / \left(T_e \int_0^{T_e} \left(\frac{dN_e}{dt} \right)^2 dt \right),$$

where T_e – extraction time, dN_e/dt – extracted beam intensity, allow one to formulate the requirements to the Nuclotron magnet power supply system under slow extraction operating conditions.

Table 2 presents the expected values of the time homogeneity coefficient obtained using the existing power supply system under the flat-top slow extraction operating conditions. (Now this system is used for ramping the magnetic field and providing flat-tops for steering the accelerated beam to the internal target of the Nuclotron.) As can be seen, for a good extraction spill, ripples in the supply system should be reduced at least from 5 to 10 times.

Table 2: Time homogeneity of the external Nuclotron beam with the use of the existing supply system.

W	200 MeV/amu		6 GeV/amu	
T_e,s	1.0	10	1.0	10
F	0.1	10^{-5}	0.95	0.1

5 INTENSITIES OF THE IONS

The works that are being performed on the ion sources [4] , allow one, after completing all the program, to expect a wide set of ions for experiments on the Nuclotron beams (Table 3).

Table 3: Nuclotron external beam intensities, part./sec.

Particles	Sources	Injection from	
		Linac 1997-1998	Linac+Booster Prolonged plans
P	Duoplasm.	$1 \cdot 10^{11}$	$2 \cdot 10^{12}$
D	Duoplasm.	$5 \cdot 10^{10}$	$1 \cdot 10^{11}$
D $\uparrow$	POLARIS	$1 \cdot 10^{8}$	$2 \cdot 10^{9}$
He^{2+}	Duoplasm.	$2 \cdot 10^{9}$	$4 \cdot 10^{10}$
C^{6+}	Laser	$2 \cdot 10^{9}$	$1 \cdot 10^{10}$
O^{8+}	Laser	$1 \cdot 10^{9}$	$5 \cdot 10^{9}$
F^{9+}	Laser	$1 \cdot 10^{9}$	$5 \cdot 10^{9}$
Mg^{12+}	Laser	$2 \cdot 10^{8}$	$1 \cdot 10^{9}$
Ar^{16+}	EBIS	$2 \cdot 10^{8}$	$1 \cdot 10^{9}$
Fe^{24+}	EBIS	$1 \cdot 10^{8}$	$5 \cdot 10^{8}$
Xe^{44+}	EBIS	$2 \cdot 10^{7}$	$1 \cdot 10^{8}$
U^{82+}	EBIS	—	$\sim 5 \cdot 10^{6}$

6 ACKNOWLEDGEMENT

The authors would like to express their thanks to Prof. A.M. Baldin, Dr. A.D. Kovalenko and Dr. A.I. Malakhov for the support and permanent attention to the work on the Beam Extraction System.

7 REFERENCES

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