BEAM INJECTION INTO THE NUCLOTRON

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Abstract

The system for the single-turn injection of 5 MeV/u heavy ions into the Nuclotron is described. The system comprises a superconducting septum-magnet, kick electric plates, beam diagnostic apparatus and magnet correctors. The septum magnet has an iron yoke. The coil and septum made of a hollow superconductor, are cooled with a two-phase helium flow. The magnetic field is 1T. The electric field and its fall time in the fast kicker are 7 kV/cm and about 100 nsec, respectively. The beam diagnostics are composed of the Faraday cups and multi-wire collector chambers for current and profile measurements over a wide range of intensities. The magnetic correctors in the beam line and the Nuclotron ring are used for injection adjustment.

The system has operated since 1992. The experimental results are presented.

1 INTRODUCTION

The superconducting heavy ion synchrotron Nuclotron [1]-[3] was put into operation in 1992 as a replacement of the 35-year Synchrophasotron. The Nuclotron ring was placed in the cable tunnel at a mark of -3.76 m below the median planes of the Synchrophasotron and the injector (the Alvaretz type linac [4]). The latter accelerates ions with a charge-to- mass ratio of $0.28 < \mathrm{q/A} < 0.5$ up to 5 MeV/u and protons up to 20 MeV.

The existing set of heavy ion sources [5]: a duoplasmatron (protons, deuterons, and α-particles), a source of polarized deuterons, a laser source and an electron beam ion source (EBIS) permits us to get ion beams over a wide range of masses.

There are two reasons why the single turn injection was chosen:

– beam pulse durations of the laser source and EBIS are comparable to the time of one turn;

– the minimization of the lattice magnet apertures and cross section sizes allows the power consumption to be decreased substantially. As for the storage of light ions (protons, deuterons and α-particles), we are planing to include booster [6] into the Nuclotron layout.

2 INJECTION LAYOUT

Taking into account the features of the Nuclotron position, the injection scheme was chosen to provide the beam deflection in the vertical plane.

A standard layout of the single-turn injection comprises two main elements: a deflecting septum- magnet and a kicker. In our case, the principal demand to these devices is to have low levels of heat and gas releases. The superconducting septum magnet and kick electric plates obviously satisfy these conditions better than their warm magnetic analogs.

A low level of the magnetic field and a large thickness of the septum allow one to make the coil and septum of the superconducting cable. A traditional magnetic kicker was also substituted by an electric one because of the low magnetic permeability of a ferrite yoke under cryogenic temperature. The cross sections of the septum-magnet and plates were determined by parameters of the injected and circulating beam parameters:

– transverse emittance of the injected beam	$30\pi\mathrm{mm}\cdot\mathrm{mrad}$,
– horizontal emittance of the circulating beam	$40\pi\mathrm{mm}\cdot\mathrm{mrad}$,
– vertical emmitance of the circulated beam	$45\pi\mathrm{mm}\cdot\mathrm{mrad}$,
– relative momentum spread	10^{-3}

The parameters of these devices for the injection of protons and heavy ions with a charge-to-mass ratio of 0.5 are presented in Table 1. A scheme of beam injection is given in Fig.1.

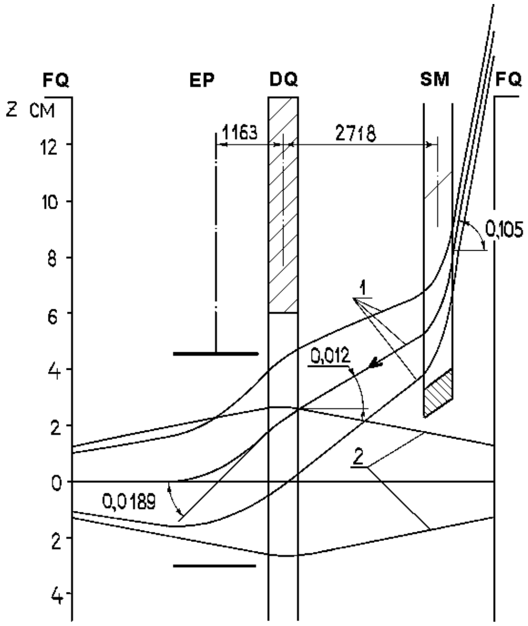

Figure 1: The injection scheme. 1 – injected beam, 2 – circulating beam.

Table 1:

No	Parameters		Ions	Protons
1.	Energy	MeV/u	5	12
2.	Charge-to-mass ratio	q/A	0.5	1
3.	Magnetic rigidity	$\mathrm{T \cdot m}$	0.647	0.649
4.	Electric rigidity	MV	19.95	39.58
5.	Revolution time	μsec	8.152	4.125
6.	Magnetic field in the septum-magnet	T	0.120	0.121
7.	Length of the septum-magnet	m	0.5	
8.	Electric field of the plates	kV/m	250.9	497.7
9.	Length of the plates	m	1.5	

3 SUPERCONDUCTING SEPTUM-MAGNET

The superconducting septum-magnet (Fig.2) comprises a C-shaped iron yoke and a coil . The coil is made of a hollow superconductor and cooled with a two- phase helium flow.

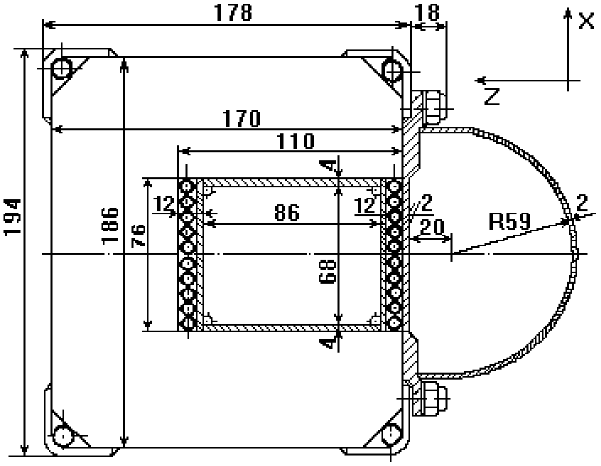

Figure 2: The cross section of the septum-magnet.

The magnetic yoke is made of steel plates (electrotechnical steel E330-A) 0.5 mm in thickness. The plates were compressed at a 6000 kg pressure. The compaction factor of the steel plates was 0.985. For cooling the septum-magnet to cryogenic temperature the four copper tubes 10 mm in diameter were soldered on four external corners of the yoke.

The superconducting coil consists of 300 windings. The superconducting cablec 0.5 mm in diameter twisted 2970 filaments is covered with special lacquer and wounded on a copper-nickel 5 mm diameter tube with a two-phase helium flow inside. The cable consists of 30 isolated superconductors, wounded with a step of 40 mm. The superconducting coil has more than 30 soldered junctions [7] to obtain a successive connection of windings. This connection allows one to increase the number of windings up to 300 and to reduce the current as well as the load in the current lead-ins. The coil has 3 exits to protect it from quenching.

The cryogenic test of the septum magnet has given the following results:

Coil current	(A)	0	70	120	150
Heat releases	(W)	10.6	12.4	14	21

The current septum 21 mm in thickness has two rows of windings, limited by steel plates. They are also used as protection from a beam halo. The septum-magnet in cryostat is shown in Fig.3. The magnetic field measurements were carried out by means of harmonic coils in the warm and cold regimes. The results of these measurements in the areas of the injected and circulating beams are presented in Fig.4.

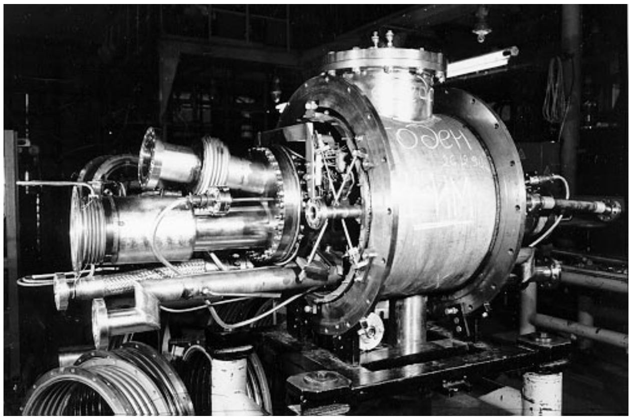

Figure 3: The septum-magnet in cryostat.

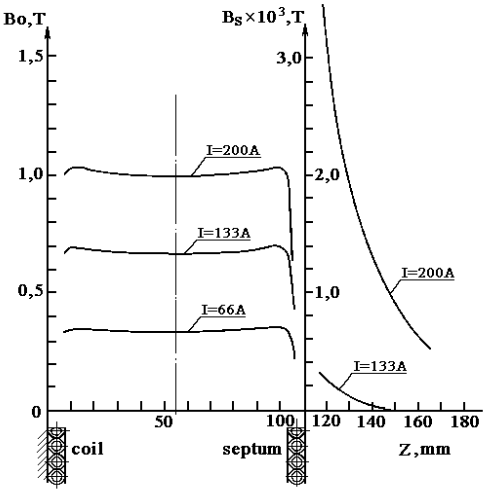

Figure 4: The working and fringing fields in the septum-magnet.

4 KICK ELECTRIC PLATES

A principal scheme and main characteristics of the electric plates are given in Table 2 and Fig.5.

The device of fast voltage removal with a given fall time is the line with distributed parameters: plates as a strip line and a commutating thyratron circuit as a coaxial line. Both lines are matched by wave impedance.

The values of resistance, linked to the thyratron anode circuit, are selected to get a voltage fall smaller than 100 nsec according to the nonperiodic law. A subsidiary scheme was included in the discharge of the high voltage cable.

Table 2:

1.	Nonlinearity of electric field in the working area	$< 1\%$
2.	Voltage on the plates	(40 + 0.4)kV
3.	Discharge time	$< 0.1\mu$sec
4.	Rest voltage for 1msec after discharge	$< 2\%$
5.	Total capacity of the potential plate relative to the ground	280 pF
6.	Total inductance	0.4μH
7.	Wave impedance	37.8 Ohm

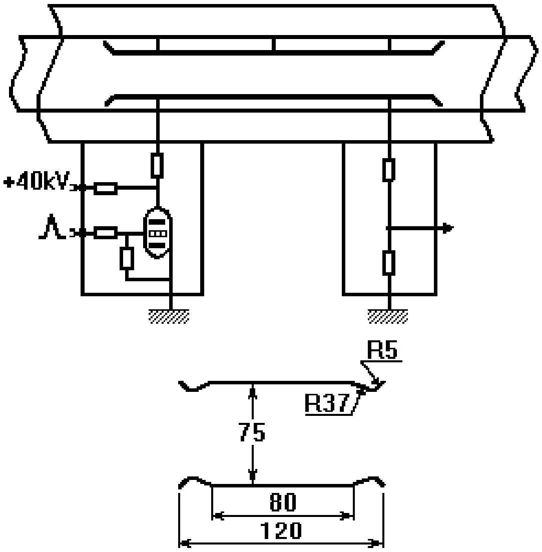

Figure 5: The simplified scheme of the electric plates.

5 DIAGNOSTICS

Faraday cups, beam current monitors, multi-wire collector profilometers, scintillation observation stations and pickup electrodes are used for tunning the injection and first turn of the Nuclotron ring. Intensities of the beams ($> 10^9$) and their profiles are obtained using the collector current profilometers. They are placed at the entrance and exit of the septum-magnet.

The Faraday cup and three collector plates are combined by four observation stations. The sensitivity of the Faraday cups is 10^7 elementary charges/pulse. The transparancy of the first station is about 95%. It is used with another station for the adjustment of the first turn.

Two beam current monitors located in the ring are intended of intensity beam measurements from 0.5 mA and more.

6 CONCLUSION

The first two octants were installed in the tunnel in February,1992, and its cooling down, the 5 MeV/u deuteron injection and transportation through 1/4 of the ring were performed. The total assembly of the Nuclotron was completed in January, 1993, and the first run of cooling and beam circulation were carried out in March 17-26. The first acceleration experiment took place in July, 1993. Then 10 runs were carried out and there were no reclamations for the injection system.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

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