NUCLOTRON: STATUS & FUTURE

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Abstract

The results of operation and development of the first superconducting synchrotron based on 2T cold iron fast cycling SC-magnets are presented. The essential news - beam resonance extraction from the Nuclotron is discussed.

1 INTRODUCTION

The Nuclotron accelerator complex at Laboratory of High Energies is the basic facility of JINR for generation of proton, polarized deuteron (also neutron/proton) and multicharged ion (nuclear) beams in energy range up to 6 GeV/amu.

The Nuclotron was built during 1987-92. This accelerator based on the unique technology of superconducting magnetic system, has been proposed and investigated at the Laboratory. All design, tests and assembling works were carried out at the LHE. Production of the structural cryomagnetic elements was done by the JINR workshops. The first results on the commissioning of the Nuclotron had been presented earlier [1,2].

Basically all of the design parameters have been achieved. Very high reliability of the liquid helium supply and the magnet cooling system were practically demonstrated. Data taking for physics was started at the internal target in 1994. The completion of the construction and first tests of beam extraction system as well as reassembling of the part of the accelerator ring 12 m in length were fulfilled in 1999. Pilot experiments at extracted beam were performed in March this year.

2 OPERATION

Seventeen runs of a total duration of 3930 hours were carried out up to now. Annual running time is limited by real budgetary resources. Total running time includes: cool down ~ 1692 h, the machine development and beam dynamic investigations ~ 1522 h, physics experiments ~ 716 h.

The achieved parameters are presented in Table 1. It should be mentioned additionally that an excellent flexibility of variation both as the accelerated beam energy and the magnetic field flat top duration were obtained. The discrepancy between design and achieved peak energy and repetition frequency is connected with the needed upgrade of a quench detection, power supply and energy dump systems. Sometimes extremely large losses of the beam were observed during the runs in 1994-1997. The reason was the partial local deformation of 0.5 mm stainless steel beam pipe due to the pressure difference between insulation volume of the cryostat and the beam pipe.

Table 1: General parameters

Parameter	Design	Achieved
Accelerated particles	1<Z<92	p, d, α, ^{12}C, ^{84}Kr
Energy, GeV/amu	6 (A/Z=2)	4.2
Magnetic field, B	2.0	1.5
Injection energy, MeV/amu	5	5
Beam intensity	(see Table.3)	
Vacuum pressure, Torr	$1\cdot10^{-10}$	$1\cdot10^{-10}$
Slow extraction	(see Table.2)	
Repetition frequency, Hz	0,5	0,2
Magnets ramp rate,T/s		
at stand tests	4	4.1
at the ring	2	1.0

3 BEAM EXTRACTION

The beam extraction system (BES) of the Nuclotron is intended to eject ion beams over the energy range from the unjection to about 6 GeV/amu. The extraction is realized by the excitation of the third order radial betatron oscillation resonance $Q_x = 20/3$. The resonance is provided by means of two pairs of sextupole lenses while four special quadrupole lenses, installed in the ring, make a shift of the radial betatron frequency from $Q_x = 6.78$ to $Q_x = 6.66$. The particles involved into the resonance cross the operating gap of the electrostatic septum (ES) and after that enter to the Lambertson magnet (LM). The electrostatic septum deflects the beam in horizontal plane at the angle of 5 mrad while the Lambertson magnet should provide deflection of the beam in vertical direction at the angle of 96 mrad. The last parameter was chosen to satisfy both as the needed displacement of a beam under extraction from the yoke of structural quadrupole installed after the LM and needed conjugation of the extracted beam with the existing system of transfer lines inside the experimental area. The main elements of the Nuclotron BES were described in [3]. The ES high voltage part is similar to the used at other laboratories. But in our case it has special design because superconducting electrical buses of the structural dipoles and quadrupoles are passing through its vacuum shell. The LM consist of two sections 1.5 m in length each. The iron yoke is cold and SC-winding made of a tube superconductor cable similar to the Nuclotron. So, the cross-section of the LM and its cryostat system is almost the same as for the

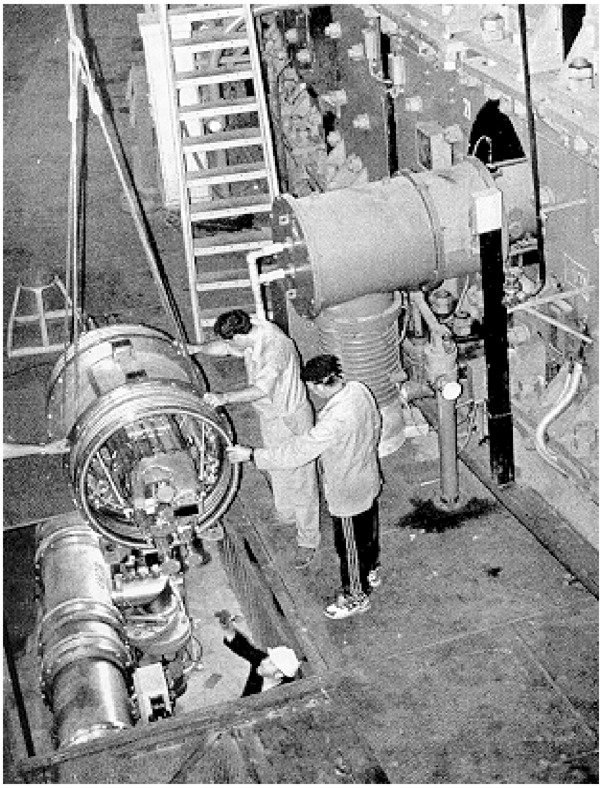

Figure 1: Transportation of the Lambertson magnet section in the tunnel.

structural units (see Fig.1,2). The LM sections are supplied by current in series with structural dipoles. As a result of such connection all the particles entering in the operating gap of the LM at some energy will be extracted from the accelerator if the choice of the LM effective magnetic length was made correctly.

Special power supply connected with the first section of the LM and additional current leads were used to compensate a possible errow of the extraction vertical angle over maximum expected value of ± 6 mrad.

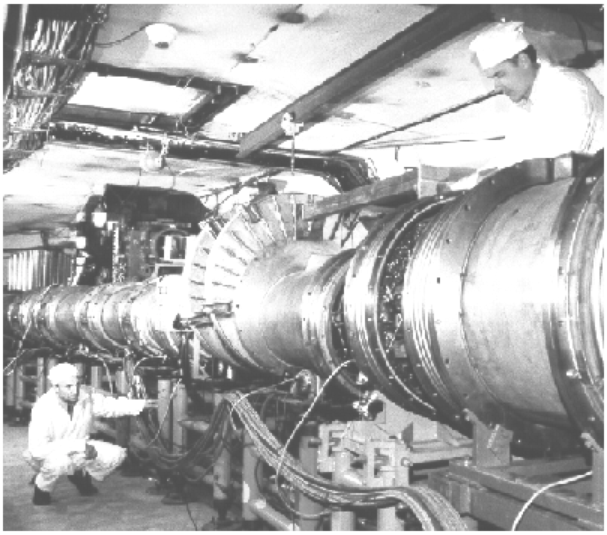

Figure 2: The beam extraction area of the Nuclotron ring.

The results of the BES commissioning are given in more details in the separate paper presented at the Conference. Briefly some of the parameters are shown in Table 2. The time structure of the extracted deuteron beam during the first tests is shown in Fig.3.

Table 2: Nuclotron Beam Slow Extraction

Parameter	Design	Achieved
Energy range, GeV/amu	0.2 ÷ 6.0	0.2 ÷ 2.2
Duration, s	up to 10	0.5
Efficiency of extraction, %		
at 0.2 GeV/amu	90	75
at 2.2 GeV/amu	95	60
Extraction beam intensity, ppc:		
at 0.2 GeV/amu		$3 \cdot 10^9$
at 2.2 GeV/amu		$1 \cdot 10^9$
Extraction angles, mrad		
horizontal	5	5
vertical	96 ± 6	96 ± 1
Nominal ES voltage, kV	200	150
Operating ES voltage, kV	up to 200	up to 40
LM supply current, kA	up to 6.3	6.3
Repetition rate, Hz	1.0	1.0

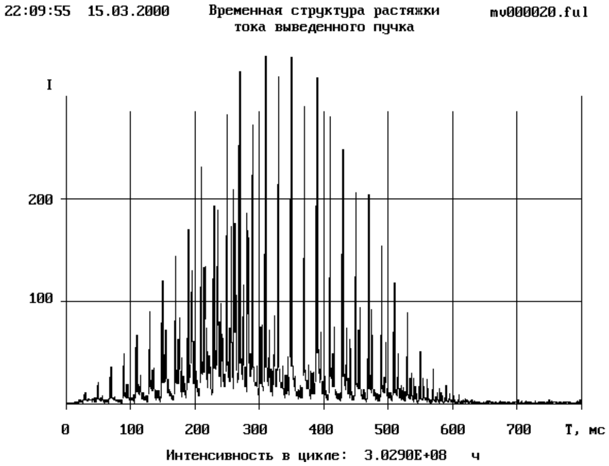

Figure 3: Time structure of the extracted deuteron beam.

A lot of technical and technological problems were solved during the BES construction. In particularly, the possibility of the displacement ± 20 mm in horizontal plane both as the LM and the ES under operating cold state was provided. Search for optimal position of the LM and ES has been performed several times during the test runs in December’99 and in March this year. Now we can conclude that the «hardware» of the Nuclotron slow beam extraction system is put into operation. So, the problem of the beam extraction from superconducting synchrotron is practically solved. Of course, we need make further improvement of the power supply sources, the closed orbit correction, the electrostatic septum operating parameters.

The works have to be carried out before the next Nuclotron run in October are in a progress.

4 FUTURE DEVELOPMENT

The main directions of the Nuclotron development during the nearest years are the following:

- Improvement of the Nuclotron beam slow extraction system.
- Development of the injector complex including ion sources, partial reconstruction of the linac LU-20, technical design and construction work on the Nuclotron booster.
- Upgrade of cryogenic supply, quench detection and energy dump as well as diagnostic, control and r.f. systems.

Some progress earlier mentioned has been reached. In particularly:

- new CO_2 - laser for the laser drived source was designed and constructed;

- reflecting mode of the electron beam ionizer KRION operation was investigated as well as fast extraction (T ~ 30 mks) of ions from the KRION source was obtained;

- peak intensity of polarized deuteron beam from POLARIS ion source was increased by factor of 3;·

- the front section of the LU-20 main cavity was reconstructed to decrease the minimal charge-to-mass ratio of accelerated ions from 0.33 to 0.28;

- conceptual design of the booster ring based on the Nuclotron-type technology was made. (The work is supported by the RFBR grant N.18 400);

- upgrade of the Nuclotron cryogenic supply system is carried out. All designed parameters of the Nuclotron cryogenic system were achieved. The reliability of the system as high as 95%. The average cool down time of the Nuclotron magnetic system (cold mass ~ 80 tons) is 100 hours. About (20 ÷ 25) tons/day of liquid N_2 are usually used during this period. After that the consumption of liquid N_2 is about (12 ÷ 15) tons/day. It can be decreased to (8-10) tons/day by means of special turbines cooled by helium flow instead of LqN_2 at the main refrigerators of liquid He. The set of such turbines was tested in June. The experimental results were closed to the predicted ones.

Construction of the booster will make it possible to increase significantly the intensity of accelerated beams (see Table 3). The cost of the project based on a conventional accelerator technology (published in 1991) was estimated at the level of $3M. It can be decreased to about $1.5M in the case of the Nuclotron technology application. The conceptual design of such accelerator has been made. The period of technical design and construction will take about 3 years after approval of the project.

The maximum energy of the booster is 250 MeV/amu. Multiturn injection of the beams from existing linac in the booster ring will be realized. The system of electron cooling is proposed to minimize the beam emittance. The designed repetition rate of the booster is 1 Hz. More detailed data on the booster design is presented in separate paper.

Table 3: The Nuclotron beams.

Beam	INTENSITY (Particles per cycle)		
	Nuclotron (at present)	Nuclotron + Ion sources development	Nuclotron + Booster
p	$2 \cdot 10^{10}$	$1 \cdot 10^{11}$	$1 \cdot 10^{13}$
d	$2 \cdot 10^{10}$	$5 \cdot 10^{10}$	$1 \cdot 10^{13}$
^{3}He			
^{4}He	$8 \cdot 10^{8}$	$5 \cdot 10^{9}$	$2 \cdot 10^{12}$
^{7}Li		$2 \cdot 10^{10}$	$5 \cdot 10^{12}$
^{12}C	$1 \cdot 10^{8}$	$7 \cdot 10^{9}$	$2 \cdot 10^{12}$
^{16}O			
^{20}Ne		$1 \cdot 10^{8}$	$5 \cdot 10^{9}$
^{24}Mg		$3 \cdot 10^{8}$	$5 \cdot 10^{11}$
^{28}Si			
^{32}S			
^{40}Ar		$3 \cdot 10^{7}$	$2 \cdot 10^{9}$
^{56}Fe			$1 \cdot 10^{11}$
^{84}Kr	$1 \cdot 10^{3}$	$2 \cdot 10^{7}$	$5 \cdot 10^{8}$
^{96}Mo			$1 \cdot 10^{10}$
^{131}Xe		$1 \cdot 10^{7}$	$2 \cdot 10^{8}$
^{181}Ta			$1 \cdot 10^{8}$
^{209}Bi		$3 \cdot 10^{6}$	$1 \cdot 10^{8}$
^{238}U			$1 \cdot 10^{8}$

5 CONCLUSION

New technology of superconducting magnetic system has been tested during the Nuclotron construction and operation. The results obtained can be useful under design of a modern fast cycling superconducting synchrotrons of different applications.

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