INJECTOR COMPLEX OF THE NICA FACILITY

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Abstract

The injector complex of the NICA facility consists of existing Alvarez-type linac LU-20 and new heavy ion linac HILac. The LU-20 is under modernization now, the HILac will be constructed during coming years. Parameters of the accelerators are presented.

INTRODUCTION

General goal of the NICA/MPD project under realization at JINR is to start in the coming 5÷7 years an experimental study of hot and dense strongly interacting QCD matter and search for possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions. The Nuclotron-based Ion Collider fAcility (NICA) and the Multi Purpose Detector (MPD) are proposed for these purposes. The NICA collider is aimed to provide experiment with heavy ions like Au, Pb or U at the kinetic energy range from 1 to 4.5 GeV/u with average luminosity of 10^{27} $cm^{-2}\cdot s^{-1}$ and to provide collisions of light ions in the total energy range available with the Nuclotron.

The goal of the NICA project is construction at JINR of the new accelerator facility that consists of [1]:

- cryogenic heavy ion source of Electron String type (ESIS),
- source of polarized protons and deuterons,
- the “old” linac LU-20,
- a new heavy ion linear accelerator (HILac),
- a new superconducting Booster-synchrotron,
- the existing proton synchrotron Nuclotron,
- two new superconducting storage rings of the collider,
- new set of transfer channels.

Two acceleration and stacking chains of heavy ions and polarized protons and deuterons are pressumed:

- ESIS → HILac → Booster → Nuclotron → Collider
- Source of polarized ions → LU-20 → Nuclotron → Collider

The main elements of the NICA injection complex (source of polarized ions, LU-20, ESIS and HILac) are described in this paper.

POLARIZED ION SOURCE

Presently the maximum achieved intensity of polarized beam in the Nuclotron is about $2\cdot10^8$ particles per cycle. The main direction of work aimed at increase of the intensity is connected with the design and construction of a new high current polarized ion source with charge-exchanged plasma ionizer (IPSN) based on the equipment of CIPIOS polarized proton and deuteron source transferred to Dubna from Bloomington (Indiana University, USA) [2]. The work is carried out in collaboration with INR (Troitsk). Some parts of suitable equipment for the new source were presented by DAPHNIA (Saclay). The IPSN will provide the output beam current up to 10 mA of $\Uparrow d^+$ and $\uparrow p$ ions. $\Uparrow d^+$ ion polarization of 90% of the nominal vector mode +/-1 and tensor mode +1,-2 is expected. That will result in increase of the accelerated polarized beam intensity at the Nuclotron up to above 10^{10} part/cycle.

ALVAREZ-TYPE LINAC LU-20

LU-20 Linac Status

At present time, the injector of the Nuclotron is the Alvarez-type linac LU-20 (Fig. 1), which was built in 1974 as a proton injector with output energy of 20 MeV. Main parameters of LU-20 were presented in paper [3]. LU-20 was originally designed as so-called the $L=\beta\lambda$ Alvarez drft-tube linac (DTL).

Fig. 1. Inner view of LU-20 resonator.

It can also operate in the second harmonic mode as the $L=2\beta\lambda$ DTL allowing acceleration of light ions with output energy of 5 MeV/u, it was experimentally proved that it is also possible to accelerate ions with $Z/A\geq1/3$ ions at increased levels of RF field. In the middle of nineties, the front part of the LU-20 was upgraded in order to ensure acceleration of ions with

$Z/A \approx 0.28$ [4]. At that time, the first 11 drift tubes of LU-20 were replaced by new ones.

LU-20 Parameters for proton acceleration

The linac LU-20 accelerates protons from 600 keV to 20 Mev. Its resonator with the length of 14.4 m and the diameter of 1.4 m operates at the frequency f_0=144.5 MHz and consists of 58 accelerating cells with the length $L = \beta\lambda$.

Fig. 2 shows the parameters of LU-20 for proton acceleration at constant average accelerating field along the resonator of E_0=1.8 MV/m. At connection of 11 upgraded front cells with rest original cells the parameters have some jumps: the gap factor α changes from 0.20 to 0.25; the slightly growing transit-time factor T becomes almost constant; the energy gain ΔW changes its growing rate, and synchronous phase φ after linear growth comes to its constant value.

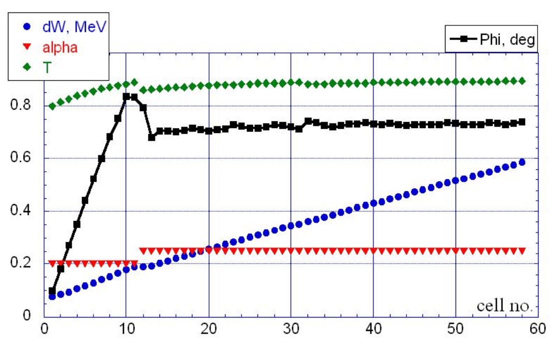

Fig. 2. Parameters of LU-20 vs the cell number.

Upgrade of LU-20 drift-tubes

Due to ageing of LU-20, it is necessary to replace and upgrade its most critical components. It is presently discussed to replace all drift tubes with new ones. Every drift tube of existing linac contains the magnetic quadrupole lens operating in CW mode. To ensure more reliable operation of LU-20, the pulsed magnetic quadrupoles will be used. In the seventies, the cell sizes were approximately calculated with simplified model (R_{int}=0, R_{out}=0) with some available at that time code. Afterwards, precise tuning of the accelerating cells was ensured by tuning rings located on the drift tube outer surfaces. These rings bring a lot of operational troubles.

In order to preserve existing accelerator parameters of LU-20, all longitudinal sizes of the drift tubes are kept without modifications, while other accelerating cell sizes can be varied to adjust resonance frequency of every cell to f_0=144.5 MHz. The cells of upgraded LU-20 have been recalculated with the Superfish-code [5], which simulates axially-symmetrical cells with a real configuration including the drift-tube chamfer radii R_{int} and R_{out}. As results, tuning rings are not needed anymore. As example, a typical sketch of half cell used in numerical simulations with Superfish-code is shown in Fig. 3. The cells of existing LU-20 have a simple cylindrical configuration with α_f=0. This configuration is still assumed for the new drift tubes. The tuning of each accelerating cell to the resonant frequency f_0 is realized by varying the drift-tube diameter d.

At first step, the cells have been simulated with the tuning program DTLfish of the Superfish code, assuming a symmetric location of the gap in the cell. The DTLfish sets up Superfish runs for only half the cell as shown in Fig. 3. The drift-tube diameters for symmetric cells have been calculated at f_0=144.50 MHz. At the second step, the full cells using actual positions of gaps have been simulated with a direct usage of Superfish. The resonant frequencies for full cells are equal to about f_0=144.38 MHz. Such deviation of the resonant frequency is negligible.

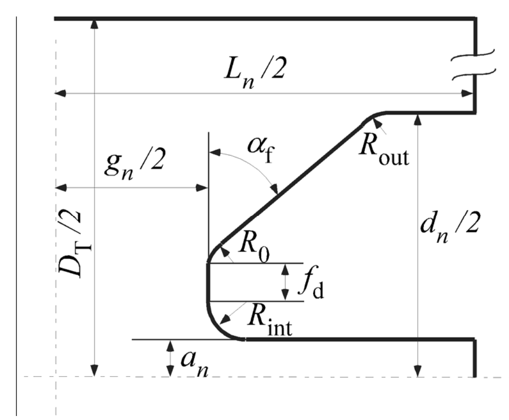

Fig. 3. The DTL half cell set up by the code DTLfish.

Every drift-tube is supported by pair of cylindrical stems of radius R_{stem}=0.04 m. Calculation of the frequency perturbations due to the drift-tube supporting stems have shown that f_0 deviates withing +- 0.2 MHz along the whole structure that is acceptable for LU-20. Another option with conical drift-tubes $(\alpha_f \neq 0)$ allowing unification of magnetic quadrupoles is now under discussion.

ESIS

Electron beam ion sources (EBIS) invented at JINR [6] are used widely in many accelerator centers for production of highly charged ions. In the reflex mode of the EBIS operation the electrons do not reach electron collector after one pass through the drift space of the source. Instead they are reflected back towards the electron gun, where are reflected again near the gun cathode, travel one more to the reflector, and so on. Thus, the electrons are bouncing between the cathode and the reflector of the source and can be used for generation of highly charged ions much as a direct electron beam does.

It was found that in certain conditions the ”cloud” consisting of the multiply reflected electrons confined in a strong solenoid magnetic field exhibits properties similar to a phase transition. It leads to a stepwise increase of the confined electron plasma density in a new steady state called "the electron string". Various highly charged ion beams have been produced with the ESIS “KRION-2” constructed at JINR (Fig. 4) and used in three Nuclotron runs during recent years [7].

Fig. 4. ESIS “KRION-2” operated at JINR.

New stand ESIS “KRION-6T” aimed to achieve parameters required for NICA (Table 1) is under construction now.

Table 1. Main parameters of the ESIS sources

	“KRION-2” achieved to date	“KRION-6T” expected
Magnetic field, T	≤ 3	≤ 6
Electron energy, keV	≤ 8	≤ 25
Ions	Au^{30+}	Au^{32+} (U^{32+})
Ionization time, s	$2{\cdot}10^{-2}$	0.015
Work frequency, Hz	40	50
Number of ions per pulse (at given charge state)	$5{\cdot}10^{8}$	$2{\cdot}10^{9}$
Extraction time, μs	8	6 - 8

RFQ AND RFQ DTL

The RFQ section was chosen as the initial part of the HILac. At low ion velocity RFQ permits a continuous acceleration and perfect adiabatic conditions to produce a very good bunching efficiency (~ 100%).

For the main part of the HILac we considered four versions:

1) Alvarez-type accelerator,

2) an accelerator with the Alternative Phase Focusing (APF),

2) hybrid type of the focusing proposed at GSI,

4) RFQ DTL developed in IHEP (Protvino) [8].

At the moment, *the 4^d version* - RFQ DTL is chosen as the basis for the main part of the HILac design and construction. In operation it is simpler than the Alvarez-type linac, in contrast to the APF structures utilizes focusing by quadrupole components of the RF field and provides a strong focusing in both longitudinal and transverse planes. As result, the maximum ion beam current can reach of about 100 mA. Conceptual design of the RFQ and the RFQ DTL [9] was prepared by the IHEP group (founded by one of the inventors of the RFQ accelerator Vladimir Teplyakov), wich has more than 30 years experience in design and construction of such structures.

The RF in both accelerators - the RFQ and the RFQ DTL - is equal to 75 MHz. The accelerator is designed to accelerate the beam of initial normalized rms emittance of 0.1 π·mm·mrad and the emittance growth during acceleration does not exceed two times. To avoid electron load of the cavity (cold emission) the maximum electric field at the electrode surface is chosen to be limited by the value about 350 kV/cm for RFQ DTL and about 220 kV/cm for RFQ . The accelerator consists of the RFQ section (of the length of about 7 m) and four RFQ DTL sections (of the length of about 5 m). The section number and length are determined by technological reasons. The RF, water cooling, vacuum systems and the beam diagnostics along the accelerator will be designed and constructed on the basis of the IHEP long experience in the design, construction and exploitation of RFQ structures.

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