STATUS OF R&D ON NEW SUPERCONDUCTING INJECTOR LINAC FOR NUCLOTRON-NICA

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Abstract

The new collaboration of JINR, NRNU MEPhI, INP BSU, PTI NASB, BSUIR and SPMRC NASB started in 2015 the project of SC linac-injector design . The goal of new linac is to accelerate protons up to 30 MeV and light ions to ~7.5 MeV/u for Nuclotron-NICA injection. Current results of the linac general design and development taking into account real cavities parameters and technological limitations are presented in this paper. Beam dynamics simulation results in the first SC accelerating section is discussed in detail.

INTRODUCTION

Nuclotron-based Ion Collider fAcility (NICA) is new accelerator complex developing and constructing at JINR [1-4] for ion collision and high-density matter study. NICA complex will consist of operating ion synchrotron Nuclotron and new booster and two collider rings. The injection system is under upgrade now. It includes the old Alvarez-type DTL LU-20. The pulse DC forinjector was replaced by the new RFQ linac which was developed and commissioned by joint team of JINR, ITEP and MEPhI [5] and is operating since December, 2015. It can to accelerate ions of charge-to mass ratio Z/A>0.3. The first technical session of Nuclotron with new injector was ended on May-June, 2016, [6] and two experimental sessions were ended on November, 2016 and on February-March, 2017. The LU-20 with new RFQ forinjector was used for p, p↑, d, d↑, He, C and Li ions acceleration till now. The other heavy ion linac for beams with *Z*/*A*=1/8-1/6 was developed by joint team of JINR, Frankfurt University and BEVATECH and commissioned in 2016.

The possibility of LU-20 replacement by the new superconducting (SC) linac of 30 MeV energy for protons [7-10] and ≥7.5 MeV/nucleon for deuterium beam is discussed now. Project should also include an option of the linac upgrade for the proton beam energy increase up to 50 MeV by means of a number of SC cavities in additional section.

The development of the SRF technologies is the key task of new Russian - Belarusian collaboration started on March 2015. Now the JINR, NRNU MEPhI, ITEP of NRC “Kurchatov Institute”, INP BSU, PTI NASB, BSUIR and SPMRC NASB are participate in new collaboration. Current results of the linac beam dynamics simulation and cavity development are presented in this paper.

NICA SUPERCONDUCTING LINAC GENERAL SCHEME

Superconducting linac will consist of a number of superconducting independently phased cavities and focusing solenoids. Starting 2014 three SC linac designs were proposed, simulated and discussed [7-9]. The normal conducting 2.5 MeV RFQ and five [7] or four [8] SC cavities groups respectively were in the first and the second linac designs. After a number of meetings the linac general layout was modified. The injection energy for SC part of linac is increased to 5 MeV (as LU-20 yields at present). The normal conducting part will now consist not only of 2.5 MeV/nucleon RFQ linac for the acceleration of beams with charge-to- mass ratio Z/A>1/2 but a number of identical normal conducting cavities also for the beam acceleration from 2.5 to 5 MeV. The accelerating RF field was limited by 7.5 MV/m for QWR for all three designs. Contrary to it the peak solenoid field was increased to 2.0-2.5 T and a beam envelope limitation was also increased form 3 to 5-6 mm [9].

Later such parameters were corrected after the design of the 162 MHz and β_g=0.12 QWR was done. The simplest design of QWR with cylindrical central conductor (see below) was chosen to work out fabrication and testing routines. But the peak to accelerating field ratio E_p/E_{acc} for this design is high ~6 and we should use only E_{acc}=6 MV/m of RF field instead of 7.5 and 7.75 MV/m for QWR with β_g=0.12 and 0.21 respectively as it was proposed for the second version of the linac design [8] (the limit surface field should not exceed 35 MV/m). The beam dynamics simulation should be done one more time for the first group of cavities due to it.

BEAM DYNAMICS SIMULATION FOR QWR WITH LIMITED FIELD

The beam dynamics simulation was done using BEAMDULAC-SCL code designed at MEPhI [11-13]. For the chosen types of accelerating cavities and in assumptions noted above the third version of SC linac design was developed and now the accelerator is divided into three groups of cavities with geometric velocities β_G = 0.12, 0.21 and 0.314. The number of cavities in the 1st and the 2nd groups should be increased due to lower accelerating gradient E_{acc} (≤6 MV/m instead of 7.5 MV/m). The beam dynamics of deuterium ions was studied also.

Today the characteristics of the 0th and the 1st groups of cavities in SC linac are shown in Table 1. The slipping factor will be not higher than 24% for proton and deuterium beams here (see Figure 1). The number of QWR cavities in the 1st group should be increased from five to eight both to decrease the accelerating field and to have deuterium ion beam of 7.5-8.0 MeV/nucleon after the 1st group (see bellow). The total length of the linac increases by 1.9 m. The proton beam dynamics in the polyharmonic field was simulated using these parameters. We chose initial beam parameters (Fig. 2, top) that provide particles matching the longitudinal channel acceptance without dissipative effects (blue curve) and taking into account the oscillations decay (magenta curve). Initial beam radius was equal to 6 mm, beam current being not taken into account. Results of the beam dynamics simulation are presented in Figure 2.

The deuterium beam dynamics was simulated later for this version of linac layout. The amplitude of RF field of 5.86 MV/m is quite enough to accelerate deuterons up to energy 8.3 MeV (see Table 1), it corresponds to the project aim and the 2nd and the 3rd groups of cavities can be used in transit regime for deuterium beam. Note that the solenoid field in the 1st group of cavities should be increased up to 2 T for deuterium beam. The deuterium beam dynamics in the polyharmonic field was also simulated basing on the chosen parameters of the 1st cavities group (see Fig. 3). The beam dynamics in the 2nd and the 3rd groups will be studied in the future.

Note that now only one group of QWR is necessary and correct choice of cavities for 2nd and 3rd groups is now under discussion but 2-gap HWR cavities seems preferable because of similar technology with QWR.

Table 1: Current Parameters of the SC Linac for Proton and Deuterium Beams Acceleration

Cavity group	0*	1	0*	1
	Proton beam		Deuterium beam	
β_g	0.12			
F, MHz	162			
T, %	24			
N_{gap}	2			
L_{res}, m	0.222			
L_{sol}, m	0.2			
L_{gap}, m	0.1			
L_{per}, m	0.622			
N_{per}	3	8	3	8
L, m	1.87	4.98	1.87	4.98
E_{acc}, MV/m	4.50	5.86	4.50	5.86
U_{res}, MV	1.0	1.3	1.0	1.3
Φ, deg	–20	–20	–20	–20
B_{sol}, T	1.35	1.3	1.8	2.0
W_{in}, MeV	2.5	4.9	2.5	3.65
β_{in}	0.073	0.102	0.073	0.088
W_{out}, MeV	4.9	13.47	3.65	8.3
β_{out}	0.102	0.168	0.088	0.133
K_T, %	100	100	100	100

* cavities in 0th group are normal conducting.

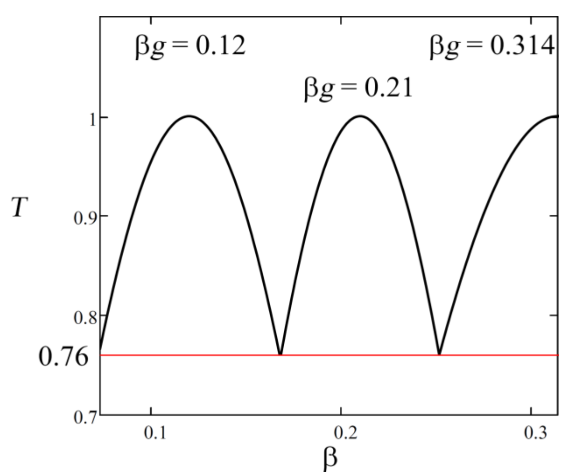

Figure 1: The sliding factor T for proton and deuterium beams.

SC CAVITIES DESIGN

The operating frequency of the linac was chosen equal to 162 MHz for QWRs with further increase to 324 MHz for CH- or Spoke cavities. QWR parameters were simulated (see in more detail [9]). The QWR design for the first group of superconducting resonators and its RF parameters are presented in Figure 4 and Table 2 (detailed QWR design is presented in [14]). Simple design of this prototype satisfies the initial data. In addition, it helps to

ISBN 978-3-95450-182-3

decrease time for fabrication and necessary funding for SRF technology development.

Further the design of the helium vessel and the cryostat was started at the PTI NASB and the SPMRC NASB. The design of the vessel (see Figure 5) includes QWR placed inside, frequency tuning plunger on the bottom of the resonator, two beam ports with flanges, RF load loop, measurement loop, helium and vacuum ports, etc.

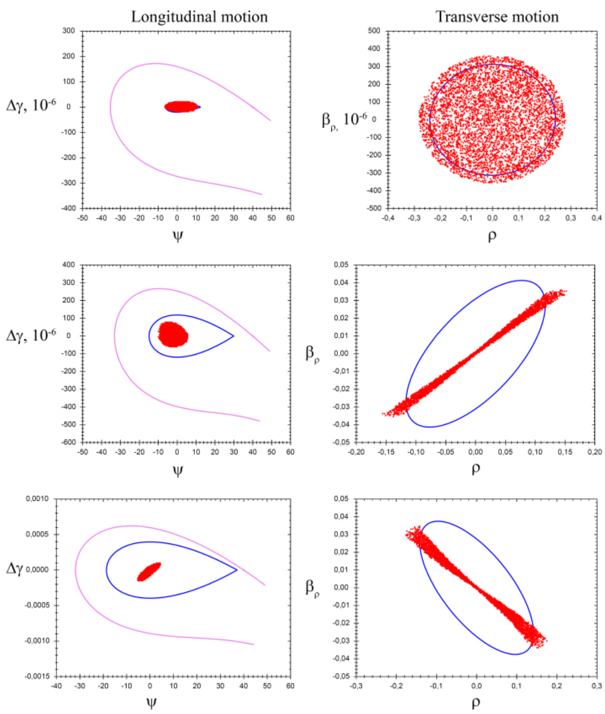

Figure 2: The longitudinal and transverse phase spaces for proton beam (injection and after 0th and 1st sections).

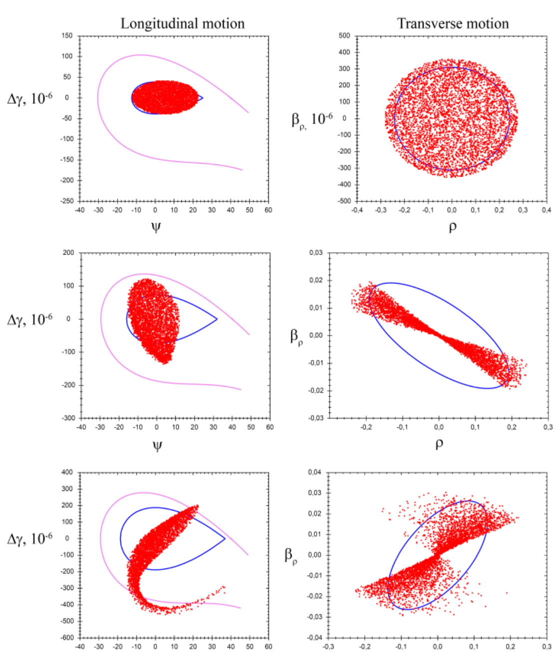

Figure 3: The longitudinal and transverse phase spaces for deuterium beam.

Table 2: RF Parameters of 162 MHz QWR for $\beta_G = 0.12$

Parameter	Value
Geometrical velocity, β_G	0.12
Maximal RF field on the axe, $E_{acc\ max}$, MV/m	6.0
E_p/E_{acc}	6.4
B_p/E_{acc}, mT/MV/m	11.4
Effective shunt impedance, r/Q_0, Ohm	488
Geometric factor, $G=R_s/Q$, Ohm	37
Transit time factor, TTF_0	0.88

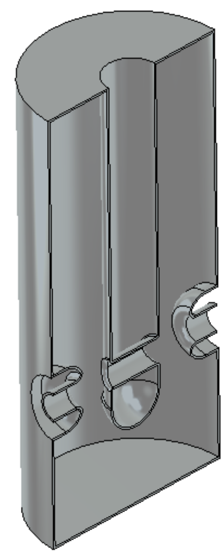

Figure 4: General view of 162 MHz QWR for $\beta_G = 0.12$.

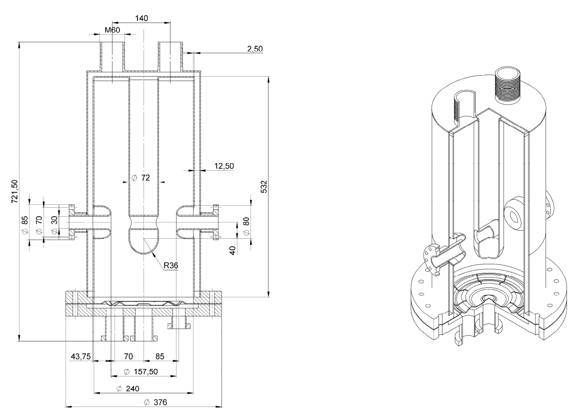

Figure 5: General view of 162 MHz QWR for $\beta_G = 0.12$, RF load loop and measurement loop are not seen.

CONCLUSION

Current results of new SC proton linac development for JINR NICA project were discussed. Beam dynamics simulation and cavities results were presented.

ISBN 978-3-95450-182-3

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