ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO012

COMPACT MULTIPURPOSE FACILITY - BELA

T. Kulevoy[1,2,§], R. Fatkullin[2], A. Kozlov, G. Kropachev, D. Seleznev, A. Semennikov, A. Sitnikov
NRC Kurchatov institute - ITEP, 117218, Moscow, Russia
[1]also at NRC Kurchatov institute , 123182, Moscow, Russia
[2]also at NRNU MEPhI, 115409, Moscow, Russia

Abstract

In ITEP the project of multidiscipline facility Based on ECR ion source and Linear Accelerator (BELA) is started. The injector part of facility is based on combinations of ECR ion source and dc H^+ and He^+ source will provide the multi beams irradiation of the reactor materials for modeling experiments. The cw RFQ and following DTL will enable the set of experimental activity both for fundamental physics and for practical applications.

INTRODUCTION

After long time the mega science project NICA (Nucotron-based ion Collider fAcility) based on the modern accelerator technologies is under development in Russia [1]. In framework of this project national research center "Kurchatov institute" – Institute for Theoretical and Experimental Physics (ITEP) developed the new RFQ for polarized ion program which is inder operation for more than two years [2]. Several other mega-science projects are under discussion in Russia. In Dubna that is the DERICA project (Dubna Electron-Radioactive Ion Collider fAcility). DERICA is proposed as the next step rare isotope beam facility. From the accelerator point of view DERICA will include the driver LINAC-100 (energy up to 100 MeV/u) with the operating mode close to CW, the fragment separator, the re-accelerator LINAC-30 (energy up to 30 MeV/u), the fast ramping ring (energy <300 AMeV), the collector ring and the electron storage ring with an injector. DERICA general concept and first results of LINAC-100 and LINAC-30 general layout is presented in [3]. Another project which is under discussion now is a Spallation Source for neutron generation. The need for a next-generation neutron source is evidenced by the analysis of a specially established ESFRI Physical Sciences and Engineering Strategy Working Group [4]. Several neutron generator is either under operation (IPNS [5], Los Alamos Neutron Science Center [6], ISIS [7], SNS [8] and JPARC [9]) or under construction (ESS [10]).

The NEPTUN project where the high intensity linac and the target from neptunium are used for neutron beam generation is under discussion as a Russian Spallation Source [11].

The main trend of the ion linac are the development of (i) cw RFQ and DTL up to 3-10 MeV/n, (ii) different types of superconducting RF cavities (SCRF) and solid state RF amplifiers (SSA).

Development of cw RFQ and DTL enables the construction of compact devices both for physical researches and industrial application. Today several projects based on compact linacs are under development. First of all it is the IFMIF-EVEDA neutron generator for fission reactor material investigation. The facility is under commissioning in Rokkasho (Japan) [12]. As well it can be mentioned SARAF in Israel [13] , FRANZ [14] in Germany, MUNES in Italy [15] and others.

The project of multidiscipline facility **B**ased on **E**CR ion source and **L**inear **A**ccelerator (BELA) is under development in ITEP. Taking into account the current research activity the facility will provide the experiments for fission and fusion reactor materials investigation, β-nuclear magnetic resonance and semiconductor device modification by ion beams. The technologies developed in framework of this project will be used for serial production of compact facilities based on cw linac for PET, as well as compact neutron generators for BNCT and activation analysis. The further development of the project will lead to construction of Spallation Source and RIB complexes in Russia.

GENERAL LAY-OUT

The general layout of the BELA project is shown in Fig. 1. It consists of injector complex (pos. 1 and 2), proton RFQ, several bunchers and 3-gap DTLs. Such structure enables the material science with ion beams from hydrogen to uranium at injector complex and the semiconductor irradiation by proton beams with variable energy. After the output energy of linac reach the 3 Mev level the neutron generation from lithium target will be started for BNCT and neutron experiments.

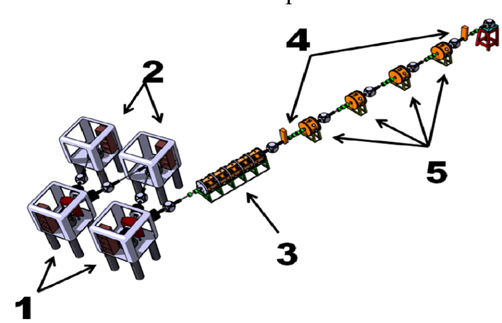

Figure 1: General layout of BELA.

INJECTORS COMPLEX

Injector complex includes several high voltage platforms (HVP) and beam lines connecting them. At HVPs two ECR ion sources are located (pos 1, Fig. 1) and targets (pos. 2, Fig. 1). Ion sources are located at the HVP

§kulevoy@itep.ru

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO012

with positive potential meanwhile targets are located at HVP with negative one. For simulation experiments of material radiation resistance, the heavy ion ECR as well as a proton one are used. Now the imitation experiments are carried out at heavy ion RFQ HIPr-1 [16]. HIPr-1 operates in pulse mode that limits the beam intensity by the irradiated sample temperature instability. To generate the required dpa (displacement per atom) the dc iron Fe^{10+} ion beam generated by ECR will be used with intensity at least 10 eμA and energy up to3-4 MeV. According to estimation it would be possible to provide 100 dpa for three days operation. Simultaneously either the hydrogen or helium ions will be implanted in the sample of the investigation from another ion source located at the second HVP. The ECRs developed in JINR are planned to be used for heavy ion beam generation both for heavy and light ion generation [17]. To minimize the price of the development, the compact ECR will be used at the beginning till the RFQ is manufactures [18] (see Fig. 2). The compact ECR can provide the proton and helium beam with intensity up to 300 μA.

The target used for the experiment has the heating system providing the irradiated sample temperature stability better than 0.2°C in range from room temperature till 700°C during the experiment.

The second target HVP is used for semiconductor implantation experiments.

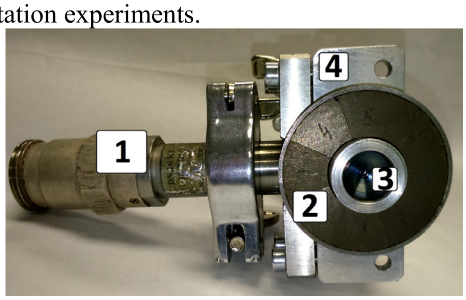

Figure 2: Compact ECR ion source for hydrogen and helium ion beams generation. 1 – RF power input, 2 – ECR magnet, 3 – ion source puller, 4 – support.

RFQ

As an RFQ structure we will use the «shifted coupling window» structure for over than twenty ears [19]. The main advantages of the structure are a high coupling between the RFQ quadrants and the fact that the quadruple mode of fields has the lowest frequency. It provides the high stability of the structure during the operation. That structure was used for single in the world superconducting RFQ in LNL-INFN [20] as well as for RIB RFQ in ANL [21]. The 3D view of the RFQ structure is shown in Fig. 3. The output energy for proton beam at the output of RFQ is 3 MeV. Such energy provides the experiments with neutron beam generation immediately after RFQ start. However the variant with 1.5 MeV RFQ is under discussion now as well. It is the lowest energy required for experiments with semiconductor diods and triods. Providing the radiation damages in the p-n junction it is possible to improve the RF parameters of the semiconductors.

To provide 6D beam matching with RFQ the input buncher is used. As it was shown in [22] the buncher can provide the minimal beam emittance growth along the RFQ as well as the 100% beam transport throughout the RFQ channel with accelerating up to 99% of beam.

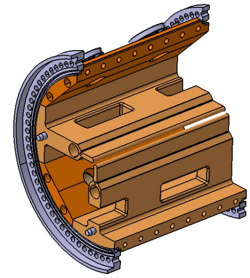

Figure 3: 3D layout for one section of the structure with shifted coupling windows.

DTL

Since the facility have to provide the wide range of proton beam energy the set of short DTL sections with focusing quadruples are used. It enables the beam energy variation at the output of the linac. Some of the section can be switched off so the beam will drift throughout them when the proper magnetic field distribution is set along the linac. Several cavity types were investigated to find the best one for BELA linac. The normal conducting QWR and HWR take too high level of power. The five gap CH and IH resonators have too long focusing period. It results the large diameter of drift tube aperture. As a compromise the three gap IH cavity was chosen (see Fig. 4)

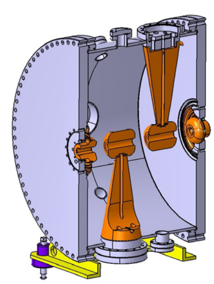

Figure 4: IH three gap resonator for BELA linac.

The preliminary design of linac is shown in Figure 5. The linac parameters are given in Table 1.

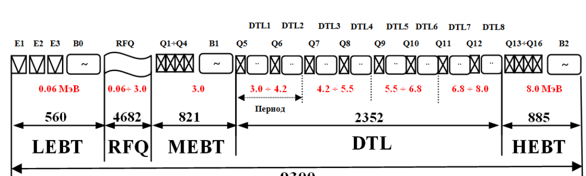

Figure 5: Layout of BELA linac.

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO012

Table 1: Main Parameters for Linac, H^+ Beam of 10 mA

	RFQ	DTL
Frequency, MHz	148.5	
Energy, MeV	0.06÷3	3÷8.0
Beam emittance, π mm mrad	1	
Acceptance, π mm mrad	10	
Max field, Kp	1.6	1.6
Average radius, mm	9	15
Length, mm	4682	2440
Number of sections	1	8
Length of cavity, mm	4682	200
Gap length, mm		40
Phase, °C	-90÷-35	-30
Max focusing gradient, T/m		27
Accelerating rate, MeV/m	0.7	2.1

TIME SCHEDULE

The project has two milestones. At the end of first one with length of 5 year the injector complex as well as RFQ will be under operation. At the end of second stage with length of 2 - 3 years the normal conducting linac with energy up to 8 - 10 MeV will be manufactured, assembled and put under operation. As the following upgrade the superconducting RF cavities will be developed to increase the accelerated ion beam energy. ITEP participates in the common activity for SC RF cavity development in collaboration with JINR, NRNU MEPhI and several Institutes and University from Belorussia [23].

CONCLUSION

In ITEP the project of multidiscipline facility Based on ECR ion source and Linear Accelerator (BELA) is under development. The technologies developed in framework of this project will be used for serial production of compact facilities based on cw linac for PET, as well as compact neutron generators for BNCT and activation analysis. The further development of the project will lead to construction of Spallation Source and RIB complexes in Russia

REFERENCES

[1] G. Trubnikov *et al.*, “The NICA project at JINR”, in *Proc. Int. Particle Accelerator Conf. IPAC2016*, Busan, Korea, May 2016, pp. 2061-2065. doi:10.18429/JACoW-IPAC2016- WEZA02

[2] V. Aleksandrov *et al.*, “Commissioning of New Proton and Light Ion Injector for Nuclotron-Nica”: In *Proc. Int. Particle Accelerator Conf. IPAC2016*, Busan, Korea, May 2016, pp. 941-943. doi:10.18429/JACoW-IPAC2016-MOPOY041

[3] L.V. Grigorenko *et al.*, “Design of LINAC-100 and LINAC-30 for new rare isotope facility project DERICA at JINR”, in *Proc. Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams HB2018*, Daejeon, Korea, to be published.

[4] ESFRI Report, "Neutron scattering facilities in Europe, Present status and future perspectives", ESFRI SCRIPTA Vol.1 Published by Dipartimento di Fisica - Universita degli Studi di Milano, September 2016.

[5] IPSN: www.aai.anl.gov/history/project_pages/ipns.html

[6] LANSCE: http://lansce.lanl.gov/

[7] ISIS: http://www.isis.stfc.ac.uk/

[8] SNS: http://neutrons.ornl.gov/sns

[9] JPARC: http://j-parc.jp/index-e.html

[10] ESS: http://europeanspallationsource.se/

[11] V.L. Aksenov, V.D. Ananiev, G.G. Komyshev, A.D. Rogov, and E.P.Shabalin, “On the limit of neutron fluxes in the fission-based pulsed neutron sources”, *Phys. Particles and Nuclei Letter*, v. 14, N 5, 2017, pp. 788-797.

[12] E. Fagotti *et al.*, “Beam commissioning of the IFMIF EVEDA very high power RFQ”, in *Proc. Int. Particle Accelerator Conf. IPAC2018*, Vancouver, Canada, Apr.-May 2018, pp.2902-2907. doi:10.18429/JACoW-IPAC2018-THXGBF2

[13] N. Pichoff *et al.*, "The SARAF-LINAC project 2018 status", in *Proc. Int. Particle Accelerator Conf. IPAC2018*, Vancouver, BC, Canada, Apr.-May 2018, pp.994-996. doi:10.18429/JACoW-IPAC2018-TUPAK015

[14] C. Wiesner *et al.*, "FRANZ and small-scale accelarator-driven neutron sources", in *Proc. Int. Particle Accelerator Conf. IPAC2015*, Richmond, VA, USA, May 2015, pp.1276-1280. doi:10.18429/JACoW-IPAC2015-TUXB1

[15] A. Pisent, E. Fagotti, and P. Colautti, "MUNES a compact neutron source for BNCT and radioactive wastes characterization", in *Proc. Linear Accelerator Conf. LINAC2014*, Geneva, Switzerland, Aug.-Sep.2014, pp.261-263. doi:10.18429/JACoW-LINAC2014-MOPP088

[16] S.V. Rogozhkin *et al.*, “Effect of irradiation by heavy ions on the nanostructure of perspective materials for nuclear power plants”, *The Physics of Metals and Metallography*, Vol. 113, No. 2, 2012, pp. 200–211.

[17] S. Bogomolov *et al.*, “Recent development in ECR ion sources at FLNR JINR”, in *Proc. Russian Particle Accelerator Conf. RUPAC2012*, St-Petersburg, Russia, Sep. 2012, pp.203-207, doi:10.18429/JACoW-RUPAC2012-FRYOR01

[18] R. Fatkullin, S. Bogomolov, K. Kuzmenkov, and A. Efremov,"Compact 2.45 GHz ECR Ion Source for generation of singly-charged ions", *EPJ Web of Conferences* 177, 2018, 08003.

[19] V.A Andreev and G. Parisi, “90°-apart-stem RFQ Structure for Wide Range of Frequencies”, in *Proc. Particle Acc. Conf.*, Washington DC, May 1993, pp.3124-3126,

[20] A. Pisent *et al.*, “Beam commissioning of the superconducting RFQS of the new LNL injector PIAVE”, in *Proc. Particle Acc. Conf. PAC2005*, Knoxville, Tennessee, May 2005, pp.2696-2698.

[21] P.N. Ostroumov *et al.*, “Development and beam test of a continuous wave radio-frequency quadrupole accelerator”, *Phys. Rev.* ST–AB 15, Nov. 2012, 110101.

[22] A.I. Balabin and G.N. Kropachev, “6D-High Current Beam Matching at RFQ Entrance”, in *Proceedings European Particle Accelerator Conf. EPAC1994*, London, England, Jun.-Jul. 1994, pp.1180-1182.

[23] A.V. Butenko *et al.*, "Status of R&D on new superconducting injector linac for Nuclotron-NICA", in *Proc. Advanced Beam Dynamics Workshop on High-Intensity and High- Brightness Hadron Beams HB2018*, Daejeon, Korea, to be published.