STUDY OF POSSIBILITY OF 600-1000 MeV AND 1 MW PROTON DRIVER LINAC DEVELOPMENT IN RUSSIA

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Abstract

Alternative nuclear energetic's technologies as fast reactors and accelerating driven systems (ADS) are necessary to solve a number of problems as U-238 or thorium fuel reactor and nuclear wastes transmutation. ADS subcritical system should consist of megawatt-power proton accelerator, neutron producing target and breeder. A number of ADS projects are under development in EU, Japan, USA, China, S.Korea at present. Superconducting linacs or their complexes with high energy storage synchrotron are under design in main projects as a megawatt power proton beam driver. In Russian Federation the complex design for accelerator-driver was carried down more than ten years ago.

INTRODUCTION

A number of ADS projects are under development in EU (EUROTRANS including MYRRHA, EFIT, AT-ADS, Trasco ets. [1-2]; MERIT [3]; ThorEA [4]), Japan (OMEGA, KART, [5]), PRC [6], S.Korea (HYPER [7]), India [8], USA [9-10]. The review of main projects was done in [11].

It should be noted that complex study of driver linac in Russia was carried down more than ten years ago in cooperation of ITAP, IHEP and Moscow Radiotechnikal Institute [12-14]. Blanket studies are carried now in IPPI. The new OMEGA project at IHEP which includes a high power 400 MeV proton linac should be also noted.

The new approach to the ADS complex is now under development in framework of the project carried out by collaboration between Russian scientific centers MEPhI, ITEP, Kurchatov Institute. This project was supported in 2013 by the Ministry of Science and Education of Russia. A brief results observation for accelerator part of the project is presented in this paper. It includes accelerator-driver general layout, beam dynamics simulation, electrodynamics simulations of accelerating cavities and analysis of technological background in Russia.

ACCELERATOR-DRIVER GENERAL LAYOUT

The conceptual design of the linac is presented in Figure 1. The linac will consist of an RFQ for beam bunching and low energy acceleration (up to 2 MeV), RF focusing section(-s) for medium energies (up to 30-50 MeV) and SC modular configuration sections for higher energies. SC QWR and HWR were also discussed for 20-50 MeV range. Several different types of RF focusing linacs were discussed for the medium energies. They are RF crossed lenses [15], modified electrode profile RFQ [16], axi-symmetrical RF focusing (ARF) [17]. The conventional modular configuration linac [18] based on spoke-cavities and 5-cell elliptical cavities were designed for high energies. The linac layout has three intermediate energy output beam lines which can be used already during the linac construction to different experiments with neutron production targets or for radiation testing of reactor construction materials.

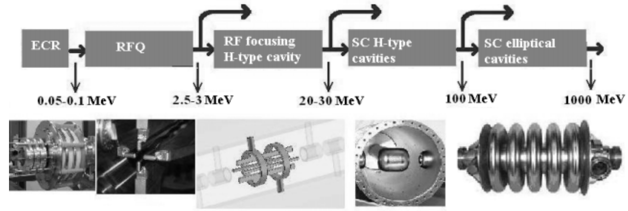

Figure 1: The linac general layout.

Note that such driver linac layout is now conventional and similar designs are proposed in main ADS projects as [1, 2, 6, 7]. The idea to use RF focusing sections for medium energy range is the main difference of our scheme.

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BEAM DYNAMICS SIMULATION RESULTS

The designed 2 MeV RFQ section operates on 162 MHz. The section length is 2.4 m and the accelerating potential between electrodes equal to 120 kV was used [19]. Such potential limit is caused by needs to limit the surface field by 1.2-1.5 of Kilpatrick criterion value for CW mode. The injection velocity is 0.01c. The current transmission coefficient is equal to 96 % for zero current beam and slowly decrease to 94 % for 20 mA.

The different types of RF focusing sections as RF crossed lenses, modified electrode profile RFQ and axi-symmetrical RF focusing were studied for medium energy region with short SC cavities system. Results of beam dynamics simulation were presented in [20-21]. A method of ion focusing in linac by RF decelerating fields of crossed lenses (RFCL) permits to obtain energy-independent focusing strength and high acceleration rate. The RFCL linac having the FOODOO focusing periods was considered and it was shown that the stability of proton motion can be realized for 2-30 MeV energy range. The design parameters are the following: energy 2÷32.64 MeV, operating frequency162 MHz, peak field on surface 250 kV/cm (1.8 Kp), field amplitudes in the accelerating and decelerating gaps 100 kV/cm, focusing period 3βλ (FOODOO), number of focusing periods 8, number of lenses in period 2÷6, pulse current limit 60 mA, acceleration rate 4.4 MeV/m, linac length 7.0 m, normalized acceptance of the RFCL channel is 0.33 π cm·mrad, which is three times more than the beam emittance from the RFQ.

Beam dynamics in ARF section was also studied. It was shown that the rate of the energy gain can reaches to 2.5 MeV/m and section can be very compact. But the transverse emittance growth is very serious (more than 70 % with 10 mA initial beam current).

The modified electrode form RFQ can be also used as the second section to accelerate the beam in 2-15 MeV energy range, averaged rate of the energy gain is equal to 1.3 MeV/m. It should be noted that such sections provide the lowest transverse emittance growth: about 5 % for 1 mA and 70 % for 100 mA.

Beam loses are absent for all three RF focusing types.

The high energy linac section consisting of independently phased SC cavities (spoke and elliptical type) and focusing solenoids was studied. The synchronous phase slipping is the serious difficulty in such linac because it provides to longitudinal stability degradation and energy gain decreasing. The phase slipping factor was limited by 20 % for this project [21]. It was shown that linac should consist of five groups of identical cavities with phase velocities 0.31, 0.36, 0.48, 0.65 and 0.875 (see Fig. 2). First group are 2-gap (or 3-gap) spoke cavities with 324 MHz operating frequency, other groups – 5-cell elliptical cavities operating on 628 or 972 MHz. Total length of SC linac part is 173 m, it consist of 158 cavities. The solenoid fields necessary for focusing not exceeds 2.6 T and the beam loses are absent.

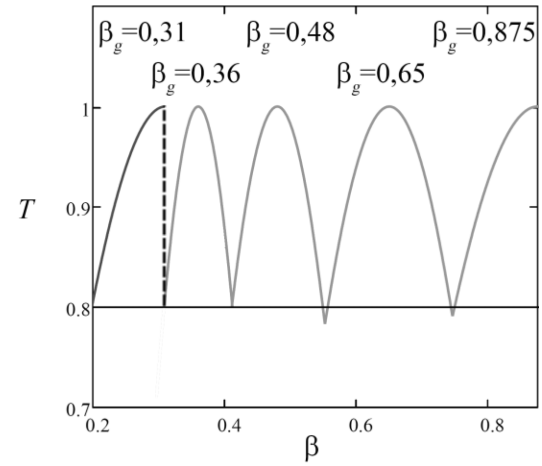

Figure 2: Slipping factor T versus beam velocity β in the high energy stage.

ELECTRODYNAMICS SIMULATIONS OF ACCELERATING CAVITIES

The linac will consist of an RFQ, RF focusing sections and SC modular configuration sections as it was noted above. RFQ and RF focusing section should be realized on CW normal conducting design

The segmented vane RFQ (SVRFQ) with coupling windows was simulated for beam bunching and low energy acceleration. Original modification of elliptical coupling windows was proposed. IH- and CH- cavities were simulated and it's electrodynamics characteristics were optimized. The magnetic coupling windows CH-cavities were studied. The normal conducting cavities design is detailed discuss in [22].

The SC part of developed linac can include spoke-cavities and elliptical cavities and QWR, HWR also if superconducting variant for 20-50 MeV energy range will be discussed further. Medium energy cavities (spoke, OWR and HWR) will operate on 324 MHz and elliptical one on 972 MHz [1, 2]. The detailed discussion of SC cavities electrodynamics simulation is presented in [23].

ANALYSIS OF TECHNOLOGICAL BACKGROUND

All technologies needed for contemporary accelerators construction were developed in our country till 1990th. But large numbers of technologies were lost during 20 last years. The minimal list of technologies which are necessary for accelerator-driver manufacturing are presented in Table 1 and the present state of such technologies at Russia is illustrated. Modern RF power sources and RF superconductivity looks most critically. Only last 2-3 years RF SC technology development starts in JINR [24] and first cavity was designed and manufactured. The design of modern RF sources in Russia is in inchoative stage. Now we also have very serious problem with human resources and there training.

It should be recommended to become accelerator-driver activities immediately and to realize such project step by

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step starting CW RFQ as it was now planning in EU [1], China [6] or India [8] projects.

Table 1: Technological background in Russia analysis.

	R&D	Prototype	Industrial technology
Beam dynamics, engineering design	yes	yes	yes
ECR ion sources	u.d.*	u.d.	no
Normal conducting cavities	yes	yes	u.d.
SRF	u.d.	no	no
Permanent magnets	yes	yes	no
SC magnets	yes	yes	u.d.
Contemporary RF feeding systems	u.d.	no	no
Beam transport	yes	yes	u.d.
Diagnostics and control	yes	yes	u.d.

*under development

CONCLUSION

The brief results observation for high power high energy accelerator-driver design is presented in this paper. Results of beam dynamics simulation, electrodynamics simulations of accelerating cavities and analysis of technological background in Russia are discussed.

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