SUPERCONDUCTING CW PROTON LINAC FOR THE ENERGY OF 1 GeV AND CURRENT OF 2-3 MA - DRIVER OF THE DEMONSTRATION ADT FACILITY

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Abstract

Conceptual design of CW superconducting proton linac - driver of demonstration ADT facility for the power up to 100 MW is considered. Linac scheme and its characteristics are presented. Main system and design scheme of typical cryomodule are described. Concept is developed in the frame of Russian Minatom program on ADT researches.

1 INTRODUCTION

Proton linear accelerator is the base of safe electronuclear power installations. Such ADT are dedicated to various purposes: weapon plutonium conversion, "energy amplifier", transmutation of radionuclear wastes etc.. A set of demands place on accelerators according to its functions. Solution of the tasks of weapon plutonium conversion and nuclear power tasks requires proton beams with energy 1 GeV and average current up to 30 mA.

For essential increase of accelerator efficiency in 1994 MRTI proposed to use superconducting accelerating cavities (SAC). On the base of these proposal it has been demonstrated that SAC linac for the energy of 1 GeV and current of 30 mA has unique performances: radiation-free installation with efficiency higher than 50% and cost of about 160 M$.

At the moment there are no problems of fundamental nature in such linac construction. That is way the main problems have economic and technical aspects [1, 2]: it is necessary to have high economic efficiency (total electric efficiency ~ 50%), high reliability (exploitation factor not less than 85-90%) and radiation purity, linac design have to permit modernization with changing of beam performances demanded, linac design have to be optimize for manufacturing costs and exploitation charges, linac design have to apply perspective methods and materials tested in actual practice.

In October 1998 the Russian Minatom decided to initialize ADT research program [3]. The first stage of the program includes among other things conceptual design of the demonstration ADT facility based on 1 GeV 1-3 mA proton linac and 50-100 MW sectioned blanket. Conceptual design of CW superconducting proton linac - driver of demonstration ADT facility is considered below.

2 MAIN STATEMENTS

The following statements are used in the design of CW superconducting proton linac for the energy of 1 GeV and current up to 3 mA.

Reliability: low voltage injector (100 keV), low beam losses (10^{-5}), CW mode, decrease number of RF channels, functional control; reserve of RF channel.

Radiation purity: beam losses are not higher than 10^{-5} because of acceptance reserve of accelerating-focusing channels.

Economical efficiency: superconducting cavities in main part, short length because of high accelerating rate, apply klystrons with high efficiency.

It is demonstrated that for linac with the current of 1-3 mA (and 30 mA) it is appropriate to use mixed version: “warm” accelerating cavities (RFQ and DTL) are used up to 50 MeV, further – practically tested superconducting cavities with high accelerating gradient of 15 MV/m are used. In this case design realization is simplified and economical performances vary only slightly.[1]

Subprogram data for CW linac with SAC for the energy of 1 GeV and current of 3 mA is presented below. Subprogram propose to manufacture in short notice new type linac to gain experience on design of high-current linac with SAC for high energy and high proton (ion) beam intensity suitable for ADT. Main technique decision will be tested as well.

3 LINAC DESIGN AND PERFORMANCES

Linac consist of three parts:

- Initial part — RFQ structure, accelerating field frequency $f_1 = 352$ MHz, proton energy - from 100 keV to 5 MeV,
- First part — three DTL cavities, frequency $f_1 = 352$ MHz, proton energy -from 5 MeV to 50 MeV,
- Main part (95% of proton energy gain) consists of axially symmetric cavities with elliptical shaped cell excited at the frequency

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[1] It should be noted that ITEP continues to investigate superconducting cavities with few gaps number for first accelerator part.

f_2 = 1056 MHz. (Consideration on cell number in cavity will be presented below).

Odd frequencies ratio $f_2/f_1 = 3$ allows if necessary simultaneous acceleration of proton and negative hydrogen ions. RFQ structure and DTL operates at room temperature. Cavities of main part are cooled to 2K by liquid helium.

RF system of main accelerator part is based on the scheme presented at the fig.1.

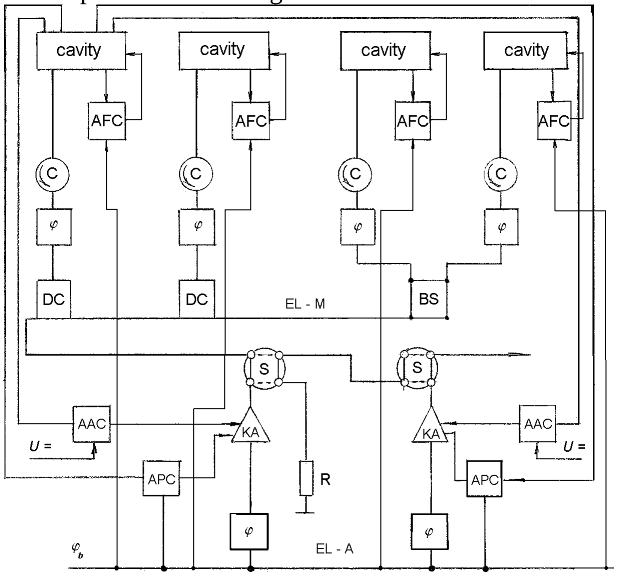

Fig.1. RF Supply Scheme for Cavity Set
of SC Accelerator Main Part.
(with automatic control system and redundancy)

EL-A – exciting line of accelerator, EL-M – exciting line of cavity, DC – directional coupler, BS – bridge splitter, S – switcher, φ - phase control, C – circulator, R – load, AFC – automatic system of frequency control, AAC - automatic system of amplitude control, APC - automatic system of phase control, KA – klystron amplifier

To decrease the number of RF amplification channels the cavity group is excited from one klystron channel through directional coupler. The cavity group number is decreased from 16 to 7. Cavity automatic control system is based on the classical scheme [4]. Cavity tuning and slight correction of accelerating field phase is accomplished by phase measuring element. It measures cavity RF signal phase in reference to base phase signal. Stabilization of RF field amplitude in cavities group is accomplished by AAC system by way of klystron electrode (anode) control. In the case of klystron amplification channel breakdown alternate amplification channel is put into operation with the help of switcher S.

Accelerator main part consists of the short SAC set. So it is possible to simplify technique of cavities design and manufacturing. Total cavity set can be grouped including identical cavities. Accelerator efficiency decrease will be the consequence of this unification.

Let us consider the possible versions of main part channel consisting of identical cavities. Let us assumed that ratio of minimal accelerator efficiency to maximal one in one group is 0.8:1. This ration increase leads to decrease of size type number and simultaneously to accelerator efficiency decrease and vice versa.

For comparison let us consider two channel: first one includes 5-cell cavities and second one - 9-cell cavities.

5-cell cavities channel: range of β possible change in one group is 0.88 β_s - 1.18 β_s. So in the energy range from 100 to 1000 MeV we obtain 3 size types

W_{ini}	W_{int}	W_f
100	136	210
210	303	549
549	1050	

With mean cavity field of 15 MV/m the cavity number in each group is 31, 72, 71 respectively (total number is 174), the mean energy gain in one cavity of each group is 3.5, 4.7, 6.3 MeV respectively.

9-cell cavities channel: range of β possible change in one group is 0.93 β_s - 1.09 β_s. So in the energy range from 100 to 1000 MeV we obtain 5 size types

W_{ini}	W_{int}	W_f
100	119	147
147	178	224
224	277	364
364	472	678
678	1011	

With mean cavity field of 15 MV/m the cavity number in each group is 7, 11, 16, 32, 28 respectively (total number is 94), the mean energy gain in one cavity of each group is 5.96, 7.0, 8.22, 9.65, 11.3 MeV respectively.

Accelerating channel consisted of different cavities (the number of size-types is equal to cavity number) with the same mean field of 15 MV/m and the same mean equilibrium phase consists of 76 9-cell cavities.

Since size-type number decrease leads to manufacturing simplification, but concurrently leads to real acceleration rate decrease, it is necessary to chose optimal version as trade-off of first against second conditions.

At present, design with 5 group of 9-cell cavities with mean field of 15 MV/m for the energy range from 100 MeV to 1 GeV is considered as base one. Various SAC versions are considered for the 50-100 MeV energy range. SAC with 4-5 elliptical-shape cells ($3\beta\lambda/2$ accelerating period) is considered as well.

At present, experimental cryo-module design for investigation of main part SAC was developed. Cryo-module general overview is presented at the fig.2.

The main parameters of demonstration ADT driver linac are listed in the table.

Main technical decisions of this cryo-module are supposed to use for linac cryo-module. Design with SAC group placed in cryo-module and excited by one 400 kW klystron is considered. 1.3 MW klystrons are used for RFQ and DTL parts.

Parameter	Initial Part	First Part	Second Part
Temperature, K	300	**300**	2
Injection energy, MeV	0.1	5	50
Output energy, MeV	5	50	1000
Accelerating rate, MeV/m	0.7	0.85	5-12
Number of resonators	1	3	~100
Acceptance, specified, π cm·mrad	0.27	2.0	1-1.2
Effective emittance, specified, π cm·mrad	0.07-0.1	0.1-0.15	0.15-0.2
Phase length, degree	360-36	36-20	60-20
Pulse spread at output, %	±0.32	±0.1	±0.04
Resonator length, m	7.2	18	0.41-1.1
Diameter of resonator, cm	20.2	56.0	29-26
Aperture diameter, mm	5	20	30
Part length, m	7.2	55	180
Power for beam, kW	15	135	2850
Heat removed by helium, kW			12

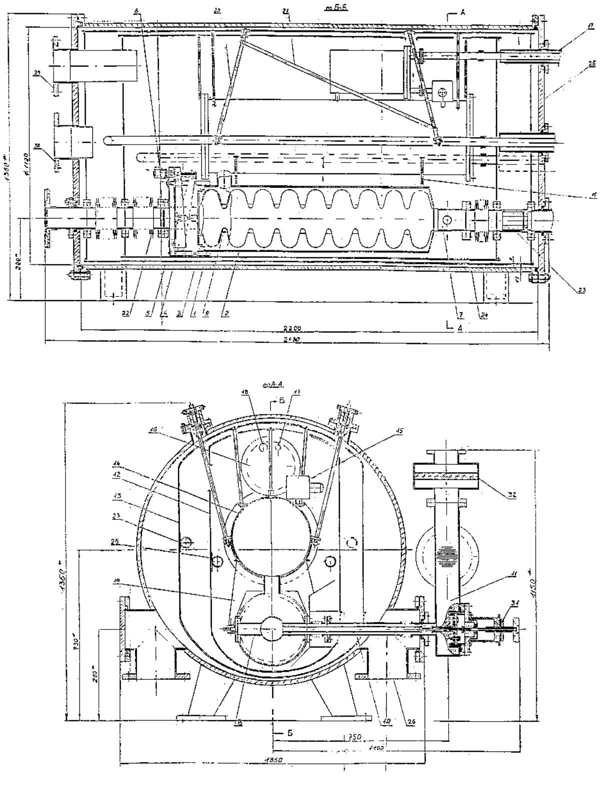

Fig.2. Experimental Cryo-Module Design.

1 - SC cavity, 2 - helium container, 3 - bellows, 4 - mechanical lever, 5 - ACF mechanism, 6 - step-by-step motor, 7 - transit pipe branch, 9 - ring, 10 - RF power input, 11 - coaxial-waveguide transition, 12 - radiation screen, 13 - heat screen, 14 - double phase 2K helium tank, 15, 16 - controlled constrictor and heat exchanger of overcooled liquid helium from 4.5K to 2K, 17 - 4.5K liquid helium, 18 - 4.5K gaseous helium, 22 - bellows, 23 quadrupole lens, 24 - vacuum enclosure, 25 - end cover

4 CONCLUSION

In the nearest perspective manufacturing and investigation of experimental 2K cryo-module of main part SAC becomes the main challenge in parallel with further efficiency, reliability and cost optimization of accelerator scheme, improvements of beam dynamic simulation codes, design and investigations of main part cavities, RF and control systems.

Proton linear accelerator for the energy of 1 GeV and current of 3 mA is scheduled to be manufacture in seven years after start. Design and manufacturing of demonstration linac makes it possible to test principal and technological decisions for new type of SC proton linac. Its will be used for design of industrial proton SC linac for the current of 30 mA and beam power of 30 MW.

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