HIGH POWER PROTON LINACS FOR DIFFERENT APPLICATIONS

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Abstract

High power proton linacs for different applications are considered. CW proton linac with output energy 1 GeV and beam current 10-30 mA is proposed for power production during weapon plutonium conversion inside thorium circle. The accelerator for APT (the Accelerator Production of Tritium) Project is a 100 mA CW proton linac with output energy of 1500-2000 MeV. Depending on the tritium production capacity a 250-300 mA CW proton linac with output energy of 1000-1500 MeV also may be used. The last one can be used also for Accelerator-Driven Transmutation Technology (ADTT) as a possible means of destruction of nuclear waste and of generating nuclear power. Conceptual design of CW superconducting proton linac - driver for ADT demonstration facility for the beam power up to 100 MW is considered. Linac layout, main systems and typical cryomodule are described.

1. REQUIREMENTS TO PARAMETERS OF ION BEAMS FOR ELECTRONUCLEAR TECHNOLOGIES

In essential extent the optimum energy of accelerated protons in electronuclear installations is determined by energy cost of the neutron released. According to experimental data (see ref. in [1]) the optimum energy of accelerated ions turns out to be in the range of 1,0-1,2 GeV. Insofar as accelerated proton beam intensity is concerned, it is conditioned by those electronuclear technologies, for which an accelerator is designed. Such technologies are:

- accelerator-based breeding (production of U^{233});
- processing of weapon grade Pu;
- production of tritium;
- reprocessing of accumulated nuclear economy waste;
- production of electricity and heat;
- creation of high-flux neutron fields (~10^{16}/cm^2 s).

The proton beam current value to be accelerated is determined by the rate with which a technology process proceeds. Really, currents, which might be needed for AT, are in the range of 10-300 mA. A wish to make use of lower intensities is natural, because an acceleration of large currents causes a complication of accelerators, especially owing to rising the absolute value of an ion loss. The excessive ion loss results in serious problems when designing accelerators as well as in a necessity to develop novel technology systems of acceleration, having a big current carrying capacity. The minimum current of 10 mA might be acceptable for slightly subcritical "energy amplifiers", proposed by Rubbia et al. [2], but much higher intensities are required if AT is suggested for other electronuclear processes, e.g., for processing the huge bulk of accumulated fission products from NNPs. Besides, it is known [3], that the neutron utilization factor in a blanket decreases perceptibly as its effective multiplication factor k_{eff} increases to values of 0.97-0.99, i.e., as the spallation neutron source intensity (or proton beam power) diminishes. Therefore, from the standpoint of a technological process applied and a possibility to increase its proceeding rate, it would be more expedient to design accelerators for the future AT for currents of the order of dozens or even hundreds mA, choice of an exact value being conditioned by features of a task posed. Thus, requirements to parameters of accelerated ion beams can be formulated as follows:

a) a type of particles: protons or deuterons;

b) energy of accelerated particles: 1,0-1,5 GeV per ion;

c) beam intensities: 10-300 mA, depending on character of a problem to be solved with AT.

2. MRTI ACTIVITIES IN ACCELERATOR DESIGN

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 [4,5]: 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 [6]. 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.

3. 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

Subprogram 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 f_2 = 1056 MHz. (Consideration on cell number in cavitie 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.

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. 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.

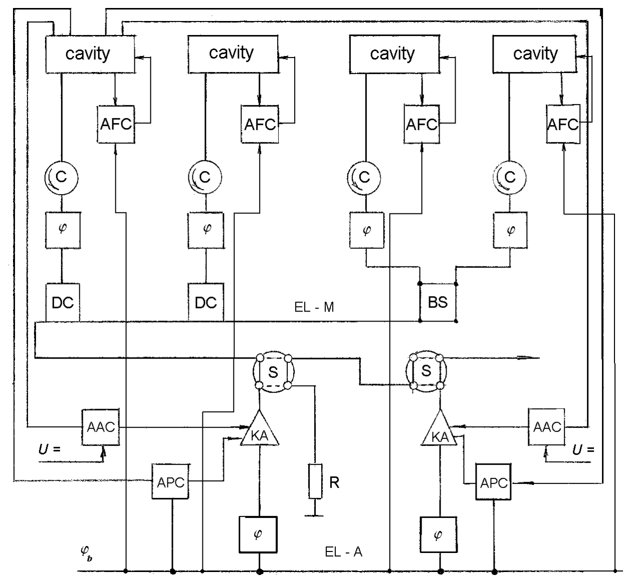


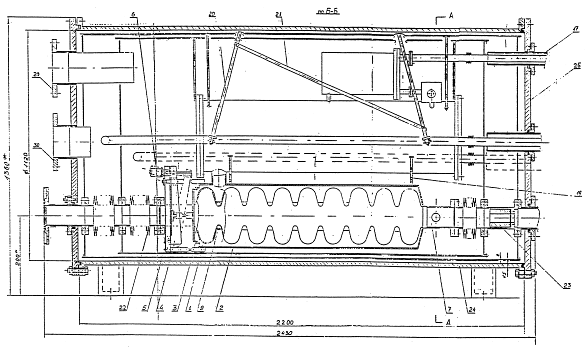
Fig.1. RF Supply Scheme for Cavity Set
of SC Accelerator Main Part.
(with automatic control system and redundancy)
EL-A – exciting line of accelerator, EL-M – exciting line of cavity, DC – directional coupler, BS – bridge splitter, S – switcher, φ - phase control, C – circulator, R – load, AFC – automatic system of frequency control, AAC - automatic system of amplitude control, APC - automatic system of phase control, KA – klystron amplifier

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.

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 ($3b\lambda/2$ 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.

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.



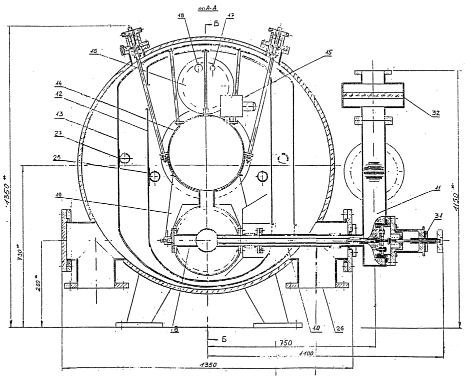


Fig.2. Experimental Cryo-Module Design.
1 - SC cavity, 2 - helium container, 3 - bellows, 4 - mechanical lever, 5 - ACF mechanism, 6 - step-by-step motor, 7 - transit pipe branch, 9 - ring, 10 - RF power input, 11 - coaxial-waveguide transition, 12 - radiation screen, 13 - heat screen, 14 - double phase 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.

REFERENCE

[1] G.I.Batskikh, B.P.Murin, I.V.Shumakov, R.G.Vassil’kov, Prospects of Development of Proton Linear Accelerators For Electronuclear Power Industry and Transmutation, MRTI Preprint No 9701, Moscow, 1997.

[2] Carminati F. et al., An energy amplifier for cleaner and inexhaustible nuclear energy production driven by particle beam accelerator, CERN/AT/93-47, 1993.

[3] Kochurov B.P., The influence of external neutron source intensity in accelerator/target/blanket system on conversion ratio and fuel cycle, *ADTT-94*, Las Vegas, NV, p.777.

[4] O.V.Shvedov, Yu.Ya.Stavisski, B.P.Murin, B.P.Kochurov, Yu.N.Shubin, V.I.Volk, P.V.Bogdanov. Weapon plutonium in accelerator driven power system. In "Joint United States/Russian Plutonium Disposition Study". pp A1-A60, September 1996.

[5] G.I.Batskikh, B.P.Murin, O.V.Shvedov. “Weapon Plutonium in Accelerator Driven Power System”, In: Proceedings of ICENES’98, Tel-Aviv, Israel, June 28 – July 2, 1998, p.475.

[6] V.N.Mikhailov et al. Russian Minatom Program on ADT Researches. Proceedings ADTTA'99, June 7-11, 1999, Praha, Czech Republic.