TESTING OF NEW 2 MeV RFQ AND PERSPECTIVE OF 433 MHz LINAC FOR APPLIED PURPOSES

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Abstract

A new 2 MeV 433 MHz RFQ has been built and tested with proton beam up to 15 mA. It has been fabricated from AMG-6 aluminium alloy and installed instead of previous 1.8 MeV RFQ. The results of frequency adjustment and field alignment are presented. There are significant improvements in field distribution and beam emittance of output injector in comparison with 1.8 MeV accelerator data. Simultaneously the working out of alternate phase focusing (APF) structure with input energy 2 MeV and output one 11 MeV was continued. Theoretical and experimental researches connected with different applications of 2 MeV linac or 11 MeV tandem RFQ and APF linacs are carrying out at NPK LUTS of the Efremov Institute last years. Methods and devices of elemental analysis and contraband detection system for 2 MeV linac and use of 11 MeV tandem for PET-system or as part of a big linac are discussed briefly.

1 INTRODUCTION

Since 1990 Linear Accelerators and Cyclotrons Division of the Efremov Institute (NPK LUTS) makes researches to create compact rf linear ion accelerators which may use as part of different complexes for applied purposes. Different output devices are worked out too. Choice of the working frequency is 433 MHz. There are five directions of researches:

- elemental express-analysis of materials or environment;
- contraband detection system (in particular detection of explosives and fission's);
- PET-system with ion rf linac;
- transported safe atomic station with undercritical nuclear reactor controlled by ion rf linac;
- rf linac as injector for medical proton synchrotron.

If one mean to use accelerated protons for all over these cases required range of final energies is from 2 up to 100 MeV.

2 ELEMENTAL ANALYSIS AND CONTRABAND DETECTION SYSTEM

Each of system consists of ion injector, 433 MHz RFQ, 433 MHz RF system, injector feed system, fast measuring and processing complex. Description of injector, RFQ and RF system was given in paper [1].

Neutron activation's analysis is used for express-analysis of environment. Maximal effect may be achieved by application of bicyclical registration method. Neutrons are produced by $Li_3^7(p,n)Be_4^7$ reaction and they are used as source of activating radiation. Pulsed sequence of radiation repeats sequence of accelerator's pulses. Tested sample, block of target change, neutron radiation monitor and semiconductor detector of induced g-ray are placed inside of interaction's chamber. There are two regimes of elemental analysis. Registration of short-lived isotopes (half live time $10^{-4}...10^{-3}$ s) is produced between current pulses of accelerator. For determination long-lived isotopes is used standard neutron activation method. Detector is defended by protective gear from directed action of ionized radiation. Detector is blocked when neutron radioactive activation and thermolysation take place. Data process and spectral analysis are produced between blocking pulses. Sensitivity of different elements is $10^{-4}...10^{-9}$ g/g. This method may be used for element analysis of isotopes that have atomic masses from 9 to 209.

Scheme of contraband detection complex is shown on fig.1. Explosive's detection is based on g-ray registration which is induced by non-elastic scattered fast neutrons and registration of induced activation on nuclei of specific elements (N,O,C) as result of thermal neutron capture. Fission's are registered by measuring of temporal neutron spectra. Specific change of neutron radiation's parameters permit to determine fission in observed object.

2 MeV RFQ is need for these purposes. In period 1993...1997 two RFQ had been fabricated and tested on laboratory stand at NPK LUTS. First of RFQ was fabricated from alloy D16. It had output energy 1.8 MeV. Results of it's tests were given in paper [1]. Second one was fabricated from aluminium alloy AMG-6, it's output calculated energy is 2 MeV. It was supposed to electroplate cavity's inner surfaces by copper but this plan was not fulfilled because financial and organizational prob-

lems. Testing of AMG-6 alloy RFQ showed correctness it's fabrication and tuning. Eigenfrequencies and field distributions of their oscillations in cavity were according to calculations ISFEL3D code [2]. Measuring of electrical field z-component along longitudinal axis showed accordance amplitude's meanings to theoretical meanings of effectiveness q. Field symmetrization of resonator's quadrants was better then 2%. Irregularity of field distribution along z-axis was less then ±2%. Convergence geometric and electromagnetic axes were less then 30 mkm along z. Dependencies of full current and energetical spectra on voltage vane were according to dynamics calculations although maximal beam energy was less then 2 MeV because bad quality of AMG surface and therefore additional electron load [3].

A new original 2 MeV RFQ is worked out now. Resonator is dismountable parallelepiped which has four rigid walls and two bottoms. Four copper vanes are placed inside parallelepiped together with plattings which are welded to vanes. Reliable mechanical contacts join the platting. Cavity's hermetization will be proved after receiving of geometric and electrodynamical parameters.

3 PET-SYSTEM

PET-system need accelerated protons of 11...16 MeV energy to produce four types of isotopes C^{11},N^{13},F^{18},O^{15}. It is evidently that first stage of accelerator is 2 MeV RFQ. But acceleration from 2 up to 11 or 16 MeV will be realized by accelerating structure with drift-tubes and crossed transversal holders (CTH) which was described in [2]. Distribution H-field of working type oscillation look like H-field in four-chamber's RFQ. CTH-structure have high shunt-impedance in energetical diapason from 2 up to 15 MeV. It is possible to use the same scheme of RF feeding for CTH-cavity as for RFQ. Using alternate phase focusing in CTH-structure permit to manage without magnetic lenses inside drift-tubes. Other advantages of this type resonators were described in [2]. If they are used as second stage accelerator and have the same working frequency as RFQ therefore here is not big problems to match RFQ then CTH-structure. 433 and 866 MHz CTH-cavities were successfully tested at NPK LUTS laboratory stands.

Required for PET's target and chemistry modules may be designed and fabricated by Efremov Institute and Main Science Research Radiological Institute at St. Petersburg in cooperation.

4 SAFE ATOMIC ENERGETICAL INSTALLATION

At the last time proposals to use accelerator as driver of under-critical reactor are discussed by many scientists. As rule there are considered schemes with big accelerators [4]. Their output beam power may be several megawatts or several tens of megawatts. Such power are need for driving of reactors with thermal power in few gigawatts. In these works cyclotrons are proposed to use as drivers. Output energy of these accelerators is supposed from 0.4 to 1 GeV. Aspiration for big accelerator drivers is explained by wish to obtain sufficient energetical gain (relation thermal power of reactor to beam power) 30 and higher. But for transported atomic installations main factor is safety. Their power may be several hundreds of megawatts. For example thermal power of transported station with ship reactor KH-3 is 300 MW. Therefore it may appear profitable that such energetical installations will be controlled by compact rf linac with about 300-500 kW beam power.

Comparison of electron, proton and deuteron beams as producers of neutrons under different targets was made in paper [5]. For produce the same quantity of neutrons power of the electron beam must be much more (approximately on order) then power of ion beams. On other hand efficiency of deuteron beam as neutron producer for energies more then 50 MeV just a little higher then proton beam one. Fabrication and exploitation of deuteron linac will be more expensive then proton linac. Therefore, best choice is proton rf linac as driver. Here is considered scheme of proton linac as energetical amplifier for reactor which works on high-enriched uranium 235. Following factors determine main parameters of accelerator. With energy's growth number of neutrons which are produced by only accelerated particle on target of total absorption are increased and compromise choice of final energy against average beam current is determined by allowable accelerator clearance and accelerating structure's acceptance which permits to pass required current without loss. For transported atomic station with thermal power 300 MW maximal proton energy 80-100 MeV will be good practice. Total density of neutron flow which proves normal working of reactor must be about 10^{14} neutron/sec$\times$cm^2. Average linac current 3-5 mA is according to this flow density.

Accelerator-driver must be compact enough to work with reactor inside the compartment of limited sizes. 80 MeV proton linac with working frequency 433 MHz satisfies this condition. RFQ is used as first stage of accelerator which is accelerating particles up to 2 MeV and permit to capture about 100% ions into acceleration. For acceleration from 2 up to 10 MeV may use CTH-structure and alternate phase focusing. Modification of CTH-structure which has focusing magnetic lenses inside some of drift-tubes is used for acceleration from 10 up to 50...80 MeV. Pulsed mode must be used instead of CW-mode because scattered power inside cavity's walls will be too big to prove reliable thermal regime for CW-mode. If duty circle is 0.1 wall scattered power density will be 2 W/cm^2 and required cooling one may proves. It is expediently to build up RF system multisectioned accelerator as separate amplificating lines. Dividing of RF power is made on low level. As output amplifier of line may be used klystron or endotron type devices to prove parameters

output pulse power 350-400 kW
average power 40 kW
pulse length 60 mks

Scheme of key blocks of accelerator-driver where is supposed dividing of the beam into seven ones before injection to reactor is given on fig.2.

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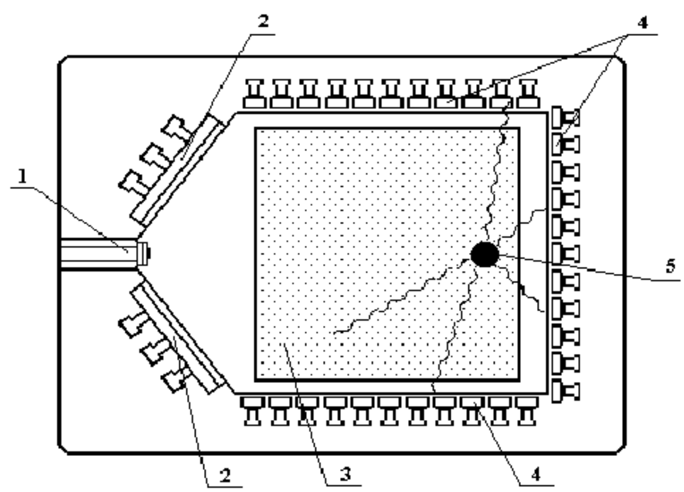

Figure 1: General view of contraband detection system. 1-target; 2-fission detection system; 3-investigated object; 4-explosive detection system; 5-location of fission or explosive.

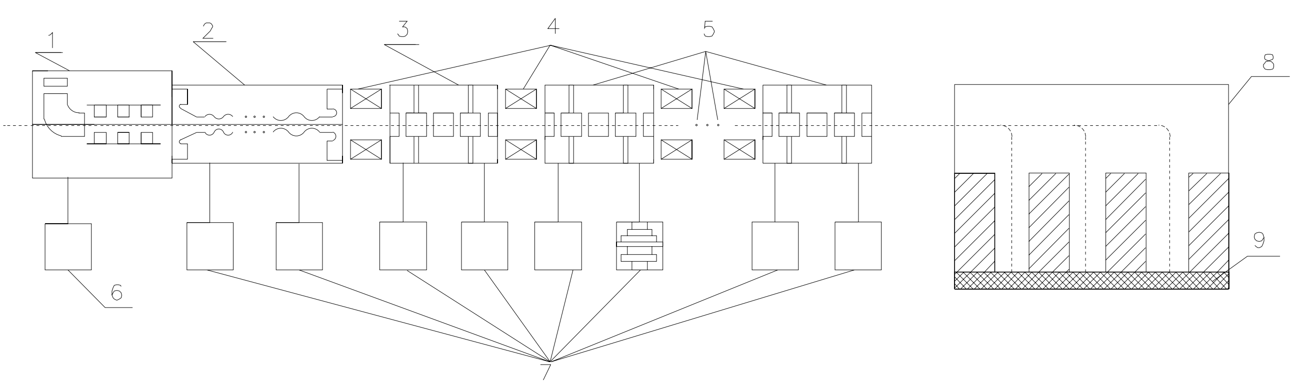

Figure 2: Key blocks of accelerator-driver.
1 - injection system; 2 - RFQ; 3 - cavity of APF; 4 - magnetic lenses; 5 - 10 cavities with drift-tubes; 6 - injector's feeding system; 7 - RF system; 8 - output pulsed magnetic system; 9 - targets.