FIRST EXPERIENCE OF WORKS WITH COMPACT INJECTORS FOR TRIALS AND DRILLS OF RF LINAC STRUCTURES

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Abstract

The problem of gas loading on vacuum conditions in RF linac structures from traditional ion injectors based on duoplasmatron type source is well known. At the stage of starting high power linac trials and drills it often requires significant increase of pumping capacity to maintain the working vacuum level in resonators. The problem is mostly vital at development of multiple aperture linac structures. To simplify the problem new compact test injectors based on spark ion sources are discussed.

1 INTRODUCTION

Recently there has been a great deal of interest in studying of possible methods of remote non-destructive object composition testing by means of nuclear detection of targets irradiated by accelerated beams of light ions.

The approach known as pulsed fast neutron analysis (PFNA) is based on measuring of gamma ray spectra from remote target after its irradiation with extremely short neutron pulses produced by RF linac [1]. The obtained time and energy gamma spectra are used for material interrogation. The information is stored by means of time-of-flight analysis between the accelerator pulse and the arrival of γ-rays to *NaI* detectors located far enough from an examining object [2]. On the other hand, pretty low angular divergence of accelerated beam is required to transport it to remote target with minimal losses. The method of simultaneous acceleration of many short pulse ion beams in the same RF accelerator structure is expected to be the most promising for this purpose. Two approaches of multiple beam injection are under consideration. The first approach is based on the ion injector with multiple individual channels. The other way is based on generation of wide common ion beam with low angular divergence within ion source placed in the nearest close to multiple aperture RF structure with beam multiple channel collimating before the structure.

A compact injector of deuterium ions based on spark ion source is one of possible decision for the second approach. On the other hand, such kind of injectors may be used as test equipment for any RF structures trials and drills due to its feature to avoid the problem of gas loading on accelerator cavity.

2 MULTIPLE BEAM SYSTEMS

2.1 General comparison of single and multiple channel accelerator systems

It is well known requirements of simultaneous high intensity and small divergence of charged beams are in contradiction because of space charge loading, and only multiple beam accelerator systems are principally able to resolve the problem [3]. Let us compare properties of single and multiple channel systems with strong focusing.

If every the channel with aperture radius of a which is among multiple $(M\cdot N)$ beam system is able to accelerate maximum beam current of i_{Mm} then total current of the system is

$$I_M=(M\cdot N)\, i_{Mm},$$

And for traditional single channel linac with aperture radius of R and the same channel characteristics, maximum beam current is I_1 and it is easy to see that

$$I_M / I_1 = (a/R)^2 (M\cdot N). \qquad (1)$$

At analogous comparison of angular divergence α at the output of single and multiple beam linac systems their relationship may be estimate as

$$\alpha_1 / \alpha_M = R / a.$$

So taking into account (1) we have

$$\alpha_M = \alpha_1 [I_M / (M\cdot N \cdot I_1)]^{0,5}.$$

It is easy to see that at the same value of total current beam angular divergence at the output of multiple channel system is by factor of $(M\cdot N)^{0,5}$ times less than it is in a single channel system. It means that at given value of beam current its output angular divergence may be decreased by increasing of number of channels.

2.2 Multiple aperture RF accelerator system with space lattice focusing

Design features of multiple channel accelerator systems with alternating phase focusing (APF) as well as with some multiple channel RFQ modification [4] considered below are promised to be adequate decision for simultaneous acceleration of some hundred beams.

Let us consider the multiple beams RFQ system by using a new focusing element called "space lattice" (SL-focusing) [5]. The main idea is based on the following feature of RF accelerating fields. At the edges of drift tubes particles are exposed to transversal focusing or defocusing pushes from RF field. In particular, in drift tube linac a particle is pushed by defocusing RF field at the input and by focusing field at the output edges of drift tubes while it is roughly free from RF field action within both drift tubes and accelerating gaps. We considered a possibility of substantial amplification of focusing action from RF field by increasing a number of indicated boundary edges. It may be possible if some additional electrodes are placed within every accelerating gap.

By making *M* horizontal grooves from one flat side of the thin electrode plate to the middle of its thickness as well as *N* vertical grooves from the other side of this electrode again to its middle we get metal space lattice with $(M \cdot N)$ rectangular aperture holes with relatively thin walls in between (see fig.1).

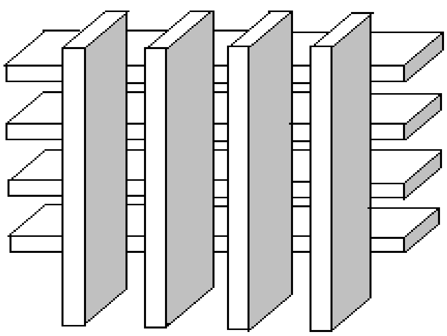

Fig.1.The fragment of Space Lattice electrode.

If several thin SLs are arranged along the common axis one after another at the equal distances between them within accelerating gaps of the multiple channel linac we have a system which can accelerate some hundred beams simultaneously. In case of circular apertures in thin electrodes focusing and defocusing forces at both edges of thin electrodes are almost mutually compensated while in SL every particle is pushed in vertical direction at the input and in horizontal direction at the output edges even at very thin electrode depth. If we arrange *n* SLs within an accelerating gap particles will be *n* times pushed by focusing strength in the vertical plane and *n* times pushed by defocusing strength in the horizontal plane. When SLs are arranged within every gap particles will be suffered some focusing action in one of transversal direction and defocusing action in other transversal direction. By turning SLs by an angle of 90^0 in every the following gap it is possible to create a sequence of sign-alternating strengths analogous to field strengths at space-homogeneous RFQ focusing. In fig.2 some possible realization of SL focusing electrodes with 324 aperture holes as well as their use in multiple channel accelerator structure is presented.

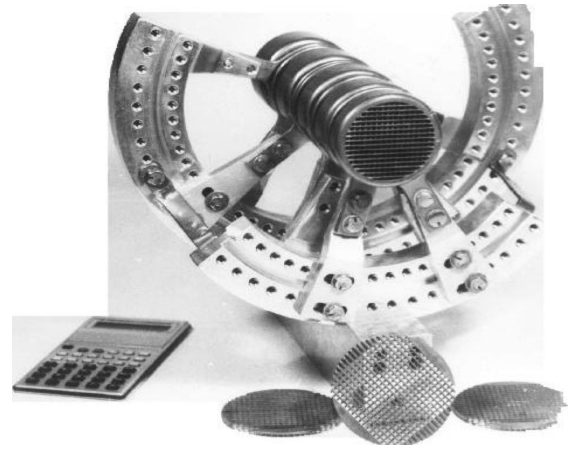

Fig.2. Space lattice electrodes and their possible arrangement in RF structure

3 SHORT PULSE TEST INJECTOR

The injector is designed for generation of very short pulses of ion beam as well as its preliminary acceleration in the range from 50 keV up to 150 keV [6]. The important feature of the injector is its small sizes due to possibility of placement both ion source and high voltage accelerator block within the same metal-ceramic package of *680 mm* long and *130 mm* in diameter. Such a configuration may produce protons, deuterons or heavy ions formed with pulses of nanosecond or microsecond ranges and followed with repetition rate up to some tens or hundred pps. On the other hand, such injector may be fixed at input flange of multiple channel RF accelerator structure at once due to the property of discharge initiation with no initial gas concentration (gas is stored in source electrodes as hydride of metal).

Vacuum accelerating tube of TNT-147 designed earlier in ARRIA for neutron generators is used as the main part of the injector. Ion generation is based on the property of desorption of deuterium occluded in metal cathode at spark charge, and its ionization in arc of spark discharge. Ion pulses are generated by formation of accelerating voltage of nanosecond range at microsecond pulse current of ion source. Ions are extracted from plasma bunches at electric field supplied between plasma gun anode and extracting electrode. Plasma gun is switching on at the moment of capacity discharge or inductive energy storage on the anode-cathode gap of the gun.

A spark-type ion source is based on the feature of some metals, such as *Ti, Zr, or Sc,* heated in the condition of hydrogen or its isotopes, to form hydride of metal as result of exothermic reaction. The process leads to saturation of a metal cathode with hydrogen. The saturated metal cathode in the form of washer is placed within the body of the ion source (fig.3).

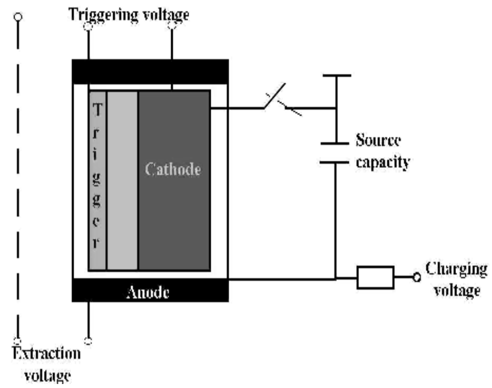

Fig.3. Short pulse spark ion source

The trigger electrode placed near the cathode supplies initial electrons to heat the cathode for gases desorption in the source volume. The electric arc is formed between cathode and anode electrodes. It is drifting to an open edge of plasma gun where ions of hydrogen are extracted and accelerated by high voltage potential. Pulse source is used as a source of trigger voltage. Pulse duration of extracted ion beam is in strict accordance with the duration of pulses of extraction which is able to be varied in rather wide time range from some nanoseconds to several tens of microseconds. The problem of electrical insulation is simplified in short pulse mode of source work. The unit of pulse formation is based on the scheme with electric capacity energy storage and pulse transformer. High voltage pulses are generated at the transformer's secondary and supplied to the gap between trigger electrode and anode.

The acceleration block of the injector includes spark ion source and trigger pulse former which contains high voltage transformer, accumulator capacitors and high voltage throttle. The elements of the acceleration unit are mounted within the same frame of metal ceramic tube. One of butt-ends of the tube is covered hermetically with the lid supplied with high voltage connectors, the other one serves to join injector with RF accelerator structure. The output flange of the accelerator structure is connected with the injector body by bellows for adjusting purpose.

Independent tests were carried out with proton and deuteron short pulse injectors. The cathode of the proton source was saturated with hydrogen. Pulse ion beam with output energy varied from *60 keV* to *120 keV* at pulse duration of about *1* μs and repetition rate up to *30 pps* was formed.

We investigated regimes of pulse output current depending on ark trigger voltage at different values of anode voltage at pulse repetition rates of *1, 10,* and *30 pps.* The beam collimator with a single aperture diameter of *10 mm* was placed *100 mm* behind the injector with output aperture diameter of *60 mm*. At the distance of *80 mm* behind the collimator beam current has been measured by the system of 13 current pickups of *5 mm* in diameter every. The pickups were placed symmetric by the beam axis in three transversal layers - the central pickup and two peripheral layers of 6 pickups every. The distances from the beam axis to peripheral pickup layers are *16 mm* and *28 mm*.

The central part of the transversal beam distribution of *20 mm* in diameter contains about *60%* of total beam current while the tendency of both beam current and core diameter rising at injection voltage increase was also noted. The instability of pulse amplitude at this stage was observed rather high and sometimes exceeded $\pm$ *100%*.

The short pulse proton injector based on spark ion source was used for first trials of experimental deuteron APF linac structure with output energy of *4 MeV* at half level of RF gradients in accelerator gaps (*85 kV/cm)*. At that stage the main purpose was to calibrate all the technological units including RF level required for supply, level of optimal injection energy, etc. The *1 m* long *148.5 MHz* RF accelerator structure based on *H*-resonator with drift tubes was jointed to the injector output edge due to the injector feature of working at pretty high vacuum. The collimator with a single axis aperture hole of *10 mm* was arranged at the flange of vacuum tank *50 mm* before the first drift tube of the RF accelerator channel.

The tests of the structure have confirmed abilities of the injector to be prepared quickly for the working with high vacuum RF accelerator structure with injection current level of some tens *mA* and its easy of handling. On the other hand, the tests have pointed to the necessity of improving some injector parameters and its stability firstly.

4 REFERENCES

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