DEVELOPMENT AND STUDY OF THE OPPOSED VIBRATOR RESONATOR FOR RFQ COMPACT ION LINACS

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Abstract

The conceptual design of a 430 MHz RFQ compact proton linac is described. The accelerator is a prototype of the deuteron linac for explosives detection in airline baggage on the base of thermal neutron analysis. To improve RFQ accelerator characteristics the rising law of the interelectrode voltage is proposed. The accelerating structure based on a combination of the H-resonator and the opposed vibrator resonator is developed to realize this law.

1.INTRODUCTION

The thermal neutron analysis (TNA) is a practical way of explosives finding in airline baggage [1,2]. For this application the neutron generator with thermal neutron flux of 10^9 n/sec and higher is needed. The deuteron linac with a beryllium target can be used as a reliable and intense neutron source [3,4]. The use of the linac operating in pulse mode allows to optimize registration and amplitude analysis of captured γ-radiation because the useful effect may be registered in the pauses between the linac impulses. It allows to improve the effect / background relation. The short pulses of several μsec and high repetition rate of 10^3 Hz are preferable for TNA. The application field of TNA systems also needs accelerator small size and low power consumption.

The deuteron energy of 1...2 MeV and the average beam current up to 0.1 mA are necessary to provide thermal neutron flux of 10^9 n/sec and higher in the ^{9}Be(d,n) reaction with further neutron moderation.

The use of RFQ accelerator is preferable in these energy and beam current regions. It is reasonable to use high value of operating frequency (in the region of 400 MHz) for the deuteron accelerator for TNA. It gives an opportunity to increase the acceleration rate and to decrease accelerator size and required RF power. To create the compact deuteron accelerator for TNA it is necessary to solve the problems of beam injection,acceleration and focusing as well as RF power generation. The characteristics of the deuteron accelerator for TNA needs to be proven by experience on the proton prototype.

2.FEATURES AND MAIN PARAMETERS OF THE PROTOTYPE

The main prototype parameters are given in Table 1. The projected layout of the accelerator is presented in fig.1.

Table 1
Main design parameters of the proton linac

Maximum beam energy	1 MeV
Pulse beam current	10 mA
Beam pulse length	5 μsec
Repetition rate	10^1...10^3 Hz
Operating frequency	433 MHz
Pulsed RF generator power	100 kW
Injection energy	50 keV
Resonator length	0.8 m

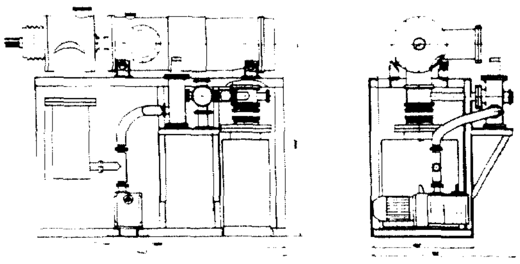


Fig.1.The projected layout of the accelerator

Most of RFQ accelerators use the four vane H-resonator with modulated electrodes to create accelerating - focusing field. However, the acceleration rate in the main part of this structure drops simultaneously with the particle velocity increase. It is reasonable to improve RFQ efficiency by use of rising law of interelectrode voltage. This may be realized on the base of the opposed vibrator resonator.The beam dynamics and accelerating - focusing structure features are described below in section 3.

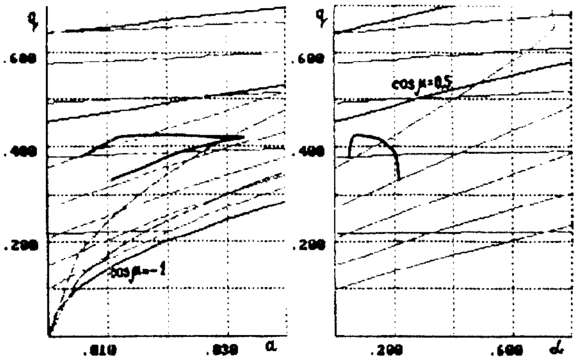
The RF generator of the prototype is developed on the base of the unified solid - state amplifier module with output pulse power of 2.5...5 kW. In the module, the transistor providing output power of 0.5...1 kW each will be used. The modules are combined in four generators with pulse power of 25 kW each which are united on the input by the common autogenerator.

The duoplasmatron will be used as an ion source in the linac ion injector. This ion source type has high beam brightness and small beam current modulation inside pulse. This is important for further beam acceleration and focusing. High gas efficiency of the source allows to minimize the size of the injector vacuum system. The injector optical system is developed on base of an electrostatic lens. The injector enables to provide the 10 mA beam with the beam diameter of 1...1.2 mm and normalized emittance of 0.02 π cm.mrad at the RF accelerating structure input.

3.BEAM DYNAMICS AND ACCELERATING - FOCUSING STRUCTURE

Calculations of required RFQ channel parameters and beam dynamics estimations are executed by means of one of the branches of the LIDOS (Linac's Ion Dynamics Optimization and Simulation) expert system.

To calculate the RFQ channel, an injection and output energies of the beam as well as distributions along the channel axis of the interelectrode voltage, the electrode modulation parameter,the average aperture radius and the synchronous phase are used as input data. Along with the table of RFQ parameters the results of the calculations are presented in the form of trajectories of representing point on the stability diagrams (the solid lines at fig.2).



(a) (b)

Fig.2.The trajectories of representing point at the Mathieu diagram (a) and at the "beam current" diagram (b).

The stability region is pictured on the first diagram in coordinates which are ordinary RFQ focusing hardness q and defocusing factor a (fig.2a). On the diagram isolines of transverse oscillation frequency, radius of the matched beam , envelope modulation coefficient as well as parametric and ordinary resonances lines are also pictured. On the second diagram the plane (q,α) is used (fig.2b). Here α is the parameter connected with the beam current I and the normalized beam emittance V:

$$\alpha = 2 I L / I_0 V p^2 ,$$

where L is the length of a focusing period, p is the reduced momentum of a particle, I_0 is the characteristic beam current.

Calculations of beam dynamics in the proper choice RFQ channel are made later on. Transverse beam dynamics is calculated on the base of envelope equations. To calculate longitudinal beam motion the disc model is used.

By means of this tool the calculations of beam dynamics in the prototype accelerator with rising interelectrode voltage were made. In this variant, the interelectrode voltage changes along the channel from 36 to 64 kV. Simultaneously, the average aperture radius increases from 1.7 to 2.2 mm. Maximum value of the electrode modulation parameter is of 2.1, maximum surface electric field is of 40 MV/m. For above mentioned parameters it is found that beam energy at the accelerator output is of 1 MeV, while longitudinal and transverse capture efficiencies are of 95 % and 100 % respectively for the input beam with the current of 10 mA and the normilized emittance of 0.02 π cm.mrad. The trajectories of representing point for this case are shown in fig.2.

To realize the rising law of the interelectrode voltage the following accelerating - focusing structure is developed. The structure represents a combination of the H-resonator and the opposed vibrator resonator (fig.3). Such structure allows to use high shunt impedance of the H-resonator, to regulate a field distribution and to provide good dispersion properties.

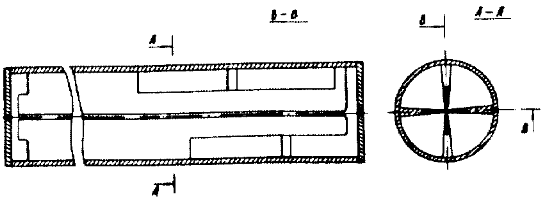


Fig.3.The configuration of the accelerating-focusing structure

The resonator consists of the following elements: an outer cylinder with bottoms, two plates of the first type and two plates of the second type. In initial part of the structure the H-wave is exited. In final part the plates have large cuts. The cuts dimensions are selected to form resonance elements - vibrators. The plates of the first and the second types have quarter- and half- wave cuts respectively on the resonator end. In the vibrator part of the structure, minima and maxima of the voltage distribution on the plates of the first and the second types are shifted on the quarter- wave relatively each other.

This design of the structure leads to a smooth lift of the field distribution to the resonator end if the vibrators are properly tuned. In reality, the vibrator resonance lengths are less than quarter- and half-wavelength because of mutual coupling of the vibrators. Calculations by means of coupled lines model [5] and measuring on RF models shows that shortening of the vibrator resonance length may be considerable (1.5...2 times), while the vibrator support position changes allow to achieve rising field with relation of initial and final voltages up to 2...3 times.

4. APPENDIX
FIELD HARMONICS IN RFQ CHANNEL

The choice of the RFQ channel parameters may be simplified if analytical expressions for the potential distribution are available. The periodic system of equivalent point charges is considered to obtain such expressions.

In this case, coefficients of Fourier series

$$\varphi(r,\theta,z) = \sum_{0}^{\infty} A_m \cos(m\pi z/h)$$

are equal to

$$A_0 = \frac{Q}{4\pi\varepsilon_0 h} \ln\frac{1-2(r/b)^2\cos 2\theta+(r/b)^4}{1+2(r/b)^2\cos 2\theta+(r/b)^4},$$

$$\begin{aligned} A_m = \frac{Q}{2\pi\varepsilon_0 h} \Big\{ & K_0\left(\pi m(r^2+b^2+2rb\cdot\sin\theta)^{1/2}/h\right) + \\ & + K_0\left(\pi m(r^2+b^2-2rb\cdot\sin\theta)^{1/2}/h\right) + \\ & + (-1)^{m+1}\cdot\Big(K_0\left(\pi m(r^2+b^2+2rb\cdot\cos\theta)^{1/2}/h\right) + \\ & + K_0\left(\pi m(r^2+b^2-2rb\cdot\cos\theta)^{1/2}/h\right)\Big)\Big\}, \end{aligned}$$

where Q is a charge, ε_0 = 8.85 pF/m, $h = \beta\lambda/2$, b is the distance from the charge to the channel axis.

Taking into account the addition theorem for function $K_0(x)$, the following expressions for field harmonics can be obtained:

$$A_0 = -\frac{Q}{\pi\varepsilon_0 h} \sum_{0}^{\infty} \frac{(r/b)^{2(2s+1)}}{2s+1}\cdot\cos 2(2s+1)\theta,$$

$$\begin{aligned} A_{2m} = -\frac{4Q}{\pi\varepsilon_0 h} \sum_{0}^{\infty} & K_{2(2s+1)}(2\pi mb/h)\cdot \\ & \cdot I_{2(2s+1)}(2\pi mr/h)\cdot\cos 2(2s+1)\theta, \end{aligned}$$

$$\begin{aligned} A_{2m+1} = \frac{Q}{\pi\varepsilon_0 h}\cdot\Big\{ & 2K_0\left(\pi b(2m+1)/h\right) I_0\left(\pi r(2m+1)/h\right) + \\ & + \sum_{1}^{\infty} K_{4s}\left(\pi b(2m+1)/h\right) I_{4s}\left(\pi r(2m+1)/h\right)\cos 4s\theta\Big\}. \end{aligned}$$

Here $K_s(x)$, $I_s(x)$ are modified Bessel functions.

The axis potential distribution coincides with the axisymmetrical case [6]:

$$\varphi(0,z) = \frac{2Q}{\pi\varepsilon_0 h} \sum_{0}^{\infty} K_0\left(\pi b(2m+1)/h\right)\cdot \cos\left(\pi z(2m+1)/h\right).$$

5. REFERENCES

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