PROGRESS ON A 27 MHZ HEAVY ION RFQ*

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Abstract

A 27 MHz heavy ion RFQ is now under construction at ITEP. It based on new ring-connected resonant structure. This structure is low frequency version of previously described "four – ladder" structure. The RFQ has been designed for acceleration of heavy ions with charge to mass ratio of 1/60 (U^{4+}) to energy 100 keV/u. At present the manufacture of the structure is completed, RFQ is assembled and installed into a vacuum tank. The RF measurements confirm the expected parameters calculated by MAFIA and SOPRANO codes – resonant frequency, very reliable mode separation and perfect electrical field distribution.

The carried out numerical simulations and experimental results show that given RFQ type is considerably promising candidate for use as initial part of high current heavy ion linac for HIF.

1 INTRODUCTION

The RFQ for acceleration of intense pulse beam of ions with charge to mass ratio 1/60 up to energy 100 keV/u is under construction in ITEP during last years. The main goal of this work is a maintenance of experimental base for reaserches of interaction of the heavy ion beam with dense plasma. At the time the accelerator was considered as a prototype of an initial part of the linac driver for heavy ion fusion. This work allow to test experimentally the results of investigations and developments for heavy ion high-power accelerator made during last years in ITEP. The main requirements produced to driver are effective acceleration of an intense beam with minimum particles losses and emittance growth. The design of the RFQ is completely based on new ITEP approach to the construction of initial part of high intensity heavy ion linac. A version of "90^0 - apart stem structure" named "ring - connected structure" has been chosen for the RFQ. The structure is the best choice to reach perfect field distributions in low frequency RFQ. Beam dynamics has been designed to minimize emittance growth for intense pulsed beam current.

The important factor influenced the design of the RFQ was very limited financial resources. It means, that from economy purposes some deterioration of radiotechnical, mechanical and operational parameters were allowed. At present the accelerator has been assembled and RF tuning is being carried out.

2 RFQ DESIGN

The described RFQ is the version of "90^0 - apart stem" structure proposed in ITEP for initial part of intense heavy ion linac. The detailed description of the structure and data of both computer simulations and results of RF measurements at the cold models are given in the earlier published works [1,2].

The basic advantages of described structure in comparison with known are:

- rather small transversal dimension;
- high RF parameters;
- reliable mode separation that provides proper field distribution;
- simplicity of mechanical design and low cost of manufacturing;
- low sensitivity to mechanical tolerances.

The mechanical construction of the RFQ is presented in Figure 1, where the RFQ is shown at assembling place before its installation into vacuum tank. The resonant structure consists of octangular shape "rings" produced together with stems. Rings are connected by longitudinal bars. Rings, bars and basements of the electrodes are manufactured of copperplated aluminum alloy. OFHC copper is used for tips of the electrodes. The stem pairs at adjacent rings are perpendicular to each other and to the beam direction. The stems in horizontal and vertical planes are connected by cylindrical electrode basements. The assembled structure represents a rigid 3-D construction allowed to reach required accuracy of electrode positioning. The thickness of the copper layer is not less

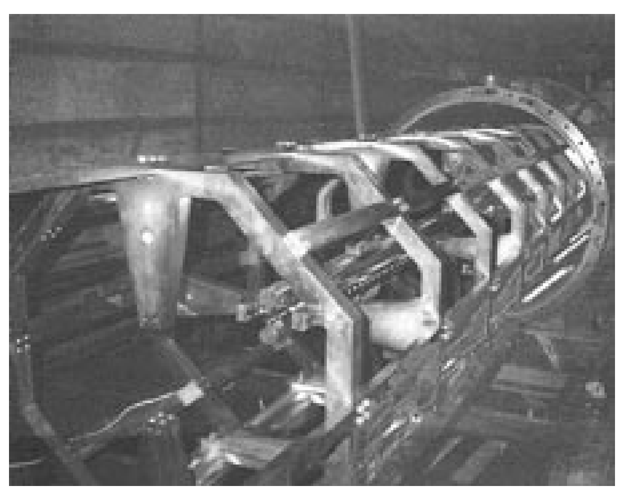

Figure 1: RFQ view at assembling place

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than 60 microns. The accuracy of machining of the structure parts was not worse than 20 microns.

The basic parameters of the RFQ construction are given in Table 1.

Table 1: Basic RFQ geometry.

Maximum outer ring size, mm	880
Maximum inner ring size, mm	780
Ring thickness, mm	50
Distance between adjacent rings, mm	580
Ring number	22
Cross-section of bars, mm x mm	50x25
Height of stems, mm	280
Height of electrode tips, mm	26
Thickness of electrodes, mm	10
RFQ length, m	12

As mentioned above the mechanical design of the RFQ was largely defined by the limited financial opportunities. In particular the cooling required for high average currents operation has been not provided. Not all of the structure elements connections design have been optimized for highest Q - factor. The expected Q factor is approximately 2 times lower then calculated one. However, it is enough to provide RFQ operation with acceptable RF losses. The improvement of RF contacts does not represent a basic problem, but would result in increasing the total cost of the RFQ.

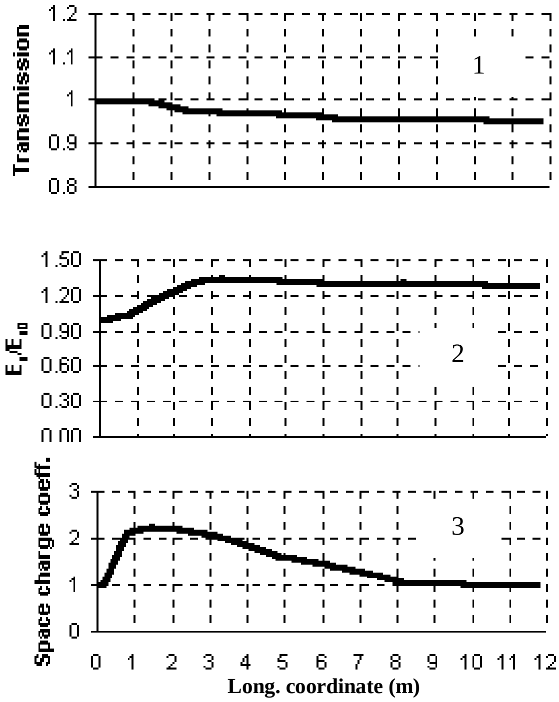

Figure 2: Calculated beam transmission (curve 1), relative transverse emittance growth (2) and Coulomb parameters (3) *h* relatively to its initial value along RFQ

3 BEAM DYNAMICS

Beam dynamics in the RFQ has been calculated using developed in ITEP procedure for high current linac design. The main goal of the procedure is to achieve maximum value of accelerated beam current with at least 95% transmission and minimum emittance growth.

The modulation parameter along part of initial bunch formation in early RFQ designs was chosen to keep geometrical length of separatrix approximately constant. If particle distribution in separatrix is uniform this method allow to keep constant space charge forces along RFQ. It should minimize beam emittance growth [3]. However, using of monochromatic beam for injection to RFQ leads to considerable variations of space charge density along formation part. The result is noticeable emittance growth for high intense beam at this part. It is also troublesome to propose in advance optimal synchronous phase and modulation along RFQ.

The described RFQ has been designed using some modification of the above mentioned approach. Cell geometry is calculated taking into account real particle distribution in phase space, obtaining from beam dynamics simulations in preceding cells. The simulation takes into account as space charge forces as real external field distribution.

In the procedure the geometry of cell is chosen to fulfill some requirements and limitations for RFQ parameters:

- space charge forces do not exceed some prescribed value;
- longitudinal stability has to be obtained not less than for 95% of particles;
- phase advance doesn't change more than on ±10 % of its chosen value;
- maximum strength of electric field on electrodes surface doesn't differ more than on 1% of its chosen value.

These requirements has to minimize emittance growth due to space charge effects and mismatching of the beam in channel with changing phase advance.

The RFQ generating procedure controls space charge effects using Coulomb parameter *h*, introduced in [3]:

$$h = \frac{\lambda}{\mu_0 \beta \gamma^2 I_0} \frac{I}{V_p},$$

where I - peak current of the beam, V_p - normalized transversal emittance, λ - wave length, β - relative velocity of particles, γ - relativistic factor, μ_0 - phase advance, I_o - characteristic current, equal $3.13 \cdot 10^7$ *A/Z*, *A/Z* - mass to charge ratio. Peak current and emittance are calculated by simulations in preceding cells.

As a rule, the monochromatic beam is injected to RFQ. It means that at bunching of the beam in initial part of structure peak current can change in width enough range with formal maintenance of separatrix length. In this case *h* in bunch formation part is always higher than

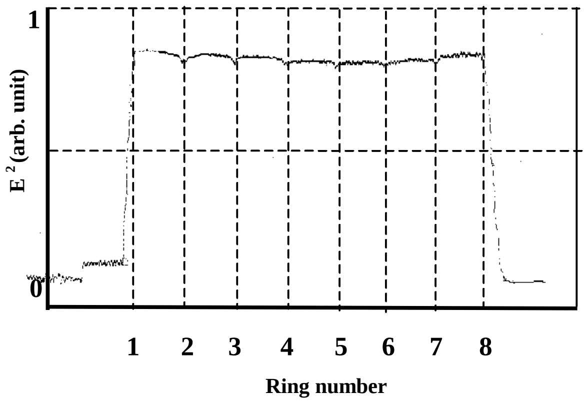

Figure 3: Measured field distribution along 8 ring assembly

in injected beam. The procedure of RFQ generating should to keep h lower than some prescribed upper limit.

Some results of RFQ design using described procedure are presented on Fig. 2. The simulations were carried out using written in ITEP code DYNAMION for beam current 12 mA and initial emittance 0.3 mm*mrad. Curve 3 shows Coulomb parameter along RFQ. At pre-bunching part (0 -1 m) Coulomb parameter smoothly increases to its prescribed value h_{max}. At formation part (1 - 3 m) h is kept under h_{max}. At gentle buncher h decreases because phase advance is dominated factor at this part. At main accelerating part the geometrical length of separatrix is constant and h is practically equal to its value in injected beam.

Curve 2 on Figure 2 shows relative growth of normalized rms emittance along RFQ. It can be seen from picture that rms emittance increases on ≈25% and main growth happens in the part of RFQ corresponding to the maximum value of Coulomb parameter. It has to be noticed that high enougth value of h_{max} = 0.34 was chosen only due to necessity of accelerating of particles up to 100 keV/u on the length limited by existing vacuum tank. Curve 1 shows that some particle losses are appeared at beam current 12 mA in spite of the fact that ratio acceptance to emittance is approximately factor 2.5. The explanation is that at given h_{max} the process of halo formation plays significant role [4].

4 FIRST RF MEASURMENTS

Measurements of the fields were carried out by means of standard bead-pull technique. Inter-electrode voltage distribution along the structure was measured for each pair of neighboring electrodes. On Figure 3 the distribution of the normalized inter-electrode voltage along structure for one pair adjacent electrodes is shown. The measurements have been carried out for the part of RFQ - 8 rings assembly. The measured non-uniformity of the field along the section is 1.5 %. It is mainly due to the measurements have been carried outside of the tank and end regions of the structure were tuned for lower frequency. The field distributions for other pairs of the electrodes have the same character. The average fields for different pairs electrodes differ within the limits of 3 %, that can be explained by the fact that the a preliminary alignment had more pure accuracy then it is foreseen for final one. Since this first measurements were made on a part of the structure, for whole structure it is possible to expect the aspiring of the frequency to design value 27.14 MHz and increasing of Q-factor. However even the given results of measurements completely confirm advantages of this variant RFQ for low working frequencies.

Table 2: Calculated and measured RF parameters

	Calculated	Measured
Frequency of quadrupole mode, MHz	27.14	27.66
Q-factor	13000	5650
Frequency of dipole mode, MHz	37.2	36
Shunt-impedance, MOhm ∗ m	1.1	0.48

5 CONCLUSION

The 27 MHz heavy ion RFQ has been designed in ITEP using new resonant structure and original procedure of RFQ generating. The computer simulations as well as RF measurements show that new resonant structure allow:

- to improve the linearity of focusing field due to significant shift of the dipole mode of oscillations;
- to have uniform field distribution along axis;
- to minimize the emittance growth due to improvement of field distribution and minimization of space charge effects;
- to decrease essentially the total cost of the RFQ due to using compact and simple construction.

Final adjustment of structure nowadays is close to completion. The first beam experiments are scheduled for the end of the 1998. In case of experimental confirmation of calculated parameters of the RFQ it will be possible to assert, that RFQ of the given type is a good option for an initial part of HIF driver.

6 REFERENCES

[1] V.A. Andreev, G.Parisi “90°-apart-stem RFQ Structure for Wide Range of Frequencies”, Proc. of the 1993 Particle Acc. Conf., Washington DC.

[2] V.A. Andreev, A.A. Kolomiets, V.I. Pershin, V.N. Sydorenko, R.M. Vengrov, S.G. Yaramyshev, O.V. Ershov, G. Parisi, " Development of the ITEP 27 MHz Heavy Ion RFQ", Proc. of the 1997 Particle Acc. Conf., Vancouver, 1997

[3] I.M. Kapchinsky, Theory of Linear Resonant Accelerators, Moscow, Energoizdat,1982

[4] A. Kolomiets, S.Yaramishev, "Comparative Study of Accelerating Structures Proposed for High Power Linac", PAC-97, Vancouver, 12-16 May 1997, Bulletin of the American Phys. Soc., May 1997, Vol. 42, N 3, p.1387