COMMISSIONING OF ITEP 27 MHZ HEAVY ION RFQ*

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Abstract

27 MHz heavy ion RFQ designed for acceleration of ions with charge to mass ratio of 1/60 up to energy of 110 keV/u has been built in ITEP (Moscow). The RFQ is the realization of proposed in ITEP new resonant structure. The computer simulation showed that the structure provides uniform field distribution and high shunt-impedance. This allows to consider it as one of the best choice for intense heavy ion linac. The main goal of the work was experimental investigation of the structure parameters and dynamics of intense beam. At the same time this RFQ is intended to the research program on the heavy ion beam interactions with dense plasma. The limited financial resources required the development of simple construction of the RFQ using cheep materials. However it must to provide the radiotechnical parameters close to the simulated one and use RFQ as experimental installation. The experience of the construction has shown that it was succeeded to build relatively cheep structure keeping good mechanical stability, large frequency separation of the operating mode and uniform focusing field distribution. The first accelerated ions of Cu^{2+} at RFQ output were obtained at the end of 1999. The results of the first beam experiments are reported.

1 INTRODUCTION

Assemblage and tuning of the RFQ were completed during 1999. The launching of the new ITEP heavy ion linac has been accomplished in December of 1999.

The accelerator assembly consists of the 150 kV terminal with MEVVA ion source, low energy beam transport (LEBT) line with two electrostatic einzel lenses, 12 m long 27 MHz RFQ section and diagnostic station at the output of the accelerator. The installation also includes the vacuum system and rf power supply up to 2 MW. To decrease the cost of the linac the resonant structure was placed into vacuum tank of disassembled 6 MHz RFQ TIPR-1. The rf system of that RFQ was reconstructed for the 27 MHz and provides necessary power for acceleration of intense beam (up to 25 mA).

The RFQ electrodes were designed to optimize the dynamics of intense beam and has been calculated to minimize emittance growth for intense pulsed beam current of 15 mA. The simulations were carried out using the ITEP code DYNAMION which takes into account as the space charge forces as the real external field distribution.

The designed accelerator parameters allows to consider it as a prototype of an initial part of the high power heavy ion linac and of a new injector for the ITEP TWAC project as well. The created accelerator assembly has to confirm the RFQ and beam design parameters.

The main principle of mechanical design of the structure was to combine the minimum expenses with the acceptable reliability and efficiency keeping high beam quality. Due to this reason the RFQ constriction was adopted to the existing stainless steel tank of 1.2 m inner diameter. A version of "90^o-apart-stem" structure [1] which has been developed in ITEP during last years satisfies to the requirements of both moderate transverse size and minimum cost. The RFQ had to provide the necessary rf voltage, mechanical stability and the required tolerances of the electrodes geometry.

Figure 1: View of the RFQ structure at the assembling place.

2 STRUCTURE ASSEMBLING AND LOW LEVEL FIELD MEASUREMENTS

Fig.1 shows the "90^o-apart-stem" structure described in the Refs. [1], [2], [3] on the assembling platform in front of the tank.

The structure is the rigid spatial construction consisting of the carrier rings with the radial stems, longitudinal connecting bars outside the rings and the longitudinal

* The work was carried out in collaboration with GSI, Germany

basements with RFQ electrodes which are installed on the stems. All parts of the structure are produced from the copperplated aluminum alloy (except of the electrodes which made from the OFHC copper) and joined by screws. The construction was assembled outside of the tank and moved inside it step by step as the new sections were added. The final adjustment of the structure after it was placed in the tank using precise optics provides the accuracy of the electrodes positioning better then 100 microns along whole 12 m RFQ.

One can see that the presented design concept simplifies the construction with the minimum amount of expensive materials and reduces the RFQ cost as much as possible. It has to note that only copper electrodes was manufactured with precise computer controlled milling machine, but the other parts required neither special manufacturing equipment no advanced technology. Meanwhile, as tests shows, the mechanical stability is quite satisfactory and electrodes alignment is well enough to prevent beam perturbation.

After completion of the assembling the rf parameters have been measured at low rf level. Table 1 gives RFQ the basic geometry and some measured RF parameters.

Table 1. Basic geometry and rf parameters of the structure.

Total length	m	12
Inner diameter of the tank	m	1.2
Ring number		21
Maximum outer ring size	mm	880
Ring thickness	mm	50
Cross-section of the bars	mm^2	50x25
Frequency of quadrupole mode	MHz	27.7
Frequency of dipole mode	MHz	36.0
Q-factor, (measured)		5600

The rf measurements confirmed the calculated parameters of the structure. The measured focusing field deviation along RFQ does not exceed ±1.0%. The measured frequency shift of the dipole mode is 8.3 MHz. However the measured Q-factor is approximately two times less to compare with simulated value. It is due to the structure has no conductive envelop and installed into stainless steel tank. As the all parts of the structure are joint with the screws the contacts between them are not perfect.

3 THE FIRST BEAM EXPERIMENTS

Following to the general concept of the simple and low cost machine, the RFQ section was powered by the feedback driven two stage generator based on GI-27 tubes. This generator takes the minimum amount of rf equipment and does not require precise frequency tuning of the cavity. The preliminary tuning of the rf circuits, feeders length and coupling loops was carried out at the low rf signal level without pumping of the tank. When the generation conditions were found and optimized, the high level of rf power was applied to the structure at the vacuum of around $2{*}10^{-4}$ Pa. The rf power of 800 kW has been reached after two weeks of conditioning under the sparking limit without considerable troubles. This power allows to accelerate the ions Cu^{2+}. At present, the design rf power level of 2 MW is reached what is enough to acceleration the ions U^{4+}. The experience of conditioning shows that the described simple construction screwed from the copperplated aluminum parts allows to achieve successfully the necessary power level in RFQ without contacts sparking and multipactoring.

The first beam experiment has been carried out with the ions of copper generated by MEVVA ion source. The beam at the source output is the mixture of ions with different charge states. As there is no separation in LEBT at RFQ input the beam mainly consists of ions Cu^{2+} and C^{3+}. The result of such beam dynamics simulation carried out with DYNAMION code for rf voltage corresponding to acceleration of Cu^{2+} ions is shown in Fig. 2.

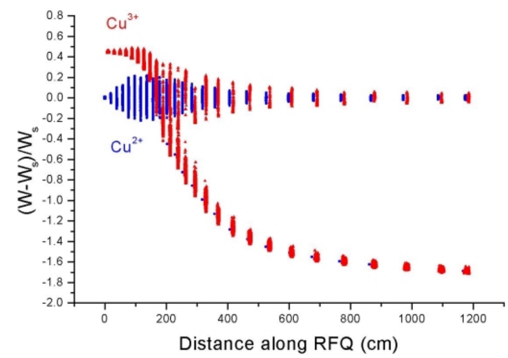

Figure 2: Relative energy of Cu^{2+} and Cu^{3+} ions at some cross sections along RFQ.

As it can be seen from picture the transmission of the Cu^{2+} ions is 100%. Approximately 30% of injected Cu^{3+} ions are also captured into acceleration.

Fig.3 shows the signal from the beam transformer installed at the MEVVA output (upper curve) and the signal from the Faraday cap installed at the RFQ output (lower curve), when the copper beam is drifting trough the structure without acceleration with the injection energy of 76 kV. It can be seen from the picture that 12 long drift allows to reliably separate ions using time-of-flight method.

The transit times for Cu^{2+} and Cu^{3+} ions are 22 µs and 17 µs respectively, that corresponds to difference of ions velocities at RFQ input. However the transit time of accelerated part of Cu^{3+} ions is the same as for Cu^{2+} ions. For unaccelerated part of Cu^{3+} ions transit time remains the same as on Fig. 3. The time of acceleration in the 382 cell structure operating at 27.7 MHz is 6.9 µs. The accelerated beam pulse at RFQ output is shown in Fig. 4.

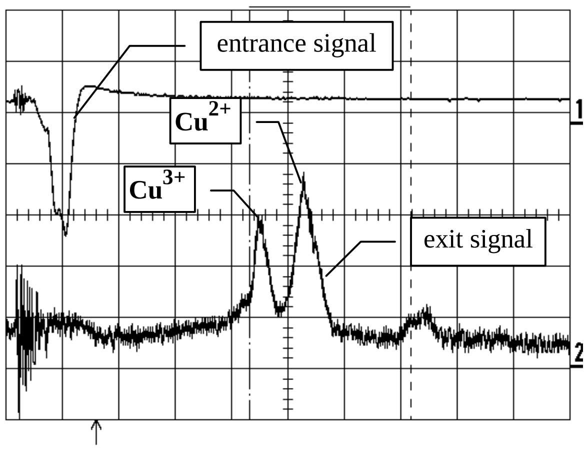

Figure 3: Time-of flight spectrum of the Cu beam (time scale is 5 μs per division) .

The time difference for ions at RFQ output in this case is fully explained by drift with different velocities in LEBT. To resolve the beam pulses the time scale is 2 μs per division. Taking into account the drift time in LEBT, the delay of the exit signals induced by the accelerated Cu^{2+} and Cu^{3+} components from the entrance signal have to be as 11.1 μs and 9.4 μs, respectively. The pulse of unaccelerated ions is outside of the oscillogram.

It is necessary to note that existing LEBT was designed for another application and actually are not optimized for beam of copper ions. For this reason we have on RFQ

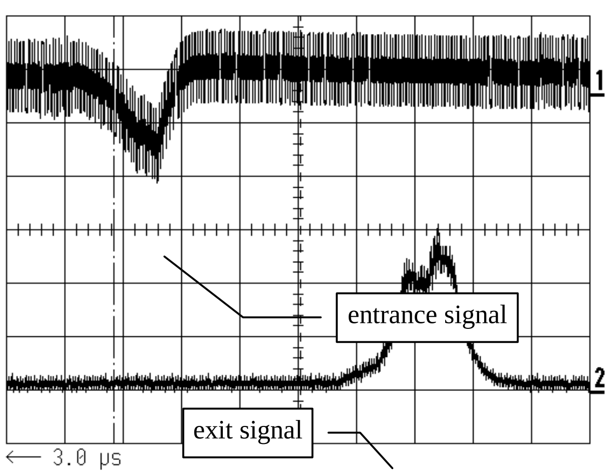

Figure 4: A time spectrum of the accelerated beam.

input only 5 – 6 mA current of Cu^{2+} ions and 4 – 4.5 mA of these ions have been accelerated in RFQ. So the transmission coefficient in first beam experiments was not worse 80%.

4 CONCLUSION

The results of commissioning of the new 27 MHz heavy ion ITEP RFQ and first beam experiments allow to conclude that:

- The new “90^{o}-apart-stem" structure provides good mechanical stability, precise electrodes alignment, large frequency separation of the operating mode from dipole one and uniform rf voltage distribution along RFQ;
- The structure allows to simplify the mechanical construction and to reduce its cost considerably;
- RF voltage between adjacent electrodes equal 2.2 Kilpatrick units was achieved after only short conditioning;
- The structure has large frequency separation of the operating mode from dipole. It eliminates beam perturbation by external fields and the allows the feedback powering taking the minimum rf equipment;
- The first beam measurements are in good accordance with computer simulations.

The next step of the work on 27 MHz RFQ is increasing of accelerated current up to design value by means installation of new LEBT and experimental investigation of the beam parameters at maximum current.

REFERENCES

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