THE 6 MHz RFQ LINAC FOR HIF DRIVER

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Introduction

A design of a rf linac is the first stage in the development of an ICF power facility with a heavy ion driver based on the conceptual scheme proposed in ITEP [1]. The block diagram and the main parameters of each section of the linac, determined in the result of calculations carried out, were discussed earlier [2]. It was indicated that in the first two sections of the linac 6.19 and 12.39 MHz RFQ's will be used. Some design information and experimental results obtained at the start-up of 6m prototype of the first section were also published [3].

The proposed report includes additional design information and also some calculated and experimental parameters of 12m long 6.19 MHz section after which 12.39 MHz RFQ structure will be used.

The 6.19 MHz RFQ section

One of the main problems in the development of the rf linac for low charge state heavy ions (as Bi^{2+}) is to provide rather high normalized acceptance in the initial part of the linac. At the given value of the surface field $E_{s\,max}$ (determined in the result of the sparking limit measurements for spherical electrodes in the frequency range discussed [4]) the normalized acceptance of RFQ section is proportional to the accelerating field wavelength squared. The estimates of current limits made in ITEP show that in order to reach Bi^{2+} ions current of 50 mA in one beam line of the first RFQ section at the chosen $E_{s\,max}$ one should use as low frequency of the accelerating field as 6 MHz. If to use a working frequency of 12 MHz it would lead to the decrease of current limit by a factor of four and accordingly to the same increase of the number of the beams. At the chosen for the main part of the linac frequency of about 200 MHz this is impossible. The design energy of 10 MeV/nucleus at which the ions will be injected into the RFQ with twice higher frequency permits to rise the current limit in one beam line of the section up to 330 mA. Such a value of the current limit allows to funnel the beams by pairs in the longitudinal phase space at the output of the first section and to reduce the number of the beam lines in the second section by a factor of two. As concerns the prototype, the transition to the twice higher frequency of 12.39 MHz is chosen to be at the Bi^{2+} ions energy of 7.5 MeV/nucleus.

An accelerating structure for Bi^{2+} ions is a resonant system made as symmetric four-wire line. Each conductor is made as a 12m long stiff girder on which the vanes with alignment devices are mounted. Copper plated vanes were machined of 40 mm steel plates. The tip of each vane was milled according to the special sine law found by calculations in order to provide spatial homogeneous focusing-accelerating field on the axis of four-wire line. At the whole length of 12 m the number of modulation periods is 80, the number of vanes - 76. The vanes mounted on the girders were fixed in the frame by means of 36 spiral-shaped supporting elements. These elements are at the same time the inductors that together with the capacity of the four-wire line form a resonant system of the accelerating structure. Intervane voltage produced by 6.19 MHz rf field is up to 190 kV. Quality factor is 600, shunt impedance - 6.6 kOm, rf power needed to achieve working rf voltage - 3 MW. The rf supply system consists of GI-27A-1 tube based autogenerator connected in grounded cathode circuit. The 40 kV, 500 μs pulse needed for the rf generator is provided by the modulator with double forming line. The modulator pulse power can reach 16 MW. Rf power of about 3 MW is transmitted from the generator to the RFQ by 6 parallel coaxial lines of 24m long each that corresponds to $3\lambda/4$. In order to suppress parasite modes the ballast resistors at the output of the generator are installed.

The aperture of the beam line is 30 mm, the calculated acceptance - 0.25 cm•mrad, the current limit for accelerated Bi^{2+} beam - 50 mA.

The tuning was made by pairs of rings mounted on the vanes and thus providing an extra capacity. The longitudinal field distribution measured by high frequency voltmeter is reproduced on Fig.1. The maximum measured deviation from the average (both axial and azimuthal) is ± 9.5 %, mean and rms deviations are 3.6 % and 1.3 % respectively. The maximum deviations from the average were observed in the points of connection to the spirals and tuning rings.

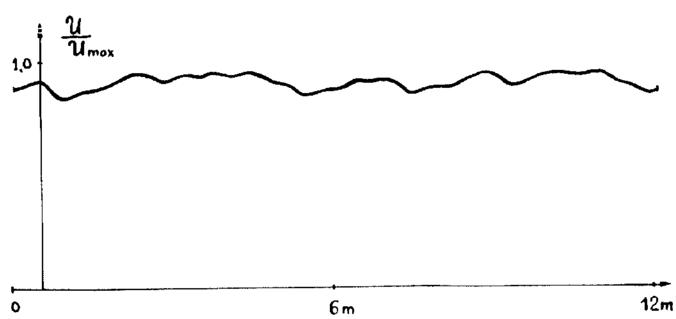


Fig.1 Distribution of rf voltage along 12 m structure.

The preliminary tuning was conducted on the alignment bench and then the tuned accelerating structure was rolled into vacuum tank (12m long, 1.2 m in diameter). Both the accelerating structure and tank consist of two 6m long parts. The works on the acceleration of the beam proceeded two stages. At first the beam was accelerated in the first part of the structure. Then the second part was connected to the first one. The connec-

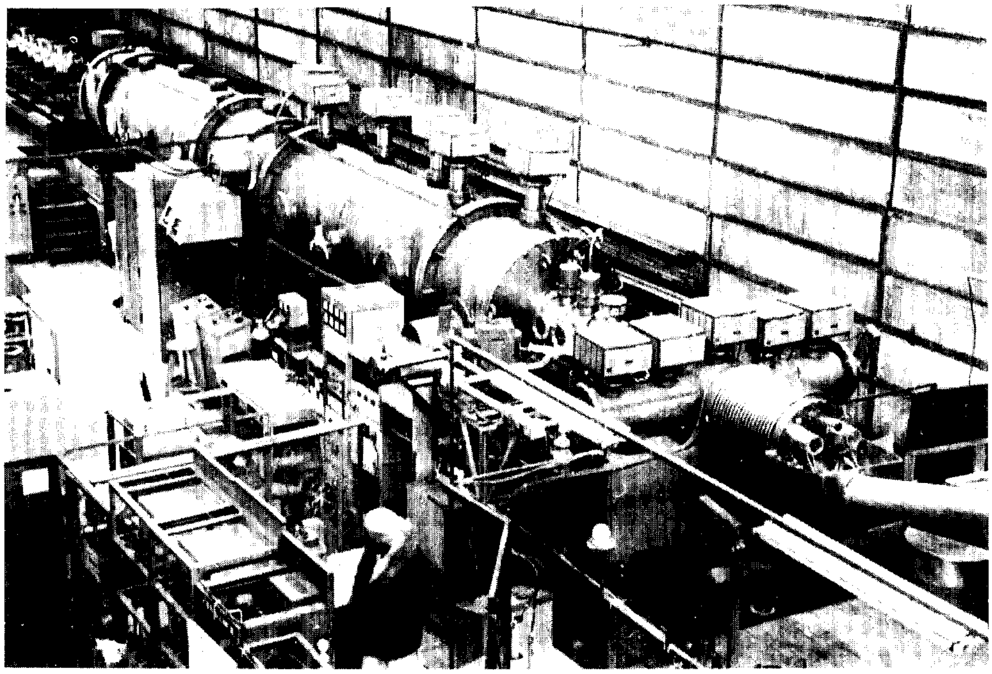


Fig.2 Photograph of linac in experimental hall

tion of RFQ's and some other auxilary operations were made inside the vacuum tank manualy. Fig.2 is the photograph of accelerator and its equipment in experimental hall.

Injector

At the initial stages of the linac investigation particulary testing and studies of accelerating mode, it was decided to start with Xe^{2+} beams, as it is much more convenient to operate the gas medium source compared to the metal vapors one. The first version of heavy ion source is a duoplasmatron optimized to produce Xe^{2+} ions. The ion optics system is equiped with control electrode that permits to study the beam by the time-of-flight technique [5].

The ion optics scheme and measurement devices are shown on Fig.3 [6]. The accelerating voltage is applied between the expander (5) and the grounded electrode (12). In the apertures of the extracting (9) and control (10) electrodes tungsten grids are installed. At the given accelerating voltage the focusing of the beam at the inlet of the matching channel is provided by the appropriate selection of potentials of the extracting (9) and focusing (11) electrodes. Beam current in the channel is measured by beam transformer BT (13). The sensitivity of the BT is 10 V/A and its frequency response permits to measure pulses of 10^{-4}-10^{-6} s with adequate accuracy. For the purpose of time-of-flight analyses at the inlet of the linac the opportunity to install the Faraday cup (14) at the distance of 0.95 m from the BT is provided.

When positive voltage (U=200-500 V) is applied to the control electrode (10) the ion optics became "non-transparent" for the beam. As a result the ions are decelerated in the area between the extracting (9) and control (10) electrodes and form a cluster in which the axial velocities of the ions are low (virtual emitter (8)). To form the ion beam the high voltage short front pulse (amplitude 3-15 kV, length 0.4-10 μs) is used.

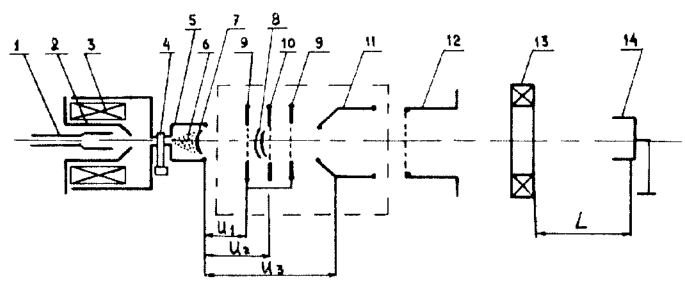


Fig.3 Schematic drawing of ion optics and measuring devices.

1 - cathode, 2 - intermediate electrode, 3 - magnet coil, 4 - pulse valve, 5 - expander, 6 - plasma, 7 - ion emission surface, 8 - virtual emitter, 9 - extraction electrode, 10 - control electrode, 11 - focusing electrode, 12 - grounded electrode, 13 - beam transformer, 14 - Faraday cup.

The charge state of Xe ions was determined by the flight-of-time technique both at 65 kV injector output (corresponding to 100 kV for Bi) and at the linac output. Peaks corresponding to the ions with different charge states were reliably determined inspite the fact that each peak represents a $Xe^{129-136}$ mixture.

Depending on the operation mode the injector with a duoplasmatron type source can provide up to 40 mA of Xe^{2+} ions, but the existing matching channel allows to receive only 10 mA at the input of the linac.

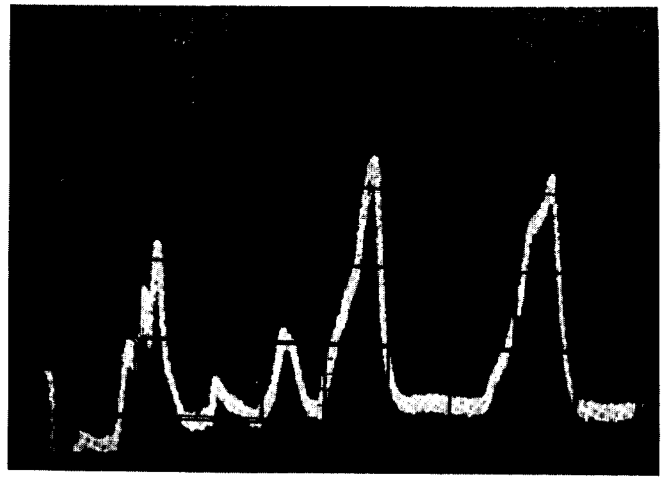
Start-up results

At the start-up the ion optics of the source was tuned so that the crossover of the Xe^{2+} beam was located at the inlet of the 2 m matching channel equiped with two electrostatic lenses and two steering devices.

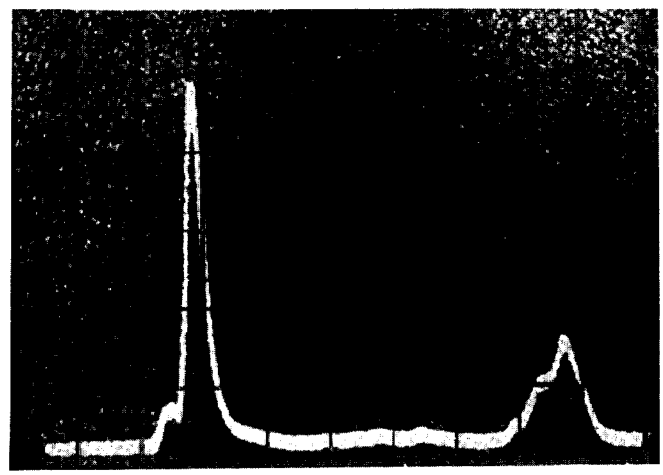
Before the rf power was supplied, the vacuum tank was evacuated to a pressure of 3-$4 \cdot 10^{-6}$ Torr. The tests showed that the calculated values of rf field needed for the acceleration of Xe^{2+} and Bi^{2+} ions could be provided without any difficulties.

In the course of start-up the beam current at the input and the output of the linac and the value of rf vane-to-vane voltage were measured. After the threshold level of the rf field was exceeded the main fraction of Xe^{2+} peak, measured at the output of the linac, shifted in time for 15 μs; this corresponds to the acceleration of these ions to the calculated energy of 4.6 MeV (Fig.4).

During the first experiments with 12 m accelerator the operating mode (U_L = 130 kV) was found at which the output current was 2.5 mA (input current being 5 mA), i.e. the capture factor was close to 50%. The future activities will be devoted to the detailed study and optimization of the accelerated beam parameters and also of the operating modes of the injector, the matching channel, and the RFQ. The results obtained will allow to be prepared for the transportation of the beam to the next section of the prototype. The design of this section will differ from the discussed one because of the twice higher frequency used there. The experiments on the acceleration of Bi^{2+} ion will be held only at the final stages of the RFQ linac prototype activities. Before to proceed to this work we have to gain enough experience in limitation of metal vapors propagation that could deteriorate the surface of insulators during the initial tests of the source.



Rf level = 0



Rf level = 120 kV

Fig.4 Oscillograms of unaccelerated and accelerated beam pulses.

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