THE PULSED PROTON PROTOTYPE OF A HIGH CURRENT ION LINAC

R. M. Vengrov, E. N. Daniltsev, I. M. Kapchinskij, A. M. Kozodaev,
V. V. Kushin, N. V. Lazarev, A. A. Nikitin, I. V. Chuvilo

Institute for Theoretical and Experimental Physics, Moscow, USSR

The using of the spatial uniform quadrupole focusing at the initial stages of acceleration proposed approximately 10 years ago[1,2] turned out to be rather fruitful for linac techniques. The accelerators of such type are being designed in several scientific centers,[3-5] where they are being called RFQ. That abbreviation is fairly convenient, though it is not completely strict because it may include general structures of other types.

The practical application of the RFQ accelerating structure in the ITEP is tightly connected with design of a new proton synchrotron injector to replace the obsolescent linac I-2 which was put into operation as long ago as 1966. This will allow placing in the same building an injector with output energy of 40-50 MeV instead of the old 24.6 MeV injector and also improvement of the parameters of the proton synchrotron beam. There will be some more improvements in the new injector besides RFQ structure: Alvarez structure will operate with doubled frequency,[6] permanent magnets will be used in drift tubes, linac control will be automatized, and will be connected with the synchrotron computer.

The program of the new injector preparation may be subdivided into stages. The first stage is the experimental study of the linac initial part (RFQ structure) and has some pure scientific purposes besides the construction of the injector.

Construction of an ion linac with average beam current more than 100 mA is a very important link in up-to-date program of alternative energy sources study. Three directions were defined in foremost scientific laboratories: deuteron linac to the energy 30-35 MeV,[7-10] proton or deuteron linac about 1 GeV,[5,11] and a low-charged heavy ion linac to approximately 10 GeV.[4,12,13]

The two to three order increase of average beam current in comparison with that achieved at the existing machines makes serious demands on the linac design and parameters. The high cost of the project and a lot of technical unsolved questions require carrying out bench tests and full examination of a prototype. The new ITEP synchrotron injector may serve as such a prototype.

Especially serious difficulties in increasing the linac beam intensity must be overcome at the initial part of acceleration, where the influence of space-charge repulsion forces due to its own beam field is maximum. The use of RFQ structure ensures the most effective solution of this problem both for the new injector and for all three above-mentioned new prospective directions. This is connected with the fact that electric quadrupole focusing in such a high frequency structure can be realized, and besides there is a possibility to vary the parameters of the acceleration period in rather wide and flexible bounds. The possibility of a sizeable injection energy reduction, particle capture broadening, and maximum accelerated particle-current increase also arises.[1,2,14]

The maximum accelerated particle current may be estimated from the expression[15]

$$I = \mu_0 \frac{\nu}{2} \beta^3 \gamma^3 \left(\frac{a}{S}\right)^2 B I_0 ,$$

where:

μ_0 - the radial oscillation phase change per period of the focusing field;

ν - nondimensional instant frequency of radial oscillations;

a - a drift tube aperture radius;

S - the length of a focusing period;

B - bunching factor;

$$I_0 = 4\pi\varepsilon_0 \frac{m_0 c^3}{e}$$ - a constant characteristic for every type of accelerated particle with dimension of current; for protons

$$I_0 = 3.14 \cdot 10^7 A ;$$

$\varepsilon_0 = \frac{10^7}{4\pi c^2} \frac{F}{m}$ - dielectric constant of the medium;

m_0 and β - mass and relative velocity of particles;

γ - Lorenz-factor.

The quadrupole channel parameters μ_0 and ν of different accelerators with polarity reversal electric focusing may be chosen approximately equal notwithstanding a concrete type of focusing (static of high frequency quadrupoles, phase alternating focusing), but the factors $\frac{a}{S}$ and B greatly depend on the focusing type and turn out to be maximum when RFQ structure is used. Just this very feature allows obtaining the intensive particle beams of different ions with rather low injection energies. It is shown[5,8,16] that the proton and deuteron beams with currents up to 200-300 mA may be accelerated with injection energy 70-100 keV. RFQ structure has also rather important advantages when accelerating super-heavy particles, as the possibility of practically 100% capture extremely simplifies the problem of heavy ion sources construction, and the use of electric focusing forces allows achieving a relatively big acceptance for ions with very low velocities.

The first operating linac using spatial uniform focusing is the 30 MeV proton injector which was put into operation in IHEP in 1977.[17,18] In 1980 a proton beam of 30 mA was achieved in Los Alamos at the pulsed prototype of the deuteron linac at operating frequency 425 MHz. The beam was accelerated from energy 100 keV to 640 keV along the length 1.1 m.[16]

The use of RFQ structure raises many grave theoretical and technical problems for designers. Firstly the question of the most optimum shape of

electrodes to ensure high effectiveness of acceleration and focusing, high electric strength and simple manufacturing arises. Hitherto, the electrodes in the form of cylindrical rods with conic modulation of diameter,[17] or electrodes of an intricate, variable, approaching the "ideal" configuration[10] were used. In ITEP the decision was made to use half-cylindrical electrodes with invariable section thickness and with sinuous modulation of the distance between the electrodes and the axis (under continuously lengthening period), Fig. 1.[19] As calculations show, the fifth harmonic of the quadrupole field may be suppressed when such electrodes are used. The electrodes are simple to manufacture. The transit-time factor and focusing effectiveness are close to the values defined by the "ideal" electrodes.[20]

Secondly the question of choosing the optimum RF cavity type to create necessary field configuration has not yet been decided. In the IHEP double H-resonators were used[17],[18] and in Los Alamos - four chamber resonators of separate sectors (clover leaf type).[10],[16] It may be considered that four chamber resonators are most convenient to create the required quadrupole fields. The main field mode of these resonators is quadrupole and the high frequency field is concentrated inside a single closed cavity. This fact considerably simplifies the cooling of the resonator.

Thirdly the scheme of high frequency power feeding, methods of tuning, adjusting and measuring of required field distribution must be chosen. The ITEP four chamber resonators are being excited by means of loop couplers placed in each chamber and phased in a proper way.

In the ITEP the experimental examination of calculations and chosen technical decisions are being carried out on the assemblies of the new injector.

The main parameters of this prototype are listed below:

- injection energy   88 keV;
- output energy   3 MeV;
- operating frequency   148.5 MHz;
- maximum current   240 mA;
- resonator length   4.9 m;
- a single quadrant diameter   0.2 m.

An Alvarez-type resonator operating with doubled frequency 297 MHz and provided with permanent magnet quadrupole lenses for focusing will be installed after the initial RFQ. The gradient of 6 kG/cm was achieved in these permanent magnet lenses of 20 mm aperture diameter.[21],[22] To get the best conditions of transition from RFQ to Alvarez resonator the energy of transition was taken to be 3 MeV. To match the beam along the longitudinal and transversal coordinates the adiabatic alteration of parameters along the channel between the initial part and the Alvarez resonator is provided.

The output tubes GI-27A are used in RF system. These tubes operate very well in the linac-injectors I-2 and I-100.[23] High vacuum pumping is done by turbomolecular and sputter-ion titanium pumps. The ion source of a duoplasmatron type with heated or cold cathode[24] will be used.

The RF tuning and preparation for putting the RFQ structure into operation is going on at present. The general view of the resonator partially in the vacuum tank is shown in Fig. 2. The resonator is assembled in 8 separate sections. The length of each of the sections varies from 574 to 602 mm. The beginnings and the ends of the electrodes of each section coincide with places where the electric strength at the electrode surface is minimum. Each of four chambers has tuning plates, coupling and measuring loops, a device for electrodes shifting in transverse directions. The electrodes parameters adiabatic alteration along the input section of the initial part assures the injector beam matching with linac. Real electrodes are shown in Fig. 3. The optimization of matching is supposed to be verified on this prototype.

The electrodes were produced by hand and by program-controlled milling machines, in accordance with the data received from correspondingly programmized computers. The main dimensions of the sections were defined by means of modelling.[25]

Before being mounted, all the sections were adjusted to get given distances between all the electrodes, and to equalize section areas of the chambers. Then with the aid of the tuning plates, the fields were leveled to achieve equality of the magnetic fields amplitudes. The distributions of the magnetic fields in each of the 4 chambers along the whole resonator before and after tuning are shown in Fig. 4. There are certain difficulties for tuning due to the first overtone of the dipole types of oscillations which have the magnetic field node in the middle of the resonator, and their frequency is near the frequency of the working type of oscillations.

Now, suppressing of parasitic types of oscillations in resonator and preparations for the examinations with proton beam are going on.

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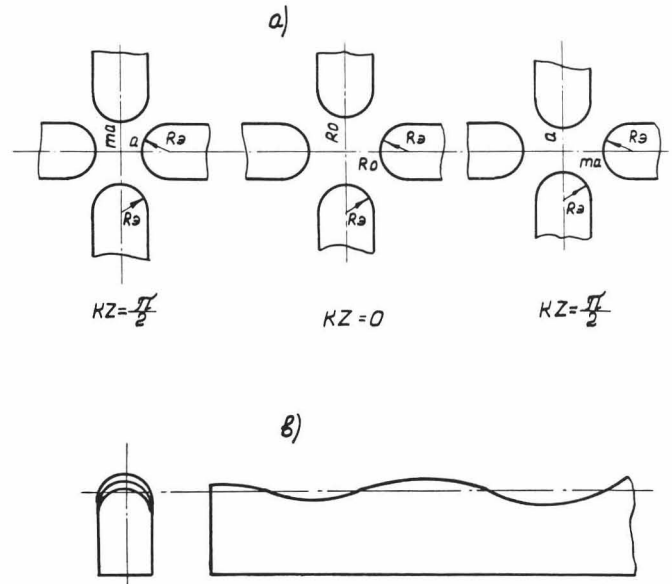   skij et al., ITEP-49, Moscow, 1980

Fig. 1 a) Transverse sections of modulated electrodes.
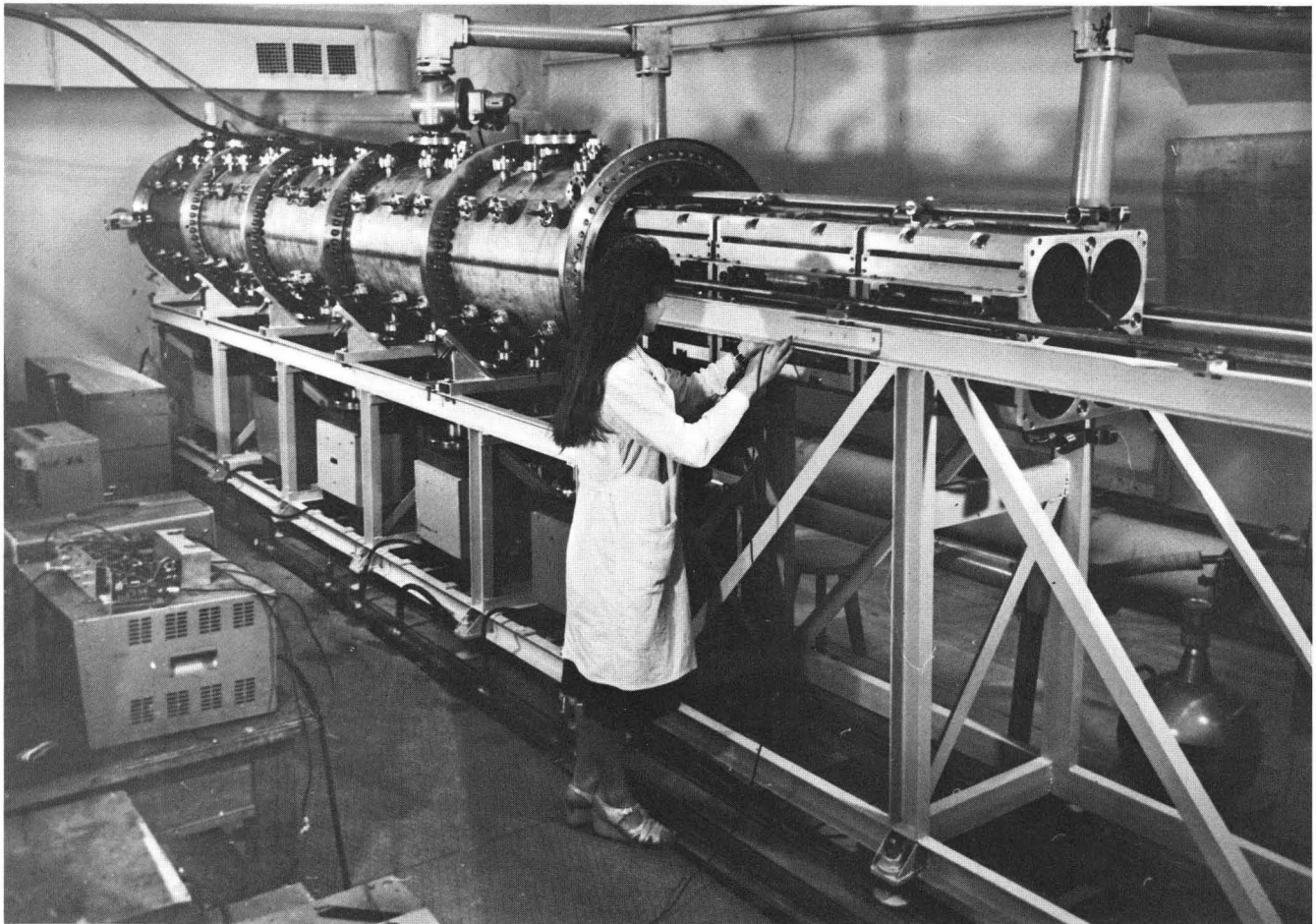b) The schematic view of an electrode.

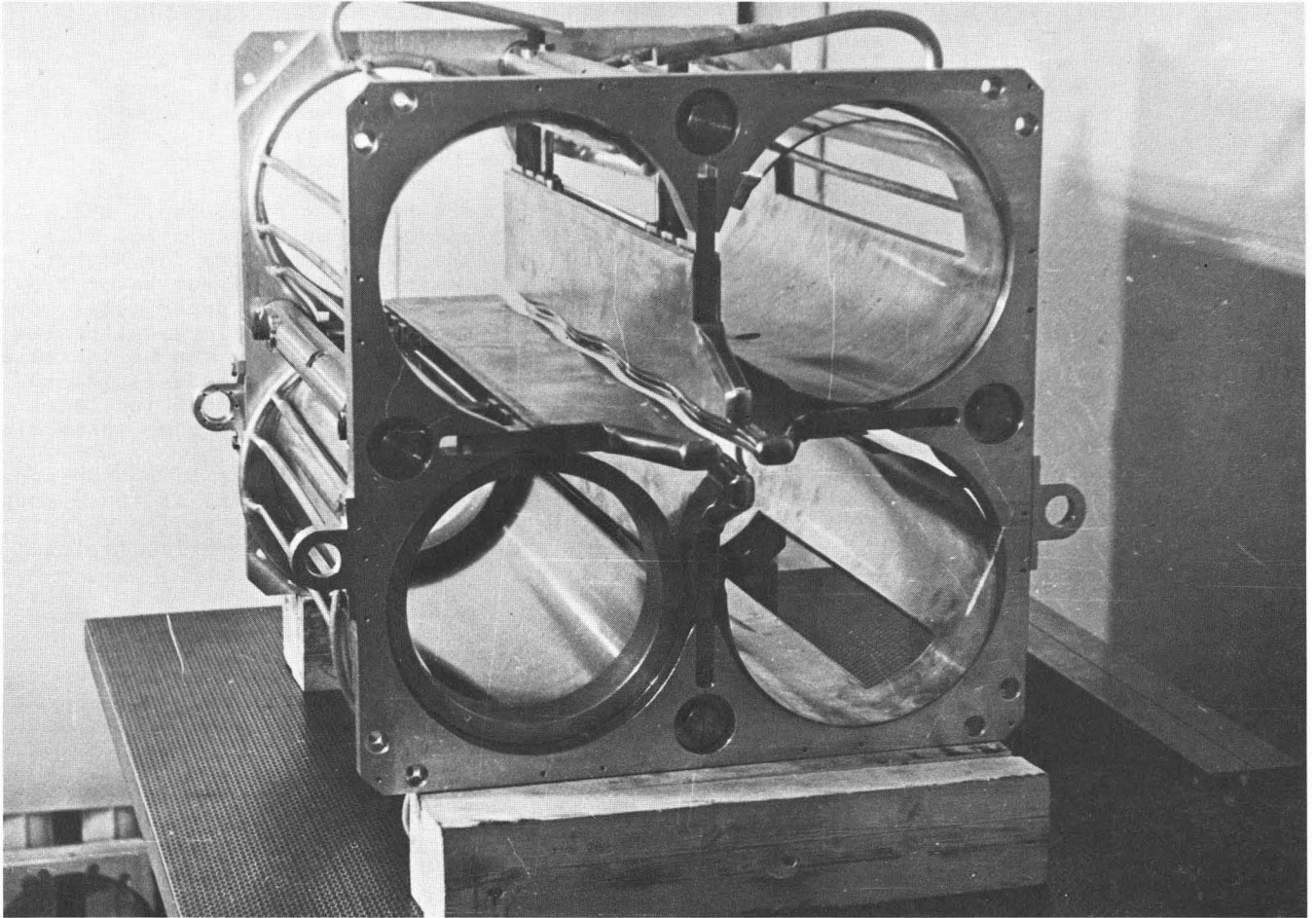Fig. 2 The initial part of accelerator - RFQ structure.

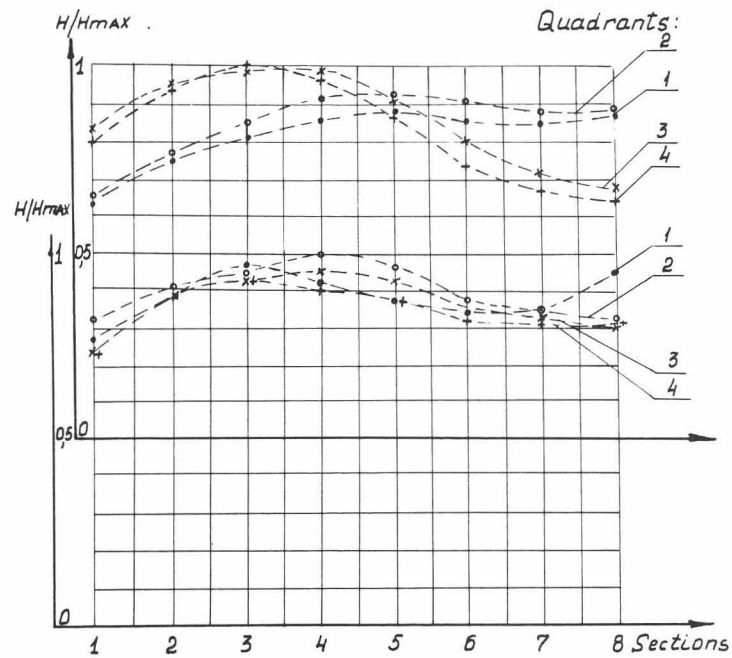Fig. 3 Electrodes of the final section of the RFQ structure.

Fig. 4 Magnetic field distribution along the quadrants of the RFQ structure. The upper curves - fields in quadrants 1 - 4 before tuning, the lower curves - after tuning.