" THE LAUNCHING OF A 3-MeV PROTON RFQ LINAC "

I.M.Kapchinskij, V.A.Andreev, V.S.Artemov, V.I.Bobylev, I.V.Chuvilo, E.N.Daniltsev, V.I.Edemskij, L.V.Kartsev, A.M.Kozodaev, A.A.Kolomiets, V.S.Kosiak, R.P.Kuibida, V.V.Kushin, N.V.Lazarev, Ju.B.Stasevitch, S.B.Ugarov, R.M.Vengrov

The Institute for Theoretical and Experimental Physics, 117259, Moscow, USSR

Summary

A 3 MeV RFQ linac [1] has been constructed in the ITEP. Values of the linac design parameters attained in practice as well as some preliminary experimental results obtained at the machine launching with output current rising up to 100 mA are in the report below.

Introduction

The spatial uniform quadrupole focusing structures [2] or RFQ (this widespread abbreviation may include spatial periodic structures also) are now widely recognized as an effective mean for the acceleration of ion beams with low β values. Calculational and theoretical problems connected with the utilisation of RFQ linac structures have been observed in the works of Soviet [3-6] and forein [7-9] authores. The first RFQ linac had been put operational and investigated in 1977 [10-12]. In a number accelerator centers HF testings of models and full-scale RFQ resonators for light or heavy ions acceleration are under way [13-18].

The present report describes the course of RFQ linac launching in ITEP with obtaining 100 mA proton beam current accelerated up to energy of 3 MeV.

Parameters and design of the linac

An accelerating-focusing channel of the RFQ linac is a four-line structure supplied by the four-chamber H-type resonator with quadrupole mode of 148.5 MHz oscillations. The main physical parameters and properties of the resonator have been obtained earlier from testing of its full-scale model.

The RFQ vanes used in ITEP [1] are strips restricted in the cross section by a semicircle with constant along the strip 10 mm radius. The distance from aperture axis to vane tips r is varied sinusoidally with gradually increasing period:

$$r = R_o\left(1 + \frac{m - 1}{m + 1} \sin kz \right),$$

where R_o - mean distance from the vane tip to the z-axis; m - modulation factor; $k = 2\pi/\beta\lambda$. Minimal distance from the vane tip to the axis $a = 2R_o/m+1$ is bore radius, it determines the channel acceptance. The field and the vane tips shape were determined by an expression for ideal poles [3]. The numerical study of the fields by a computer code POLE-1 [20] shows that the distribution of the potential in the axis-area for the vane tips of the mentioned form only slightly differs from the ideal (along the whole accelerator, except its initial part). The fabrication of such vanes is not difficult, thus form of our poles is evidently about optimum. In Los Alamos the same conclusion was reached recently [21].

The numerical analysis shows that peak vane surface field $E_{s\,max}$ is reached either in the cross sections where vane tips are most closer to the z-axis if $m < 1.2$, or in the regions of the cross sections with precise quadrupole symmetry if $m > 1.2$. The value of $E_{s\,max}$ is determined basically by the field transverse component and in our case only slightly depends on the modulation depth. Thus spark limit value of the pole-gaps is practically the same fore the parts of the channel with the same value of R_o, with the correct spacing of the vanes and equal quality of its surfaces.

In RFQ linac one can distinguish three sections: matching section, buncher and main accelerator. The manner of accelerating-focusing channel main parameters change in the matching section is shown in Fig.1 and the buncher and accelerator - in Figs.2 and 3, where ν - minimal frequency of transverse oscillations on the scale of an indimensional time, $\varkappa$- focusing efficiency, dW_s/dz - acceleration rate. In the matching section of 22 cells transverse matching is realized by tapering of the average distance between the vanes. To attained a maximum capture in the first 12 cells the equilibrium phase is kept constant with the value -90°, and further its absolute value is reduced to 85°. By the end of the section uninterrupted beam is divided on bunches following each other at a small distance.

In the buncher quasistationary bunches are accelerated. A transit time factor T as well as equilibrium phase φ_s are changing adiabatically along the z-axis with bunches length and longitudinal momentum absolute spread being constant. With the particles velosity growth bunches are separating leaving the spatial charge dencity constant.

In the accelerator section adiabatic decrease of the synchronous phase is stopped to prevent peak current redusing. With large distance between bunches its value is proportional to $|\varphi_s|^3$. A transit time factor and vanes modulation depth are becoming constant. "The core" of the bunch is pressed adiabatically and momentum spread is decreased to $\pm2.2\%$ and the phase length - to 74°.

The maximum value of the average current during the pulse I_{max} is limited by the output part of the buncher.

The 4.9 m long HF resonator of linac consists of 8 sections. The boundaries between sections are choosen in the places with the minimum field on the surface of modulated vanes, where the sparking possibility is less. The resonator has field restricting bottom ends. The diameter of each 4 resonator chambers is 200 mm. All sections are provided with the screws to adjust vanes properly, with the manual frequency tuning plates, alignment marks and measuring loops. Tuning plates enable to change a resonance frequency within $\pm1.5\%$. An unloaded resonator quality Q is 11000. Vanes have been milled by a special programme.

The vacuum pumping is provided by 12 ion 250 l/s pumps, turbomolecular pump of 500 l/s and roughing mechanical pump with a trap. Stainless steel vacuum tank has diameter 70cm,

0018-9499/83/0800-3579$01.00© 1983 IEEE

volume 3 m^3 and consists of 5 sections jointed with metallic seals.

Preparation and tuning of a resonator

The resonator was prepared by following steps: assembling of a separate sections; their mechanical pre-cleaning; HF tuning; measuring of alignment marks position; assembling of the resonator as a whole on an alignment girder; its alignment and tuning; its disassembling to separate sections; their final mechanical cleaning; washing in a vibrating bath with freon; final assembling of the resonator within a clean plastic tent; check of its tuning and rolling of the resonator into a vacuum tank (Fig.4). Alignment of the sections in the tank was fulfilled with the help of alignment gear attached to a tank wall and passing a shift in vacuum. Each section has 16 holding gears. Sections of the resonator are placed in the tank with rms deviation of 100 μm. Many cycles of pumping and filling of the tank have not shifted of the resonator.

HF preparation of the resonator included its own frequency tuning for the working quadrupole mode of oscillations, leveling of the field along the axis z and by chambers, dipole modes suppressing. Dipole modes suppressing with a slot excitation of the resonator used in Los Alamos at a frequency of 425 MHz [13] in our case is not convenient because of a lower working frequency and hence larger geometrical dimensions. Besides of that, with the slote excitation the task of resonator walls cooling becomes very complicated. Four-chamber resonator in the ITEP excitates with the help of four loops placed by one in each of the chambers and properly phased. With that way of excitation and quality of the resonator in a loaded condition Q = 4700 it was possible to adjust fields so, that dipole field components were not felt within the measurement accuracy 2%. Field disturbancies in the longitudinal as well as asimuthal directions was not more than 10%. At the same time it was found that small displacement of a separate sections (about 100-150 μm) caused noticable changes of a reached magnetic field distribution along the resonator as well as by separate chambers. Preliminary estimations show that requirements to accuracy of the vanes placement from the point of view of HF resonator tuning might be more rigid than those, which are defined by tolerances on transverse field distortions.

Launching of the linac

During the preparation of the linac to physical start-up all technological systems were adjusted individually. The pressure after 36 hours of pumping was $3\cdot10^{-6}$ torr and in the course of following several days did not change noticably.

The output power of HF generator while working with a load equivalent at pulse duration of 120 s and repetition rate of 0.25p/s reached 1.5 MWt. For the first time HF power was put into the resonator at $2.6\cdot10^{-6}$ torr (later it was being done at $6\cdot10^{-6}$ torr).

The process of vanes surfaces training was followed by some HF oscillations instability in the resonator. At the power rising a sparkling occured more often in the aperture area between the adjacent vanes or in the places of next vanes junction. Sparking did not cause sharp falling of HF envelope and fast local discharge of the whole stored in the resonator HF energy.

Maximum voltage between adjacent vanes U_L measured in the units of a threshold level calculated to be U_{thr} = 151.5 kV was U_L = 1.3 U_{thr}. Equilibrium phase -35° in the main accelerator section was at $E_{s\ max} \approx 250$ kV/cm and U_L = 185 kV. Actually multipactoring effects have not shown off.

A modified version of ion gun described earlier [22] was used in the injector. The ion source was a hollow cold cathode duoplasmatron with pulsing gas eject. The control of apparatuses under 100 kV pulse voltage was realized by optronic channels. The nominal injector parameters were obtained on the stand in advance. An ion source unit was placed at minimal distance (0.3 m) from linac input. The final ion gun alignment in respect aperture channel was conducted by proton beam passing through accelerating channel at low HF field levels. The acceleration was reached immediately after HF voltage rising up to level U_L = 150 kV (average value from 20 of resonator measuring loops). It corresponds a calculating value of the threshold level. The existance of 3 MeV protons was affirmed by their passing through a 70 m stainless steel foil. With that some HF envelope falling in was shown, sharp increase of γ-ray intensity and scintillation screen brilliance.

At the measurements of particles capture value a collimator was used so as to eliminate the loss through Coulombian repulsion. It restrict a normalized beam emittance of 0.06 cm·mrad. The Fig.5 shows the change of accelerated (passing through a cutting foil) current I_{acc} (solid lines) and ones kept by the foil I_f (dotted lines) versus of vanes voltage U_v (in the units of threshold voltage U_{thr}). A part of accelerated particles in output beam increases with rising of U_v and at U_v = 1.22 U_{thr} (that corresponds calculated equilibrium phase value $\varphi_s = -35°$) reached $\approx 95\%$ (Fig.6).

Measured value of optimal injection energy (92 kV) and estimation of a momentum spread on the output (< 3%) are closed to calculated values. The maximum accelerated current was 100 mA with pulse duration of 25 μs.

References

1. R.M.Vengrov, E.N.Daniltsev, I.M.Kapchinskij et al., Proc. of the 1981 Linac Conf., LA-9234c, 1982, p.92
2. V.V.Vladimirskij, I.M.Kapchinskij, V.A. Teplyakov, USSR Patent No.265312 with priority of October 25, 1968, Invention Bulletin, 1970, No.10, p.75
3. I.M.Kapchinskij, V.A.Teplyakov, Prib. Techn. Eksp. No.2, p.19
4. V.A.Teplyakov, Proc. of the 2nd All-Union Conf. on Particle Acc., V.2, Moscow 1972, p.7
5. I.M.Kapchinskij, Preprints IHEP, INJ 72-29 and 72-30, Serpukhov, 1972
6. E.A.Konoplev et al., Preprint IHEP, INJ 72-24, Serpukhov, 1972
7. R.H.Stokes, K.R.Crandall et al., IEEE, NS-26, No.3, 1979, p.3469
8. J.M.Potter et al., ibid., p.3745
9. R.H.Stokes, K.R.Crandall et al., Proc. of the 11th Int. Conf. on High Energy Acc. Geneva, CERN 1980, p.399

10. V.A.Teplyakov, Proc. of the 5th All-Union Conf. on Particle Acc., V.1, Moscow 1977, p.288
11. B.M.Gorshkov, V.A.Teplyakov et al., Zh. Techn. Phys., 1977, V.47, p.2328
12. A.A.Egorov, V.A.Teplyakov et al., Preprint IHEP, INJ 79-151, Serpukhov, 1979
13. J.E.Stovall, K.R.Crandall, R.W.Hamm, IEEE, NS-28, No.2, 1981, p.1508
14. T.P.Wangler, K.R.Crandall, R.H.Stokes, Proc. on the Symp. on Acc. Aspects of HIF, Darmstadt, 1982, GSI-82-8, p.127
15. T.Nakanishi et al., ibid., p.132
16. H.Klein, P.Junior et al., ibid., p.150 and p.248
17. M.Olivier et al., 7th Conf. on the Appl. of Acc. in Research and Industry, Denton, Texas, USA, 1982
18. J.Brown, B.G.Chidley etal., AECL-7605, March 1982, p.86
19. V.A.Andreev, I.M.Kapchinskij, et al., 8th All-Union Conf. on Particle Acc., Serpukhov, October 1982
20. A.I.Balabin, Preprint ITEP-107, Moscow, 1981
21. K.R.Crandall, J.E.Stovall, Proc. of the 1981 Linac Conf., LA-9234c, 1982, p.71
22. N.N.Kutorga, V.S.Sevostyanova, V.A. Teplyakov, Proc. of the 2nd All-Union Conf. on Particle Acc., Moscow, 1972, V.1, p.88

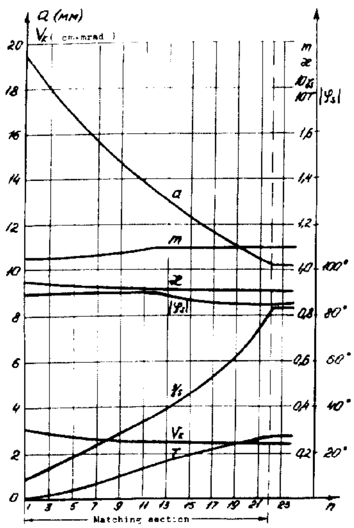

Fig.1. RFQ Linac parameters versus cell number in the matching section.

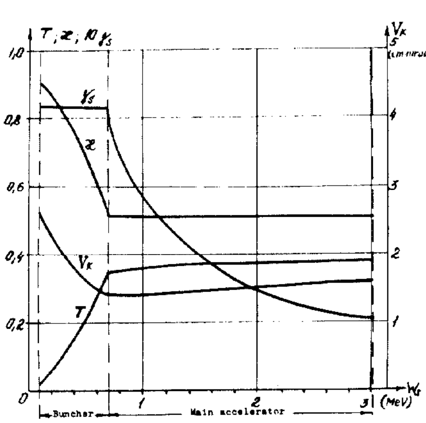

Fig.2. RFQ Linac parameters T, ϰ, ψs, Vk versus Ws in the buncher and main accelerator sections.

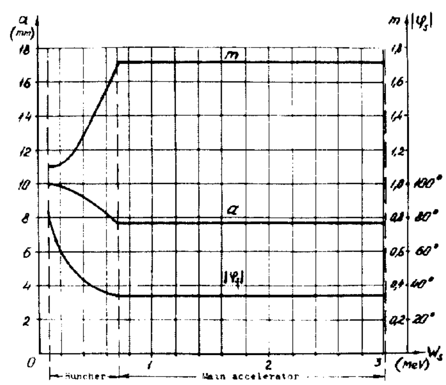

Fig.3. RFQ Linac parameters m, a and |φs| versus Ws in the buncher and main accelerator sections.

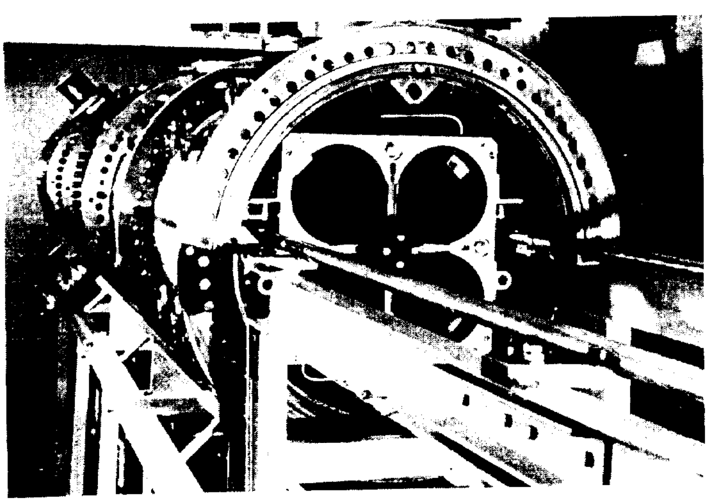

Fig.4. The RFQ Linac resonator in a vacuum tank.

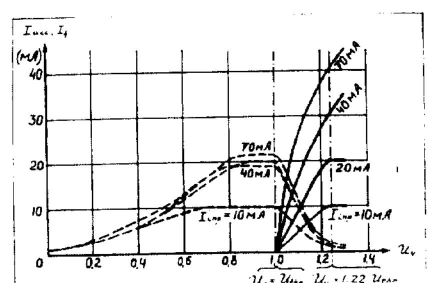

Fig.5. The RFQ Linac output current versus vanes voltage.

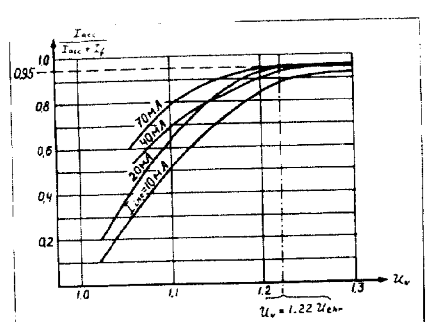

Fig.6. The relative values of accelerated current versus vanes voltage.