PRESTRIPPING SECTION OF THE MILAC ACCELERATOR BASED ON THE PRINCIPLE OF ALTERNATING–PHASE FOCUSING WITH THE MOVING BUNCH CENTER

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INTRODUCTION

The main task facing the personnel of the linear accelerator of multicharged ions (MILAC) at the NSC KIPT was carrying out the fundamental investigations in the field of nuclear physics and material engineering. Since its construction [1] it was somewhat improved, and in 1989 it was completely redesigned on the basis of the effective accelerating structure of the interdigital type excited at H_{111} wave [2, 3, 4]. Other systems were replaced by the systems upgraded on the basis of the latest achievement technologies of RF-power systems, sources of multicharged ions, high-voltage equipment and modern systems of the beam control and diagnostics.

The MILAC consists of two parts, prestripping section (PSS) and poststripping main section (MS), designed for the energy of 0.975 and 8.5 MeV/u, respectively. The average intensity of the current at the output of the sections is ($10^{12}\div10^{10}$) and ($10^{11}\div10^{9}$) particles/s for ^{14}N, ^{20}Ne, ^{40}Ar etc. The PSS is designed for acceleration of ions with the mass-to-charge ratio A/q=15, and MS is designed for A/q=5. In recent years it became necessary to adapt the accelerator to applied research. Among them the most promising is organization of the track membrane production and radionuclide production. The parameters of MILAC provide a possibility to solve both problems profitably. However, the requirements for beams of heavy ions are rather different. For the track membrane production it is necessary to have masses of ions as high as possible and of moderate intensity, but the radionuclide production requires only light ions (protons, deuterons, helium ions (^3He, ^4He) with the beam current as high as possible (from 100 to 1000 μA). It is hardly possible to design an accelerator combining the two requirements. The bottleneck is found to be the prestripping section. At the present time it is possible to use it for the track membrane production with use of 40Ar ions accelerated to 1 MeV/u. However, to organize the commercial production of the membranes with unique properties (sterilizing effect) heavier ions (^{96}Mo, ^{184}W) are required. In that case the existing PSS must be replaced by that designed for acceleration of ions with higher A/q. The results of calculation of the new PSS designed for acceleration of the intense beams of light ions are presented in the report [5] of this Workshop.

At the present time the personnel of the Department of the Linear Accelerator of multicharged ions are developing a new PSS. It is designed for acceleration of ions with the A/q=32 (PSS-32) which will provide a possibility to increase the current of the accelerated ions in an order, and to extend considerably the range of the atomic masses. Ions with this A/q ratio are the most intense component of the source of ions of metals [6]. Besides these ions it will be possible to accelerate other ions for which A/q =32, Cu^{2+}, Kr^{3+}, Xe^{3+}, W^{6+}, U^{7+} for example, and so on. The ions accelerated at the PSS-32 to 0.975 MeV/u, after stripping at the solid target will be accelerated at MS section of MILAC to the energy of 8.5 MeV/u. Optimization of the PSS-32 parameters is necessary to develop convenient, cheap, and efficient accelerator having improved beam parameters.

The new PSS-32 is based on two important innovations: i) the accelerating structure of the interdigital type is used, adequate on three parameter – compactness (large operating wavelength), high acceleration rate, shunt impedance [4, 7, 8]; ii) radial-phase beam stability is provided by alternating-phase focusing with bunch moving center (APF with the BMC). In the paper the different aspects of beam dynamics in PSS-32 are discussed.

1. THE METHOD OF THE APF WITH THE BMC

M.L.Good [9] and Ya.B.Fainberg [10] proposed the principle of alternating-phase focusing early in 50s. In succeeding years it was improved [11,12].

The version of the alternating-phase focusing with the bunch moving center was discussed earlier [13,14]. Its distinctive feature is the mismatch between the center of the bunch of accelerated particles and synchronous particle both in energy and in phase. In the course of acceleration the bunch moves relative to the synchronous particle. The idea of the mismatch between the synchronous phase and phase of the bunch center was discussed earlier and was used in the designs of the heavy ion linear accelerators [15, 16, 17]. However, due to the fact that the zero phase (φ_s=0) was chosen as synchronous, both longitudinal and transverse capture are small, therefore the radial stability is achieved mainly by use of quadrupole triplets alternating with the regions of the accelerating structure, and the phase capture did not exceed 30°.

The version of the APF with the BMC under discussion is based on the periodical shift of the bunch from the region of negative phases to the region of positive phases, and conversely, with the constant excess of bunch center energy over the synchronous particle energy both in positive and in negative phases. As a result, at every region of the structure all of the bunch move in the direction of the smaller phases in the (ΔW, φ) plane, where ΔW is deviation in the energy of the bunch particles relative to the synchronous particle energy, φ is the phase of the bunch particles. That allows to enhance the focusing and bunching action of the RF-fields. The continuous distortion of the phase portrait of the bunch and shifting of the particles relative to the bunch center is accompanied by the attenuation of the phase oscillations of particles. The best compromise between the conflicting requirements for the radial and phase stability is achieved by selecting the region of phase shift, the number of accelerating cells along focusing and bunching regions, and by the excess of bunch center energy over synchronous particle energy.

2. BEAM DYNAMICS

As a result of the optimum selection of each of the three degree of freedom the accelerating structure is obtained, the parameters of which are presented in the Table. The beam dynamics is a complicated process of maintenance of the phase-radial stability of bunches during acceleration.

Parameters of the PSS-32 accelerator

Input energy of ions,	keV	14
Output energy of ions,	keV	655
Mass-to-charge ratio,	A/q	32
Operating frequency,	MHz	23,7
Electric field in gaps	MV/m	9,5
Length of accelerating structure,	m	6
Number of drift tubes		47
Aperture of drift tubes,	mm	16-24
Synchr. phase of bunching regions,	deg.	- 40
Synchr. phase of focusing regions,	deg.	+ 40
Number of bunching regions		6
Number of focusing regions		6
Acceleration rate,	MeV/m	3,2
Longitudinal capture,	deg.	100
Longitudinal output bunch	deg	18
Longitudinal acceptance,	π·(keV/u)mrad	777
Radial acceptance,	mm·mrad	491
Normalized radial acceptance,	π·mm·mrad	0,87

In Fig.1 the combined diagram of phase and energy parameters of the particle dynamics along the PSS-32 is presented. On the abscissa the sequence numbers of the cells grouped in 12 regions (6 bunching and 6 focusing regions) are given. On the ordinate phase characteristics is at the left, and energy parameters is at the right (total energy of the synchronous particle (W_s) and shift in energy of the bunch center relative to the synchronous particle energy (ΔW). As one can see from the Fig.1, the initial acceleration with bunching takes place when the phase is large in modulus (- 70°). At the following bunching regions the phase is equal to – 40°, at the focusing regions it is equal to +40°. The phase of the bunch center at the following bunching regions does not change considerably being, in average, several degrees above the synchronous phase. At the same time the significant shift of the phase of the bunch center occurs during its moving along the focusing regions. First, the center of the bunch enters a center of the focusing gap at large positive phase that results in significant focusing. Further the center of the beam moves to the smaller phases. Its average value at the focusing regions varies from 44° to 20°. Therefore, the high acceleration rate is conserved. The excess of the energy of the bunch center over the energy of the synchronous particle varies from 2 keV/u at the input of the bunching sections to 1 keV/u at the output. For the focusing sections this value varies in the wider limits and as a more complicated function.

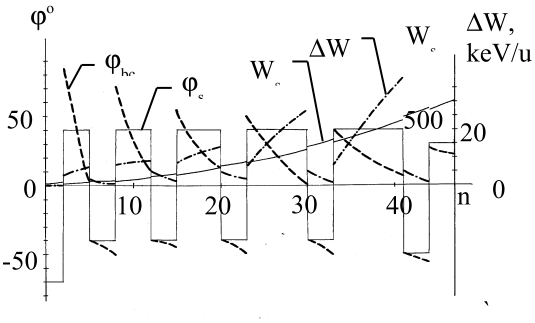

Fig.1. Phase and energy beam dynamic along POS-32. φ_s-synchronous phase, φ_{bc}-beam center phase, W_s- synchronous particle energy, $\Delta W=W_{bc}-W_s$

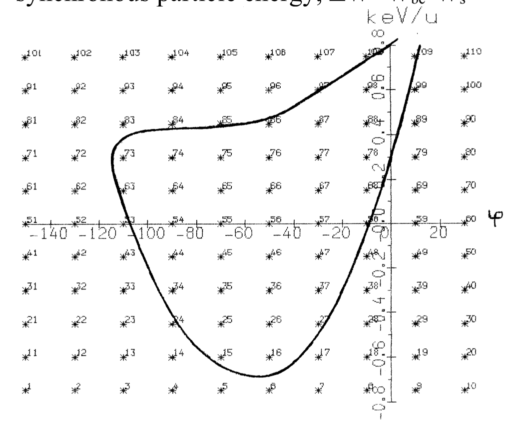

Fig.2. Injection beam separatrix POS-32

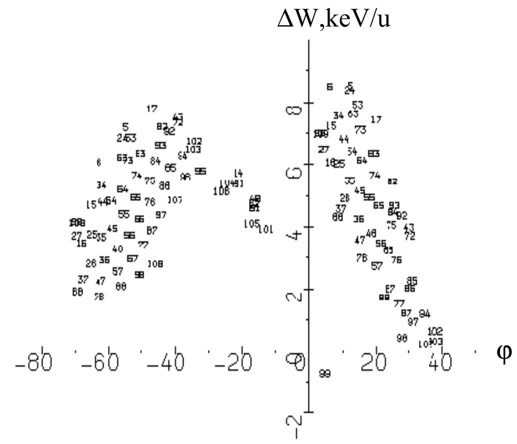

Fig.3. Phase portrait at output 7th and 8th regions.

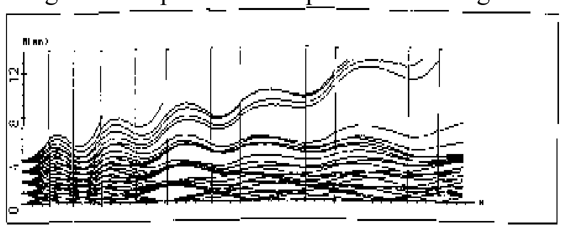

Fig.4. Particle radial trajectory of POS-32

The separatrix that determines the capture of the injected beam to stable acceleration is presented in Fig.2. The portraits of the beams at the focusing and bunching regions combined in the common scale are given in Fig.3. The radial trajectory of particles for theinput radii of 1, 2, 3, and 4mm with the angular discrepancy of 6, 3, 0, -3, -3 mrad are given in Fig.4. The trajectories of the stable radial motion correspond approximately to the normalized emittance of the ion beam of 0.2 π.mm mrad at the input. The total normalized acceptance is POS-32 0.87 π.mm. mrad.

RESULTS

As indicated in the Table, we were able to meet the demands for adequate compact accelerating structure using the method of APF with the BMC. With the acceleration rate of 3.2 MeV/m at the 6m length the gain in energy of 650 keV/u was achieved (the total gain in energy is 20.8 MeV).

The demands on radial-phase stability were fulfilled using by using RF-field without complementary focusing device. The longitudinal capture was 100°. Further optimization of the parameters will give a possibility to increase the capture up to 120-140°. The normalized radial acceptance (0.87 π.mm.mrad) is of the order of magnitude of that as in RFQ at the considerably higher acceleration rate, and the prestripping section is simple in construction.

REFERENCES

1. L.I.Bolotin, et al. International Conf. On High Energy Accelerators and Instr. CERN, Geneva, 1959, p. 643.
2. V.A.Bomko, B.I.Rudyak, G.M.Skoromny, N.A.Khiznyak, Trudu IX Vsesoyusnogo Soveshchania po Uskoritelyam Zaryazenych Chastits, Dubna,1985, v.1, P.68 (in Russian).
3. V.A.Bomko, A.F.Kobetz, Ju.P.Mazalov, B.I.Rudyak, Ukrainsky Physichesky Zurnal. 1988, v.43. P.1144.
4. V.A.Bomko, A.F.Kobetz, Ju.P.Mazalov, B.I.Rudyak. Review of Scientific Instruments, 1998, v.69, N 10, p.3537-3540.
5. V.A.Bomko, A.F.Kobetz, Ju.P.Mazalov et al. // VANT, 1999, # 4 (35). P. 27.
6. V.A.Batalin, Yu.N.Volkov, T.B.Kulevoy, S.V.Petrenko «Vacuum-dicharged source of metal ions» Preprint ITEP 91-37, Moskva, 1991, 28 p.
7. V.A.Bomko, E.I.Revutsky. Zhurnal Technicheskoy Physiky, 1964, v.24, N7, p.1259.
8. V.A.Bomko, A.F.Dyachenko, A.F.Kobetz, B.I.Rudyak. Issledovanye structur dlya uskoryenya tyazeluch ionov - M.: TsNII Atominform, 1988, 26 p. (in Russian).
9. M .L Good, Phis. Rev. 1953, 538.
10. Ya.B.Fainberg. Proc. Symposium on High Energy Accelerators and Hion Phisic, ERN, Geneva, 1956, p. 91.
11. V.V.Kushin. Atomnaya Energia. v. 29, N2 (1970), p.123.
12. V.G.Papkovich, N.A.Khiznyak, N.G.Shulika. Vopr.At.Nauki i Techn. Ser.: Technika Fis.Experimenta, iss2(2), Kharkov, 1978, p.51.
13. V.A.Bomko, Ju.P.Mazalov, Ju.V Meleshkova. 16 Soveshchanie po uskoritelyam zariazhenhych chastitz, Protvino, 1996, v.2, p.50.
14. V.A.Bomko, Ju.P. Mazalov, Ju.V. Meleshkova. 16 Soveshchanie po uskoriteliam zaryazenych chastitz. Protvino, 1998, v.2, p.123.
15. E.Nolte et al. Nucl. Instr.&Methods, 1979, 158, 311.
16. U.Ratzinger. The New GSI Prestripper Linac for High Current Heavy Ion Beams, Proc. of the Linac - 96, Geneva, 1996, v.1, pp. 288-292.
17. P.Lapostolle. IEEE Trans. on Nuclear Science, 1983, pp 1957-1961.