BEAM DYNAMICS ISSUE IN HIGH POWER LINAC WITH THE USE OF METHOD OF SEMIINVARIANTS AND CLUSTER ANALYSIS

I.A. Vorobyov, D.A. Liakin
Institute of Theoretical and Experimental Physics
117259 B.Cheryomushkinskaya, 25, Moscow, Russia, ITEP
E-mail vorobjev@vitep5.itep.ru

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For the beam dynamics issue in the ITEP structural scheme of the high power Linac [1, 2] a necessity in development of methods of beam dynamics analysis, which are sensitive to the space charge redistribution and able to reveal particularities in halo formation at all stages of acceleration, is appeared[1].

Development of semiinvariants method began in 1995 year, results obtained were presented at first at XVI Workshop on charged particle accelerators in Alushta in 1997 [3]. The method has a high sensitivity to space charge redistribution in a phase space and a convenient property for comparison with the Gauss distribution. For the Gauss distribution all semiinvariants from the third order are equal to zero. Following investigations of charged particle dynamics for initial transverse KV distribution with the use of this method revealed three stages in space charge evolution and stability conditions of simulation results according to the number of macroparticles [4, 5]. Calculations were made with the use of a PROTON code [6, 7].

Dependences of the RMS normalized beam emittance at the end of RFQ [8] with an initial emittance of 0.2 cmmrad and a semiinvariant of six order at its beginning on the number of macroparticles are shown in Fig. 1. As is seen from this figure the stability region begins from 3000 macroparticles. Dependences of semiinvariants on the RFQ cell for 1000 and 10000 macroparticles have the same character as in Fig. 3.

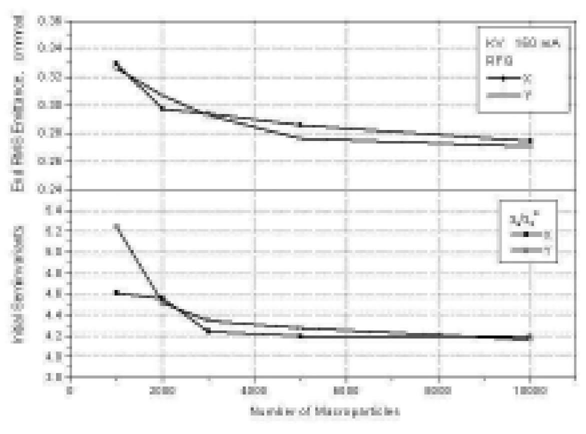


Fig. 1. Dependences of RMS normalized emittances at the RFQ exit and initial (at the beginning of RFQ) semiinvariant of six order in transverse planes for KV distribution on the number of macroparticles for the injected beam current 150 mA.

1 Development of Linac structural scheme was made under ISTC project No.17.

Beam dynamics simulation in the whole ITEP structural scheme of Linac is made without proper matching at crossing between the initial, intermediate and main s. The following main parameters are accepted in calculations: the initial part with the RFQ structure at 150 MHz to the end energy 3 MeV, the intermediate part with the Alvaretz structure at 300 MHz to the end energy 100 MeV and the main part with the single gap resonators at 600 MHz to the end energy 1.5 GeV. Phase advance in the main part is equal to 1.0 at the whole length. Calculation was made for an injected beam current of 30 mA with the initial emittance 0.2 cmmrad and the matched initial uniform transverse distribution of charged particles with the energy spread ±1%. In the numerical simulation 5000 macroparticles were used.

Data obtained were analyzed with the use of the method of semiinvariants. The results are shown in Fig. 2 for the Linac and in Fig. 3 for the initial part with the RFQ structure.

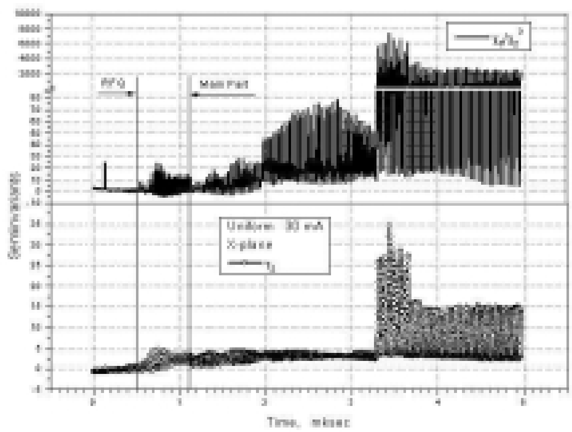


Fig. 2. Dependences of access coefficients γ_2 and semiinvariant χ_6/χ_2^3 on the time of acceleration in the Linac.

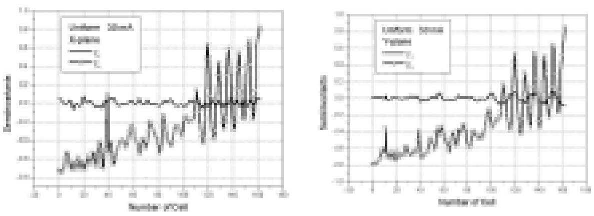
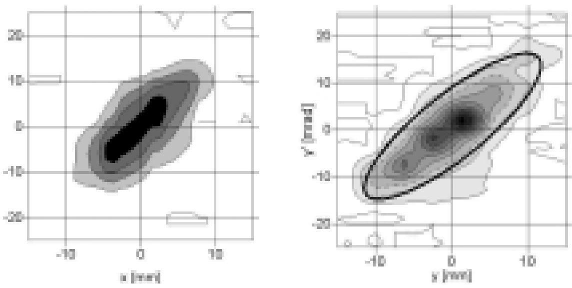


Fig. 3. Dependences of asymmetry and access coefficients on the RFQ cell number.

The results obtained in investigations of beam dynamics with a uniform initial distribution confirm the earlier conclusion for the KV distribution [4, 5] about tree stages of space charge evolution: 1) stage of fast relaxation, 2) stage of relative stabilization of charged particle distribution, 3) stage of distribution destabilization and beam halo formation. Also, the results confirm the tendency in space charge evolution to the Gauss distribution revealed in the initial part.

The requirement for development of the method of semiinvariants was a possibility of its application to experimental data analyzing. The measurements of beam proton distribution on the phase plane were made at the RFQ structure [9] of the ITEP “Istra” accelerator with the use of measurement installation [10]. This method allows to make measurements at one pulse of accelerator work, that significantly accelerate the process of different characteristics and dependences removal. The basic principle of measurements is selecting the beam particles, located in small regions, which have fixed coordinates in perpendicular to the accelerating axe planes. After some drift space the selected particles, which have initially a δ-space distribution, redistribute according to the transverse component of their motion. Measuring a brightness of luminosity scintillating under influence of crossing through it particle screen, it is possible to obtain information about phase distribution of beam. In these measurements for selecting particles with fixed coordinates an immovable wolfram screen with a net step of 2.5 mm and hole diameter of 0.1 mm was used. Drift of 110 mm allowed to obtain the angle separation 1 mrad. Measurement data processing was made with the use of the method of semiinvariants developed in [3-5], the results are shown in Fig. 4 and Table 1.

As it is seen from Table 1 and Fig. 3, the range of measured values of asymmetry γ_1 and access γ_2 coefficients is well agreed with data of numerical simulation with the use of the PROTON code, which was applied for designing the RFQ structure [8, 9].



a b

Fig. 4. Measured phase portraits of the beam for a beam current of 20 mA in horizontal (a) and vertical (b) planes at the RFQ exit. In 4b, for comparison with the canonical shape, the ellipse is shown.

Table 1. Experimental values of asymmetry and access coefficients for the beam at the exit of RFQ

Parameter	**Plane**	
	Horiz.	**Vert.**
γ_1	-0,26	0,132
γ_2	0,4	-0,74

Method of semiinvariants begins to extend in physics of charged particle beams [11], that confirms actuality of development of such a method.

For revealing specific conditions of halo formation in each constructive part of the Linac the method of cluster analysis of beam dynamics in radial and longitudinal phase planes was developed. This method revealed coupling of longitudinal and transverse motions .for initial KV distribution, made dependent by the resonance of the third order [5].

For continuous run of a beam in the Linac with initially uniform transverse particle distribution, the Poincare surfaces for all particles in radial and longitudinal phase planes are shown in Fig. 5 at last 50 focusing periods of the main part. For the radial surface we determined the radius value 1.0 cm to select a halo particle group. The selected at the whole length, main part group of particles with maximal deviation from the channel axe above this radius consists from 341 particles. The results of cluster analysis for these particles are shown in Fig. 6 – Fig. 9.

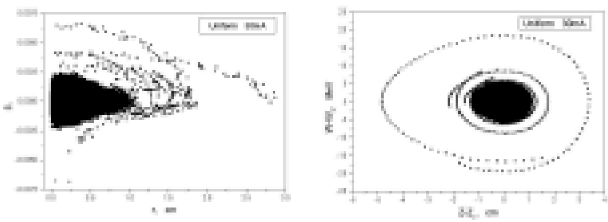


Fig. 5. Radial and longitudinal Poincare surfaces at last 50 focusing periods of the main part of the Linac for all particles.

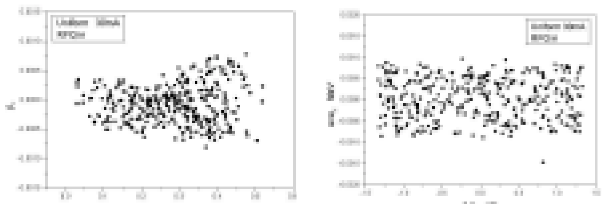


Fig. 6. Radial and longitudinal phase portraits at the beginning of the RFQ electrodes for the halo group.

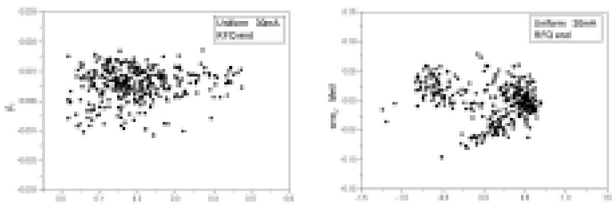


Fig. 7. Radial and longitudinal phase portraits at the end of the RFQ electrodes for halo group.

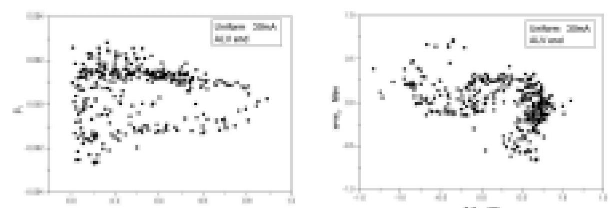


Fig. 8. Radial and longitudinal phase portraits at the end of the intermediate part for the halo group.

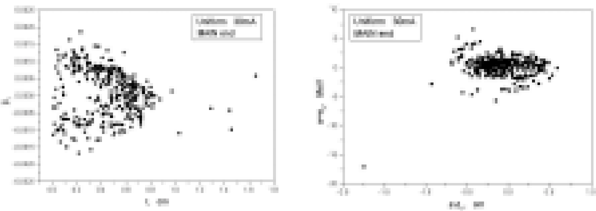


Fig. 9. Radial and longitudinal phase portraits at the end of the main part for the halo group.

As it is seen from Fig. 6 – Fig. 9, particles of halo group, having no significant particularities in longitudinal distribution while injecting the monochromatic beam, move mainly in the peripheral region of longitudinal phase portrait of bunch to the end of RFQ and in the end of intermediate part redistribute in the periphery of radial one. In the main part picture of halo particle group dynamics is maintained in the both phase planes while carrying out particles to large distances from the channel axe and redistributing to the center of separatrix.

CONCLUSION

The methods of semiinvariants and cluster analysis developed allow to reveal the processes, leading to carrying out the part of particles into halo and tendencies in evolution of charged particles distribution, determine the parameters of nonstationary processes, make physically and mathematically well-founded conclusion about possibility of using the beam stationary model in calculations, obtain the necessary data for choice of a parametric family of functions.

The methods developed have revealed coupling of transverse and longitudinal particle oscillations, objective laws in halo particles dynamics and specific particularities of halo formation in each constructive part of the Linac. This allows to optimize the structural scheme with taking into account the objective laws in the beam dynamics and halo particle group and to calculate the effective system of halo scrapping.

Applying the method of semiinvariants for experimental data analyzing at the end of the RFQ structure showed a good agreement with simulation results with the use of the PROTON code.

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