

# COMPARATIVE STUDY OF ACCELERATING STRUCTURES PROPOSED FOR HIGH POWER LINAC

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## Abstract

The basic problems for design of high intensity linear accelerator are providing of high efficiency, reliability and reduction of induced radioactivity in its parts. In spite of very wide studies of processes leading to beam halo formation, there are no reliable methods to evaluate the small particle losses. The possible method based on analysis of beam dynamics simulations are discussed. The particle coordinates stored in output file and representing particle trajectories are considered as sequences of random points and spectral density of correlation function for each sequence is calculated. It allows to study spectral properties of the particle trajectories as well as growth of their amplitudes.

The method has been applied for analysis of beam dynamics simulation carried out for test accelerating - focusing structures which represent a intermediate part of hypothetical high power linac. The obtained results are discussed.

## 1 INTRODUCTION

The projects of the high power proton linacs have been offered in various laboratories. They are designed practically under the same block scheme with very similar parameters of the beam. The value of the beam current 100 mA and output beam energy  $\approx 1000$  MeV are chosen. The proposed projects are the realistic solution of a high power accelerator design. However to build the linac with high average beam power it is necessary to solve a critical problem of the accelerator parts activation. The permissible value of particle losses under conditions of hand - operated service of installation is equal  $\approx 0.2$  nA/m and depends on energy of the beam [1]. It means, that in the powerful linac constructed in accordance with the proposed schemes and with the parameters mentioned above, the level of relative losses should be reduced in two order of the magnitude in comparison with achieved in LAMPF linac level.

## 2 SIMULATION OF BEAM DYNAMICS

Beam of charged particles in accelerating focusing structure in presence of space charge is very complicated system. The numerous analytical and computer investigations have been carried out to study beam dynamics, especially beam halo formation processes [2]. Computer simulations used very widely for study of evolution of charged particle beam taking into account

space charge forces. The goal of such simulations is usually determination of beam emittance growth in dependence on beam current and parameters of focusing channel. The evaluation of small particle losses for high power linac requires, however, study of the beam with parameters which do not lead to remarkable emittance growth. In this case calculation of rms emittances do not lead to any reliable methods for quantitative evaluation of halo formation and consequently of particle losses. It is mainly due to limited number of particles used in simulations and absence of suitable methods for analysis of simulation results.

Recently made simulations as well as analytical works showed the great importance of stochastic component of charged particle beam dynamics. According to the general nonlinear mechanics the main mechanism of appearance of stochastic dynamics is local instability of particle motion when it is in vicinity of separatrix of nonlinear resonance [3].

The result of simulation of particles motion is usually file containing their coordinates and velocities, recorded at some discrete time moments. It means that each trajectory is represented in simulation output file as a discrete sequence of the points. It is well known that in the case of linear motion transverse coordinates of the particle determined at the same cross section of focusing periods belongs to sinusoid

$$x_k = A \sin(\mu_0 \tau_k + \theta_0) \quad (1)$$

here  $\mu_0$  is transverse phase advance at absence of space charge,  $\tau$  - dimensionless time,  $\theta_0$  - initial phase.

The appearance of stochastic component of particle motion means that sequence of coordinate calculated for each focusing period can be written as

$$x_k = A \sin[\mu(I) \cdot \tau_k + \theta_0] \pm \Delta x_k \quad (2)$$

where  $\mu(I)$  is depressed phase advance at beam current  $I$  and  $\Delta x_k$  is some random value. It can be assumed that local instabilities can be the main source for occurrence of random component in particle trajectory.

The consideration of some specific spectral properties of dynamic system in the transition region from order to chaos is given in [3]. It is based on the study of the spectral densities of the correlation function  $R_N(\omega_m)$  calculated for sequence of particle coordinates  $x_k$  stored at certain cross section in every cell during the simulation. The spectral density of correlation function is:

$$R_N(\omega_m) = \frac{1}{N} \sum_{-\frac{1}{2}N \leq k \leq \frac{1}{2}N} R_N(k) e^{-ik\omega_m} \quad (3)$$

$$R_N(k) = \frac{1}{N} \sum_{-\frac{1}{2}N \leq j \leq \frac{1}{2}N} x_j x_{j+k} \quad \omega_m = 2\pi \frac{m}{N}$$

In this expression  $N$  determines the number of stored points for every particle trajectory.

### 3 IMPLEMENTATION OF CORRELATION FUNCTION TO SIMULATION

This discussed method was used to analyze simulation results, obtained in ITEP in framework of feasibility study of high power linac. The spectral densities in terms of phase advances were calculated for transverse coordinates of particles obtained in numerous beam dynamics simulations under different conditions. The results of the work contains in [4].

It is follow from [3] that the appearance in the spectra well marked peak  $R_N(\omega_m = 0)$  (so called ‘‘central peak’’) is universal spectral property of nonlinear system. It is due to some trajectories pass the vicinity of hyperbolic points of the separatrix for a very long time. It means the appearance of constant term in the correlation function. It is clear that for stable motion of particle in quadrupole channel there is no permanent displacement of the trajectory, so we can consider this effect as jump of particle oscillation amplitude due to local instability occurred during its movement in the focusing structure.

The values  $R_N(\omega_m = 0)$  have been calculated for proton trajectories obtained by beam dynamics simulations in two test accelerating structures with different numbers of accelerating gaps per focusing period. Lengths of focusing periods were  $2\beta\lambda$  and  $4\beta\lambda$ . The channels have the parameters given in Table 1.

**Table 1**

Parameter	$2\beta\lambda$	$4\beta\lambda$
Focusing lattice	FODO	FODO
Number of RF gaps in period	2	4
Number of focusing periods	382	382
Transverse phase advance	$60^\circ$	$60^\circ$
Synchronous phase	$-90^\circ$	$-90^\circ$
Relative velocity of protons	0.4282	0.4282
RF wave length (m)	1	1

The parameters of the channels have been chosen to model structures proposed for intermediate parts of high power linac. Structure with  $2\beta\lambda$  corresponds to conventional DTL, period with  $4\beta\lambda$  was chosen to represent structure similar to CCDTL. The synchronous phase  $-90^\circ$  allows to keep constant average particle energy taking into account defocusing action of RF gaps.

Simulations were carried out in two steps. The truncated gauss distribution with parameters for best matching was used for first run. The output particle distribution was considered as fully matched with channel and has been used as initial for second run. The simulation results obtained by second step have been used for further analysis.

The results of the analysis of these simulation are shown in Fig.1, Fig. 2 and Table 2. In figures are presented distributions of particles on their mean value of displacement from axis. These histograms are plotted for both simulated structures and for beam currents 10, 20, 40 and 100 mA. The distributions can be described by function:

$$f(x) = 4 \cdot \frac{x^2}{\sqrt{\pi} \xi^3} e^{-\left(\frac{x}{\xi}\right)^2} \quad (4)$$

Distributions of particles on transverse coordinate in our simulation can be approximated by function:

$$g(x) = \frac{2}{\sigma \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2} \quad (5)$$

It is clear that particle with transverse coordinate  $x$  which have got on some focusing period additional random impulse and increased its transverse amplitude on  $\Delta x$  will be lost if

$$x + \Delta x \geq a, \quad (6)$$

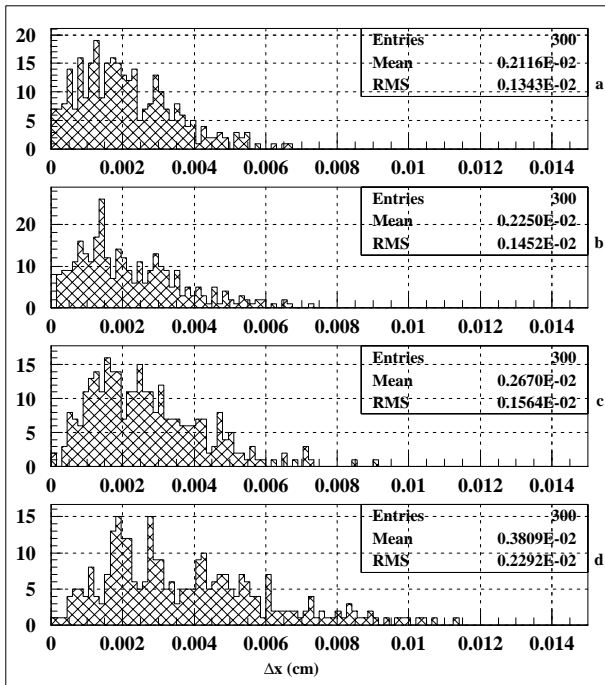
where  $a$  is focusing channel aperture. Therefore losses of particles per focusing period can be expressed by

$$\int_0^a g(x) \int_{a-x}^a f(z) dz dx \quad (7)$$

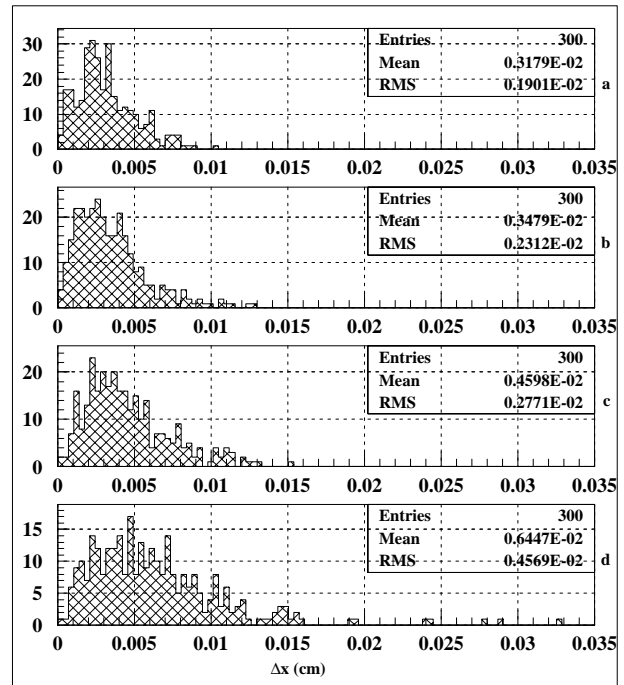
Parameters of particle distributions  $\sigma$  and  $\xi$  calculated from simulation results as well as space charge parameter  $h \approx 1 - \mu/\mu_0$  are given in Table 2. These parameters have been used to evaluate the relative particle losses per meter for both considered structures. The losses in dependence of channel aperture are given in Fig.3 and Fig.4. As it follows from the figures the particle losses less then  $10^{-7}$  per meter for 100 mA of beam current can be achieved in structure with length of focusing period  $2\beta\lambda$  at aperture 0.8 cm. Aperture 1.2 cm is required for the same beam current if focusing period is  $4\beta\lambda$ .

### 4 CONCLUSION

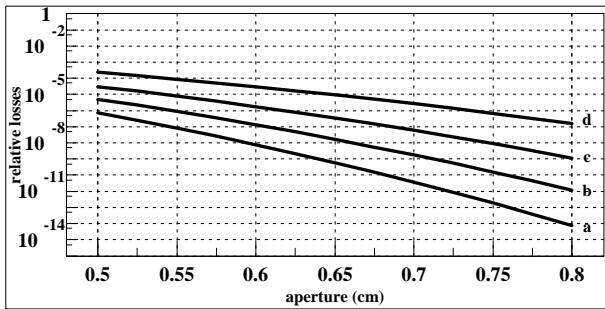
The method for evaluation of small particle losses in linac using spectral densities of correlation function is proposed. It has been applied to comparison of structures with different focusing periods, proposed as intermediate part of high power linac. The first results show that the method can be useful for calculation of small particle losses taking into account different perturbation factors.



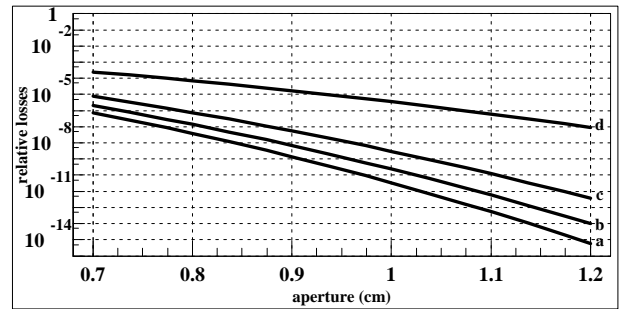
**Fig. 1.** Particle distributions on  $\Delta x$  for structure with focusing period  $2\beta\lambda$ . Beam currents 10 mA (a), 20 mA (b), 40 mA (c), 100 mA (d).



**Fig. 2.** Particle distributions on  $\Delta x$  for structure with focusing period  $4\beta\lambda$ . Beam currents 10 mA (a), 20 mA (b), 40 mA (c), 100 mA (d).



**Fig. 3.** Relative particle losses in  $2\beta\lambda$  structure in dependance of aperture. Beam currents 10 mA (a), 20 mA (b), 40 mA (c), 100 mA (d).



**Fig. 4.** Relative particle losses in  $4\beta\lambda$  structure in dependance of aperture. Beam currents 10 mA (a), 20 mA (b), 40 mA (c), 100 mA (d).

**Table 2**

I (mA)	h	$\sigma$ (cm)	$\xi \cdot 10^{-3}$ (cm)
$2\beta\lambda$			
10	0.0052	0.11	2.12
20	0.0101	0.12	2.25
40	0.0183	0.14	2.67
100	0.0461	0.16	3.81
$4\beta\lambda$			
10	0.0101	0.16	3.20
20	0.0182	0.17	3.48
40	0.0370	0.18	4.60
100	0.0520	0.25	6.45

## REFERENCES

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