SIMULATION OF PROTON BEAM BEHAVIOUR IN HIGH ENERGY LINAC WITH FEW-GAPS RESONATORS AT FAILURE OF ONE OR SOME OF THEM [*]

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Abstract

The longitudinal proton beam behaviour simulation in the main part (MP) of the linear high-current accelerator at failure of one or five sequentially located accelerating gaps is reported. The beam destabilization is compensated by automatic correction or RF field amplitude or amplitude and phase in several tens of normal operating gaps. The beam parameters on a phase plane thus obtained are transferred up to normal (at failure of one gap), or are coming closer to them (at a failure of 5 adjacent gaps).

1 INTRODUCTION

In the powerful linac-driver the sudden spontaneous interruption of beam feed on an electronuclear installation target is extremely undesirable because of sharp change of a thermal regime of a reactor target assembly and possible severe consequences for it [1]. The reliability of a whole accelerator in a major degree is determined by reliability of RF supply system. In 1966 the ITEP employees have suggested a variant of unceas-ing operation of RF system and resonators in the MP of accelerator [2-4]. Later it was found that the similar proposition was considered for design of SNQ linac [5].

For deriving the non-failure RF system operation, the idea of so-called “elegant degradation” is developed in the reports [2-5], where building-up of composite systems from set of unified elements is suggested. When some of separate unit malfunction occur then compensation will be achieved by functionality redistribution between the rest operating ones. Such regime ensures a little bit worse properties (RF system degrades), however these changes are small and do not affect system serviceability as a whole.

The purpose of the report is further study of an opportunity to maintain serviceability of the linac MP, consisting of great number of one- or few-gaps resonators with individual RF generators at failure of some of them.

2 PROCEDURE AND CONDITIONS OF SIMULATION

At the given stage of investigation only the longitudinal particle motion was considered, for just it changes greatly at the absence of acceleration in a separate resonator. On a preliminary simulation step we use the model of charged particle beam behaviour without the Coulomb force influence. The acceleration process is described by restricted number of parameters. At separate steps of simulation we use the various models, for example, a model with a moving coordinate system fixed to a synchronous particle. In this case particle motion becomes nonrelativistic, that simplifies the equations, which describe their motion. The relativism, which really takes place, is taken into account by adiabatic change of parameters.

The carried out simulation can be useful in application to any accelerator, and here it is illustrated on a concrete example of a high-energy superconducting linac part of the TRASCO design [6].

Fig.1 shows the view of a potential energy of particles for synchronous particle energies W_s = 450 MeV (a) and W_s = 1600 MeV (b). The adiabatic expansion of a potential well is equivalent to phase oscillation amplitude and frequency attenuation in a laboratory coordinate system. As the approach of particles to the stability area border in high-current accelerators cannot be acceptable, the particles should be inside a rather small area nearby synchronous particle ($\Delta z = 0$ in a Fig.1) a majority of the time. This condition can be moderated on a short period of time necessary for correction of accelerator RF field parameters at failure of some resonators.

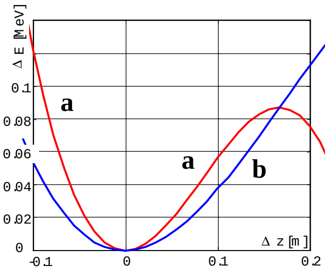

Figure 1: Dependence of a potential energy of particles at shift in moving coordinates system:
a) W_s = 450 MeV; b) W_s = 1600 MeV.

For longitudinal proton beam behaviour simulation the written program permits to observe beam behaviour during its motion from gap-to-gap. The interface of the program is shown on Fig.2. For obviousness the initial beam phase volume is enlarged, and the acceleration rate is diminished. The basic algorithms and models used in

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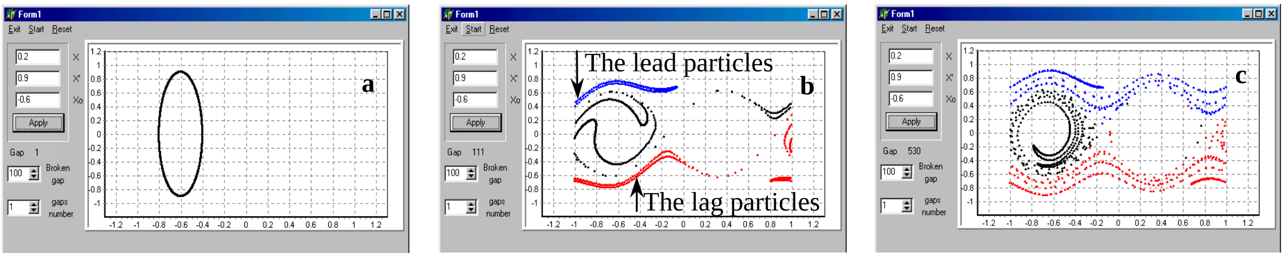

X 0.2
X' 0.9
Xo -0.6
Gap 1
Broken gap 100
gaps number 1

X 0.2
X' 0.9
Xo -0.6
Gap 111
Broken gap 100
gaps number 1

X 0.2
X' 0.9
Xo -0.6
Gap 530
Broken gap 100
gaps number 1

Figure 2: The interface of the program simulating a longitudinal beam motion in structure. Stages of passage of gaps No 1 (a), No 111 (b) and No 530 (c).

the program, beforehand were formulated and were organised with MATLAB.

Some simulation results are given below. During simulation the beam is represented as a contour, which can have some treatments, for example, as a line of equal beam density. Later one a more common procedure can be applied, for example, with technique of specially constructed Lyapunov's function levels at the account of particle charge interaction.

3 BEAM BEHAVIOUR AT PERTURBATIONS

3.1 Accelerating gap switching-off

The accelerating gaps failures lead to subsequent beam phase portrait jump to the smaller energy and greater phase area. These variables are not invariant at a coordinate transformation and should be consequently enumerated at transition from one system to another.

Fig. 3 shows deficiency ΔW_s of particle energy at a failure of 1 and 5 sequential gaps in a point (z) of acceleration path at the range from 450 up to 1600 MeV.

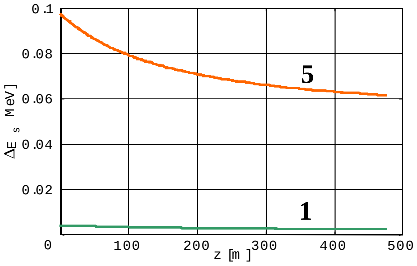

Figure 3: Shortage of energy in synchronous particle coordinates system at switching-off one (1) and five (5) gaps.

The diagrams are given in synchronous particle frame. In laboratory system ΔW_s will be 2 and 10 MeV respectively. Comparing curves of a Fig.1 and Fig.3 it is obvious that only the failure of 5 sequential gaps in the initial stage of the given acceleration path (z = 0, ΔW_s = 0.1 MeV, the Fig.3) can result beam losses, as the energy barrier runs lower (see curve "a" in Fig.1: ΔW = 0.087 MeV). The failure of smaller number of sequential gaps does not lead to it. But even at failure of 5 gaps it is possible to correct the situation if acceleration rate would be reduced on this acceleration path.

The influence of beam perturbation at energy 600 MeV on following motion is shown in Fig.4. One can see, that a beam contour and its subsequent transformation in a direction of arrows spring after the beam passage of failure gaps. The acceptability of effective beam emittance growth during small time (~1 ms), necessary for automatic correction of RF field parameters, should be estimated in each separate case. However immediate particle losses do not appear in the case.

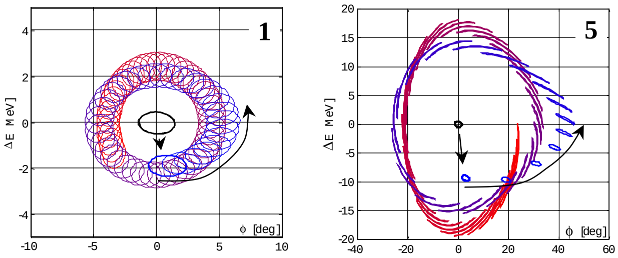

Figure 4: Effect of switching-off one (1) and five (5) of sequentially placed accelerating gaps.

3.2. Single gap failure with the correction by RF field amplitude

At gap failure automatic control systems should quickly return a beam on an initial trajectory. This is the problem of an accelerating channel regime optimisation that should be solved at particular restrictions on the peak field reserve and on an amount of beam energy de-viation with respect to nominal value on an accelerator exit. Last requirement defines a form of functions specifying distribution of an accelerating field phase.

The example of perturbation caused by a failure of the one-gap resonator at energy near 600 MeV and correction due to only RF field amplitude change within 10 % from a nominal value in 30 subsequent gaps, is shown in Fig.5. As it is seen from Fig.5-b the unperturbed beam contour and corrected one after beam perturbation practically coincide.

3.3 5-gaps failure with the correction by RF field amplitude

It is harder to correct a failure of 5 subsequent gaps (Fig.6) by the only change of RF field amplitude. In the case the correction process requires some greater time

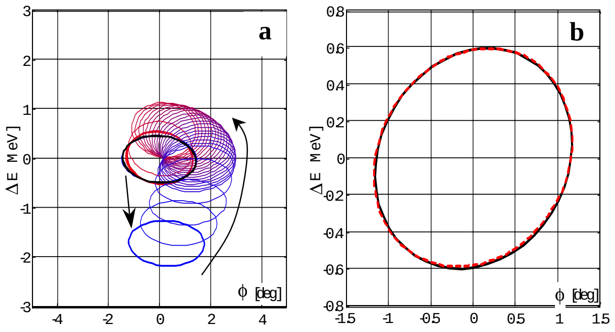

Figure 5: Compensation process of accelerating voltage disappearance in one gap (a) and comparason of beam representing contours before and after perturbation with subsequent compensation (b).

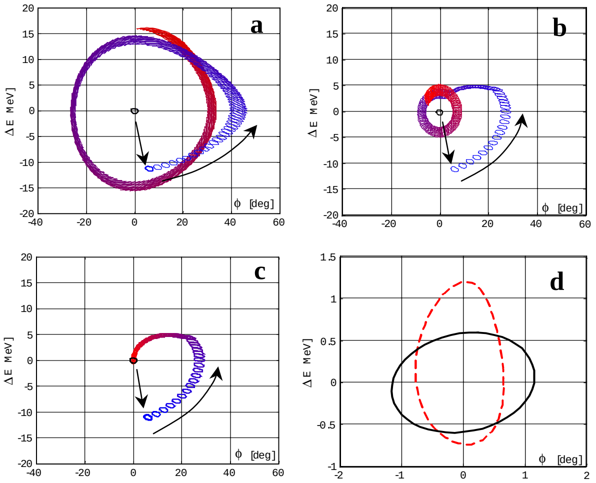

Figure 6: Compensation of switching-off 5 following one after another gaps:

a – absence of compensation,
b – case of poor compensation,
c – optimum compensation,
d – unperturbed beam (solid line) and beam after compensation of perturbation (hatched line).

and representing beam contour has time to turn on some angle. The rotation results that some beam part displaces and appears on trajectories with higher energies of longitudinal oscillations (Fig.6-d), and at the end it will inevitably give an effective emittance growth.

3.4 Combined correction

For minimisation of beam losses it is required, that particles should be near a potential energy minimum (Fig.1). Therefore accelerating RF field phase should trace a location of a particles bunch along the accelerator at all regimes of operations. From this point of view the correction using only RF fields amplitude tuning is not optimal. The combined approach with simultaneous change of the field amplitude and phase is more exact and flexible.

The correction process at failure of 5 subsequent gaps is shown in Fig.7. Particles get additional energy on 100 gaps before failure ones. As the beam on this path goes a little bit faster, than at absence of correction, there are shifts of phases, which require a phase tuning in all resonators following the failure ones.

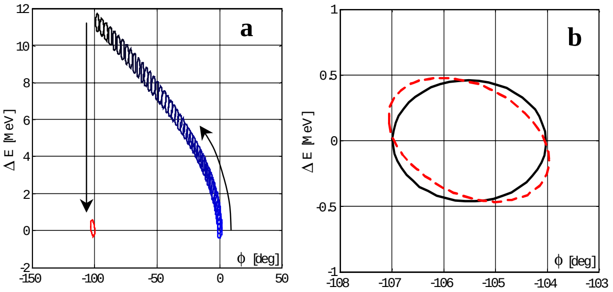

Figure 7: Advance correction in case of switching-off 5 gaps with simultaneous change of amplitude and phase of accelerating field:

a – advance addition of particles energy before switching-off gaps;
b – comparison of the beam: unperturbed (solid line) and corrected (hatched line).

4 CONCLUSIONS

- The failure from one up to five sequential accelerating gaps in nigh-energy part of a powerful linac without field correction in the rest gaps, as a rule, does not give beam loss. The acceptability of effective beam emittance growth should be solved in each separate case
- The beam location on a phase plane is practically completely recovered at failure of one gap with relevant small increase of an accelerating field in the operating gaps.
- To correct a beam location it is preferable to use RF field amplitude and phase tuning simultaneously. It is effective even at failure of 5 sequential gaps.

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