SPACE-CHARGE DRIVEN EMITTANCE COUPLING IN CSNS LINAC

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Abstract

In the conventional design of RF linac, the space-charge is not thermal equilibrium in three dimensions. The space-charge couples the particle motions between the longitudinal and transverse planes and will cause equipartitioning process. Furthermore this process causes the emittance growth and the halo formation. In the design of the China Spallation Neutron Source (CSNS) linac, three cases are investigated using the Hofmann stability charts to analysis the layout. In this paper, we present the equipartitioning beam study of the CSNS Alvarez DTL linac.

INTRODUCTION

In the high-current linac as well as in the high power synchrotron, the emittance coupling induced by the space-charge is very important issue [1]. The space charge driven coupling reveals the collective and nonlinear behavior which causes the emittance growth and the formation of halo [2,3]. There, the exchange can happen between the longitudinal and transverse degrees of freedom known as "equipartitioning". Furthermore halo formation [4] and the associated beam loss due to this equipartitioning process may cause excessive radioactivity especial for high power accelerators.

China Spallation Neutron Source mainly consists of a high-intensity linac and a rapid cycling synchrotron (RCS) of 1.6GeV. As shown in Figure 1, the main parts of the CSNS linac are a 3.0-MeV RFQ accelerator and the conventional Alvarez DTL structure which accelerates the H^- particle from 3.0 MeV to 81/134 MeV in phase I/II respectively. The operation frequency is 324 MHz and a duty factor of 1.1% has been chosen for all of the RF structures. Table 1 shows the main reference-design parameters of the CSNS DTL linac [5].

The emittance exchange in unstable areas of the instability charts developed by Hofmann has already been demonstrated for idealized cases [6]. The goal of this study is to analysis the layout of the CSNS linac using this valid chart.

SIMULATION

In the following we calculate the actual linac tune values of various designs and plot the tune footprint on the Hofmann charts for the nominal emittance ratios $\varepsilon_z/\varepsilon_{x,y} = 2$ [7].

Table 1: CSNS DTL linac Design Parameters.

	PhaseI	PhaseII
Length	34.46 m	61.57 m
Beam energy	81 MeV	134 MeV
Max. repetition rate	25 Hz	
Peak current	15 mA	30 mA
Average current	78.75 uA	157.5 uA
Average pulse current	7.5 mA	15 mA
Chopper beam-on factor	50%	
Max. beam pulse length	0.42 ms	
Max. beam duty cycle	1.1%	

The shaded areas of the chart indicate where emittance exchange between the longitudinal and the transverse plane is to be expected (the degree of shading indicates the speed of the process). The dashed line indicates the condition for an equipartitioned beam. The characteristic regions (in grey) where third and fourth order modes of collective space-charge density oscillations expected to cause emittance transfer.

The simulations use the actual layout of the DTL linac sections of the CSNS (3.0 - 132 MeV, 30 mA current) and start with an initial K-V distribution. The extension of the K-V distribution to 6-dimensional phase space leads to a nonlinear space-charge force in longitudinal direction. Our simulations have been carried out with PARMILA using the space-charge routine SCHEFF.

The stability chart and the tune footprint relating to the CSNS DTL linac design is shown in Figure 2. The quadrupole gradients are modified so that we can obtain three different lattices that fall into various areas of the stability chart in Figure 2. The tune ratio *kz/kx* for three cases varies over a large scale (0.122-1.23).

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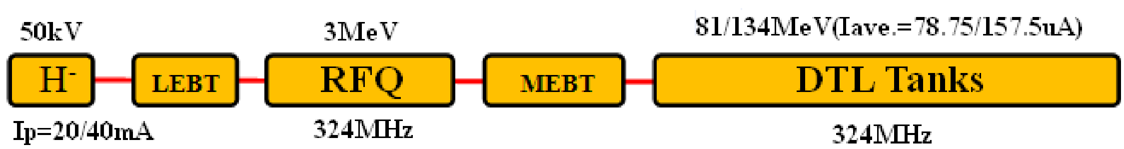


Figure 1: Layout of CSNS Linac.

RESULTS

As the chart indicates that the "case 1" and the first four periods of case2 are located in an unstable area, while the rest periods of "case 2" and "case 3" lattice should both be stable. In the designs of case1 and case2, the emittance coupling must occur because the pronounced 2:2 resonance center at the tune ratio *kz/kx* = 1 is not avoided. Furthermore the design of case1 with increased tune ratio shows overlap with the resonance band unfortunately at *kz/kx* = 1.1, where an e-folding distance of only 3-4 betatron periods is predicted. The design of case2 has a similar effect at its beginning section. For case3, it locates at the "safe" region and the coupling does not occur.

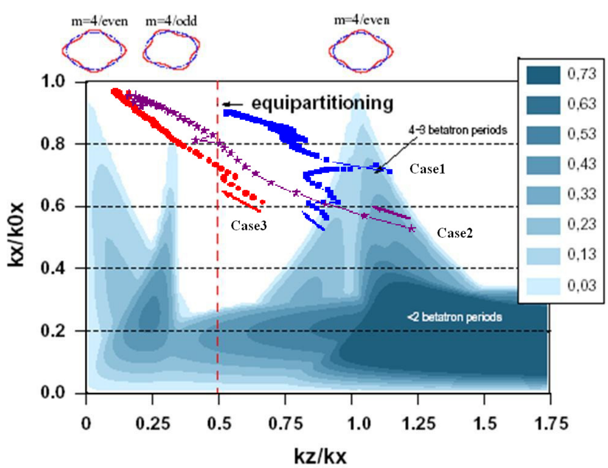
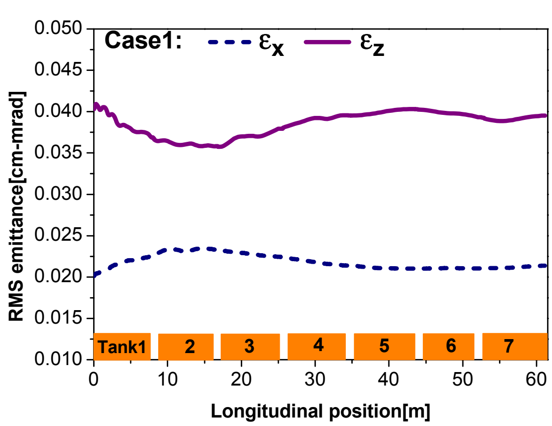
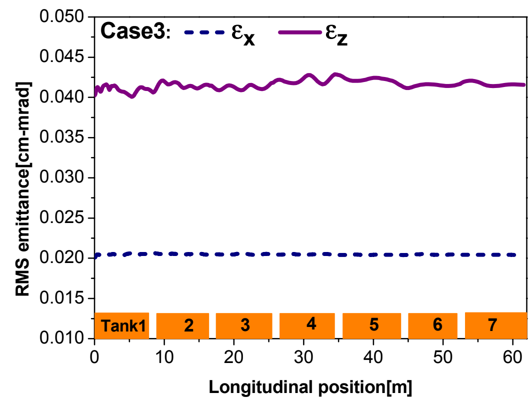


Figure 2: Stability chart for CSNS DTL linac nominal emittance ratio $\varepsilon_z / \varepsilon_{x,y} = 2$ with set-ups for various simulations.

The evolutions of rms emittances simulated by PARMILA for three cases are shown in Figure 3.





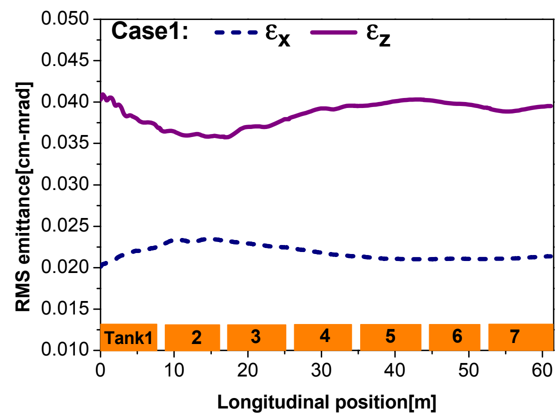


Figure 3: R.m.s emittances evolution for three designs.

Obviously, in the case1 and the initial parts of the case2, there exist visible emittance couplings between the longitudinal and the transverse plane, which were predicted by the Hofmann chart. For the case 3, in agreement with the chart, we cannot observe any emittance transfer in the longitudinal and transverse planes. It is deserved to notice that in the case1 the change of the longitudinal emittance is more pronounced than the changes of the transverse ones, since the "energy" associated with it is shared by both transverse degrees of freedom. In other words, there is one "hot" plane, the longitudinal one, which is fed by the two "cold" transverse planes. For this reason the rms emittance evolution in longitudinal plane has more intensive oscillation than that of transverse. This explanation also can be used in case2. The final transverse (longitudinal) rms emittances change by +5% (-1.25%) for case1, compared with +13.3% (-0.75%) for case2, and 2% (+3.75%) for case3.

In an actual linac one should try to avoid a design that the transverse emittance is higher than the longitudinal emittance, because the two "hot" planes feeding one "cold" plane would increase the longitudinal emittance in consequence.

CONCLUSION

Hofmann's stability charts have been successfully applied in various high intensity linac projects such as CERN-SPL, the SNS and the ESS superconducting linac [8,9,10] and should be regarded as a valid tool in the design of linac lattices. We get the conclusion by observing that rms emittance conservation of matched beams can be considered as "safe" as long as the major fourth order 2:2 resonance is avoided just as the Hofmann chart prediction. These studies using the Hofmann stability charts to analysis the layout as well as the halo formation on the CSNS linac should be further investigated in the near future.

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