SIMULATION OF LONGITUDINAL BEAM INSTABILITY CAUSED BY HOMs

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Abstract

Superconducting cavities are employed in C-ADS linac to accelerate 10 mA CW proton beams from 3.2 MeV to 1.5 GeV. High order modes in superconducting cavities are found by using the simulation tools CST and HFSS, then power dissipation caused by HOMs have been investigated, it is indicated that the Qext should not go beyond 10^7 in order to limit the additional heat load. Beam instabilities caused by high order modes in elliptical cavity sections are investigated using the code offered by Dr. Jean-Luc Biarrotte (CNRS, IPN Orsay, France). Beam errors, linac errors and high order modes frequency spread are investigated in detail. It shows that the monopole modes do not affect the proton beam critically and need no HOM couplers if high order modes frequency spread is more than 100 kHz.

INTRODUCTION

Beam instabilities caused by high order modes are concerned using code bbusim. It was first offered by Jean-Luc Biarrotte (CNRS, IPN Orsay, France). We did some modification to adapt for the C-ADS real situation. Based on these simulation and analysis, machine specific HOM damping requirements can be defined.

LONGITUDINAL INSTABILITY SIMULATION

The introduction of basics of high order modes excitation and beam interaction are based on [1-4]. Our code was written by matlab. Simulation results can be obtained by tracking the energy and time error of the particles at the linac end. Lately some modifications were carried out to adapt to the C-ADS real lattice and to understand the instabilities growth. We have also improved the code to reduce the simulation time and memory consuming.

Longitudinal Model and Input Parameters

A drift-kick model was used in the simulation. As [5] refers, in this model the cavities are compressed to a plane located at the cavity mid-plane, where particle cavity interaction takes place instantaneously. Drifts are spaced between the cavities. The drift lengths are not identical, which are based on the real linac layout.

Results attained from the main linac of C-ADS simulation are set as the input parameters. They are listed in Table 1. The beam current is set to <Ib>=100mA as a safety margin, which corresponds to 10 times the nominal current. The accelerator is operated in a CW motion. The linac consists of two sections. In the medium beta section (βg=0.63), the RF frequency is 650 MHz, twice the bunch frequency, as well as the high beta section (βg=0.82). The layout of these two sections are shown in Figure 1 and 2. Bunch noises, such as arrival time errors, energy errors and charge jitters are also considered as the input parameters. All these noise is set as Gaussian distributed.

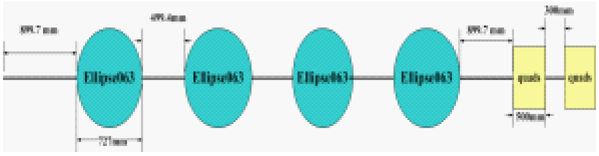

Figure 1: Schematic layout of one cell of the Elliptical063 section.

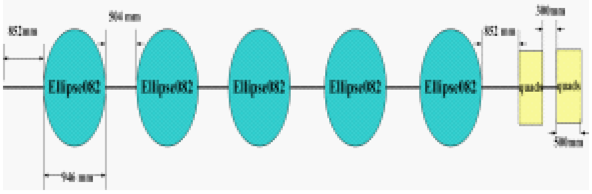

Figure 2: Schematic layout of one cell of the Elliptical082 section.

Table 1: Beam Input Parameters. The Variation Values are Assumed Based on Projects-X and SPL

Parameter	Value	σ	
Input Energy	170	0	MeV
Accelerating Phase	actual RF phase	0.1	deg
Beam Current	100	1%	mA
Duty Factor	100		%
Cavity Numbers	131		
HOM Frequency	1950/1787.5 /1414.6	0.1/1	MHz

SIMULATION RESULTS

We separate the simulation into three main parts.

Firstly a center HOM frequency <fH> falling on the machine line is discussed, which is assumed to 1950 MHz, corresponding to 6 times the fundamental mode frequency of 325 MHz. The influence of bunch noise,

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HOM frequency spread and RF errors are investigated in detail as a function of beam current and HOM damping.

In the second part, HOM frequency is set to 1787.5 MHz, distant to the machine line. In this case, the HOM damping (Q_{ext}) is assumed to 10^8. The HOM frequency spread is 100kHz, which is reasonable based on the experience at DESY [6] and Jefferson Laboratory [7].

In the third part, mode based on our high order modes simulation of the C-ADS elliptical cavity is studied. CST Microwave is chosen to find the most dangerous monopole mode with large R/Q value and close to the machine lines.

HOM Frequency Meeting the Machine Line

The most dangerous situation is a HOM which falls in a machine line. In this situation a resonance excitation from bunch to bunch occurs and a significant HOM voltage can build up in the cavities.

We assume R/Q = 50 circuit and a beam current of 100 mA, 10 times the nominal current. The HOM frequency spread is set to σ_{fHOM}=100 kHz. 100000 bunches are assumed and the time and energy errors of these bunches at the lattice end are recorded. Q_{ext} is firstly set to 10^8. Figure 3 depicts the dt-dE phase space at ejection. Most bunches are lost in this case.

Figure 4 shows the HOM voltages in the 131 cavities after the last bunch passes the lattice. The maximum HOM voltage is about 2.4 MV.

Figure 5 to 8 show the dE/E-dφ phase space of bunch 1, 1560, 1561 and 100000. At first, high order mode has little effect of bunch energy. The contour shown in Figure 5 is mostly determined by the injected arriving time error, which is assumed to 0.1ps. The dE/E-dφ phase space of Figure 6 shows a clear excursion to Figure 5. This means high order mode field starts to be the leading factor to affect the dE/E-dφ phase space. Phase space of the last bunch shown in Figure 8 means that in this case the instability caused by high order modes should not be neglected.

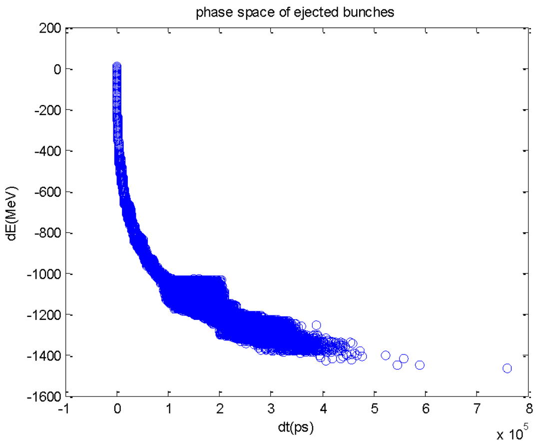

Figure 3: dt-dE phase space at the end of the linac. R/Q= 50 Ω. I_b=100 mA. f_{HOM}=1950 MHz. σ_{fHOM}=100 kHz.

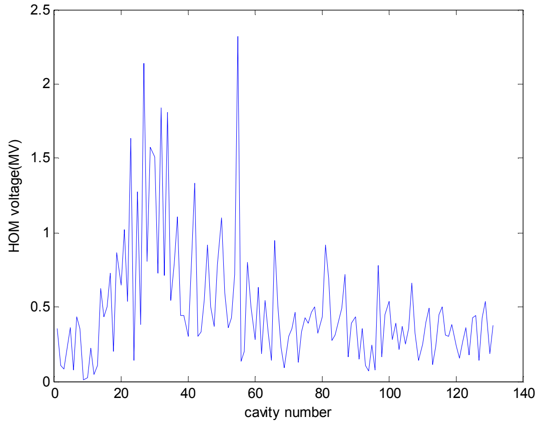

Figure 4: HOM voltage left in the 131 cavities after the last bunch passes the linac end.

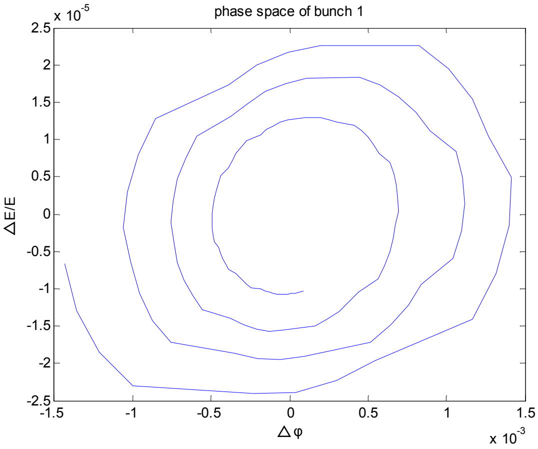

Figure 5:dE/E-dφ phase space of bunch 1. Condition as Figure 3.

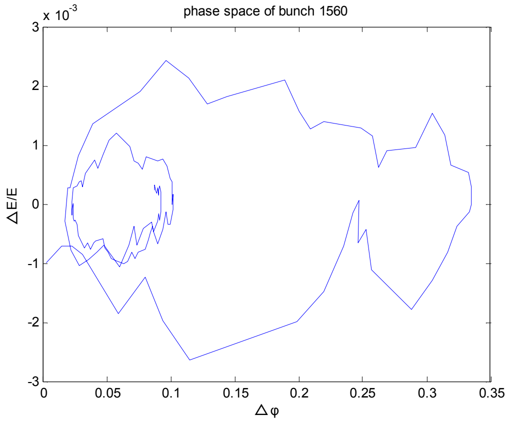

Figure 6: dE/E-dφ phase space of bunch 1560.

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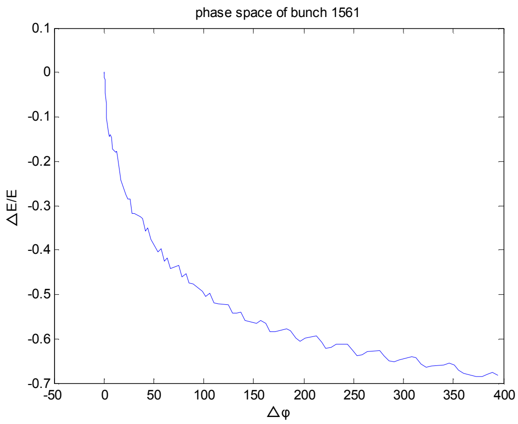

Figure 7: dE/E-dφ phase space of bunch 1561.

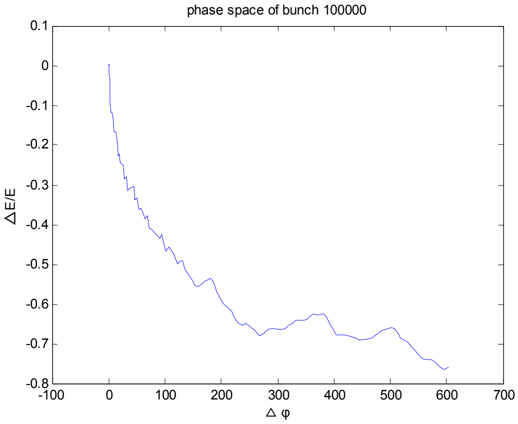

Figure 8: dE/E-dφ phase space of bunch the last bunch (100000).

Figure 9 shows the dE-dt phase space plot for $Q_{ext}=10^5$, else same conditions as before. This corresponds to the strong damping condition. As it shows, same with Figure 3, most bunches are quickly lost.

Now Q_{ext} is set to 10^4 in Figure 10. Clearly, no bunches are lost. High order modes are effectively damped.

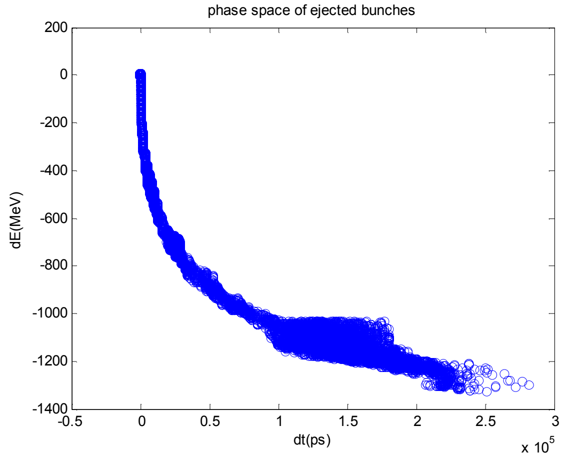

Figure 9: dt-dE phase space at the end of the linac.

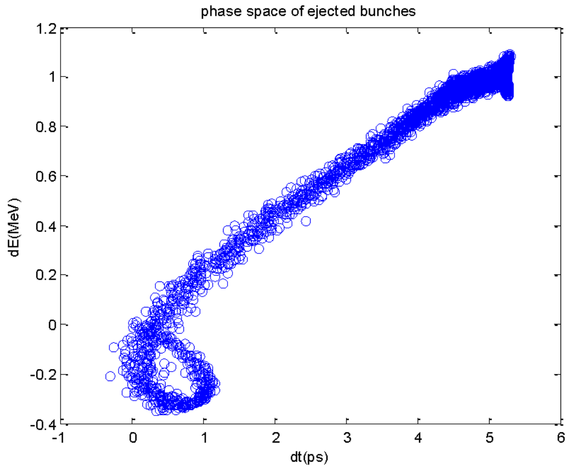

Figure 10: dt-dE phase space at the linac end.

Past studies [8,9] have shown that HOM frequency spread plays a important role in building up beam instability. We also investigated the HOM frequency spread effect. σ_{fHOM} is improved to 1 MHz from 100 kHz. The simulation result is shown in Figure 11. Compared to Figure 3, no bunches are lost. This clearly shows that if a larger HOM frequency spread is presented, high order modes can be efficiently damped. The expected HOM frequency spread in the SPL cavities is assumed to be greater than 1MHz for all modes beside the fundamental passband [10]. However, in our C-ADS cavities, high order modes frequency spread should be discussed further.

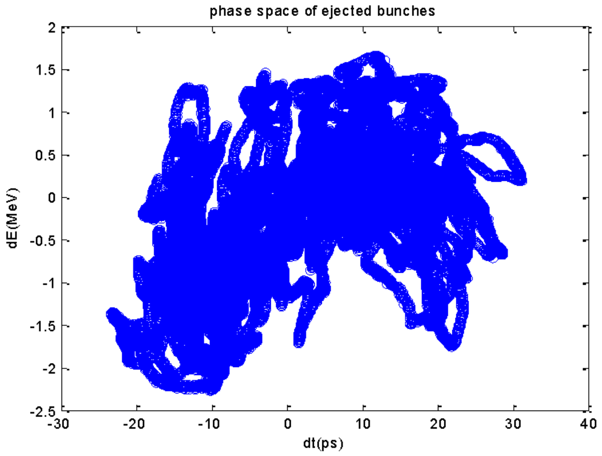

Figure 11 dt-dE phase space of the ejected bunches.

HOM Frequency Distant to the Machine Line

In this section, we will talk about the second part of our simulation. Similar to what is done in the first part, the HOM frequency is set to 1787.5 MHz, corresponding to 5.5 times the fundamental bunch frequency. According to the first part, we only consider the most severe situation in this simulation. Beam current is 100 mA. Qext is 108 and HOM frequency spread σ_{fHOM}=100 kHz. Figure 12 shows the dt-dE phase space of the 100000 bunches at the end of the linac. As it is seen, a tiny excursion of energy and time is presented. Hence, for this case, HOM frequency distant to the machine lines should not be a problem.

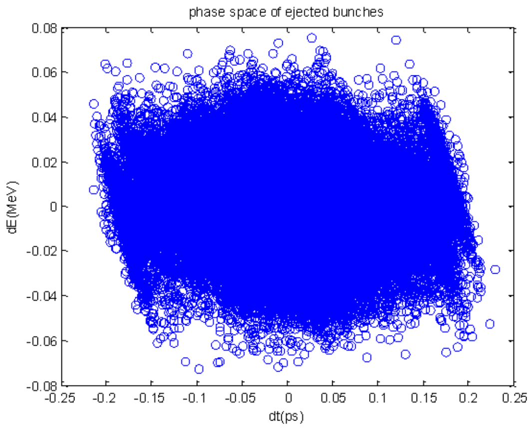

Figure 12: dt-dE phase space of ejected bunches.

Figure 13 depicts the equivalent plots of the Figure 5 to 8. Compared to Figure 5 to 8, HOM voltage grows slowly. For the bunch 1560 and 1561, we have not seen any instabilities. This can be explained that high order modes voltage is much smaller compared to the case when HOM frequency falls on the machine lines. This voltage, compared to the arriving time error, is not large enough to effect the energy and phase space. The phase space of bunch 100000 is also shown in Figure13. Clearly it is different to the previous three pictures. High order modes caused beam instability has been seen. To prove our discussion, the HOM voltage left after these four bunches pass the linac is shown in Figure 14. The HOM voltage left after the 100000 bunch passes the end of the linac is in the order of 10^{-3}, while the other cases are 10^{-5}, 10^{-4} and 10^{-4}.

Since the situation talked about is the most severe case and it turns out that high order modes in this case can be negligible, other cases should not be considered.

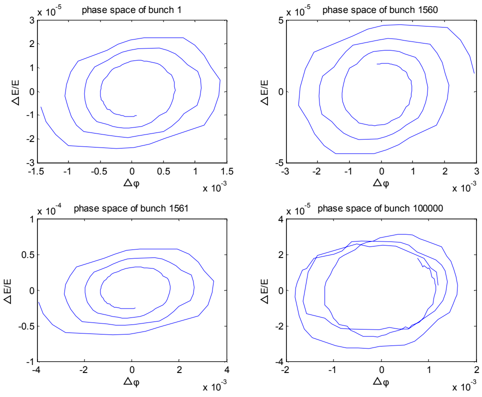

Figure 13: dE/E-dφ phase space of bunch 1, 1560,1561, 100000.

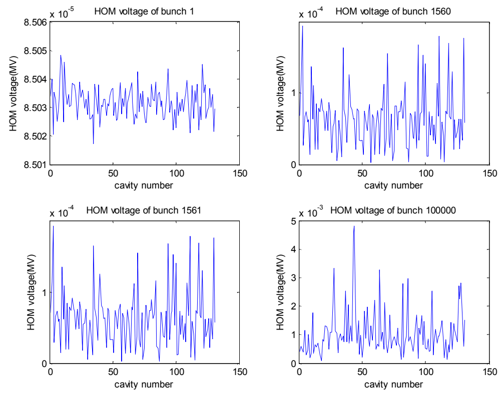

Figure 14: HOM voltage left in the 131 cavities after bunch 1, 1560, 1561, 100000 pass the end of the linac.

Meeting the Real C-ADS Case

In this part, high order modes frequency based on the CST simulation has been chosen as the input parameter. The most dangerous mode is the TM020 1/5π mode. Its frequency is 1414.6 MHz and it has the R/Q value of 2. However, we set R/Q value in this simulation to 50 as a safety margin. Beam current is assumed to 100 mA and . There is no HOM frequency spread in this case. Figure 15 shows the dt-dE phase space of the 100000 bunches at the end of the linac. Tiny excursion of dt and dE are shown in this figure. Beam instabilities caused by high order modes in the real C-ADS case seems to be not a problem according to our simulation.

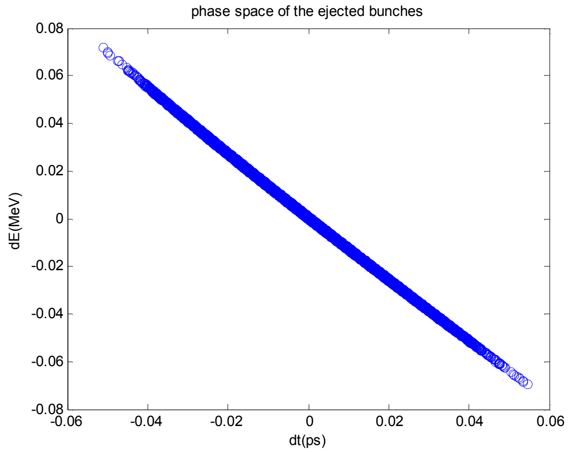

Figure 15: dt-dE phase space of ejected bunches. HOM frequency is 1414.6 MHz, based on the CST simulation of the real C-ADS cavities.

CONCLUSION

From above simulation and discussion, the influence of high order modes should not be a problem in the case where high order modes are distant from the machine line. HOM spread is of great effect to the damping of high order modes. The critical case is that high order modes frequency falls on the beam machine line, which can strongly build up the resonance. If HOM spread is introduced, high order modes induced longitudinal beam instability can be neglected. The real C-ADS high order modes have been chosen as the input parameters as well. Based on the simulation, beam instability in this case is not severe and should not be a problem.

ACKNOWLEDGMENT

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