STUDY OF THE C-ADS LONGITUDINAL BEAM INSTABILITIES CAUSED BY HOMS

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Abstract

The C-ADS accelerator is a CW proton linac which accelerates the 1.5 mA proton beam to 1.5GeV. It has the characteristics of very high beam power and very high reliability that are not possessed by any of the existing proton linacs. The high energy section of the linac (from about 150 MeV to 1.5 GeV) is composed of two families of elliptical five cell superconducting cavities (with geometry β=0.63 and 0.82). The High Order Modes (HOMs) of the elliptical cavities, especially the monopole modes, may be exicted by the beam and can severely degrade the beam quality. The monopole modes with ratively large R/Q value are found by Microwave Studio Suite of CST. The longitudinal instability caused by these monopole modes are primarily investigated with code bbusim. Simulation results show that monopole modes induced longitudinal instability is not a problem if HOM frequency spread is greater than 1MHz. However, further investigations are still necessary before making a final decision.

INTRODUCTION

The C-ADS linac consists of two injectors and a main linac section as shown in Figure 1. Two types of cavities (spoke and elliptical) are used in the main linac [1]. Beam instabilities caused by HOM existing in these cavities are of concern in C-ADS linac. The spoke cavity is single cell cavity. The frequency deviation between High Order Modes is large and the R/Q values of these modes are all smaller than 5Ω, so HOM induced instabilities in spoke cavities are not discussed. In this paper, the influence of HOM is simulated with the code *bbusim,* which is offered by Jean-Luc Biarrotte (CNRS, IPN Orsay, and France). HOM damping requirements can be defined based on these simulations.

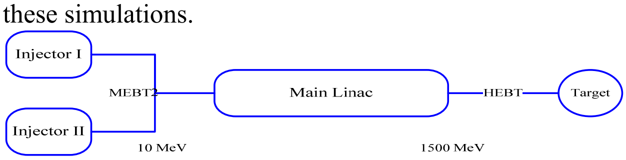

Figure 1: Layout of the C-ADS linac.

LONGITUDINAL INSTABILITY SIMULATION

The high order modes excitation and interaction with beams can be found in reference [2]. The code bbusim was written based on the platform of matlab. Simulation results can be obtained by tracking the energy and time deviations of the bunches at the linac end. In order to adapt the C-ADS real lattice and understand procedure of the instability development along the linac, some new functions were intruduced into the code. The algrithm optimization are also performed to reduce the time and memory consuming.

Monopole Modes Analysis

Each kind of the five-cell elliptical cavities is approximated by a single cell cavity and simulated by using Microwave Studio. From the results, we can get an overview of the eigenmode frequencies of the cavity. Then the modes of five-cell elliptical 063 and 082 cavities are carried out with some symmetry planes. The monopole modes below the beam pipe cutoff frequency are found. Table 1 and 2 list the mode frequency of the TM020 and TM011 passband modes in the βg=0.63 and 082 cavities.

Table 1: TM020 Passband of Elliptical 063 and 082

βg	Mode	*f*(MHz)	R/Q (Ω)
0.63	TM020	1459.45	0.08
0.63	TM020	1456.43	0.61
0.63	TM020	1452.20	0.24
0.63	TM020	1447.83	0.25
0.63	TM020	1444.50	5.47
0.82	TM020	1422.11	0.05
0.82	TM020	1418.20	1.56
0.82	TM020	1412.05	1.79
0.82	TM020	1405.34	2.28
0.82	TM020	1400.36	8.84

Table 2: TM011 Passband of Elliptical 063 and 082

βg	Mode	*F*(MHz)	R/Q (Ω)
0.63	TM011	1646.28	2.89
0.63	TM011	1649.36	1.81
0.63	TM011	1672.61	5.70
0.63	TM011	1675.52	5.04
0.82	TM011	1345.01	93.57
0.82	TM011	1342.07	44.30
0.82	TM011	1338.49	12.79
0.82	TM011	1334.89	1.62
0.82	TM011	1332.12	0.15

Beam Spectrum Analysis

The dt-position and intensity noise of bunches at injection are critical for the excitation of monopole modes as reference stated [2]. Figure 1 shows the beam spectrum of ideal beam and real beam. The ideal beam assumes that

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the current of every bunch is strictly 100 mA and its arriving time is regularly n/*f*, where *f* is the bunch frequency. However, for the real bunches, the dt position and intensity noise of bunches cannot be neglected. If a Gaussian distribution of the arriving time errors and current errors with σ =0.4ps and σ =1%, respectively, are applied. From Figure 2, one sees that the real beam spectrum has been widely spread. That means even the HOMs far away from the ML, it is still possible that such modes may be excited.

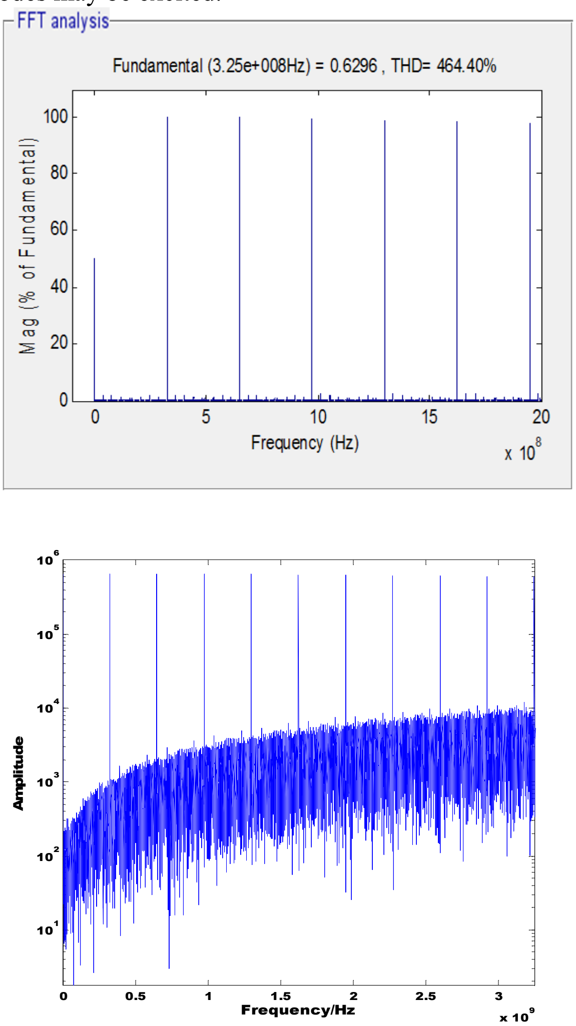

Figure 2: Beam spectrum. The top one is the ideal beam spectrum. The bottom one is of the real beam where the arriving time error and bunch current error are applied.

Which Modes should be Considered

As there is some possibility that any modes can be excited, it is important to understand which mode is the severest one. The influence of two modes, 1345 MHz and 1646 MHz, are compared. Their R/Q values are 70Ω and 10Ω respectively. The 1646 MHz mode is closer to the Machine Line than the 1345 MHz one. Figure 3 shows the energy error at exit of the linac as function of bunch numbers. One sees that the amplitude of the 1345 MHz case shows a clear growth while the effect of 1646MHz mode can be negligible. The beam energy deviation of mode 1646 MHz is mainly caused by the initial bunch noise. Comparing with the noise effect, this mode plays a negligible role to the energy deviation. From above, the modes with larger R/Q values are the ones that we should take a detailed consideration. In next simulations, HOM frequency is set to 1345 MHz when only one mode is considered. The beam current, external damping and the HOM frequency spread are investigated in detail.

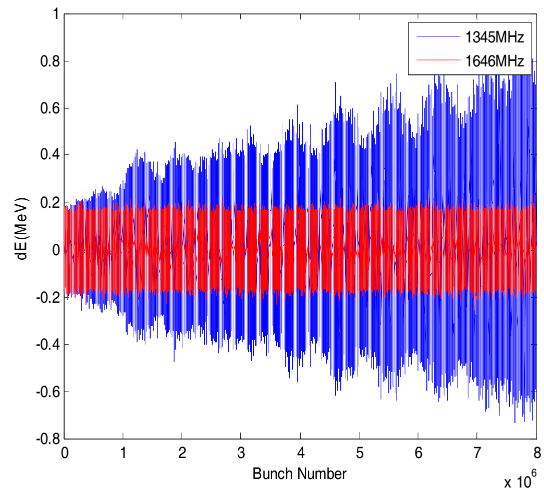

Figure 3: dE at ejection of bunch 1 to 8000000.

Evaluation Criterion

The code bbusim tracks the arriving time error and energy error of the simulated bunches at the end of the linac. The diffusion of the bunch center can be defined as follow for convenience.

$$\varepsilon = \pi\sqrt{\langle dE^2\rangle\langle dt^2\rangle - \langle dE\cdot dt\rangle^2} \ ,$$

where dE is the energy error and d*t* is the arriving time error.

To evaluate the influence of the HOM to the beam, we compare the above defined diffusion with the longitudinal beam emittance at the end of the linac. The input rms emittance of the main linac is 0.497 MeV. ps, and longitudinal emittance growth of 11.86% has been simulated when all static and dynamic errors are included, which means the output emittance of the linac is 0.556MeV. ps. HOM induced bunch centre diffusion leads to the growth of longitudinal beam emittance, so damping this diffusion to safety margin is necessary. We define the 10% of the output beam emittance growth, which is corresponding to 0.05MeV.ps of bunch center diffusion, as the safety margin.

Bunch Current and External Damping

The bunch current is investigated. Figure 4 shows the bunch center diffusion when beam current varies from 10 mA (the nominal current) to 100 mA. The external Q factor in these cases is 10^8. HOM frequency spread width is 100 kHz. The curve is approximately proportional to I_b^2 and fits the conclusion in reference [3]. From Figure 3 we can see that the HOM induced longitudinal center diffusion is too large when the beam current is greater than 50 mA. This enormous diffusion will undoubtedly cause the beam emittance growth and may cause beam lost. But at nominal current (10 mA), the diffusion value is about 0.004MeV.ps, smaller than 1% of the nominal beam emittance.

Figure 4 depicts the beam centre diffusion against the bunch current for different damping condition Q_{ext}. We can see if Q_{ext} is less than 10^7, then the HOMs effect can be neglected for beam current even up to 100 mA.

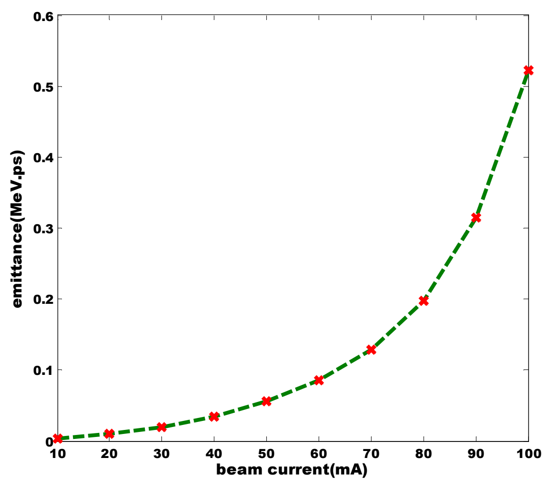

Figure 4: Diffusion for different beam current

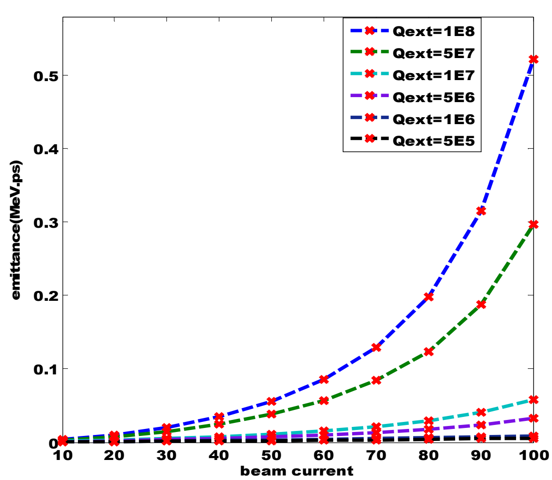

Figure 5: Diffusion against different bunch current for different external damping.

HOM Frequency Damping

The HOMs frequency spread is another important parameter that can affect the influence of the HOMs. Previous study [4] shows that the HOM spread is critical to the building up of the beam instability and larger HOM frequency spread helps in depressing the instabilities. In this part, systematical study on the HOM frequency spread effect has been taken out. The HOM frequency spread is Gaussian with σ_{fhom} varies from 100 kHz to 1MHz; while the beam current is 100 mA and Q_{ext} is 10^8. The result is plotted in Figure 6. When σ_{fhom} is larger than 500 kHz, the longitudinal beam centre diffusion is smaller than 0.05 MeV.ps, the emittance growth caused by such bunch center diffusion is less than 10%. However, more linacs are needed to get the statistical data. The expected σ_{fhom} in SPL cavities is greater than 1MHz for all modes except the fundamental one. This value in the C-ADS elliptical cavities has not been decided yet.

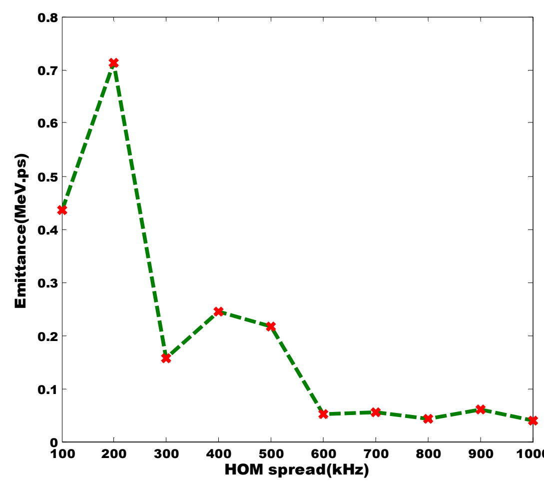

Figure 6: Diffusion against different width of the Gaussian distributed HOM frequency spread.

CONCLUSION

The results obtained from CST have been used as the input parameters. Beam spectrum analysis explains that any modes can be excited when bunch noise exists. These modes induced beam instability has been investigated in detail with different bunch current, external damping and HOM frequency spread. 10 times the nominal current is adopted as the safety margin. Damping the Q_{ext} to 10^7 with HOM coupler or a HOM frequency spread larger than 500 kHz is recommended to diminish the longitudinal centre diffusion. However, the HOM induced instability should not a problem when the current is at its nominal value.

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