ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS045

SIMULATION ANALYSIS OF LLRF FEEDFORWARD COMPENSATION TO BEAM LOADING FOR CIADS LINAC

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Abstract

A simulation is coded to calculate the beam loading in the cavity of CiADS and the response of the LLRF system. In the pulse operating mode, the fluctuation of amplitude and phase of the cavity field contributed by the transient beam loading is traced. During the simulation the effect of beam current fluctuation, and timing jitter were determined. The deviation margin of relational parameters is lined out to meet the requirement for cavity stability with amplitude 0.1% and phase 0.1°.

INTRODUCTION

The CiADS linac is a superconducting proton linac which consists of an electron cyclotron resonance(ECR) ion source, a low energy beam transport(LEBT) line, a 162.5MHz radio frequency quadrupole(RFQ) accelerator with four-vane type copper structure, a medium energy beam transport(MEBT) line, a SC section which is the main accelerating section, and a high energy beam transport(HEBT) line. The projects need a high stability to deliver 500MeV,10mA proton beam in CW operation mode[1].

The interaction between the beam and the cavity fields when the beam pass through the cavity in accelerating mode are referred as beam loading. It may degrade the beam quality even beam loss, So it is necessary to compensate it.

The required amplitude stability of cavity field is 0.1%, and phase stability is 0.1°. In order to meet the specification, traditional PI feedback algorithm can hardly regulate the cavity field affected by heavy beam loading. It is therefore essential for the LLRF system to implement feedforward and other advanced control methods.

The purpose of this paper is to determine the effect of beam fluctuation, and timing jitter with feedforward system in the cavity field.

This topic was identified as being of importance to CiADS LLRF system in proving it the threshold of relational parameters.

CAVITY MODEL

In order to simulate how the cavity will behave when it is excited by a RF field, a model of the cavity should be used[2], the equation of the cavity model as below:

$$V_{n+1} = V_n(1 - \frac{\pi}{Q})e^{j2\pi\Delta f(n)} + [I_b(n) + I_g(n)] + \frac{\pi}{Q} \quad (1)$$

where $I_g(n)$ and $I_b(n)$ are the current caused by the beam and the generator. V_n is the voltage of the cavity excited by both I_g and I_b.

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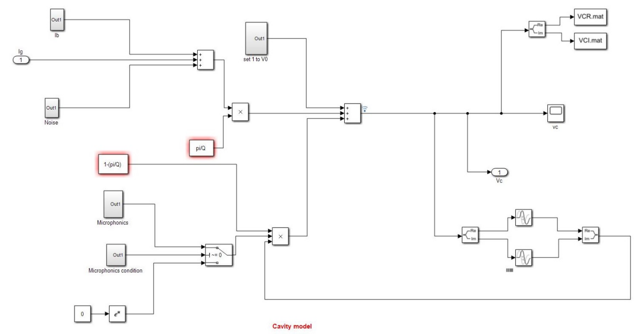

Figure 1: Cavity Model.

Then according to the equation, we can build a model in Simulink, which shown in Fig. 1. And some necessary cavity parameters for the simulation is given in Table 1.

Table 1: Parameters Used in the Simulations.

RF Parameters	Value	Unit
V_c	0.994	MV
sync phase	-44.1	deg
R/Q	153	$M\Omega$
f_0	162.5	MHz
f_{HBW}	100	Hz

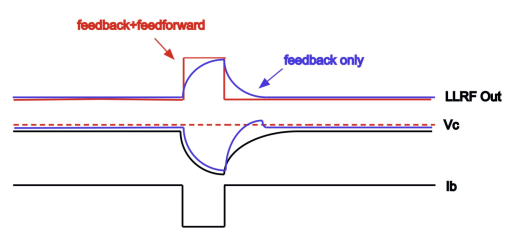

Figure 2: Feedback and Feedforward mechanism.

FEEDBACK AND FEEDFORWARD MECHANISM

When the beam is accelerated in pulse mode, it causes repeated perturbation. In the case of low beam power , the feedback control is an effective way to deal with it in the loop, However in the case of the heavy beam loading, in the first few tens of microseconds, because of the delay and high gain of the feedback loop, there will be obvious oscillations of the cavity. So the repetitive perturbation cannot well suppressed by it and may cause the power overshoot[3].

Feedforward control is a technique for compensating the error [4]. Figure 2. shows the typical mechanism of feed-

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back and feedforward. The principle of FF control system is to generate an opposite signal of pulse beam to the cavity when the beam arrives. Ideally it can completely eliminate the effects of the beam loading. However The inaccurate parameters may cause instability in the loop, so it is necessary to determine the effects of different parameters, and line out a deviation margin to meet the requirement.

EFFECTS OF INACCURATE PARAMETERS

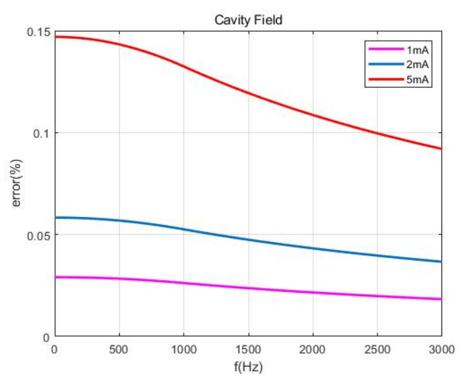
Fluctuation of the Beam Current

The inaccuracy of the beam current magnitude refers to the deviation of the real setting point to the design value. For more specific, there is a ripple of the beam.

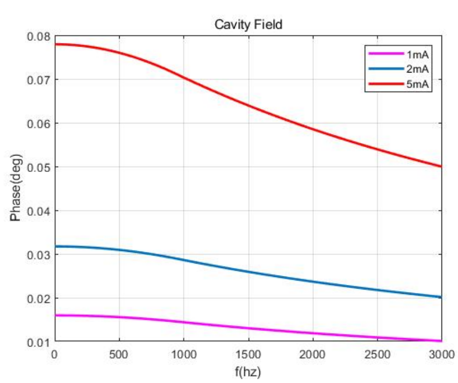
The pulse beam with ripple can conclude as follow:

$$I_b = I[1 + A\cos(\omega t)]e^{j\theta} \tag{2}$$

The simulation result of beam current ripple(Fig 3.) shows that when the frequency of the ripple $\omega = 0$, the deviation of the cavity field is the largest. By adjusting the frequency of ripple, we could find that as the frequency increases, the fluctuation decreases.



(a) Amplitude

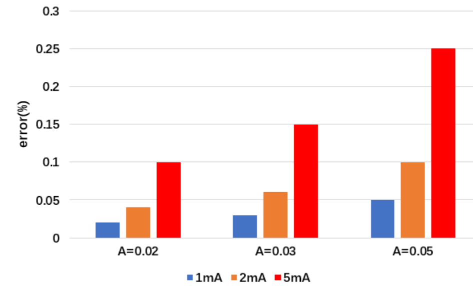


(b) Phase

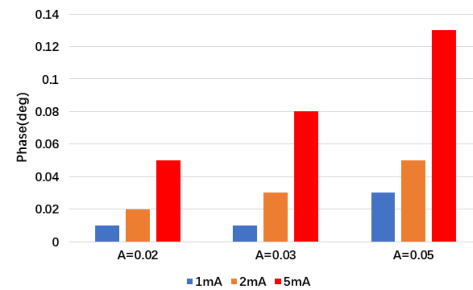
Figure 3: Beam current fluctuation with different frequency

As shown in the Fig. 4, the frequency of the ripple is 0Hz, when the magnitude of ripple $A \leqq 0.02$, the influence of the ripple could be ignored.

So the frequency of the ripple should greater than 2500Hz and the magnitude fluctuation of the beam should less than 2%.

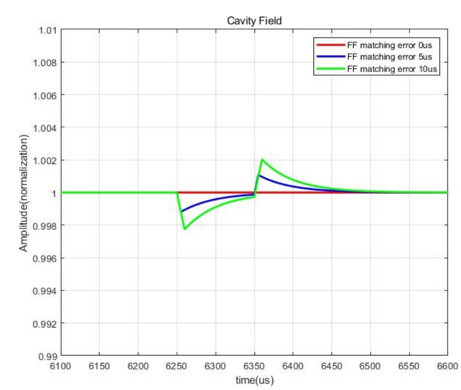


(a) Amplitude

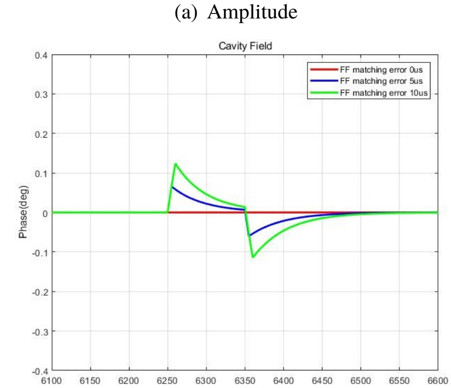


(b) Phase

Figure 4: Beam current fluctuation during with different I_b



(a) Amplitude



(b) Phase

Figure 5: Beam arrival time matching errors

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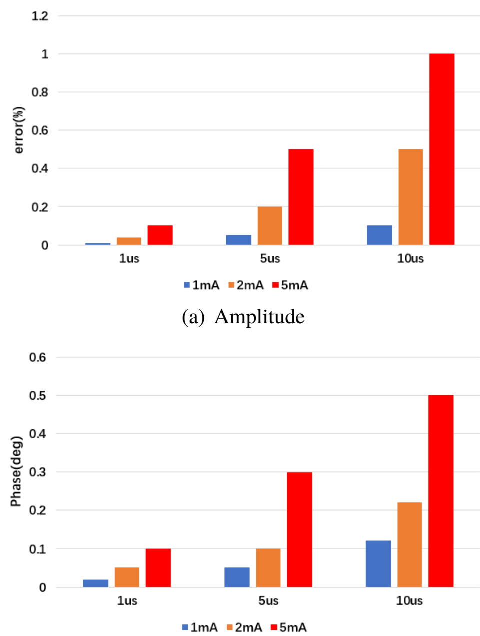
Injection Time Jitter

During the operation, beam arrival time may change, and the mismatching time between feedforward and beam current may cause the field in the cavity unstable. When $I_b = 1mA$, timing jitters affect the cavity field can be seen in Fig.5. Figure 6 shows the beam arrival time matching errors with different beam currents.

The result is that when the timing jitter within $1\mu s$ the cavity field can meet the requirement, so the influence of it can be ignored.



(a) Amplitude

(b) Phase

Figure 6: Beam arrival time matching errors

CONCLUSION

Feedback combine with feedforward control algrithms is an effective way to supress the beam loading. A LLRF simulation model was built to verify the effectiveness of beam fluctuation and timing jitter. The margins of feedforward control for those perturbations were given. And the simulation result shows that as long as the perturbation is whithn the deviation margin, the cavity field stability can meet the requirement for the cavity stability with amplitude 0.1% and phase 0.1°. In further research the pre-detuning of the cavity and the resonance between the ripple and the cavity could take into consideration.

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