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CROSSTALK EFFECT IN THE LEReC BOOSTER CAVITY*

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Abstract

The Linac of the Low Energy RHIC electron Cooler (LEReC) is designed to deliver a 1.6 MeV to 2.6 MeV electron beam, with peak-to-peak *dp/p* less than ±7e-4. The booster cavity is the major accelerating component in LEReC, which is a 0.4 cell cavity operating at 2 K, with a maximum energy gain of 2.2 MeV. It is modified from the Energy Recovery Linac (ERL) photocathode gun, with fundamental power couplers (FPCs), pickup (PU) couplers and HOM coupler located close to each other. Crosstalk effects in this cavity are simulated and measured. A correction method is proposed to meet the energy spread requirement.

INTRODUCTION

The LEReC design is a non-magnetized cooling scheme that uses electron bunches at kinetic energies between 1.6 MeV and 2.6 MeV that match the ion beam velocity, with peak-to-peak *dp/p* less than ±7e-4, to cool RHIC ion bunches [1]. The electron linac of LEReC consists of a DC photoemission gun, a 704 MHz SRF booster cavity, and three normal conducting cavities [2, 3]. The 704 MHz SRF booster cavity accelerates 400 keV bunches from the DC gun, near crest with an accelerating voltage up to 2.2 MV. It is modified from the ERL photocathode gun [4]. It has two FPCs, two PUs, and one HOM coupler, with a PU (HOMPU) on the HOM coupler. All couplers are on the same side of the cavity, shown in Figure 1. Please note the second PU is located opposite to the one shown in the figure.

Typically, the FPC and the PU are positioned on different sides of the cavity, and thus isolated by the cavity with no direct coupling (normally capacitive) between them. In an SRF gun, however, one side of the cavity is reserved for photocathode with its stalk, thus the FPC and PU are installed on the same side of the cavity that is opposite to the photocathode. The only exception so far is the 112 MHz SRF gun for the Coherent electron Cooler (CeC) experiment at BNL, in which the PU is on the same side of the photocathode, and the FPC is on the other side of the cavity. In that design the coupling strength (Q_{ext}) of the PU in the 112 MHz gun varies with the insertion depth of the photocathode, thus calibration is required every time after cathode installation.

With FPC and PU on the same side of the cavity, the direct coupling between FPC and PU causes distortion of the RF response, the so-called crosstalk effect. This effect was first studied by Zhao at BNL using an equivalent circuit model of the cavity with couplers, by applying an additional capacitor between FPC and PU [5]. Later He at PKU proposed a simple method to extract the resonance frequency and loaded quality factor Q from the RF response with crosstalk [6]. As pointed out by both Zhao and He, the crosstalk effect severely distorts the RF response (S-parameter) between FPC and PU when the cavity is at room temperature, and makes it difficult to measure the resonance frequency and Q. While in the superconducting state, the distortion of the RF response is insignificant.

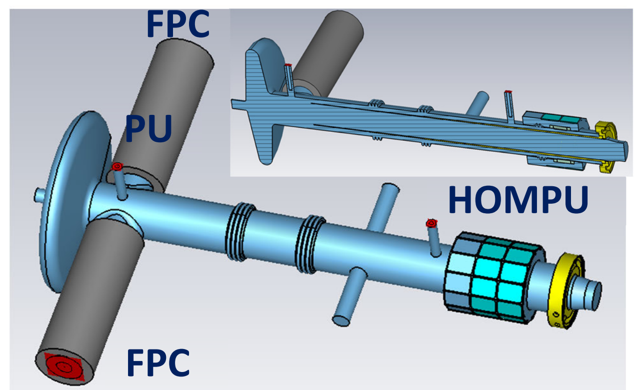

Figure 1. LEReC booster cavity with cross-section view (top-left).

In the LEReC booster cavity, however, the crosstalk effect is important, and its effect needs to be corrected. During operation, due to the limited life time of the main tuner, a "dead band" is applied to limit total tuner motion. Within this dead band, the cavity resonant frequency is allowed to vary, and LLRF feedback loops must stabilize the cavity voltage and phase (V_{pu}) using available RF power. It is found that there is a ±1000 Hz slow frequency drift, and a ±100 Hz frequency shift due to microphonics, with its source yet to be identified during operation. These frequency shifts cause a deviation between amplifier's output frequency and cavity's resonance frequency. Since the S-parameter is slightly distorted by the crosstalk effect in superconducting state, it is no longer in Lorentz form. With V_{pu} fixed, the cavity accelerating voltage V_{acc} deviates from the reference accelerating voltage without crosstalk effect, $V_{acc\text{-}ref}$. With the tight *dp/p* requirement, at 1.6 MeV, the voltage fluctuation should be within ±1.12 kV for the whole LEReC system, the fluctuation from V_{acc} should be a small portion of this number. Even though the crosstalk effect insignificantly distorts resonance frequency and Q, the voltage fluctuation caused by it might not be tolerable. In this paper the crosstalk effect in the LEReC booster cavity is analyzed. A method of correction is proposed so that the design specification can be met.

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CROSSTALK EFFECT IN BOOSTER CAVITY

The crosstalk effect gives a distortion in S_{21}, with a valley adjacent to the resonance peak (In some special cases the valley might not appear though). In a polar plot, it is a translation of the Lorentz curve. It can be expressed as a standing wave in the cavity (Lorentz curve) with an additional travelling wave between FPC and PU (translation), as shown in [6]:

$$Signal_{whole} = \frac{K}{\left(f_0^2 - f^2\right) + i\frac{f_0 f}{Q_L}} + Md \times e^{iPd}$$

In the RF simulation, two FPC ports are connected to form a new 25 Ω FPC port (port 1), one of the PU is used (port 3), and the HOMPU is assigned as port 4. Field monitors are assigned to the on-resonance frequency and ±1 kHz, ±2 kHz, ±3 kHz off-resonance frequencies. Please note in the simulation the power source's frequency is changing, and cavity's resonant frequency is fixed, while during operation, amplifier's frequency is fixed, and cavity's resonant frequency is vibrating. For comparison, similar simulation is done with port 3 (PU) move to the other side of the cavity, in which the crosstalk is insignificant. The S_{31} in dB (amplitude), and in polar plot are shown in Figure 2. The S_{41} results are similar to those for S_{31}, with differences in the amplitude (Md) and phase (Pd) of the crosstalk effect.

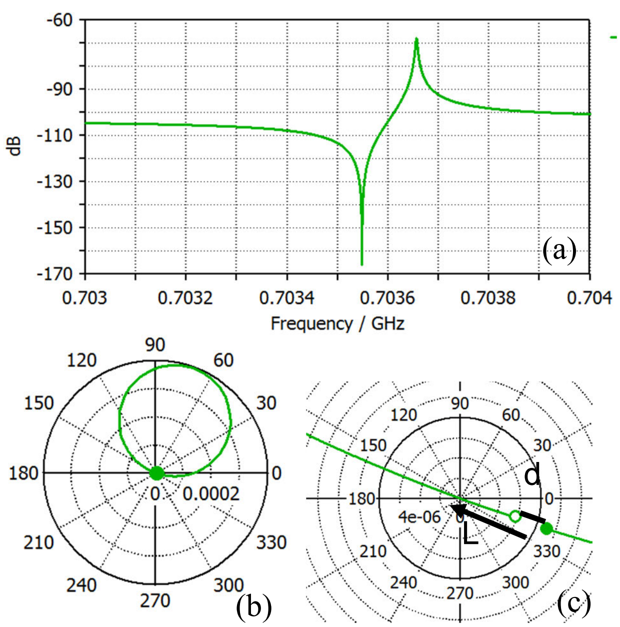

Figure 2. S_{31} in (a) dB (amplitude), and in (b) polar plot with (c) a zoom in near the original point.

In the field monitor which is normalized to 0.5 W input power, one can extract the power coming out of each port, as well as V_{acc}. The results are then normalized to the same PU power. Using the on-resonance results as references, with fixed PU power, the V_{acc} changes linearly with frequency deviation, with -0.94%/kHz, the HOMPU power also changes linearly with frequency deviation, with 5.56%/kHz. For comparison, the V_{acc} change with frequency deviation for the case without crosstalk is -1.5e-4/kHz, by using a reference PU on the other side of the cavity to suppress the crosstalk effect. This result implies that the simulation accuracy is better, or at least not worse, than this number.

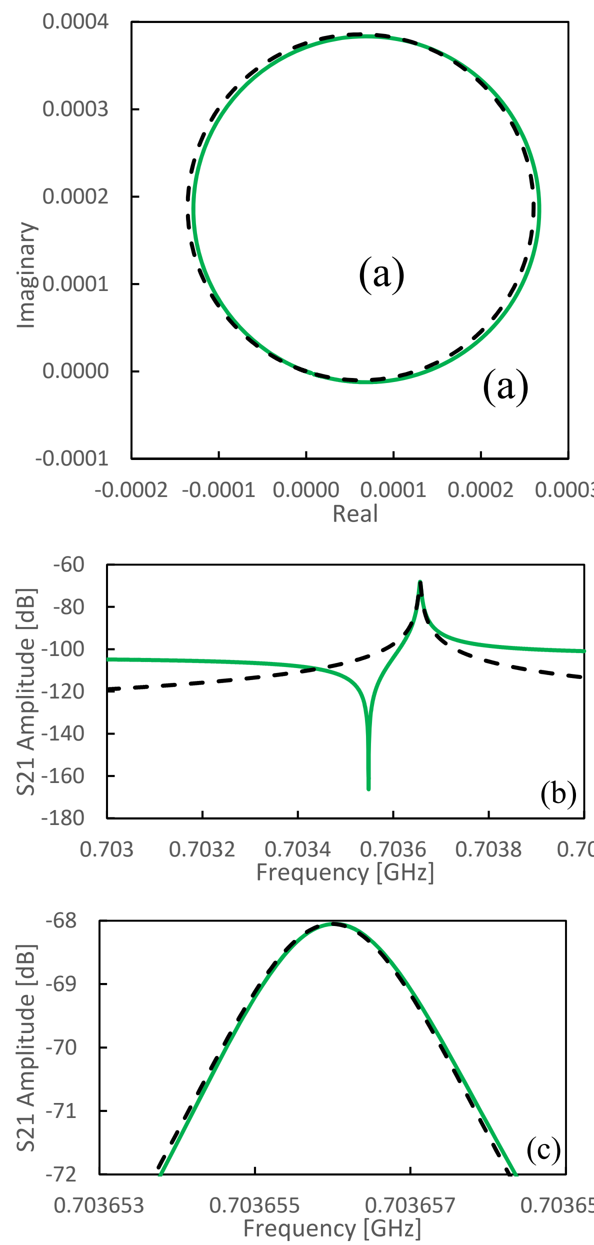

Figure 3. Correction of S-parameter to separate the crosstalk effect from Lorentz curve, with green curves with crosstalk, and black dash curves without. (a) polar plot, (b) in dB amplitude, (c) zoom in of (b) near the resonance.

The above results can also be understood from the S-parameter. To separate the crosstalk effect from the Lorentz curve, one needs to translate the S-parameter in the polar plot so that the point between highest frequency and lowest frequency (with the same distance from the resonant frequency, the middle point of d shown in Figure 2(c)) to the original point, shown as the arrow line (vector L) in

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Figure 2(c). The results are shown in Figure 3. Based on Figure 3 (c), with 1 kHz deviation, there is a 0.08 dB difference between the curve with crosstalk and the one without, corresponding to 0.93% difference in voltage. With 2 kHz deviation, it is 0.17 dB, 2.03% in voltage, and with 3 kHz, it is 0.26 dB, 3.08% in voltage. It is roughly -0.99%/kHz, close to the result based on field monitor analysis.

Based on the above simulations, with a ±1000 Hz slow frequency shift, the V_{acc} deviates ±0.99%, and even though this slow frequency shift can be suppressed, a ±100 Hz frequency shift due to microphonics, the V_{acc} still deviates ±0.1%, beyond the design specification.

An additional simulation was done by cutting the PU probe by 5mm, with 3kHz away from resonance, there is still a ~0.26 dB deviation between the curves with and without crosstalk, corresponding to 3% in voltage, thus changing the PU probe length is not helping. The reason is that cutting the PU probe shorter not only changes *Md*, but it also changes *K*, it changes the Lorentz term and the crosstalk term simultaneously, and in a proportional way.

There is another effect that needs to be investigated. During operation, the two FPCs are driven by two LLRF systems and two amplifiers. Efforts are made to keep the amplitude and phase of the signals from two amplifiers the same by controlling the LLRF, however they are still slightly different, estimated to be within 5% in the amplitude, and within 10 degrees in the phase. It is not easy to model this effect in CST. In this case the S-parameter of the booster cavity with 2 FPCs, 1 PU and 1 reference PU on the other side of the cavity, similar to the above simulation without crosstalk, are modeled. With this set of S-parameter, signals with different amplitude and phase can be assigned to 2 FPCs. Please note using the loss in the cavity to get V_{acc} is difficult since most of the power is reflected back, and only a tiny fraction of power is dissipated on Nb cavity wall, so the power coming out of the reference PU port (without crosstalk) is used to monitor the V_{acc}. This method was proved to be accurate previously. This method is further crosschecked with the on-resonance and ± 1, 2, 3 kHz off-resonance cases with crosstalk effect that analysed above by assigning identical amplitude and phase to 2 FPCs. Results from this analysis showed that for the signals on 2 FPCs, with difference within 5% in the amplitude, and within 10 degrees in the phase, and with frequencies ranges within ±3 kHz of the resonant frequency, the V_{acc} deviation from the case with crosstalk and with the same frequency deviation is better than 10^{-4}, thus the crosstalk effect is not sensitive to the slight input difference between 2 FPCs.

CORRECTION OF CROSSTALK EFFECT

During the correction of S-parameter shown in Figure 3, a method was proposed to correct the fluctuation in V_{acc} induced by the crosstalk effect. First the S-parameter should be measured to get the resonant frequency f_0. Then the complex S-parameter at two frequency points $f_0 \pm \Delta f$, or frequency bands near these two points, should be measured, with the selection of Δf big enough so that the amplitude of L is much larger than the amplitude of d, shown in Figure 2 (c). During this measurement fine IF bandwidth should be used to resolve the small signals. Vector L can be calculated using the above measurement results. The S-parameter can then be corrected by applying vector L into LLRF system to get the Lorentz curve without crosstalk.

CONCLUSIONS

During operation, a dead band is assigned to the main tuner, and LLRF system is adjusting the amplitude and phase of two amplifiers to get a fixed voltage on the PU. Due to the resonant frequency drifting in the LEReC booster cavity during operation, the crosstalk effect caused by direct coupling between FPC and PU brought fluctuation in V_{acc}. This fluctuation is analyzed to be larger than the longitudinal momentum spread specification, and thus needs to be corrected. The effect of slight imbalance between two FPC input signals is also studied, conclusion is made that crosstalk effect is not sensitive to this imbalance. A method to correct the crosstalk effect is proposed.

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