HOM CONSIDERATION OF 704 MHZ AND 2.1 GHZ CAVITIES FOR LEREC LINAC*

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Abstract

To improve RHIC luminosity for heavy ion beam energies below 10 GeV/nucleon, the Low Energy RHIC electron Cooler (LEReC) is currently under development at BNL. The Linac of LEReC is designed to deliver 2 MV to 5 MV electron beam, with rms dp/p less than 5e-4. The HOM in this Linac is carefully studied to ensure this specification.

INTRODUCTION

To map the QCD phase diagram, especially to search the QCD critical point using the Relativistic Heavy Ion Collider (RHIC), significant luminosity improvement at energies below $\gamma = 10.7$ is required, which can be achieved with the help of an electron cooling upgrade called Low Energy RHIC electron Cooler (LEReC) [1]. \

An electron accelerator for LEReC linear accelerator (Linac) consists of a DC photoemission gun and a 704 MHz SRF booster cavity. The booster cavity is converted from the SRF gun of the ERL project [2]. In LEReC Phase I (electron kinetic energies up to 2 MeV) a one cell 704 MHz normal conducting cavity and a 3-cell third harmonic (2.1 GHz) normal conducting cavity will be added to de-chirp the energy spread and to compensate its non-linearity.

The electron beam in the LEReC Linac is relatively soft, with its energy at around 2 MeV. The electron beam can be disturbed by the Higher Order Modes (HOMs) in the cavities, especially when considering the energy spread should be limited to 5e-4 rms in dp/p. In this case the HOMs in the 704 MHz SRF booster cavity, and in the 2.1 GHz and 704 MHz normal conducting cavities should be carefully evaluated to ensure these limitations. In this paper, we calculate the energy spread from the longitudinal modes of the 704 MHz SRF cavity, as well as the 2.1 GHz and 704 MHz normal conducting cavities. The emittance growth from the transverse modes of these cavities, as well as the HOM power estimation will be discussed elsewhere.

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RF DESIGN

The RF design of the 704 MHz and 2.1 GHz normal conducting cavities is covered in references [3, 4]. Some of the high R/Q There is no specific HOM damping design for these two cavities. One can refer to [5] for the details of the 704 MHz SRF booster cavity. Here we will briefly introduce the HOM damping for the 704 MHz SRF booster cavity. The design described in reference [6] will not work for our purpose since the most dangerous mode TM_{020} is below the longitudinal cut-off frequency of the beam pipe. The frequency of the TM_{020} mode is insensitive to the frequency tuner and the phase shifters connected to the FPC ports, and the design doorknobs connected to the FPC ports has a narrow passing band near 704 MHz, they are not suitable for adjusting the frequency or coupling of the TM_{020} mode.

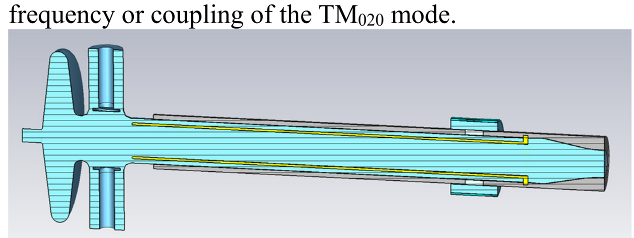

Figure 1: Coaxial HOM damping design of the 704 MHz SRF booster cavity.

In this case, a coaxial HOM damping design is proposed to lower the HOM induced energy spread, as shown in Fig. 1. A Cu tube is inserted into the large beam pipe of the cavity, with one end electrically shorted to the beam pipe. The ferrite absorber is placed outside the beam pipe, and get separated from the beam pipe vacuum using a ceramic window. With the wavelength of the fundamental TM_{010} mode to be λ_{010} and that of the TM_{020} mode to be λ_{020}, the distance d between the center of the ceramic window and the electric short should be $\sim(M/2+1/4)\lambda_{010}$ and $\sim(M/2+1/2)\lambda_{020}$, and the length l of the Cu tube should be $\sim N/2\lambda_{010}$ and $\sim(N/2+1/4)\lambda_{020}$, with M and N non-negative integers, so that the damping to TM_{010} mode could be suppressed while the damping to TM_{020} mode could be maximized. Since λ_{010} is not exactly twice of λ_{020} as P_{02}/P_{01}=5.520/2.405, optimization is done by slightly adjust the value of d and l to get the maximum ratio between the quality factor of TM_{010} and the quality factor of TM_{020}. Optimization to further suppress the

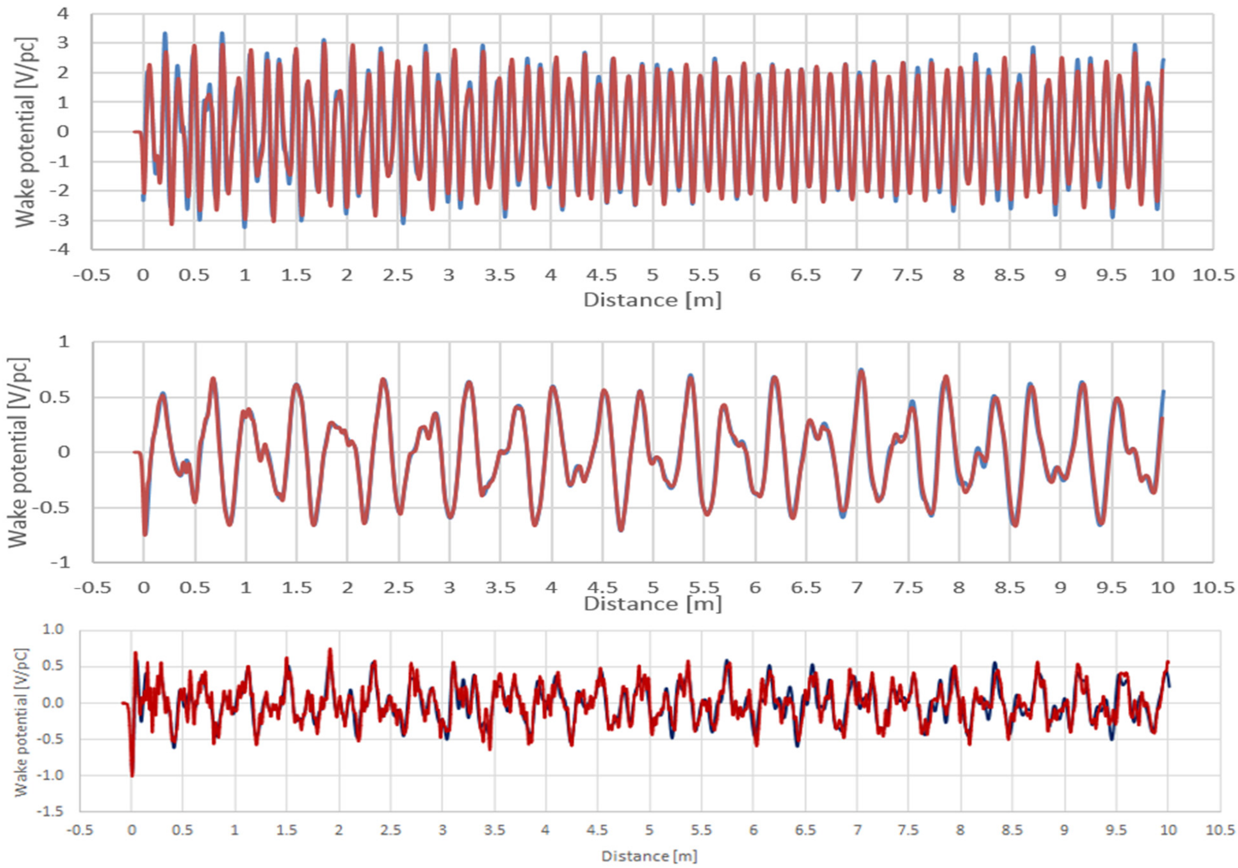

Figure 2: Single bunch wake potential in 10m for a) 2.1 GHz warm cavity (top); b) 704 MHz warm cavity (middle); c) 704 MHz booster SRF cavity (bottom). Blue curves are from the reconstruction of Eigen mode simulation, and red curves are from CST Particle Studio™.

TM_{020} mode is possible, with the cost of more TM_{010} power damping on the ferrite.

ENERGY SPREAD FROM THE LONGITUDINAL MODES

To calculate the energy spread from the longitudinal modes, Eigen mode simulation is first done using CST Microwave Studio™, with the simulation frequency ranges from the fundamental mode to the first longitudinal cut-off of the beam pipe. Then the single bunch wake potential is constructed using the Eigen mode simulation results. This single bunch wake potential from the Eigen mode is further compared with the CST Particle Studio™ result. The multi bunch wake potential is calculated by shifting – adding the single bunch wake potential.

A. Eigen Mode Simulation

For the 2.1 GHz warm cavity, the beam pipe is 1.925" in diameter, with the cut-off frequency 3.60 GHz for TE_{11} mode and 4.70 GHz for TM_{01} mode. We calculate the HOMs using CST Microwave Studio™ Eigen mode simulation with frequency up to 4.70 GHz.

For the 704 MHz warm cavity, the beam pipe is 82 mm in diameter, with the cut-off frequency 2.14 GHz for TE_{11} mode and 2.80 GHz for TM_{01} mode. We calculate the HOMs using CST Microwave Studio™ Eigen mode simulation with frequency up to 2.80 GHz.

For the 704 MHz SRF booster cavity, the downstream (closer to 2.1 GHz warm cavity) side beam pipe is 50 mm in radius, and this pipe is further taped to 30.2 mm radius before 2.1 GHz cavity. The beam pipe cut-off frequency for 30.2 mm radius is 2.91 GHz for TE_{11} mode and 3.81 GHz for TM_{01} mode. We calculate the HOMs using CST Microwave Studio™ Eigen mode simulation with frequency up to 3.81 GHz.

For all the longitudinal modes, we use the accelerator definition R/Q at β=1:

$$\left(\frac{R}{Q}\right)=\frac{|V_z|^2}{\omega U}$$

B. Single Bunch Wake Potential

For each longitudinal HOM, the impedance is given by:

$$Z_{\parallel}(\omega)=\frac{R_s}{1+jQ_r(\omega/\omega_r-\omega_r/\omega)}$$

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where R_s is the shunt impedance in accelerator definition, Q_r the quality factor and ω_r the resonant frequency. The wake function can be found from its Inverse Fourier transform, and its real part with $Q_r >> 1$ (narrow band HOMs) is [7]:

$$G_{\parallel}(\tau) = \frac{\omega_r R_s}{2Q_r} e^{-\frac{\omega_r \tau}{2Q_r}} \cos(\omega_r \tau)$$

Please note in [7] the impedance is in circuit definition.

The single bunch is noted as as $Q\lambda(t)$, Q is the charge of the bunch.

The wake potential is the convolution of the wake function and the normalized density [7]:

$$W_{\parallel}(\tau) = \int_0^{\infty} dt G_{\parallel}(t)\lambda(\tau - t)$$

For a simplified model with a single bunch $Q\lambda(t)$ in dirac delta form with Q charge at $t=0$, with normalized density:

$$\lambda(t) = \begin{cases} na; t = 0 \\ 0; t > 0 \end{cases}$$

and $\int_{-\infty}^{+\infty} \lambda(t) = 1$.

After integration the wake potential can be written:

$$W_{\parallel}(\tau) = \frac{\omega_r R_s}{2Q_r} e^{-\frac{\omega_r \tau}{2Q_r}} \mathrm{Cos}[\omega_r \tau] \mathrm{H}[\tau]$$

H is the Heaviside step function with

$$H(t) = \begin{cases} 0; t < 0 \\ 1; t > 0 \end{cases}$$

The Gaussian bunch case can be found in reference [7].

C. Single Bunch Wake Potential from CST Particle Studio^{TM}

In this simulation, we use 100 pC bunch charge with beam velocity at the speed of light, and 10 mm bunch length for HOM frequencies up to 10 GHz. We choose indirect interfaces wake integration method. Figure 2 shows the single bunch wake potential with 10 m wake length for 2.1 GHz warm cavity (top); 704 MHz warm cavity (middle); and 704 MHz booster SRF cavity (bottom). Red curves are from the reconstruction of Eigen mode simulation, and blue curves are from CST Particle Studio^{TM}.

D. Multi Bunch Multi Train Voltage Deviation

The multi bunch (31 bunches for example) single train wake potential is:

$$MultiBunch\_W_{\parallel}(\tau) = \sum_{N=1}^{31} \sum_{HOMs} W_{\parallel}(\tau - (N-1)T_1)$$

and the multi train wake potential is:

$$MultiTrain\_W_{\parallel}(\tau) = \sum_k MultiBunch\_W_{\parallel}(\tau - (k-1)T_2)$$

Here k is a number large enough to guarantee the wake potential to saturate. Considering that it is not easy to accurately simulate the frequency of the HOMs, we assume that the modes that are close (±20 MHz) to the multiple of the frequency f_1 will beat the multiple, and all modes will beat the frequency f_2.

For the 2.1 GHz warm cavity, the 31 bunch configuration gives a ±1.57 kV peak to peak voltage fluctuation, corresponding to ±7.9e-4 dp/p peak to peak. If we shift the 3.2808 GHz mode 0.5 MHz away from the harmonic of the 9.14 MHz gives 0.57 kV total fluctuation, corresponding to ±2.9e-4 dp/p peak to peak. If we use 30 bunches instead of 31 bunches, the voltage changes to 0.55 kV. If we shift the 3.2808 GHz mode 0.5 MHz away from the harmonic of the 9.14 MHz, the 30-bunch configuration gives 0.32 kV fluctuation. It is less than the voltage fluctuation of 31-bunch configuration. The 3.2808 GHz HOM is a TM_{011} mode.

For the 704 MHz warm cavity, the 31 bunch configuration gives a 0.86 kV voltage fluctuation and the 30 bunch configuration gives 2.04 kV. With the 1.087 GHz mode 1 MHz away from the harmonic of the 9.14 MHz, the voltage fluctuation changes to 0.43 kV for 31 bunch configuration and 0.62 kV for 30 bunch configuration, corresponding to maximum ±3.1e-4 dp/p peak to peak regardless the configuration. The 1.087 GHz HOM is a TM_{011} mode.

For the 704 MHz booster cavity, the 31 bunch configuration gives a 4.68 kV voltage fluctuation and the 30 bunch configuration gives 4.92 kV. With the 1.488 GHz (measured to be at 1.478 GHz) TM_{020} mode 0.7 MHz away from the harmonic of the 9.14 MHz, the voltage fluctuation changes to 0.50 kV for 31 bunch configuration and 0.60 kV for 30 bunch configuration, corresponding to maximum ±3.0e-4 dp/p peak to peak regardless the configuration. The 1.478 GHz HOM is a TM_{020} mode.

Since the RHIC revolution frequency changes with beam energy, the 9MHz frequency will also change with beam energy. One can carefully choose the beam energy to suppress the energy spread in case it is higher than the specification.

CONCLUSIONS

In this paper, we simulated the energy spread caused by the 704 MHz and 2.1 GHz normal conducting cavities and the 704 MHz SRF booster cavity with HOM damper. With a combination of considerations in cavity design, HOM damper design, HOM frequency tuning and beam energy selection, the energy spread can be suppressed in case it is higher than the specification.

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