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IMPEDANCE SIMULATION FOR LEREC BOOSTER CAVITY TRANSFORMED FROM ERL GUN CAVITY*

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Abstract

Wake impedance induced energy spread is a concern for the low energy cooling electron beam. The impedance simulation of the booster cavity for the LEReC projection is presented in this report. The simulation is done for both non-relativistic and ultra-relativistic cases. The space charge impedance in the first case is discussed. For impedance budget consideration of the electron machine, only simulation of the geometrical impedance in the latter case is necessary since space charge is considered separately.

INTRODUCTION

Low energy RHIC electron cooling (LEReC) is designed to cool low energy ion beams at RHIC, which is crucial for beam energy scan for searching the critical point on the QCD phase diagram [1]. The electron beam energy is ~2 MeV for the first phase, and will be increased to 5 MeV on the second phase to match the velocity of higher energy ions. The electron beam will be mostly accelerated by the booster cavity on the first phase. The ERL gun cavity will be modified to be used as the booster cavity. The ERL gun cavity is shown in Fig. 1.

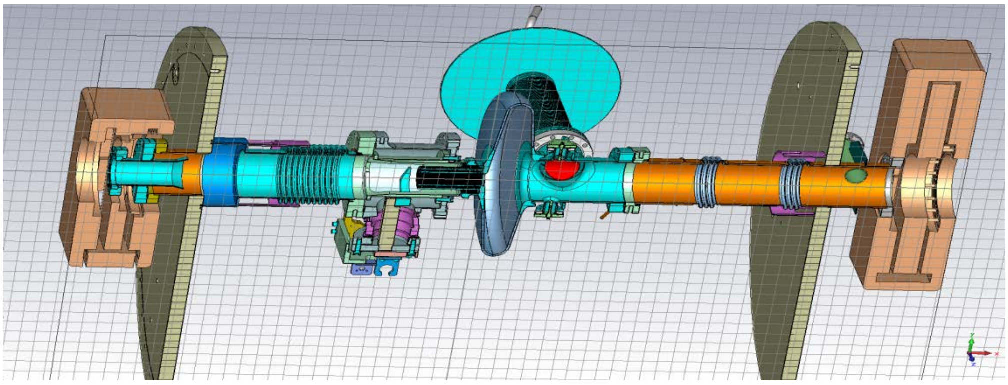

Figure 1: Three dimensional drawing of the ERL gun cavity

For effective cooling, the allowable energy spread of the electron beam is very small (relative RMS energy spread ~5E-4). Therefore, the budget of wake impedance introduced by various components in the electron machine is very tight. The sum energy spread due to resistive wall and geometrical impedance should be no greater than space charge induced energy spread [2]. A new insert was designed on the cathode side of the ERL gun in the effort of reducing geometrical impedance. The simulation of impedance of this booster cavity with the insert (Fig. 2) will be presented in the following.

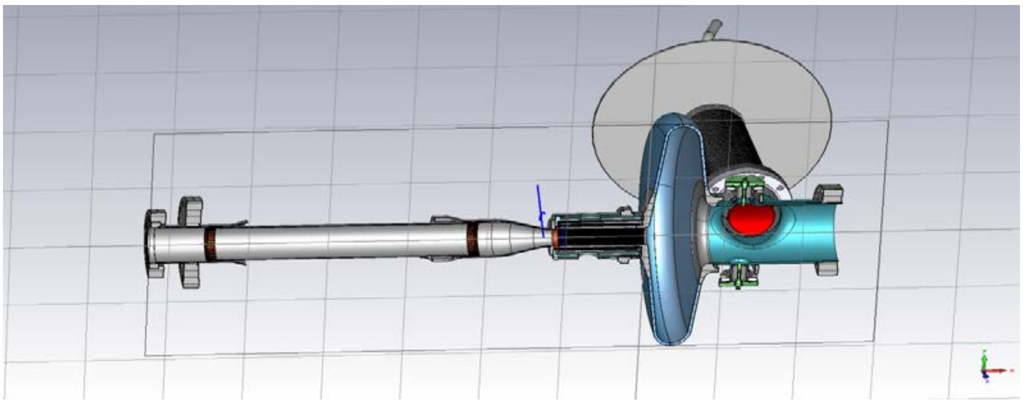

Figure 2: Three dimensional view of the booster cavity design with new insert.

SIMULATION SETUP

Electron beam parameters for the simulation are listed here. Beam energy is 400 keV, so that Lorentz β=0.8279. Bunch charge is 100 pC. Bunch rms length is 10 mm. Repetition rate of micro bunches and the fundamental frequency of the cavity is 704 MHz. Bunch spacing is 0.43 m. Repetition rate of bunch train is ~9 MHz. The following results are for single bunch simulation.

All cavity material was assigned to be PEC (perfect electrical conducting). All other materials were assigned to be "normal", which essentially means vacuum. Integration method is "Direct", because others are not applicable for non-relativistic beams [3]. The boundary was "open" at both end of the structure. The structure is symmetric with respect to the horizontal and vertical plane.

SIMULATION RESULTS

The impedance simulation was carried out for a simplified structure, which only keeps the essential parts for electromagnetic fields. The structure in CST simulation is shown in Fig. 3. On the right hand side, a transition piece was added to keep the cut-off frequencies the same on both ends of the structure.

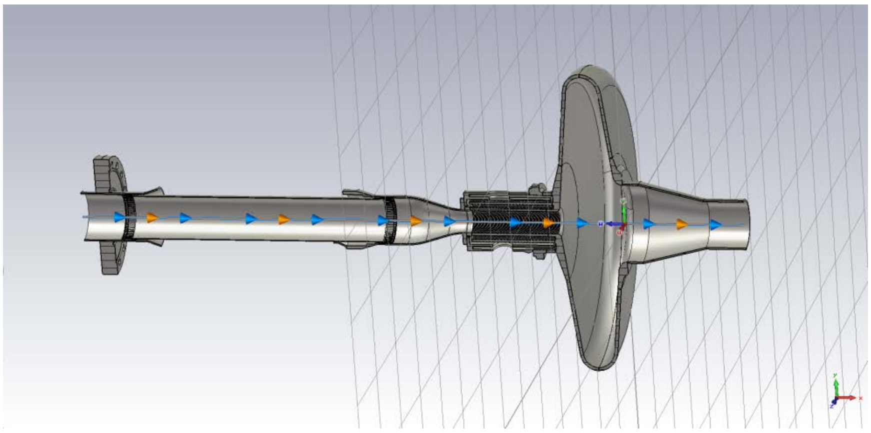

Figure 3: Simplified booster cavity structure in CST simulation.

The wake potential is shown in Fig. 4. The spikes around 0 mm in Fig. 4 was enlarged and displayed in Fig. 5. The latter part of the wake is shown in Fig. 6.

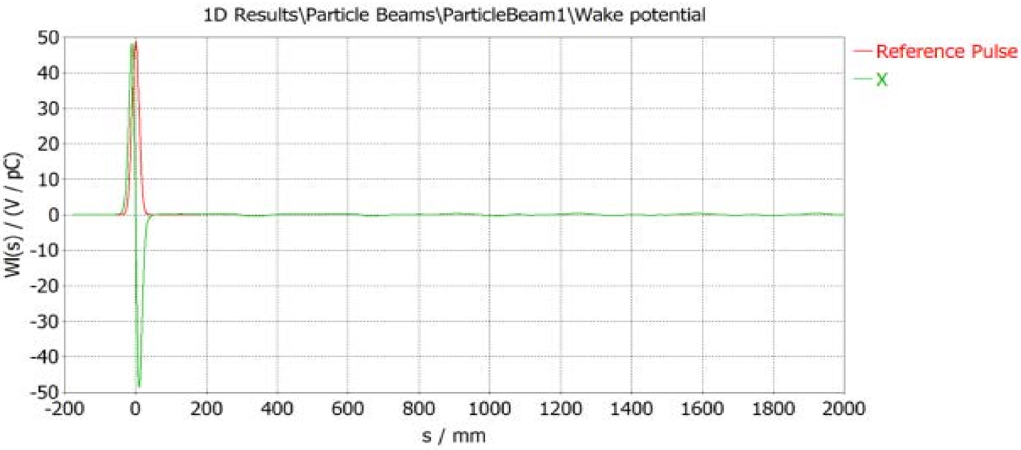

Figure 4: The longitudinal wake potential, denoted by X and shown in green, of the booster cavity with β=0.8279.

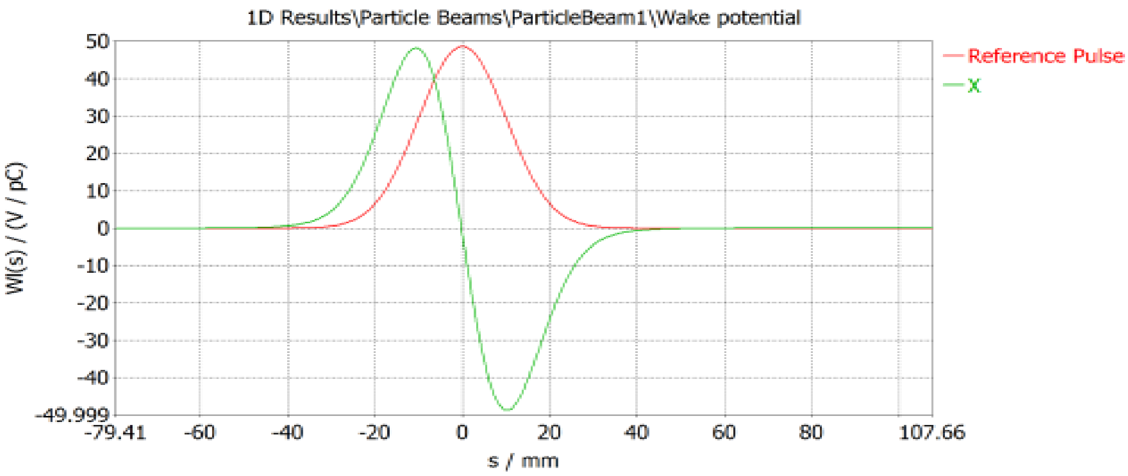

Figure 5: The zoom-in display of the spikes on the wake potential plot.

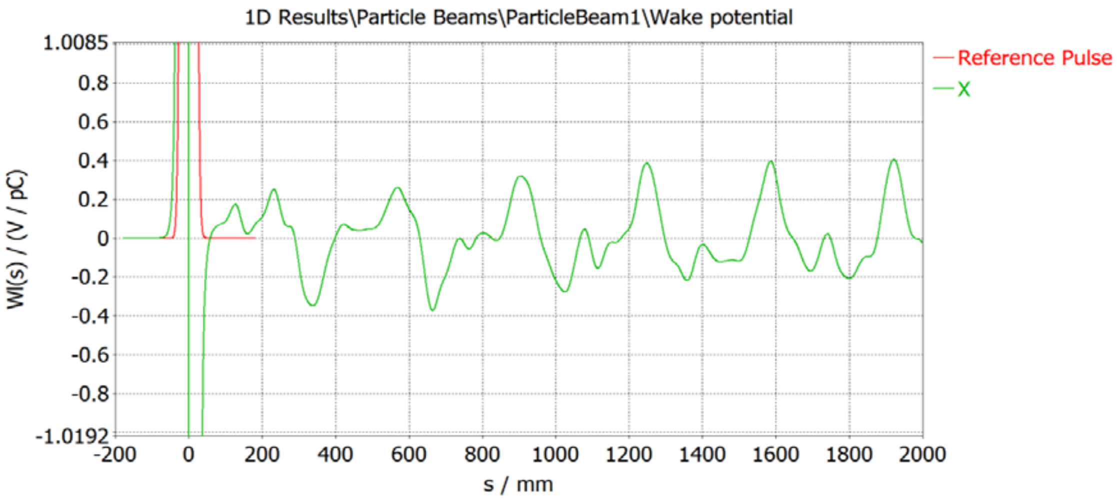

Figure 6: The zoom-in display of the long range part of the wake potential plot.

It was a puzzling question what the source of the dominating spikes in the wake potential plot (Fig. 4) is due to. A couple of tests have been done in the CST simulation to understand it. The structure was first split in two pieces longitudinally, in order to figure out where the spikes come from. The wake potential from these two pieces showed the spikes as well only with reduced amplitudes. The sum of the spikes from the two pieces equals to that from the whole structure. The simulation was done on a cylindrical PEC pipe with the same beam parameters, and the wake potential shows the spikes as well. When the Lorentz beta was assigned to 1 in the simulation, the spikes disappeared. Simulation with $0.8279<\beta<1$ was also performed. It was found the amplitude of the spikes is a smooth function of the Lorentz factor.

The results for $\beta=1$ are shown below. The loss factor is 0.59 V/pC. The head of the bunch losses energy while the tail gains energy as shown in the wake potential plot in Fig. 7. The first peak in Fig. 8 shows the impedance at the fundamental mode of the cavity [4]. The second peak in Fig. 8 shows the impedance at the second harmonic, which should be reduced as much as can be. The possible measures for reducing the quality factor of HOM, or in other word damping HOM, is a different topic [5]. The impedance is mostly reactive as shown by the real and imaginary components in Fig. 9 and 10 [6]. The -90 degree phase of the longitudinal impedance in Fig. 11 together with the linear dependence on frequency of the impedance indicates it is negative inductive.

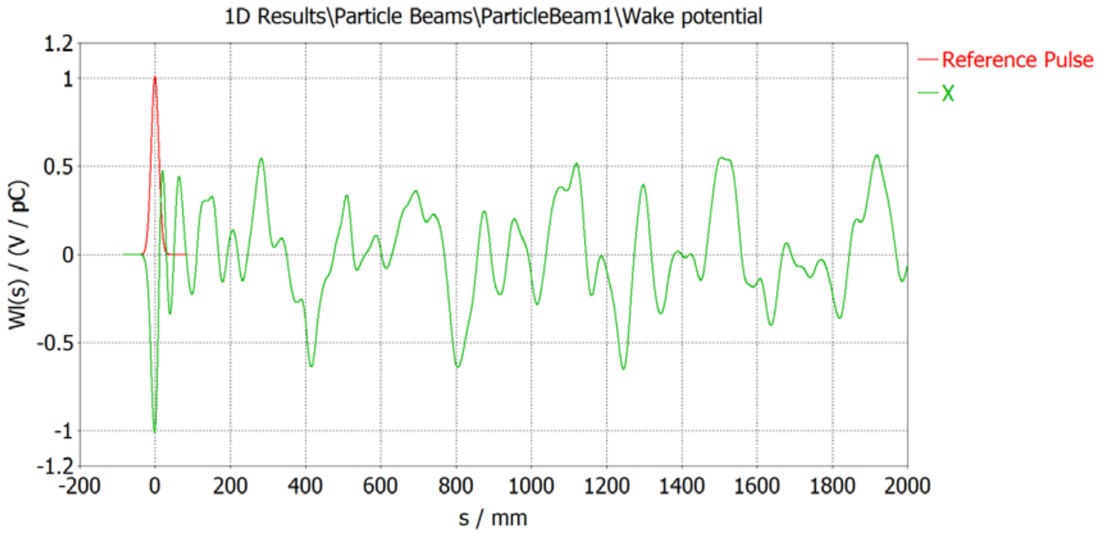

Figure 7: The longitudinal wake potential for the booster cavity with β=1.

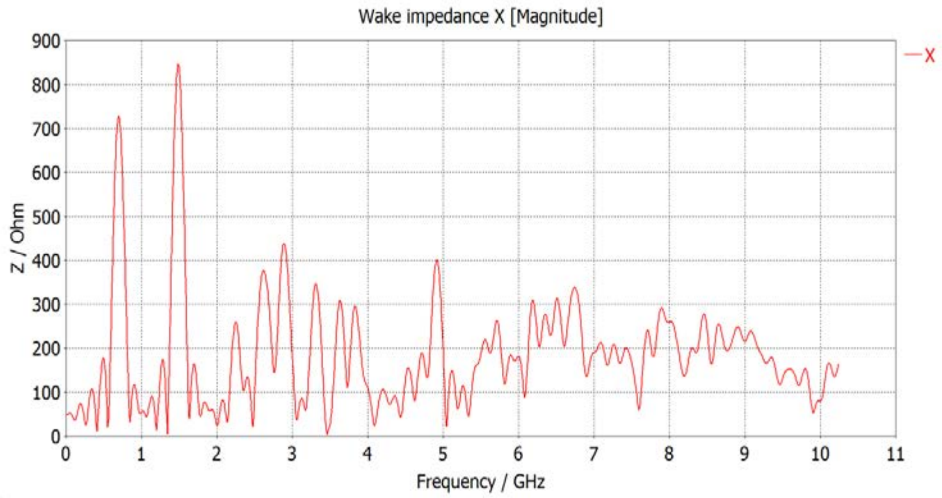

Figure 8: The longitudinal impedance of the booster cavity.

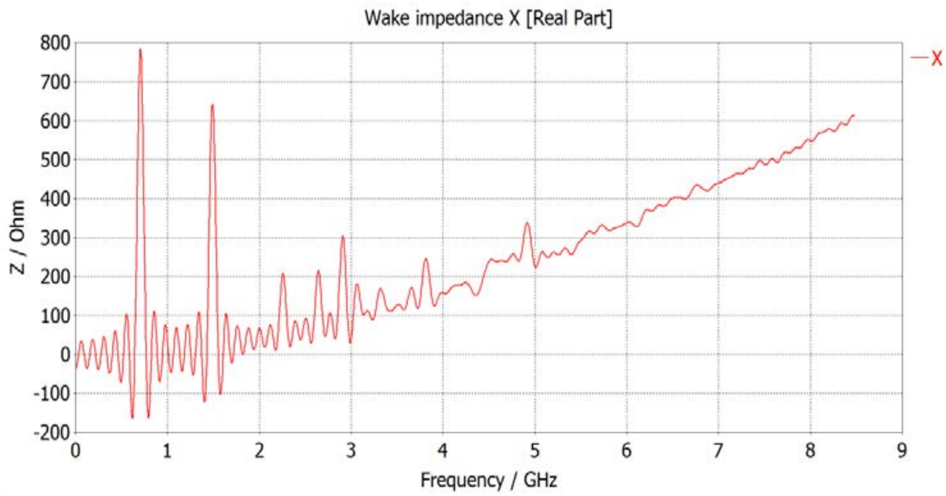

Figure 9: The real part of the longitudinal impedance.

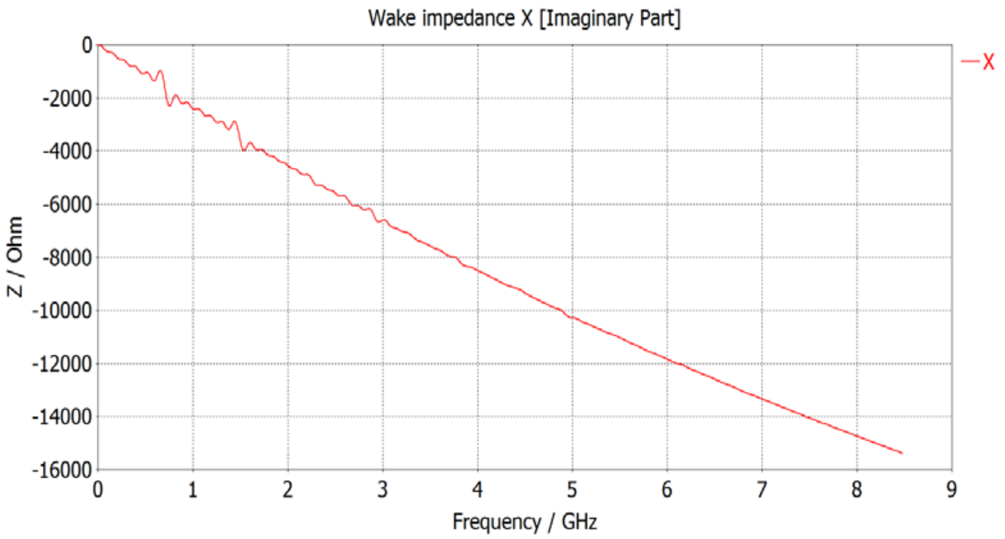

Figure 10: The imaginary part of the longitudinal impedance.

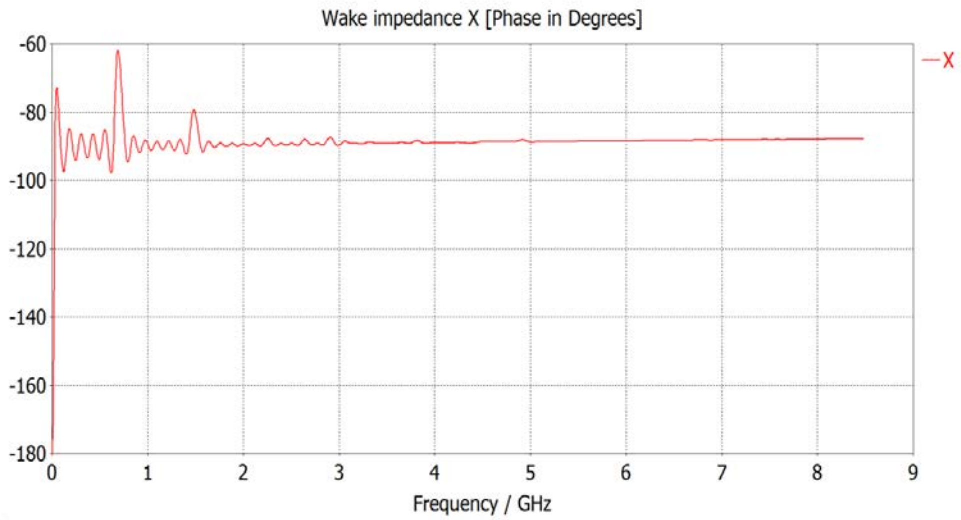

Figure 11: The phase of the longitudinal impedance.

All these results presented above verify the hypothesis that the spikes are the longitudinal space charge impedance. The CST-PS solver models the beam as a unidimensional pencil beam with Gaussian longitudinal profile. The beam size is taken as the mesh size. Various mesh size were simulated for comparison. The amplitude of the spikes increases as the mesh size decreases, as expected for space charge impedance with decreasing beam size [6]. The amplitude dependence on mesh size also implies that the space charge impedance calculated by CST bears numerical errors determined by the mesh size. This prompts the question what is the proper way to evaluate the impedance for low energy beams. Since space charge can be simulated by other codes precisely, therefore, only resistive wall and geometrical impedance, in this case only the latter, are of interest in this CST simulation. Both impedances have weak dependence on the Lorentz beta [7, 8]. Therefore, one should assign β=1 in the simulation.

SUMMARY

The impedance of the LEReC booster cavity was simulated for β<1 case. The spikes in the wake potential were studied and determined to result from the longitudinal space charge force. The space charge impedance overwhelms both resistive wall and geometrical impedances. And it is the geometrical impedance rather than resistive wall impedance that is a concern for cavities. Therefore, the geometrical impedance of the booster cavity was evaluated by assigning β=1 since space charge can be simulated by other codes precisely. The impedance and loss factor will be considered together with those from other sources to determine the overall impedance budget.

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