RF DESIGN OF A 1.3-GHz HIGH AVERAGE BEAM POWER SRF ELECTRON SOURCE

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Abstract

There is a significant interest in developing high-average power electron sources, particularly those integrated with Superconducting Radio Frequency (SRF) accelerator systems. Even though there are examples of high-average-power electron sources, they are not compact, highly efficient, or available at a reasonable cost. Adapting the recent advances in SRF cavities, RF power sources, and innovative solutions for an SRF gun and cathode system, we have developed a design concept for a compact SRF high-average power electron linac. This design will produce electron beams with energies up to 10 MeV. In this paper, we present the design results of our cathode structure integrated with modified 9-cell accelerating structure.

GENERAL CONCEPT

The use of SRF cavities may allow linear accelerators (linacs) that are less than 1.5 meters in length to create electron beams above 10 MeV with average beam powers measured in 10's of kW. Such compact SRF accelerators can have high wall-plug power efficiencies and, for example, may be compact enough to be readily transported to and operated at local sites [1].

DESIGN OF THE GUN STRUCTURE

In an electron source, the electron gun and the cathode system are critical components for achieving stable intensity and high-average powers. In our gun design, the gun cavity is integrated into the first cell of the 9-cell standard ILC/XFEL (International Linear Collider/European X-Ray Free Electron Laser) cavity [2], resulting in a modified 9-cell accelerating structure. The 1st cell (gun cell) of this structure is redesigned to match the desired parameters and the length is 0.4 of a regular-sized cell. The remaining eight cells are the standard, well-known ILC/XFEL cavity parameters. This integrated design feature is key to a compact design. The first cell is designed on the basis of RF field calculations.

The detailed study of the accelerator design was recently presented [3]. Figure 1 shows the design of 8.4-cell gun structure with the frequency matched to 1.3 GHz. The field in the 0.4-cell has been maximized based on the design conditions. These simulations were performed using CST Microwave Studio [4].

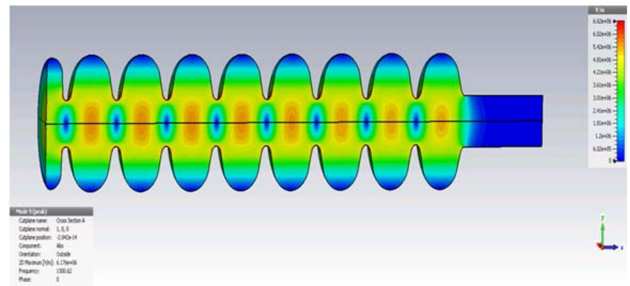

Figure 1: The 8.4-cell geometry design with the modified gun cell and the contour plot of the fields using CST MWS.

In Table 1, we summarize the design parameters of 8.4-cell accelerator structure.

Table 1. The Results of CST MWS Simulations for the Modified Gun Structure

Parameters	CST MWS results
First Cell Ratio	0.4
Frequency [MHz]	1300.6
E_{peak}, [MV/m]	22.5
B_{peak}, [mT]	44.6
B_{peak}/E_{peak} [mT/(MV/m)]	1.98
R/Q [Ω]	936

DESIGN OF THE CATHODE STRUCTURE

We have chosen a thermionic cathode for our design. Since a thermionic cathode by its very nature has a high temperature, one might assume that within a SC environment this could present an issue. The black-body radiation is quite low for the size of the cathode radius (~3 mm) we intend to use; therefore, much of this can be shadowed from the superconducting surfaces.

Choosing a thermionic cathode system creates a challenge for proper gating of the electrons from the cathode, as the electrons should be gated only during favorable RF phase conditions. This condition limits the potential of electrons striking the cold superconducting surfaces. According to this condition, we have incorporated an additional space behind the cathode plane of the half-cell that is designed to be resonant at the second harmonic of the main frequency, i.e. at 2.6 GHz, and this region will be held at a DC bias. The combination of this structure design will allow us to gate the electrons over the desire range of RF phase.

In this paper, we present the RF design of this cathode assembly part. This optimization was done in a few steps. First, the cathode region was designed to be resonant at 2.6-GHz, that is the second harmonic of the gun structure (integrated gun and remaining 8 sections).

First, we have designed the cathode structure using SUPERFISH [5] which is 2D electromagnetic simulation code that uses cylindrical symmetry. Figure 2 shows the design result and electromagnetic field distribution of the cathode structure.

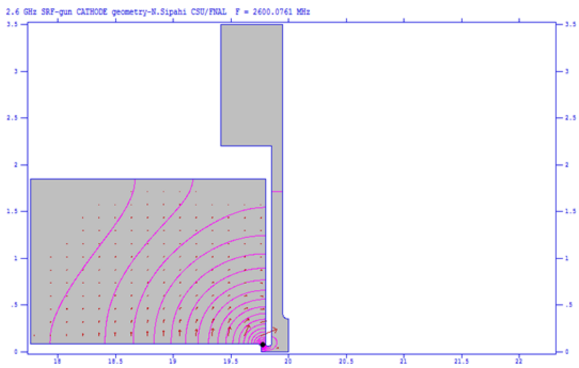

Figure 2: The cathode design geometry at 2.6 GHz with the field distribution using SUPERFISH.

As seen in Figure 2, the electromagnetic fields are mostly confined to the cathode plane, and no field propagates through to the superconducting part of the electron source.

To validate our 2D results, as mentioned above, we have also used CST MWS that is a 3D, electromagnetic simulation code. Figure 3 shows the design geometry of cathode assembly part operating at a resonant frequency of 2.6-GHz.

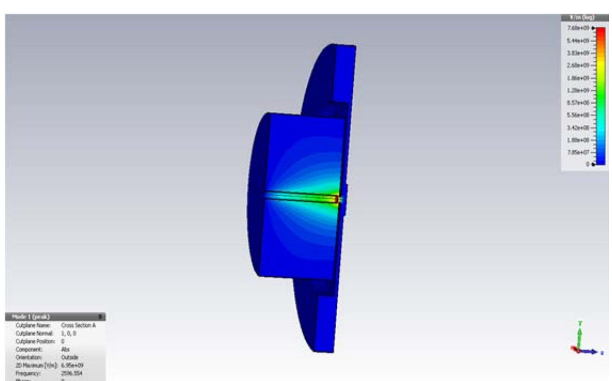

Figure 3: The cathode geometry design with the frequency matched to 2.6 GHz and the contour plot of fields all generated in CST MWS.

As seen in Figure 3, CST MWS gives near identical results to those given by SUPERFISH. The field mainly distributes near the cathode area, and it does not propagate though the gun cell.

DESIGN OF THE INTEGRATED CATHODE AND GUN STRUCTURE

In our previous studies, we have separately designed the 8.4-cell gun structure matched with 1.3-GHz frequency. In the previous part of this paper, we have presented the design results of the cathode structure designed for 2.6-GHz frequency in order to gate the charges in desired RF phase. We now will present the result of the combined design of the cathode and gun structures.

We first checked the impact on the resonance conditions when we combined the two structures as a full structure. In Figure 4, SUPERFISH results for the design of the full structure are shown.

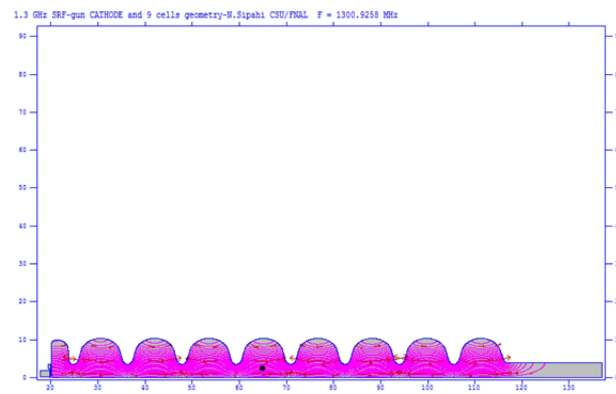

Figure 4: The design geometry of the combined structures at 1.3 GHz using SUPERFISH.

Figure 5 is the magnified view of the cathode area and the gun cell in order to better present the resultant field distribution in the integrated area. It shows that 1.3 GHz is the dominant frequency in the full structure. There is only a negligible amount of field propagating into the cathode structure.

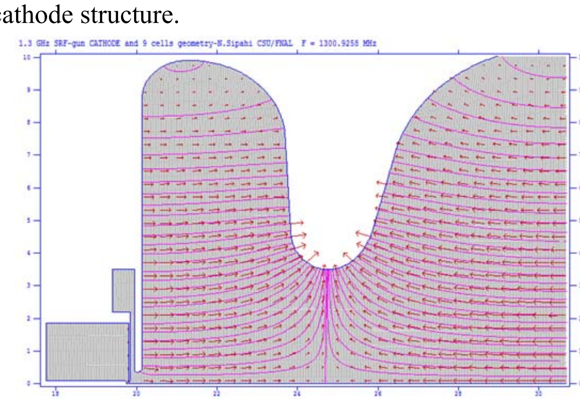

Figure 5: The magnified view of the cathode and first cell connection as shown in Figure 4 as calculated using SUPERFISH.

The simulations were repeated for the run of second harmonic for the combined structure. The result of the simulation is given in Figure 6, and the magnified view of the cathode-gun cell combination is given in Figure 7.

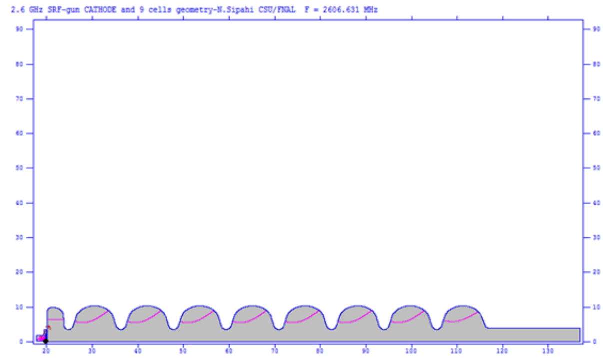

Figure 6: The design geometry of the cathode and gun structures together and the results at 2.6 GHz as calculated using SUPERFISH.

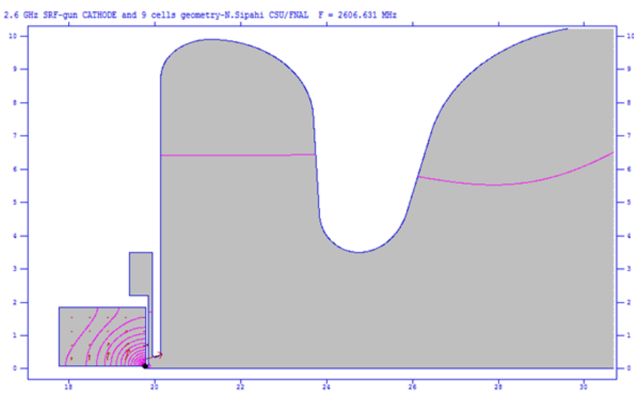

Figure 7: The magnified view of the cathode and first cell connection as shown in Figure 6 as calculated using SUPERFISH.

While there is some coupling of the 1.3 GHz to the 8.4-cell structure, it is minimal and will be completely inconsequential compared to the dominant 2.6-GHz component.

To perform these simulations in 3D via CST MWS would require an extremely fine mesh size as the cathode structure is in the smaller dimensions compare with gun structure. Therefore, we need to access to a high-performance computing system to run the full geometry and compare the results with 2D codes. As the agreement is already quite good for the simulations that are separately done for the cathode and gun structure, we have chosen not to perform the full 3D simulations. We predict that the 3D simulation will be similar to these 2D results for also the full injector geometry.

CONCLUSION

We have performed the initial simulations to design of 2.6-GHz cathode structure that is combined with the 1.3-GHz, 8.4-cell accelerator structure. These simulations were performed using SUPERFISH and CST MWS and are in good agreement with one another. Furthermore, we have also presented the simulation results of combined structure for both 1.3-GHz and 2.6-GHz frequencies via SUPERFISH. These results also show that the design of the combined structure work well together with a DC bias field, and this will allow us to easily gate the electrons into the main accelerating structure over a range of RF phases favorable to acceleration without loss of beam on the SC surfaces or back-bombardment. As a next step, the beam dynamics simulations will proceed using these design results.

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