# RF CAVITY CHARACTERIZATION WITH VORPAL *

C. Nieter[†], P. H. Stoltz, C. D. Zhou, P. J. Mullowney, C. Roark
Tech-X Corporation, Boulder, CO 80234, USA
F. Marhauser, Jefferson National Laboratory, Newport News, VA 23606, USA

## *Abstract*

Numerical modeling of radio frequency accelerating structures can provide insight into the performance of an accelerating cavity before any physical prototypes are built. We highlight some recent developments in the VORPAL simulation framework [1] that provide improvements to VORPAL's cavity modeling capabilities. Improved field calculations in the cells cut by the boundary allow for improved calculations of geometry based figures of merit such as the ratio of the shunt impedance to the quality factor (R/Q) for accelerating cavities. Recent developments in GPU based electromagnetic solvers provide considerable speed up for cavity mode simulations in VORPAL. The labeling and tracking of individual particle trajectories allows VORPAL to identify potential multipacting trajectories by tracking the number of impacts for a multipacting electron along with the population growth created by that electron. We present figure of merit calculations for a simple pillbox cavity and the CESR-B cell cavity using VORPAL. A mode extraction simulation of a possible Project X cavity design from Jefferson National Laboratory is used to demonstrate the speed up from using the GPU solvers. Multipactor analysis of the power coupler for the Jlab ProjectX design is also presented.

## IMPROVED ENERGY CALCULATIONS FOR MEASURING FIGURES OF MERIT

Cavity designers use a series of figures of merit to understand how well a particular cavity design will perform for a specific application. These figures of merit tend to depend on several different physical measurements of a cavity when the accelerating mode only is excited in the cavity [2]. These measurements include the total energy stored in the cavity, the surface integral of the fields on the cavity surface and the peak fields on the cavity surface.

Using the Dey-Mittra cut-cell method [3, 4] VORPAL is able to model cavity oscillations to a high level of accuracy but the way the fields are represented in the cells cut by the boundary can make the physical measurements needed for the figures of merit problematic. For example, the standard energy calculation for the electromagnetic fields in VORPAL does not account for the reduced volume of the fields in the cut cells or that the location of field in the cell is not the same as the cells that are not cut by the boundary.

To correct for this we have modified the energy calculation for both the electric and magnetic fields in the cut cell by accounting for the reduced volume and the location of the field in the cell. This is done by looking at an integral formulation of the equations of motion and extracting the appropriate expression for the energy for each type of cut cell. To demonstrate the improvement this provides to figures of merit calculations we run simulations of a pillbox cavity where there are known theoretical values for the ratio of the shunt impedance to the quality factor (R/Q). We use the same physical dimensions for our pillbox as was used in the example in Ref. [2]. For these dimensions the theoretical value for R/Q is 196 Ω. The results of these simulations for a variety of grid resolutions is shown in Table 1 where they are compared to calculations done with the old method of measuring field energy. The new method gives a R/Q that is already very close the theoretical value at very low grid resolution.

Table 1: R/Q for Pillbox Cavity

| Number of Cells | Old method | Improved Method |
|---|---|---|
| 25 x 25 x 25 | 182 Ω | 195 Ω |
| 50 x 50 x 50 | 190 Ω | 196 Ω |
| 100 x 100 x 10 | 192 Ω | 196 Ω |

We run a set of similar simulations for the well known CESR B-cell cavity and compare the results to the known value for R/Q for this cavity of 88 Ω [5]. These results are found in Table 2. Again for the new method we are able to reproduce the known value for R/Q for the cavity at very low grid resolution.

Table 2: R/Q for CESR B-cell Cavity

| Number of Cells | Old method | Improved Method |
|---|---|---|
| 50 x 25 x 25 | 78 Ω | 88 Ω |
| 100 x 50 x 50 | 83 Ω | 88 Ω |
| 200 x 100 x 10 | 86 Ω | 88 Ω |

R/Q is just one of several important cavity figures of merit. Many of the other figures of merit depend on field measurements at the cavity surface. We plan to expand the improvements made to the energy calculations in the cut cells to the calculation of the surface integral of the fields and the peak value of the fields at the surface so VORPAL can provide accurate values for the important figures of merit for cavity designs.

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[†] nieter@txcorp.com

## SPEEDING UP CAVITY MODE CALCULATIONS WITH GPU'S

The use of graphical processing units (GPU's) in computational physics is a growing field of interest since for the right problems and algorithms considerable speed up can be achieved. The finite difference time domain (FDTD) method is one algorithm that can benefit from being run on a GPU. VORPAL's FDTD electromagnetic solver has already been ported to GPU's sometime ago. Since the cut cell method in VORPAL requires specialized updates in the cells cut by the boundary some additional work was required. Now that the cut cell methods work on the GPU's we ran cavity simulation with both the standard FDTD method on CPU's and with the new FDTD method on GPU's determine what speed up can be achieved with GPU's.

Figure 1: Physical prototype of Jefferson Lab's Project X design.

We ran simulations of the Project X accelerating cavity design being developed at Jefferson National Laboratory [6]. This is a five cell cavity consisting of 650 MHz elliptical cavities. A physical prototype of one of the 650 MHz cavity can be see in Fig. 1. In the simulations a current source is driven at 650 MHz with a phase shift between each of the cells so the $\pi$-mode of the cavity is excited. The cavity is then allowed to ring for several periods so an FFT of the signal can demonstrate the only the $pi$-mode is present. Fig. 2 shows the effective speed of the CPU and GPU simulations for several different numbers of CPU's and GPU's. In each case the GPU simulations ran approximately five to seven times faster than the CPU simulations. These simulations demonstrate that for electromagnetic simulations of radio frequency accelerating cavities, the use of graphical processing units can provide considerable improvement in performance.

## MULTIPACTING SIMULATIONS OF PROJECT X CAVITY DESIGN

Whenever a new cavity design is developed multipacting can be a concern, especially for wave guide and coupler structures used to provide power to the cavity and remove higher-order modes from the cavity. Researchers at Jefferson National Laboratory are developing a possible accelerating cavity design for Project X. A picture of a physical prototype of a single cell from their design can be seen in Fig. 1. The geometry of power coupler design for can be seen in Fig. 3. To the researchers at JLab determine whether multipacting would be an issue we ran a series of simulations at different power levels of the coupler to identify any multipacting resonances that might exist.

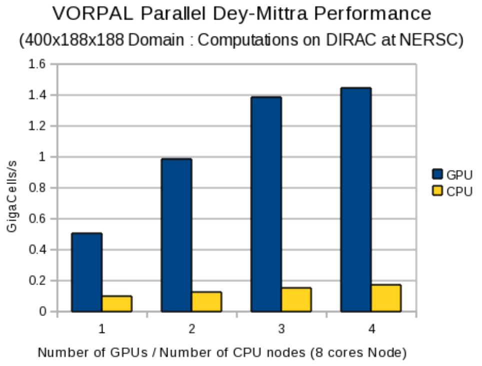

Figure 2: Speed of up cavity mode simulation using GPU's.

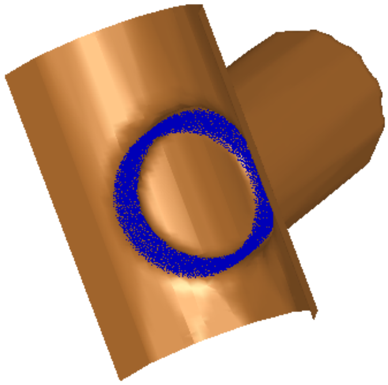

Figure 3: Location of seed electrons in Project X cavity coupler.

Our simulations consist of driving a traveling wave down the coupler structure into the beam pipe where the radiation is then removed from the simulation with open boundaries. Once the wave is established in the structure a population of seed electrons is introduced into the structure where multipacting is thought to be a possible problem. Fig. 3 shows the positions of these seed electrons relative to the coupler geometry. The simulation is then run for several more wave periods and the trajectories of the electrons are tracked. Whenever any electron impacts the boundary a secondary electron is released when the impact energy gives a secondary electron yield (SEY) above one for a functional parameterization of the SEY curve for niobium. The effective weight (ratio of simulation particles to physical particles) is increased by this SEY value. After the simulation is finished any electrons that have survived 20 impacts are identified as multipacting resonances. Fig. 4 show the effective SEY which is the average of the SEY for each impact along the trajectory. We see that multipacting could be an issue at powers around 10-20 kW and 40-50 kW. These are outside the operating powers for the cavity design in question.

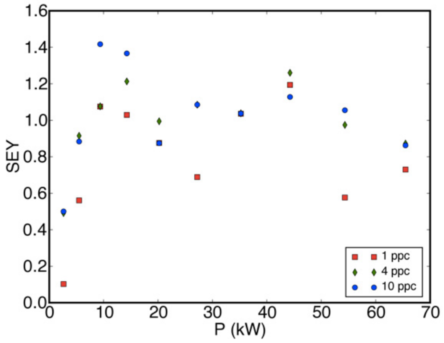

Figure 4: Effective SEY for multipacting electrons in cavity coupler.

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