DETAILED MODELING OF THE SNS RFQ STRUCTURE WITH CST MICROWAVE STUDIO

Derun Li, John W. Staples, Steve P. Virostek, LBNL, Berkeley, California, U.S.A.

Abstract

We report detailed RF modeling on the SNS RFQ structure using CST Microwave Studio code. Due to the complexity of the RFQ structure, a three-dimensional model with large mesh ratio is required to adequately model the necessary details of the structure. Old 3-D codes are not capable of giving accurate predictions of resonant frequency and fields, or for including mode stabilizers and terminations. A physical prototype is needed to verify resonant frequency and field profile, including mode stabilizers and end terminations, which is expensive and time consuming. Taking advantage of the Microwave Studio's Perfect Boundary Approximation (PBA) technique, we constructed a 3-dimensional computational model based on the as-built SNS RFQ dimensions with pi-mode stabilizers, end cutbacks and tuners and simulated it in the frequency domain using the CST Eigen-value Solver. Simulation results accurately predicted the resonant frequency and field distributions. We are applying the simulation technique to the design of another RFQ.

INTRODUCTION

Once a good beam dynamics design for an RFQ is achieved, one needs to perform the RFQ structure design that can provide the electromagnetic field properties required by the beam dynamics design. An RFQ structure design involves iterations of electromagnetic field simulations on the RFQ structure to achieve a design that has good transverse and longitudinal mode stabilization, right resonant frequency and coupling. Traditionally the three-dimensional MAFIA code was used to do the simulations [1]. Although the general RF properties could be obtained, the absolute frequency, details of structure such as π-mode stabilizers, radial matcher and two end-cut-backs could not be precisely determined. Therefore, the common practice was to build an RF model prototype that can be used to confirm the final dimensions of the cavity, and in particular the geometry of the two ends.

However, with the advent of modern computers and adaptive meshing technique to handle the structure boundaries and geometries that need large aspect ratios of meshes, improved three-dimensional electromagnetic field simulation codes are now available for design use. We have recently purchased the CST Microwave Studio code (the same company that produced the MAFIA code) which is a three-dimensional electromagnetics code using Perfect Boundary Approximation (PBA) technique [1]. To benchmark the code, we simulated a section of the SNS RFQ (~ one meter long) with the as-built dimensions that include the two ends: the entrance plate, radial matcher and exit plate [2]. We compared the simulation results with experimental measurements and achieved excellent agreements. We are applying the same simulation tool and technique to a new RFQ design for an accelerator driven neutron source project [3].

MWS MODEL FOR THE SNS RFQ

We built a three-dimensional CST MWS model of the SNS RFQ with the as-built dimensions. The CST MWS has features for building three-dimensional models that can be parameterized. This feature is very useful for fast parameter studies and optimizations of RF structure. We have built a three-dimensional MWS model with ~ 0.93 meter long section of the SNS RFQ with three pairs of π-mode stabilizers (rods) in both horizontal and vertical directions, and closed the model with as-built dimensions of the radial matcher, cut-backs and two end plates. A sectional view of the model is shown in Figure 1 where the radial matcher, π-mode stabilizers and cut back at exit can be seen.

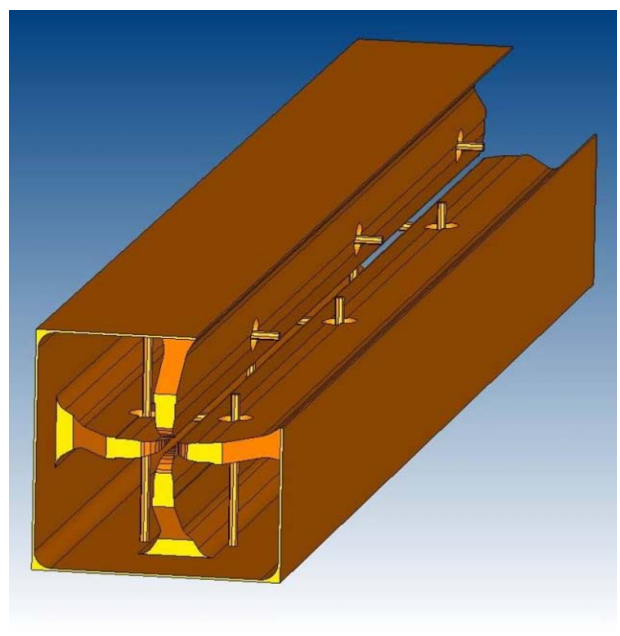

Figure 1: A sectional view the 3-D simulation model of the SNS RFQ by CST Microwave Studio. Radial matcher, π-mode stabilizers (rods) and exit cut-back are included in the model.

The two end plates that have rather complex geometry are also included in the RFQ model with the as-built dimensions to simulate the termination of the RF fields. The PBA technique helps greatly in dealing with the geometries that need large aspect ratio, such as π-mode stabilizers, radial matcher and two end plates. Figure 2 shows the MWS models of the entrance and exit plates. The level of the geometry details and small gaps between the RFQ and the plates, and as well as the π-mode rods are modeled carefully by choosing finer local meshes as necessary.

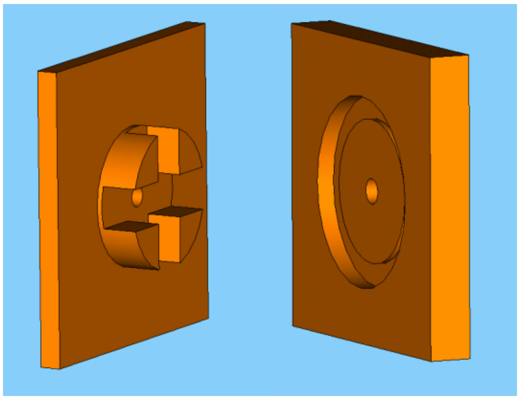

Figure 2: The MWS models of the SNS RFQ's entrance plate (left) and exit plate (right)

SIMULATION RESULTS

Once the MWS model is established, one needs to put right boundary conditions to simulate the RF fields. To save memory and CPU time, we simulated only 1/4 of the model as the RFQ has two symmetry planes at the axis. To simulate quadrupole model we put magnetic boundary conditions at both x and y planes; electric boundary in x (or y) and magnetic boundary in y (or x) boundary planes for dipole modes. We found that the simulation results had excellent agreement in frequencies and field flatness for both the quadrupole and dipole modes.

Quadrupole Mode

Considering how complex the RFQ geometry is and how much details in the model, the MWS simulation results agreed very well with the measurement. It is better than any three-dimensional codes we have used before. We believe that it is possible to skip cold-test model which we have done for all previous RFQs, and go directly for future RFQ fabrications based on the MWS designs. Table 1 summarizes the simulation results of the quadrupole mode from the model, in comparison with the measurements.

Table 1: MWS Simulation Results of the Quadrupole Mode

Parameters	**MWS simulation**	**Measurement**
Frequency	403.45 MHz	402.5 MHz
Q value	8,779	7554

Both the RFQ frequency and Q value agreed well with the measurements within ~ 0.24% and ~ 86%, respectively. Moreover, as the MWS can simulate the *EM* fields of the RFQ structure with better accuracy, we could study the perturbation effects from π-mode rods on frequency, power dissipation on the rods and the RFQ structure (body). As an example, Figure 3 shows the RF power dissipation distributions of the quadrupole mode on the RFQ structures where hot spots are seen (red color) to be located at those cut-backs of the vanes, which agreed with the previous predictions and measurements.

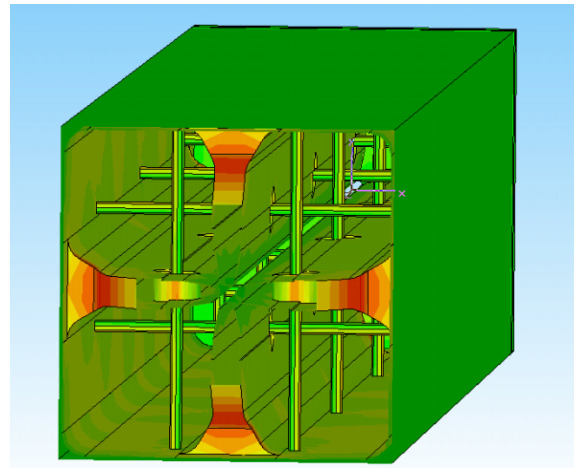

Figure 3: RF power dissipation distributions on the SNS RFQ structures. Hot spots (red color) or high power dissipation areas are located at the cut-backs of the vanes.

Field flatness is always one of the most important tasks for RFQ tuning an RFQ. We plot the electric field distribution along the ~ 1 meter long RFQ model of the quadrupole mode at ~ 1cm and 45^{o} off the axis between two vanes as shown in Figure 4. The field distribution is quite flat (based on the final as-built dimensions and tuner positions).

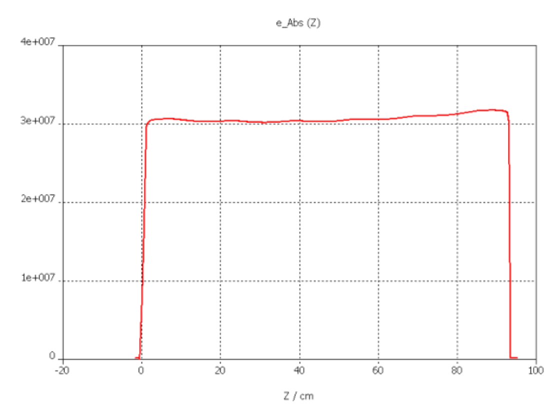

Figure 4: Simulated electric field flatness of the quadrupole model along the MWS RFQ model with as-built SNS RFQ dimensions and final tuner positions.

Dipole Modes

Dipole modes at two different polarization directions are simulated by alternating x and y symmetry planes with electric boundary conditions. The simulated results are listed in Table 2.

Table 2: MWS simulation results of the dipole mode

Parameters	**MWS simulation**	**Measurement**
Frequency (x)	437.609 MHz	432.881 MHz
Frequency (y)	439.941 MHz	434.169 MHz

The MWS model for the SNS RFQ is only ~ 1.0 meter long including two end plates. It is impractical to simulate the SNS RFQ with its full length of ~ 3.8 meters long. One obvious effect as we can see from the simulation results in Table 2 is the effects of the cut-backs and end plates on the dipole mode. These cut-backs and end plates are designed to terminate or matched to the quadrupole mode, not the dipole mode. Short model has stronger effects on the dipole mode frequencies, as it indicated on the simulated dipole frequencies in comparison with the measured ones in Table 2.

EFFECTS OF π-MODE STABILIZERS AND TUNERS

Tuners and π-mode stabilizers are included in the MWS model for the SNS RFQ with final dimensions and positions. A cut view in Figure 3 shows the layout of the π-mode rods and tuners. The effects of the π-mode rods and tuning sensitivity of the tuners were predicted by cold-test model or analytically. Simulation tools were not available at the time to deal with the complex geometry with large aspect ratio with trustable accuracy. We have simulated these effects with the MWS model and again achieved a very good agreement with our predictions. RF power dissipation on the π-mode rods are calculated numerically for the first time. It contributed to about 8% of the total power dissipation on the structure.

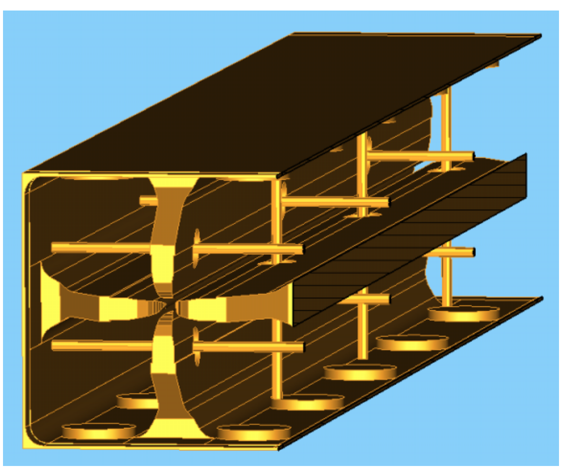

Figure 5: The MWS model shows the layout of the π-mode rods and tuners for the SNS RFQ.

A 200 MHZ 6 MEV D+ RFQ FOR ADNS

We have applied the WMS simulation tool and technique to a 200 MHz 6 MeV deuteron RFQ design for an Accelerator Driven Neutron Source (ADNS) project [3]. With the successful simulation experience with MWS, we do not think it is necessary to build a cold-test model as we did before to check designs for mode separation and end terminations. We plan to skip the cold-test model and go directly for the final RFQ structure design. A parameterized three-dimensional MWS RFQ model was created with the π-mode stabilizers similar to the ones used for the SNS RFQ. The current model does not have the radial match section and cut-backs at both ends yet, but will be added later as the project proceeds. The model is a 127.5-cm long RFQ section (one module) with equal number of pairs of π-mode rods in both horizontal and vertical directions. The number of the π-mode rods are determined based on mode separation obtained from MWS simulations. Figure 6 shows the quadrupole and dipole mode frequencies as a function of the π-mode rods per module. Up to ~ 15 MHz of mode separation can be achieved with 16 π-mode rods per module. This is adequate for the transverse mode separation. We also found that the radius of the π-mode rods also perturbs the mode separation, and it can be increased to achieve wider mode separation if it is necessary. RF loss introduced by the π-mode stabilizers are estimated for the case of 12-rod per module, it is estimated to be about 8.6% of the total RF dissipation on the RFQ structure.

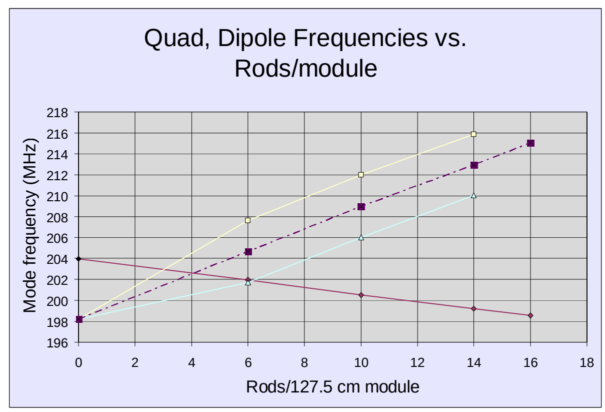

Figure 6: MWS simulations of quadrupole and dipole frequencies as a function of the number of π-mode rods per 127.5-cm long module.

ACKNOWLEDGEMENTS

We thank Dr. G. Huang for his assistance in building the WMS model for the SNS RFQ.

This work was supported by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 and by the U. S. Department of Homeland Security under contract No. HSHQBP-05-X-00033.

REFERENCES

[1] CST MAFIA code; CST Microwave Studio Suite 2006, www.cst.com

[2] A. Ratti, et al, “The Fabrication and Initial Testing of the SNS RFQ”, PAC-2001, Chicago, IL

[3] John W. Staples, M. D. Hoff, J. W. Kwan, D. Li, B. A. Ludewigt, A. Ratti, “Design of an RFQ-Based Neutron Source for Cargo Container Interrogation”, This conference.