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3D ELECTROMAGNETIC/PIC SIMULATIONS FOR A NOVEL RFQ/RFI LINAC DESIGN *

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Abstract

Using the commercial software *VSim 9*, a highly parallelized particle-in-cell/finite difference time-domain modeling code, the performance of an existing novel RFQ/RFI linac structure designed by Ion Linac Systems (ILS) is evaluated. This effort is aimed towards having an updated full 3D start-to-end simulation of the accelerator system, which does not presently exist. The structure used is an efficient 200 MHz, 2.5 MeV, CW, RFQ/RFI proton linac. The methods employed in *VSim 9* for modeling and parameter set-up are presented, along with the simulation procedures for the electromagnetic solver. The important figures of merit for the structure are given including the *Q* factor, field distributions, shunt impedance, and important beam properties. These are then compared with the initial design values and bead-pull measurement.

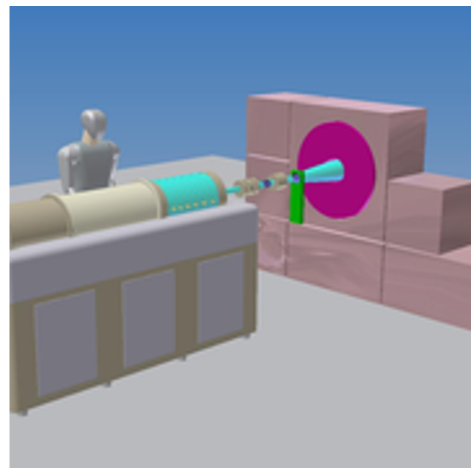

Figure 1: Conceptual view of a full BNCT setup.

INTRODUCTION

The machine discussed in this paper was designed by Ion Linac Systems (ILS) for use in Boron Neutron Capture Therapy (BNCT), a non-invasive therapy for treating locally invasive malignant tumors [1]. In this approach, the tumor is tagged through an injection with a tumor-localizing medication. Boron capture slow, epithermal neutrons. The resulting nuclear reaction releases the energy dose in the micro-meter range, thus avoiding damage to healthy tissue. This therapy has traditionally been done with neutrons produced in nuclear reactors, but there is recent interest in an accelerator driven system approach, where a linac produces an ion beam, which is then brought into a dense target, where neutrons are released through a process called *spallation*. Using a linac has the advantage of a narrow-band energy spectrum of the neutron beam, as well as reduced operation costs as compared to using a nuclear reactor. It also has a significantly smaller footprint [2]. Figure 1 shows a conceptual view of such system.

The linac discussed in this contribution was designed by ILS, it is formed by a Radio Frequency Quadrupole (RFQ) and a Radio Frequency Interdigital (RFI) [3]. The RFI was developed by Don Swenson from ILS and has been found to be four times more efficient than current Radio Frequency Quadrupoles (RFQ) or Drift Tube Linac (DTL) designs [2]. The system consists of a 25 keV microwave ion source where the protons are extracted. The beam is then transported into the RFQ through a solenoid lens based system, it then passes through the 0.75 MeV RFQ, and then through the 2.5 MeV RFI. The length of this system and its associated power, vacuum and water cooling systems, is quite compact at 2.84 m.

For the BNCT application, it is critical to produce neutron beams with high intensity. Since the Boron-neutron cross section is very small, a higher beam intensity increases the probability of neutrons interacting with the Boron nuclei. In other words, a higher neutron beam intensity increases the efficiency of the therapy. The beam intensity can be increased by operating the linac in Continuous Wave (CW) mode. The RFQ/RFI ILS linac allows for continuous wave (CW) operation at beam currents up to 30 mA. Currently, the linac operates in pulsed power mode but there are on-going efforts on moving towards CW opearation. Operating in CW has multiple operational challenges such as complicated cooling schemes as well as operational power costs. Our motivation to numerically model the RFQ/RFI linac is to have a full start to end model, so that further optimization

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can take place virtually, where we can test multiple ideas for improving the system quickly and at a low cost.

STRUCTURES

The RFQ structure was originally simulated in PARMTEQ and the RFI in PARMIR [4]. Beam dynamics simulations were also performed using the PARMULT code for the RFQ [5]. The system has also previously been modeled with *CST Microwave Studio* [6]. In this contribution, we present the modeling results obtained with the commercial software *VSim 9* [7]. *VSim 9* is a flexible, multiplatform, multiphysics simulation software tool, based on the Vorpal engine [8]. Here we use it to calculate the electromagnetic eigenmodes in complicated structures such as the RFQ and RFI. Figure 2 shows the geometries of both the RFQ and RFI from ILS.

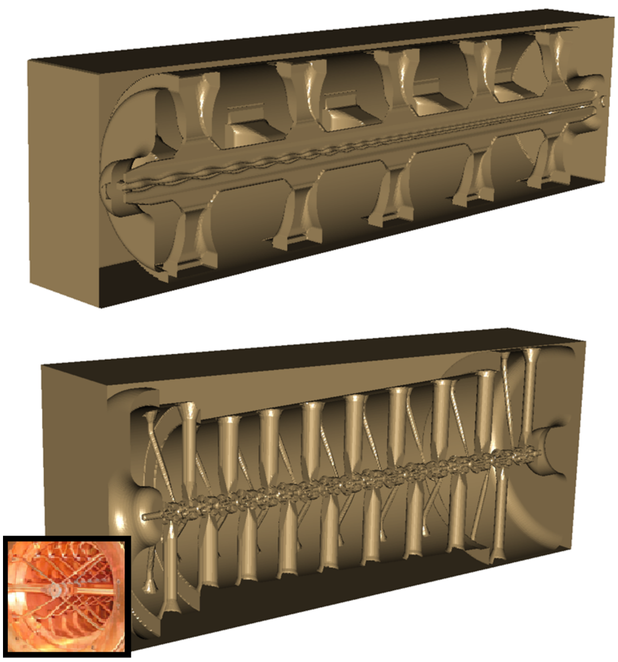

Figure 2: *VSim 9* models of the RFQ (top) and the RFI (bottom). The inset is an image of the actual RFI cross section.

SIMULATION SET-UP IN *VSIM 9*

Simulations of the RFI and RFQ are performed in two steps: first, the structures are excited using a time varying distributed current source exciting across the frequencies of interest. The current source is then switched off, and the field configurations are saved at regular intervals depending on the modes and mode spacing in the structure. The individual modes are then extracted using the filter-diagonalization method as described in [9]. Both the RFQ and RFI operate around 200 MHz, so the range selected for these simulations was 180 - 220 MHz.

Eigenmode Solver

Using the aforementioned method, we calculated the operating mode for both the RFQ and the RFI. Figure 3 top shows the amplitude of the longitudinal component of the electric field along the RFQ axis as indicated by the black line in the bottom field map. 3D field view, Q value, Field on axis, power dissipated in walls

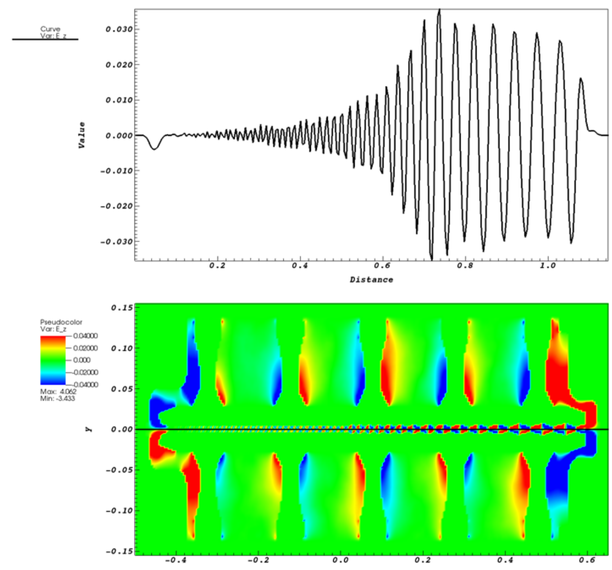

Figure 3: Amplitude of the longitudinal electric field corresponding to the operating mode at 200 MHZ of the RFQ.

Similarly for the RFI, Figure 4 shows the longitudinal component of the electric field along the axis of the RFI. We note that the field profiles do not have a well resolved structure in some regions. This is due to meshing inconsistencies with the imported CAD files, this is currently under investigation.

Comparison to Experimental Data

In this section we present a comparison between the simulation results and measured data using bead-pull measurement. As a matter of illustration, Figure 5 shows the resonant frequency of the operating mode for the RFQ using a Vector Network Analyzer, while Figure 6 shows the electric field structure in the RFI obtained with a bead-pull measurement. The corresponding comparisons between bead-pull measurement and simulation are summarized in Table 1 for the RFQ and RFI. The simulation and experimental results for the RFI agree very well, to within less than 0.01%. However, the results for the RFQ differ significantly. We believe this is due to the fact that we modified the RFQ in the frequency measurement by removing the RFI and resonant coupler and then placing a shorting plate at the end of the RFQ, but we did not make the corresponding change in the simulation. An investigation into modeling the geometry in this modified configuration is underway.

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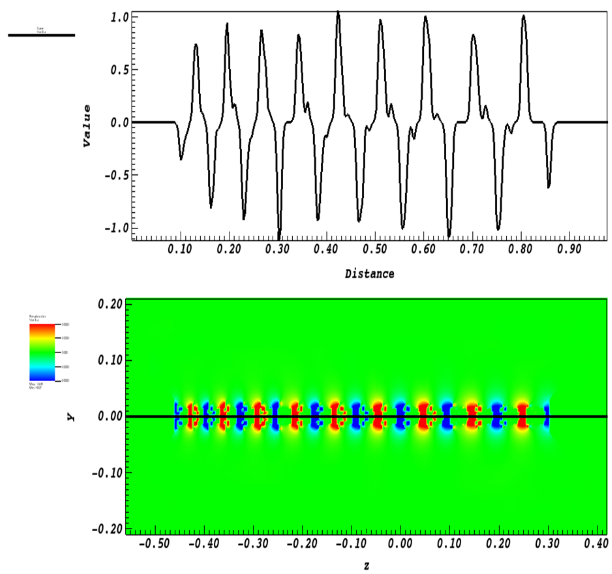

Figure 4: Electric field amplitude along the longitudinal axis for the RFI at the oparating mode.

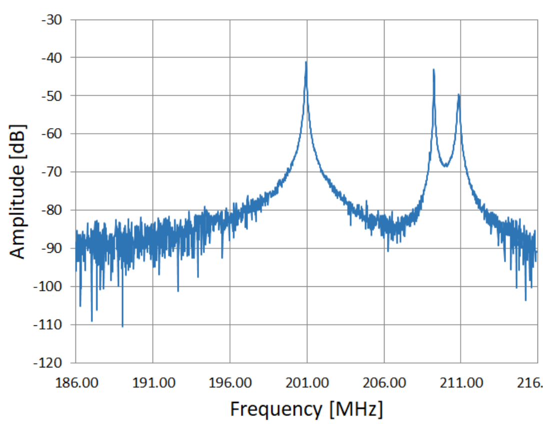

Figure 5: Mode spectrum for the RFQ; fundamental mode is close to 200 MHz and parasitic modes in the neighborhood of 210 MHz.

Table 1: Comparison Between Simulation vs. Measurement for the RFQ and RFI

	RFQ		RFI	
	VSim 9	Meas.	*VSim 9*	Meas.
Freq [MHz]	208	200.87	200.9	200.915
Q-factor	-	5925	-	9247
P. Loss [kW]	-	75	-	45

SUMMARY AND FUTURE WORK

In this paper, we have investigated the electrodynamic properties of an RFQ and an RFI designed by ILS, using the commercially available software *VSim 9*. The linac currently operates in pulsed mode. On-going efforts towards CW operation include the better understanding of the RFQ and RFI performance. We accurately represented both the RFQ and RFI in *VSim 9* and calculated the electromagnetic properties of the fundamental mode and compared to experimental data from microwave, bead-pull measurements. This is continuing work and it will be useful to identify limitations and possible areas for improvement in the linac, especially as we increase the duty factor.

VSim 9 Particle-in-Cell (PIC) suite can also model a beam passing through the electromagnetic structures. Future studies will take advantage of this tool to study the full dynamics of the beam on its way through the RFQ and RFI. This could be useful to identify limitations and possible areas for improvement in the linac.

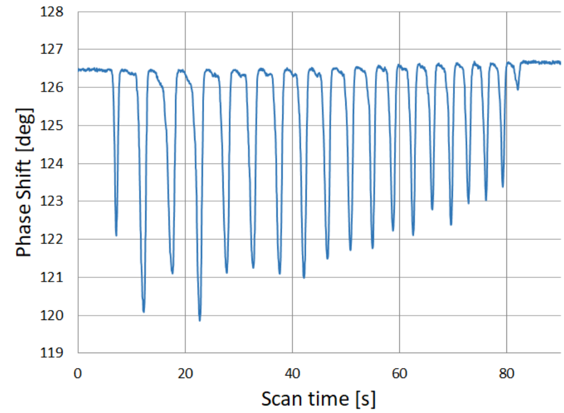

Figure 6: Bead-pull measurement data showing phase shift vs. scan time along the RFI axis.

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