COMPUTER SIMULATIONS OF WAVEGUIDE WINDOW AND COUPLER IRIS FOR PRECISION MATCHING*

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Abstract

A tapered ridge waveguide iris input coupler and a waveguide ceramic disk window is used on each of six drift tube linac (DTL) cavities in the Spallation Neutron Source (SNS). The coupler design employs rapidly tapered double ridge waveguide to reduce the cross section down to a smaller low impedance transmission line section that can couple to the DTL tank easily. The impedance matching is done by adjusting the dimensions of the thin slit aperture between the ridges that is the coupling element responsible for the power radiating into the cavity. Since the coupling is sensitive to the dimensional changes of the aperture, it requires careful tuning for precise matching. Accurate RF simulation using latest 3-D EM code is desirable to help the tuning for maintenance and spare manufacturing. Simulations are done for the complete system with the ceramic window and the coupling iris on the cavity to see mutual interaction between the components as a whole.

INTRODUCTION

SNS has reached 1MW beam power on the way to achieving 1.4MW design goal since its first operation in 2006. H^- ion generated in the RF plasma ion source is accelerated through the low-energy beam transport (LEBT) system and radio-frequency quadrupole (RFQ) to 2.5MeV. Six 402.5MHz Alvarez type drift tube linac (DTL) accelerate the beam to 86.8MeV followed by coupled cavity linac (CCL) and medium and high-β (0.61, 0.81) superconducting linac sections (SCL) all operating at 805MHz. Each DTL tank is powered by a 402.5MHz, 2.5MW klystron at 7.02% duty cycle. A rapidly tapered double ridge waveguide iris coupler is used as matched transition section between waveguide and DTL tank.

Challenges in design, installation and high RF power operation of DTL iris coupler have been reported and led numerous research and improvement efforts. Coupling factor of elliptical coupling slot is formulated analytically by J. Gao [1] and modified and applied to dumbbell shape slot on the DTL tank [2]. Analytical and numerical estimations on external quality factors of various types of cavities have been performed [3]. Due to its high power transmission through small aperture, careful design by determining precise slot dimensions was required. Local RF heating, arcing, melting and multipacting considerations are reported during the conditioning of ridge waveguide iris transition for LEDA RFQ [4]. Numerical (2-D and 3-D in time-domain) analyses and design on cavity with ridge waveguide iris transition were conducted in detail [5]. Resonance frequency shift occurs in beam loading and temperature change. It is estimated and controlled by DTL cooling system during operation. [2,6]

Since, operation with increased beam power, certain DTL tanks slowly introduced difficulties that prevented robust neutron production due to arcing around the ceramic window and the coupling iris. Due to its mechanical complexity along with coupling/matching sensitivity, the unexpected problems prompted study of the iris coupling of the DTL structures. Arcing and multipacting cause vacuum bursts, which truncate the RF pulses and prevent the RF system from normal operation. Severe arcing could result in conductive coating on the ceramic window disk that can eventually prohibit the cavity operation.

In this work, SNS DTL tank and waveguide assembly are considered in full 3-D EM modeling in RF system point of view. Frequency shifting by installation of the waveguide taper and waveguide ceramic window is observed. Coupling coefficient variation based on matching (S11) as a function of dumbbell slot dimension is observed.

DTL RF MODEL

SNS DTL tanks operate up to 2.5MW RF power through a disk type ceramic window as the vacuum barrier. The ceramic disk is located between full-height and half-height waveguide sections. Double-ridged waveguide transition tapers half-height cross-section smoothly down to the coupling slot on the DTL wall. RF power coupled into the DTL tank through a thin slot is used to accelerate the beam.

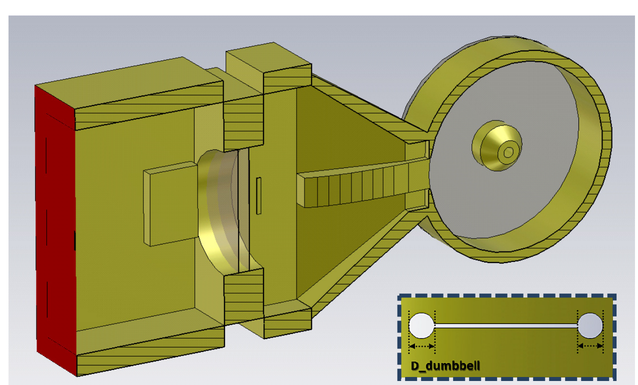

Figure 1: 3-D EM model on assembly of DTL tank cell, waveguide iris taper transition and WG window.

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

Fig. 1 shows the 3-D CST MWS model of SNS DTL RF coupling system consisting of the ceramic vacuum window, double-ridged waveguide taper iris transition and single DTL tank cell. The waveguide ceramic window is also included in the model. Small matching structures in both sides of disk are optimized for 402.5MHz (see Fig.1).

Drift Tube Linac Tank

For simplifying the numerical computation, a single drift tube section is considered to represent the SNS DTL tank (tank 3 case is shown in this paper, tank diameter = 17.877", drift space = 8.2"). Two longitudinally symmetric models are compared ignoring the length increment for beam velocity acceleration: a single cell with PEC boundaries and a longitudinally periodic structure with PRC boundaries. R over Qs for both cases were identical at 318 ohms. The quality factors are calculated based on copper boundaries. Periodic boundary case is about double the amount of the Q factor (~60,000) while the single and two-cell with PEC boundary cases show 31,000. The higher Q in the periodic boundary case is obvious because of lack of end walls.

Double Ridged Waveguide Transition

For its broadband and size-effective characteristics, double-ridged waveguide taper iris transition is employed as the RF coupler for the DTL tanks. Port impedances and cutoff frequencies of each cross-section must be determined for matching, multipacting, and power handling considerations [4]. Cutoff frequencies of the cross-sections of the ridge waveguide at various locations in the linear transition (x direction) are compared. The strengths of the electric and magnetic fields and port impedances are calculated with simulations of waveguides at the cross-section.

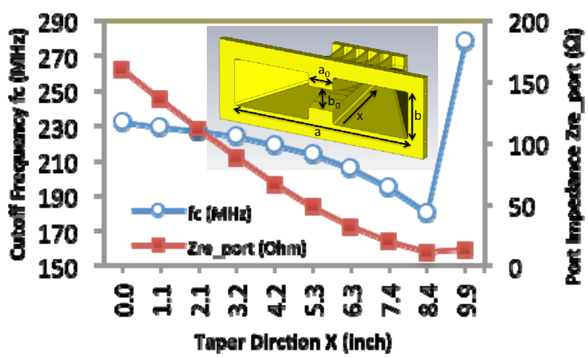

Figure 2: Double-ridge waveguide iris transition model and its cross-sectional port properties (cutoff frequency f_c, port impedance Z_{re_port}). Each point is based on CST model of waveguide with cross-section along x direction.

Simulation of Assembled Structures

The DTL iris waveguide window assembly is considered in the frequency domain analysis. Longitudinal PEC boundary is applied on DTL single cell. The drift tube stems are not included for model symmetry. TE_{10} mode propagates through the waveguide sections (window and taper) and establishes TM_{010} mode shown in Fig.3. E and H field profiles at each cross-section of iris transition (x-axis) are depicted in Fig.4. E(z) fields are flat while H(y) fields have increasing edge fields as approaching to DTL tank.

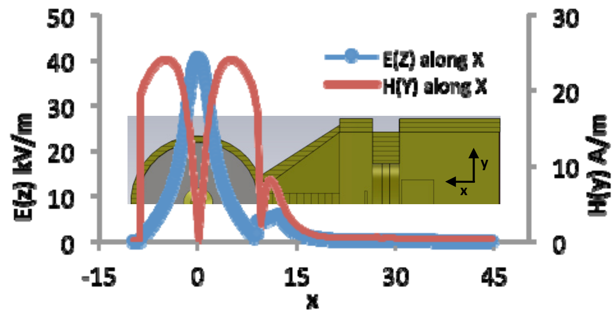

Figure 3: E(z) and H(y) field plots along the RF propagation axis (x-direction, y=z=0). Beam axis (z-direction at x=y=0), drift tube center has maximum E and minimum H field. E field drops rapidly at the coupling slot interface.

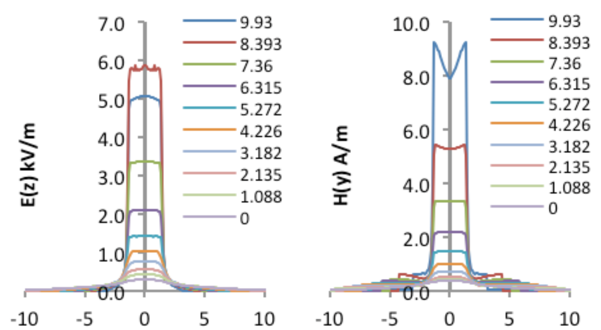

Figure 4: E(z) and H(y) field plots at each cross-section of ridged waveguide taper transition. Abscissas are transverse directions (y in inches) in model at z=0. Each curve represents distance (x) approaching to slot on DTL tank.

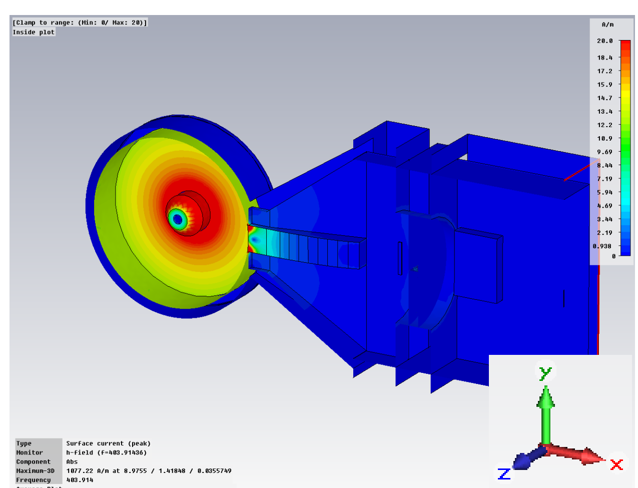

Figure 5: Surface current density plot of DTL/IRIS/ Window model at resonant frequency (403.914MHz).

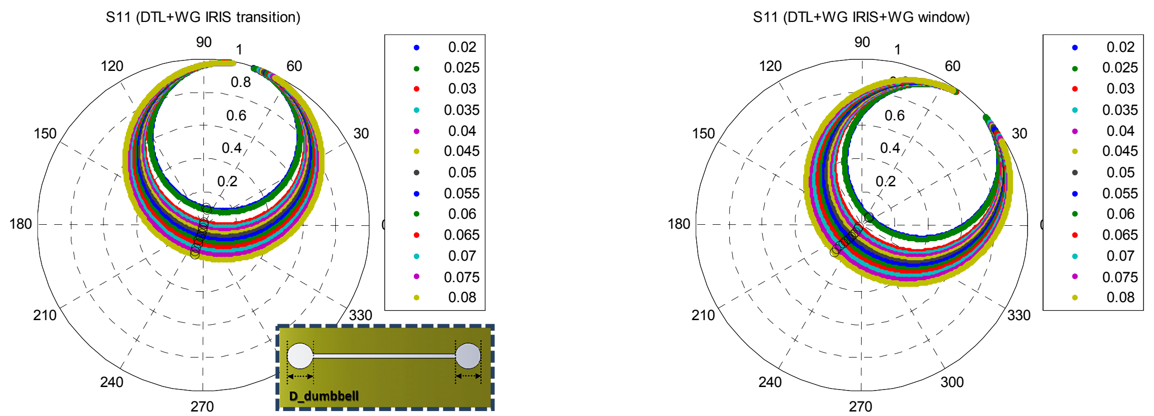

Figure 6: S11 of DTL/IRIS (left) DTL/IRIS/Window model (right) with various slot dimensions (D_dumbbell).

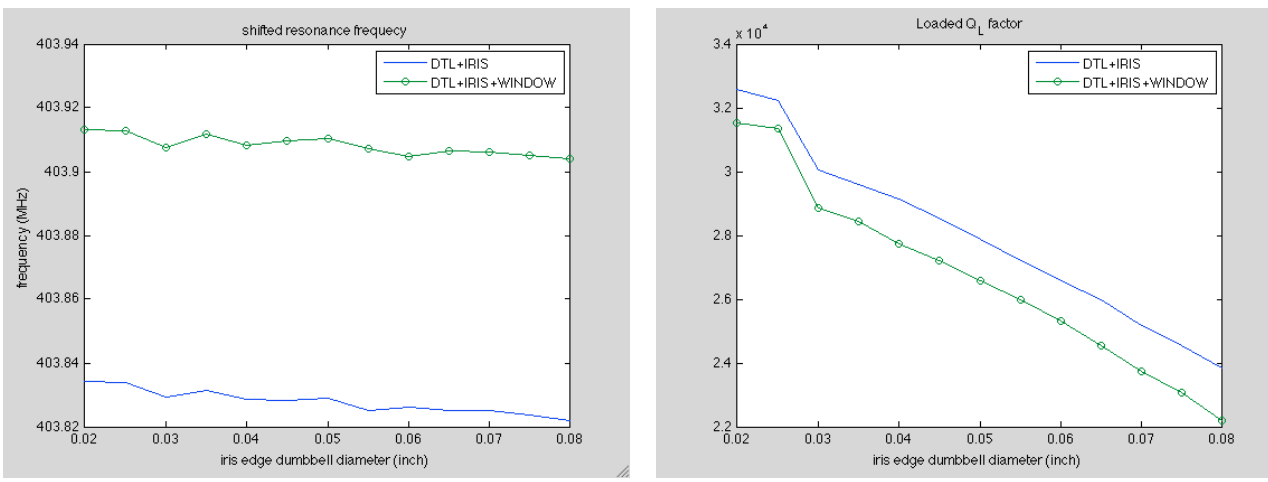

Figure 7: Resonant frequency variations and loaded Q values extracted from S-parameters (Fig.6).

In order to estimate the coupling, diameter of dumbbell end circles of the coupling slot is parameterized for optimization. Q values, coupling coefficients and the frequency shift can be easily estimated graphically from S-parameters (polar display) [7]. In Fig.6, each circle represents the coupling with respect to the coupling slot dumbbell diameter. The nearest points of each circle from origin are S11 values at resonance. Keeping the plot frequency range the same, larger circle means lower Q and origin-crossing circle represents critical coupling (β=1). With the changes in coupling, the resonant frequencies are shifted $f_{DTL+IRIS}$ = 403.83MHz ($\Delta f_{DTL+IRIS} \approx$ 1.3MHz) and $f_{DTL+IRIS+WINDOW}$ = 403.91MHz ($\Delta f_{DTL+IRIS+WINDOW} \approx$ 1.41 MHz) as shown in Fig.7.

SUMMARY

Arcing and multipacting seem to be problems in some of the SNS DTL RF systems in recent operation and require complete understanding of design and tuning of waveguide iris couplers. 3-D RF simulation of assembled components enables to investigate mutual influence between coupling slot dimension and RF components. Coupling, Q factors and frequency shifting can be quantified from S-parameter calculations. Modeling including multipacting phenomena is desirable for further studies.

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