CONSIDERATION ON DETERMINATION OF COUPLING FACTORS OF WAVEGUIDE IRIS COUPLERS*

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Abstract

Waveguide iris couplers are frequently used to power accelerating cavities in low beta sections of ion accelerators. In ORNL Spallation Neutron Source (SNS), six drift tube linac (DTL) cavity structures have been operating. An iris input coupler with a tapered ridge waveguide and a waveguide ceramic disk window feeds each cavity. The original couplers and cavities have been in service for more than a decade. Since all DTL cavity structures are fully utilized for neutron production, none of the cavity structures is available as a test cavity or a spare. Maintaining spares of the iris couplers for operations and future system upgrade without using the full DTL structure, a test setup for precision tuning is needed. A smaller single-cell cavity may be used for pretuning of the coupling irises as the test cavity and high power RF conditioning of the iris couplers as the bridge waveguide. In this paper, study of using a single-cell cavity for the iris tuning and the conditioning is presented with 3D simulations. A single-cell test cavity has been built and used for low power bench measurement with the iris couplers to demonstrate the approach.

INTRODUCTION

Six DTL cavities have been in operation for continuous neutron beam production in SNS since the commissioning of the system in 2006. The waveguide iris couplers are employed to power the cavities with 2.5MW klystrons at 402.5MHz in 8% duty cycle. In order to prepare spare couplers to support the current operation and future SNS system upgrade such as the second target station (STS) project [1], it is desirable to have a simple systematic method to evaluate and test performance of the couplers. Utilizing a single-cell test cavity was considered [2] for pretuning of the iris openings at low power in a single port configuration and for high power RF conditioning in a dual port setup.

In this paper, considerations in preparing a single-cell test cavity and methods of evaluating waveguide iris couplers are discussed in the context of ongoing work. Determining the scale factors of coupling coefficients is needed for each DTL cavity to use the test cavity. This requires accurate RF field information at the iris-cavity interface. RF simulation of SNS DTL structures in 3D involves modeling of the details in the cavity structures, which is challenging. Field flatness needs to be achieved by aligning drift tubes properly to precisely estimate the magnetic field at the coupler location in the cavity.

SNS DTLs were built in two different tank diameters (Table 1) that resulted in two slightly different iris couplers in their iris surface curvatures. The slight mechanical mismatch that can be introduced to use a single-cell cavity with the iris couplers has been examined in this study for improved accuracy. For the single-cell cavity, two types of single cell test cavities can be built: a reentrant pillbox cavity and a simple pillbox cavity. They are compared with simulation results. A prototype single-cell test cavity was built for low-power bench measurements to compare with the simulation results.

RF MODELING CONSIDERATIONS

Utilizing a simple test cavity to find the iris dimensions for the desirable couplings in DTL structures, accurate scale factors of the coupling coefficients are required. The scale factor can be obtained from the ratios of the total surface losses and the wall magnetic fields on the location of the coupling iris [2, 3].

$$\alpha_{ms} \triangleq \beta_m/\beta_s = \left[\frac{H_1^2}{P_c}\right]_m \Big/ \left[\frac{H_1^2}{P_c}\right]_s, \tag{1}$$

where *m* denotes the full multi-cell cavity, *s* for the single-cell test cavity and H_1, Pc are the cavity magnetic field on the coupling iris area without the coupler and the cavity power loss, respectively.

Longitudinal Field Flatness

Field flatness of the cavities with many cells is sensitive to the longitudinal alignments of cell geometries that include the drift tubes and their gaps. The SNS DTLs have various numbers of drift tubes depending on the particle beam velocity. Although mechanical tuning was performed in a structure, the model for the simulation has to be tuned again numerically to perform the study. This process provides a proper longitudinal field flatness in a cavity that is needed to find the magnetic fields on the coupler location. Numerical optimizations on the drift tube dimensions are performed to achieve field flatness using the eigenmode solver of CST MWS [4].

Table 1: Numbers of Drift Tubes and Tank Diameters of SNS DTLs

	DTL 1	DTL 2	DTL 3	DTL 4	DTL 5	DTL 6
Number of Drift Tubes	60	48	34	28	24	22
Diameter (inch)	17.109		17.871			

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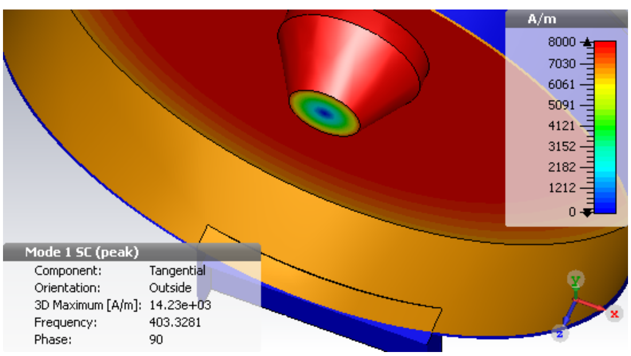
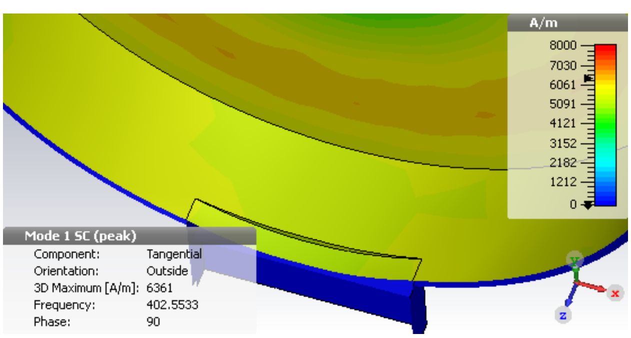
In order to reduce the complexity in a parametric study for the optimization, cell gaps and tapered nose cone lengths of each drift tube are defined for the mechanical design of the components. Then, a second-order polynomial curve fitting on the drift tube lengths was employed for optimizing the individual drift tubes in all six DTL structures to achieve field flatness less than +/- 3% at 402.5MHz resonance.

Single-cell Design and Surface Curvature

Since the single-cell cavity can be built in different shapes, the optimum design of the cavity needs to be determined for the above process. This is somewhat complicated because the DTLs have different cavity diameters. The surface curvatures at the iris-cavity interface are studied with modeling and simulation for validation of the approach. Two types of single cell test cavities are considered and compared with simulation: a reentrant pillbox cavity and a simple pillbox cavity. For testing with different iris couplers on a single-cell cavity, the mismatches of curvatures between the test cavity and the iris couplers are examined for their stability. Figures 1(a) and 1(b) show the relative electric current densities in the cavities found with eigenmode simulation at the iris-cavity surface.



(a)



(b)

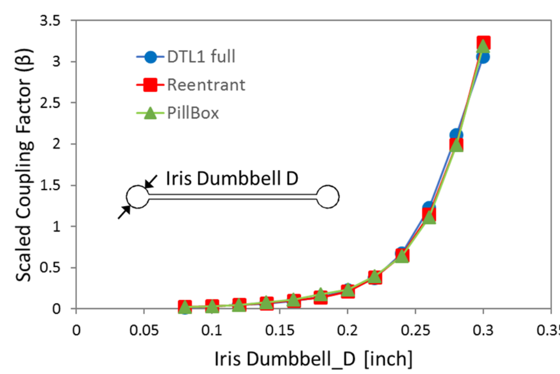
Figure 1: Surface current density distributions found with eigenmode simulation in (a) reentrant pillbox cavity (D: 17.88") and (b) simple pillbox cavity (D: 22.44"). Surface curvature mismatches between test cavities and a waveguide iris coupler (D: 17.109" for SNS DTL1, 2).

The reentrant cavity has a smaller cavity diameter that can be adjusted with the capacitance between the nose cones. It can have a smaller curvature that matches to one of the two iris surface curvatures, which minimizes the surface mismatch with the other coupler. The pillbox cavity without nose cones is a simpler structure and possibly better for high power tests but the interface cannot be precisely matched due to the constraint of the fixed diameter for a frequency as the fundamental TM_{01} cylindrical resonator. The difference in iris surface curvature may affect the resonance frequency, surface loss and the coupling fields. It seems the reentrant cavity can be better choice for better physical surface match. However, it was observed that the reentrant cavity is more sensitive than the simple pillbox cavity even if it has smaller curvature difference. In Figure 1 it can be seen that the surface current density is significantly higher in the reentrant cavity. This corresponds to higher sensitivity to iris region geometric perturbations for the reentrant cavity. The scale factors for DTL structures can be found for specified coupling factors and are summarized in Table 2.

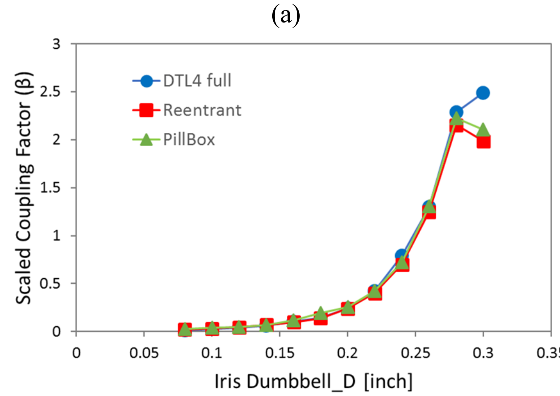
Table 2: Coupling Scale Factors of Single Cell Test Cavities for SNS DTLs

	DTL 1	DTL 2	DTL 3	DTL 4	DTL 5	DTL 6
Reentrant (D:17.88")	**0.0658**	**0.0517**	**0.0492**	**0.0484**	**0.0481**	**0.0478**
Pillbox (D:22.44")	**0.0728**	**0.0572**	**0.0568**	**0.0558**	**0.0555**	**0.0551**

*Scale factors are calculated with eq. 1 using eigenmode solutions.



(a)



(b)

Figure 2: Comparison of scaled coupling factors of iris couplers with test cavities for (a) DTL1 and (b) DTL4.

Parametric studies of the dumbbell diameters of the coupling iris were performed in frequency domain simulations for all six DTL structures. By introduction of the coupler in the model, the field flatness is disrupted from the eigenmode solution process. The deviations are removed by retuning the structure. Results of frequency domain simulation are used to verify the accuracy of the coupling scale factors. The scale factors found for two single-cell cavity designs are compared with the values for the full DTL structures in Figures 2(a) and 2(b) for the DTL 1 and DTL 4, respectively. In Figure 2(b), D=0.3" case did not have acceptable result. Further study will be performed to improve the accuracy. From the results it can be seen that either one of the two single-cell cavities can be used for the application outlined in this paper.

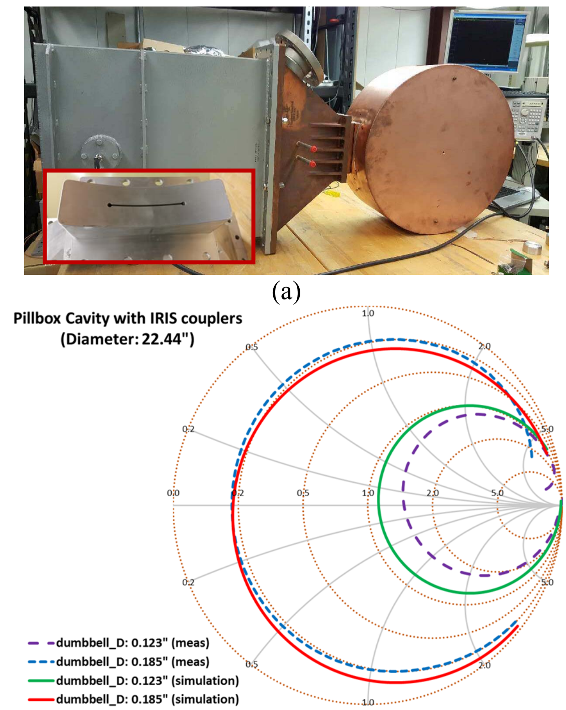
TEST CAVITY AND MEASUREMENT

A simple pillbox copper cavity was built for low power RF bench measurement as shown in Figure 3(a). Resonance frequency of the TM_{01} mode was tuned to 402.5 MHz using two 3" diameter slug tuners near the equator of the cavity. The measured unloaded Q-factor is ~ 30,000 at 402.5MHz. The coupling iris port on the cavity was prepared to have precise mechanical contact with the coupler for measurement stability. Two different ridge waveguide iris couplers were available and used for the measurement to compare with the simulated results (Figure 3(b): an aluminum iris coupler with 0.185" dumbbell opening diameter and surface curvature matched for DTL1 and a copper iris coupler built for DTL3 with 0.125" dumbbell diameter. These values are compared with the simulated results on a Smith chart in Figure 3. The aluminum iris coupler with larger dumbbell diameter that has greater coupling had good agreement between the calculated and the measurement. The copper iris coupler with smaller dumbbell diameter opening showed similar but with some greater discrepancy. The dimensional discrepancy between the actual iris opening and the computer model may affect the error and can be a subject for further study.

DISCUSSION

The primary purpose of using the single-cell test cavity is to pretune the opening of the coupling iris. This can be done at low power in a single port measurement setup. If the test cavity is built to be operational with high power RF under vacuum, the cavity can be used to RF process two iris couplers in a two-port configuration [2]. Both tasks can be performed without using the full DTL structures.

Iris opening dimensions change for the desired coupling coefficient of an iris coupler for a cavity. If a desirable coupling factor of a full DTL structure is specified, the matched iris coupler opening can be designed for the coupler on the test cavity by applying the scale factor. This pretuning process of the iris relies on the result of the computer eigenmode simulator to find the surface magnetic fields and the total power losses in the full DTL structure and the test cavity. Finding an accurate field in the structure at the location of the iris coupler surface is needed to determine the reliable scale factors. Numerical optimizations of dimensions of the drift tubes and gaps in the DTL structures are also needed to establish the design fields at the resonance frequency during the process. Frequency domain simulations are used with 3D modeling of the cavities and the couplers for the comparisons shown in Figure 2.



(a)

(b)

Figure 3: (a) Low power bench measurement setup with the cold model of a single-cell test cavity with waveguide iris couplers, (b) comparison of couplings of two couplers with simulated results.

The simulation results suggest that the proposed procedure for finding the iris coupler design using the scale factor is valid. If a simple pillbox type cavity is used as the test cavity, the curvature mismatch at the iris-cavity interface does not cause problems in finding the accurate scale factor. Bench test with the prototype pillbox cavity shows reasonable agreement between the simulations and measurements. Further measurement will be performed for complete verification of the technique.

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