

STUDY OF PRETUNING AND HIGH POWER TEST OF DTL IRIS WAVEGUIDE COUPLERS USING A SINGLE CELL CAVITY *

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Abstract

Six drift tube linac (DTL) cavities have been operating successfully at the Spallation Neutron Source (SNS). Each cavity is fed by a tapered ridge waveguide iris input coupler and a waveguide ceramic disk window. The original couplers and cavities have been in service for more than a decade. Design optimization and tuning of the couplers were initially performed prior to installation and commissioning of the cavities. Since each DTL cavity is unique, expensive, and fully utilized for neutron production, none of the cavity structure is available as a test cavity or a spare. Maintaining spares for operations and for future system upgrade, test setup of the iris couplers for precision tuning is needed. Ideally a smaller cavity structure may be used for pretuning and RF conditioning of the iris couplers as a test cavity or a bridge waveguide. In this paper, study of using a single cell cavity for the iris tuning and conditioning is presented along with the 3D simulation results.

INTRODUCTION

The SNS has reached 1.4 MW, the full design beam power and routinely been delivering > 1.0 MW beam to the target lately. The second target station (STS) project aiming to double the beam power has been planned and will require RF system upgrade as well [1]. The DTL cavities are energized by 402.5MHz, 2.5MW klystrons at 8% duty cycle. Rapidly tapered double ridge waveguide couplers with dumbbell-shaped iris opening are employed to transfer the RF power from the half height waveguides through ceramic windows into the DTL cavities. The sizes of dumbbell holes of iris couplers were optimized for desired coupling factors matched to individual cavities with the beam.

All six SNS DTL structures are in operation 24/7 for the neutron production for the beam lines. None of the complete multi-cell structures are available in testing or RF conditioning of spare couplers for operations support or future system upgrade. It would be desirable, if a simpler single cell cavity can be used for pretuning and other tests of the couplers without using a full DTL structure. The approach may work if the relationship between coupling factors of a full multi-cell and a single cell cavity is known and used properly.

In this paper, utilizing a single cell cavity instead of the full multi-cell cavity structures to pre-tune and to perform high power RF conditioning of the DTL iris couplers is presented. A system using a single coupler on the single cell cavity can be used for optimizing the iris dumbbell opening dimensions or for checking the coupling factors of

the existing couplers. A two port system using two couplers on the single cell cavity could be used for high power test. 3-D EM simulations on a 24 cells DTL structure (SNS DTL #5) and on a single cell cavity have been performed using CST MWS [2] to demonstrate the approach. Performing the RF conditioning of couplers using a single cell cavity would be possible without having RF matching of a pre-tuned coupler if the single cell cavity is used as a bridge waveguide with two couplers.

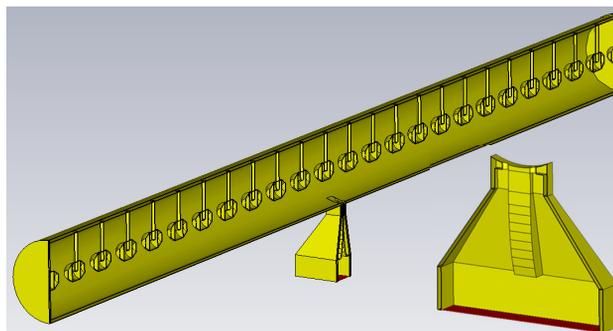


Figure 1: CST MWS model of the full 24 cell SNS DTL #5 cavity and double ridge waveguide iris coupler.

IRIS COUPLER TUNING

Scale Factor of Coupling

The coupling coefficient β of a waveguide coupler is the impedance ratio between the waveguide and the cavity. It depends on the RF parameters of the coupler, the cavity and the cavity loading. If a coupler is mounted on different cavities, the measured coupling factors will be different. Once the ratio is known, the coupling of a full multi-cell cavity can be estimated from the coupling of a single cell cavity as,

$$\beta_m = \alpha_{ms} \cdot \beta_s, \quad (1)$$

where m denotes full multi-cell cavity, and s for single-cell cavity. Using an analytical formula for the coupling coefficient through a thin iris opening on an accelerating cavity [3, 4], the scale factor of Eq.1 simply becomes a ratio of the cavity parameters as,

$$\alpha_{ms} \triangleq \frac{[H_1^2]_m}{[P_c]_m} / \frac{[H_1^2]_s}{[P_c]_s}, \quad (2)$$

where H_1 , P_c are the magnetic field on the location of coupling iris without coupler and the cavity loss, respectively. They can be obtained from a measurement or a computer simulation.

Single Cell Cavity

It is desirable to have one single cell cavity that can be used for any of the uniquely different multi-cell structures.

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To design a generalized test cavity, two single cell cavities (A, B) with different axial lengths were considered and compared for 402.5MHz. They are compared to evaluate the dimensional preferences with respect to their performances. From CST eigenmode simulations of the full SNS DTL cavity and two single cells and, the scaling factors from Eq. 2 are shown in Fig. 2.

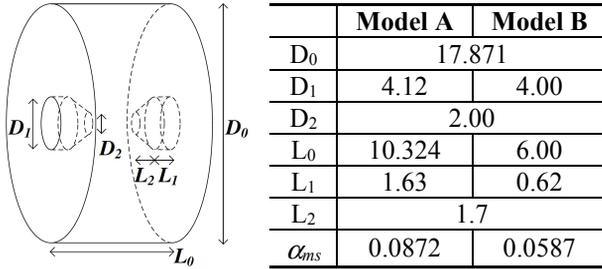


Figure 2: Single cell cavity model dimensions (in inches) and coupling scale factors (α_{ms}) for the SNS DTL5 cavity.

The cavity model A has the length L_0 to be the average cell length of the 24 cell SNS DTL #5 cavity and model B was using rather simple numbers with shorter length to compare the usability in the high power test for coupler conditioning. From the single cell models with the scale factors, the coupling coefficients of full multi-cell cavity can be estimated. For example, the iris coupler can be critically coupled ($\beta_{mDTL5}=1$) on the DTL when it was designed to have $\beta_{sA}=11.46$ or $\beta_{sB}=17.05$ for the two single cell cavities, respectively. The SNS DTL5 iris coupler was designed and tuned for $\beta_{mDTL5}=1.4$ with the beam loading. Therefore, the coupling factors of the single cell models should be 16.05 and 23.87 respectively. The large coupling factors and the cavity parameters can still be measured relatively accurately with modern RF network analyzers.

Single Cell Cavity as a Mismatched Load and Pre-Tuning

The iris opening is determined by the tapered ridge waveguide dimensions: cavity wall thickness, heights and widths of the waveguide and the ridges. The coupling can be adjusted with the dimensions of the dumbbell shape iris openings on the wall between the waveguide and the cavity [5]. Full DTL5 (Fig.1) and two single cell cavities (Fig.2) using same iris coupler were numerically modelled to compare the effect of the iris opening and to verify the scale factors.

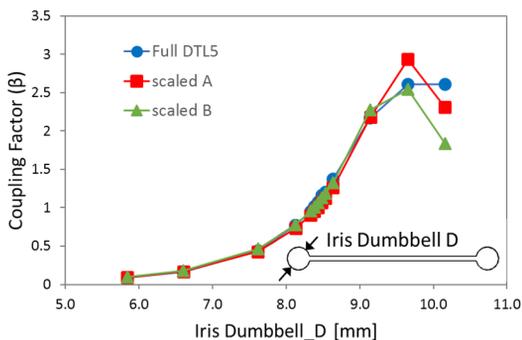


Figure 3: Coupling factors versus iris opening of full DTL5 and single cell cavities using same waveguide iris coupler.

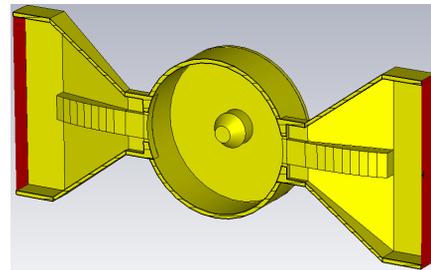
Simulation results in Figure 3 show good agreement of both scaled (α_{ms} in Figure 2) coupling factors of the single cells with DTL5 cavity up to $D \sim 9.5$ mm. Once the scale factor between a full multi-cell cavity and the single cell test cavity is precisely determined, a single cell cavity can be utilized in tuning the iris couplers in low RF power.

BRIDGE WAVEGUIDE

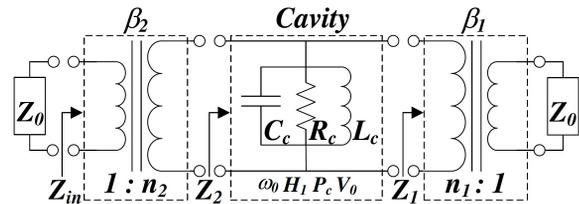
High power RF conditioning of a coupler tuned for a multi-cell cavity may not be easy using one coupler on a single cell cavity. Because the coupling becomes much stronger on a single cell cavity than on the multi-cell cavity, RF matching effort will be required to deliver the power to the cavity. However, if the matching is done, the wall loss in a small single cell cavity will result difficulties with high power handling and cooling since the full power has to be dissipated inside the single cell cavity.

Cavity with Two Couplers

A cavity with two couplers can be represented as a two-port network consisting of a resonant RLC circuit and two ideal impedance transformers as shown in Figure 4.



(a) CST model of two ridge waveguide iris couplers with a single cell cavity,



(b) Circuit model of cavity and two couplers,

Figure 4: Equivalent circuit model of a single cell cavity resonator with two couplers [6]. ($R_c=R_{sh}/2$, $C_c=(R/Q)^{-1}/\omega_0$, $L_c=(R/Q)/\omega_0$ where $R_{sh}=V_0^2/P_c$, $R/Q=R_{sh}/Q_0$ and $Q_0=\omega_0 U/P_c$ are from CST MWS eigenmode solution of cavity and normalized with energy $U = 1$ joule)

From the equivalent circuit model, the impedances at resonance are expressed as, $Z_1 = n_1^2 Z_0$, $Z_2 = R_c/(\beta_1 + 1)$, and $Z_{in} = Z_2/n_2^2 = Z_0 \beta_2/(\beta_1 + 1)$, where the coupling coefficients of individual couplers are $\beta_1 = R_c/n_1^2 Z_0$ and $\beta_2 = R_c/n_2^2 Z_0$. The coupling factor from input port is,

$$\beta_{in} = Z_{in}/Z_0 = \beta_2/(\beta_1 + 1). \quad (3)$$

When a single cell cavity is used, it becomes a function of coupling coefficients for the full multi-cell cavity with single coupler (β_m) and its scaling factor (α_{ms}) from eq. 1.

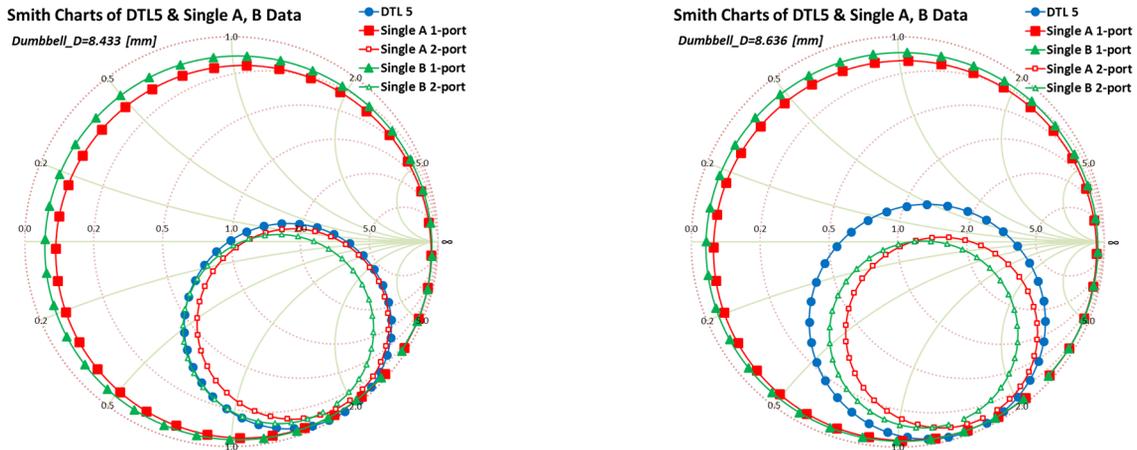
(a) $\beta_{DTL5}=1.07$ (Iris dumbbell = 8.433 mm)(b) $\beta_{DTL5}=1.37$ (Iris dumbbell = 8.636 mm)

Figure 5: S11 plots of DTL5 and single cell cavity models with single (1-port) & dual iris couplers (2-port).

$$\beta_{in} = \frac{\beta_{s2}}{\beta_{s1}+1} = \beta_{m2}/(\beta_{m1} + \alpha_{ms}). \quad (4)$$

β_{in} becomes the ratio of 2 couplers when the scale factor of coupling gets small and approaches to unity if the couplers are identical. The example cases of SNS DTL5 ($\beta_{mDTL5}=1.07$ and 1.37) used here are summarized in the table 1 and in the impedance chart plots shown in Figures 5 (a) and (b).

Table 1: Coupling Coefficients and S-parameters of Two Single Cell DTL Cavities with Waveguide Iris Couplers

	β_{mDTL5}	1 coupler (1-port)		2 couplers (2-port)	
		β_{sA}	β_{sB}	β_{inA}	β_{inB}
β_s	1.07	11.54	18.17	0.92	0.95
	1.37	14.45	22.64	0.94	0.96
S11dB	1.07	-1.51	-0.96	-27.64	-31.44
	1.37	-1.20	-0.77	-29.51	-33.31
S21dB	1.07			-1.69	-1.15
	1.37			-1.35	-0.77

It is expected from eq. 4 and table 1 that a single cell with two iris couplers will show good RF input matching even if the two couplers have different couplings since they are strongly over-coupled to the single cell cavity.

In this example, the cavity shunt impedances (R_{sh}) of model A and B without couplers are found as 10.4M Ω and 3.5M Ω . With the secondary coupler pretuned for critical coupled ($\beta_{mDTL5}=1$), the shunt impedances (Z_2 in the Figure 4) become 0.3 M Ω and 0.07 M Ω , respectively.

DISCUSSION

Accurate scale factors of coupling coefficients are essential and their verifications can be made through computer simulations. One-time measurement on each DTL cavity will be sufficient for relating and verification of the simulations to the actual cavities. Precision 3-D RF simulations of the full DTL structures and the single cell cavity with the waveguide coupler(s) can be the important tool for carrying out the proposed approach. The simulations however are time consuming with the DTL

structures which usually require dimensional optimizations of many drift tubes and cell lengths to achieve desired accelerating field profile and the right resonance frequency.

A single cell cavity with various ports to accommodate two SNS DTL waveguide iris couplers, slug tuners, and vacuum pumps has been designed and will be manufactured. The design parameters of the single cell only depend on the resonance frequency and mechanical aspects. A single cell cavity can be utilized for testing of all six SNS DTL couplers. Extended numerical studies using CST MWS are being performed on other full DTL cavities to evaluate the scale factors of coupling coefficients by simulation.

The two individually over-coupled couplers on a bridge cavity are needed in most high power RF testing since they can lower the cavity power dissipation and the field strengths inside the bridge cavity. That means the cooling requirement can be lightened and the harmful x-ray radiation can be eliminated so that the operation and control can be inexpensive. Comparing the two single cell designs, in order to reduce localized peak field with the high power, the cavity with lower shunt impedance with smaller length is desirable.

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