RF AND THERMO-MECHANICAL CONSIDERATIONS IN DESIGNING THE WAVEGUIDE IRIS COUPLER FOR THE DRIFT TUBE LINAC IN THE ORNL SPALLATION NEUTRON SOURCE *

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Abstract

The Spallation Neutron Source (SNS) employs tapered ridge waveguide iris couplers to power six drift tube linac (DTL) cavity structures with pulsed RF systems using 2.5MW klystrons at 402.5MHz. All DTL iris couplers have been operating continuously for more than a decade without replacement. Transferring high RF energy to the cavities requires robust RF and mechanical performances with respect to power dissipation, electrical breakdown, and vacuum pressure. Considering the upcoming full 1.4MW operation and the future proton power upgrade (PPU) project, the structural design and the material selection needed to be reviewed for potential spare manufacturing. The existing design and the modified design with improvements to the coupler have been numerically studied. For the study, 3D models were used for RF and structural characterizations of the waveguide iris couplers on the DTL cavity. RF and thermo-mechanical co-simulations were performed to assess the effects of using the different materials and the structural modification.

INTRODUCTION

The waveguide iris couplers in the normal conducting DTL cavities of SNS have been utilized since the beginning of operations in 2006. They are placed between the cavity and the waveguide ceramic window and operate under vacuum while transmitting from 500kW up to 1.5MW pulsed power at 402.5MHz using 2.5MW klystrons. The original six iris couplers have been continuously in operation for neutron production without spare couplers.

SNS is preparing a proton power upgrade (PPU) to increase the beam power from 1.4MW to 2.8MW for the existing first target station (FTS) and the second target station (STS) in the future. The PPU project involves extending the superconducting linac section by adding seven more cryomodules and increasing the RF power in the normal conducting linac section to handle higher beam current (26mA to 38mA). Some of the DTL structures will need power greater than 2.5MW, which could require increased power handling of the iris couplers [1]. Having a design for spare iris couplers may be desirable if the need of manufacturing of the couplers arises. Preparing spare couplers, iris tuning, and high-power operation for RF test and conditioning are not easy because there is no extra DTL cavity available for the test. Simplified systematic methods for pretuning of the iris openings and testing of the coupler performance were proposed in [2]. For the new coupler design, it is important to study the performance with the RF heating and the mechanical stress of both the existing coupler and updated design.

In this paper, thermal and mechanical properties of the iris couplers are evaluated and compared using RF and thermo-mechanical co-simulation for material selection and design modification. A model of two slightly over-coupled iris couplers on a single-cell cavity emulates matches the high-power RF conditioning setup of two couplers on a bridge cavity. Thermal analysis of iris couplers with GLIDCOP®-15 and oxygen free copper (OFC) was performed with an OFC bridge cavity. GLIDCOP® is a dispersion strengthened copper mixed with aluminum oxide ceramic particles. Mechanical analysis was focused on the structural strength of couplers under vacuum pressure in terms of material choice and design changes. The analysis recommended that a modified design of an iris coupler with body made of OFC and stainless steel (SS) flanges can be used if spare couplers are built. This approach can save manufacturing costs while achieving the RF, mechanical, and thermal properties of the couplers needed for the DTL cavity structures.

RF MODELING

The coupling coefficient (β), which is determined by the cavity structure parameters and beam-loading effects, of a waveguide iris coupler connected to a DTL cavity can be transformed to a coupler on a single cell cavity. The concept and the method of numerical design and testing of the iris couplers using a simple cavity instead of full structure is described in [2]. The iris dumbbell opening dimension was chosen for the coupling β that is needed for an over-coupled single cell cavity changed from critically coupled full DTL cavity. An RF model of an assembly of two iris couplers and a single cell cavity shown in Figure 1 emulates the setup for high-power RF conditioning of the two couplers connected on a bridge cavity.

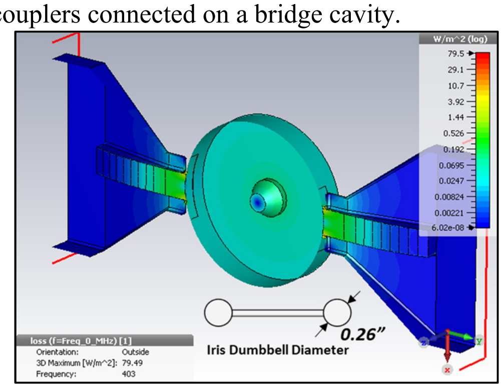

Figure 1: The surface power loss density of two iris couplers and a single cell cavity model for RF simulation. (blue is low 6e-8 W/m^2 and red high 79.5W/m^2)

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Most RF power is transmitted from the input to the output couplers through the cavity to the matched load with low RF surface dissipation in the cavity and the couplers at the resonant frequency. The distribution data of the surface power loss density from CST MWS [4] simulation were imported into ANSYS thermal simulation domain to estimate the RF heat loading on the surfaces of the couplers and the bridge cavity.

THERMAL ANALYSIS

The SNS DTL iris couplers were made of GLIDCOP® material. GLIDCOP® is known to have a good thermal conductivity (90% of OFC) and higher tensile strength than oxygen-free copper (OFC). However, the cost of the material is about two to three times higher, and the manufacturing is more challenging with GLIDCOP® because of difficulties in fabrication and in brazing [3]. To estimate the RF heat load in the iris couplers, the surface power loss density from CST RF simulation was scaled to average power of 200 kW (8% duty pulsed with 2.5 MW) and then applied as heat flux boundary data in the ANSYS thermal analysis. Adding fixed temperature boundaries around waveguide flanges in the model, local hotspots and temperatures were calculated. Fixed temperature boundary was applied on the surfaces of water-cooling channel. Water cooling near the iris opening provides significant compensation for RF heating as shown in Figure 2. Table 1 shows the temperature difference with and without water cooling.

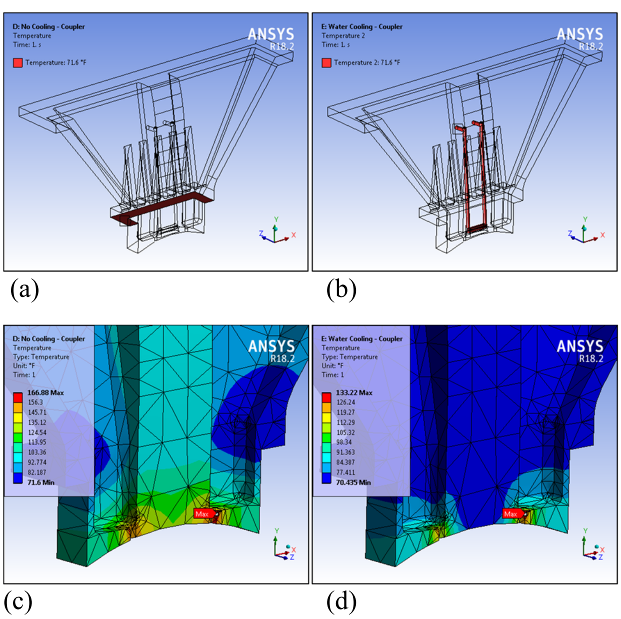

Figure 2: Iris couplers with RF heating (200kW). (a) fixed temperature boundary, (b) water cooling channels 71.6°F (c) temperature distribution with no cooling, (d) temperature with water cooling.

Table 1: Maximum Temperatures of Iris Couplers (200kW)

	No cooling	Water cooling
GLIDCOP® – 15	172.4°F	136.8°F
OFC10100	166.9°F	133.2°F

Thermal simulation results of the single cell bridge cavity with two couplers for RF conditioning show that the maximum temperature was recorded at the nose-cone area. Because two over-coupled couplers are connected to the cavity, most coupled power is transmitted through the couplers and the maximum temperature at the nose-cone was 165.16°F without cooling as shown in Figure 3. This temperature level may not require cooling and it can be controlled within safe limit by applying a cooling channel on the nose-cone area at higher power RF operation. Thermal conductivities used in the simulations for GLIDCOP®-15, OFC10100, and SS were 365W/m/K, 386W/m/K, 12W/m/K, respectively at 20°C. If RF power is increased to 500kW average, the maximum temperature on the iris coupler and the single cell cavity will reach 225.7°F and 305.5°F respectively.

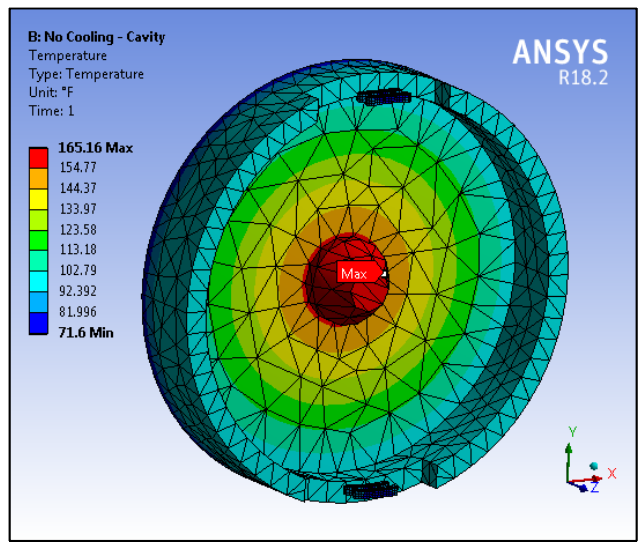

Figure 3: Thermal plot of single cell bridge cavity model with OFC. Temperature range indicates no additional cooling required at 200kW average power.

MECHANICAL ANALYSIS

High vacuum quality is required in the coupler to apply the design RF power and prevent arc damage from high electric fields during high-power RF operation. The SNS DTL iris coupler made of GLIDCOP® has struts designed to support the structure in the tapered broad-wall areas against the vacuum pressure and mechanical stress as shown in Figure 4 (a). To compare the mechanical strength with different materials, simulations were carried out applying the GLIDCOP® and OFC in the original design of the SNS DTL iris coupler. The ANSYS model was set to fixed boundary at the edges of the waveguide flanges and added 16 psi to the atmospheric boundary around the outer surface for the vacuum pressure. OFC model had 11% more maximum deformation than GLIDCOP® on the broadside waveguide wall near the vacuum port with the same supporting struts. The maximum deformations were 18.9 microns for GLIDCOP® and 21.0 microns for OFC.

Instead of monolithic GLIDCOP® design, modifications were proposed to manufacture the waveguide in OFC and the flanges in SS. Coupler waveguide in OFC is good for thermal and electrical conductivities and the SS flanges are good for mechanical stiffness. As shown in Figures 4 (b) - (d), the struts on the coupler body can be welded to the waveguide flanges to improve the stiffness and to strengthen the side wall near the vacuum port.

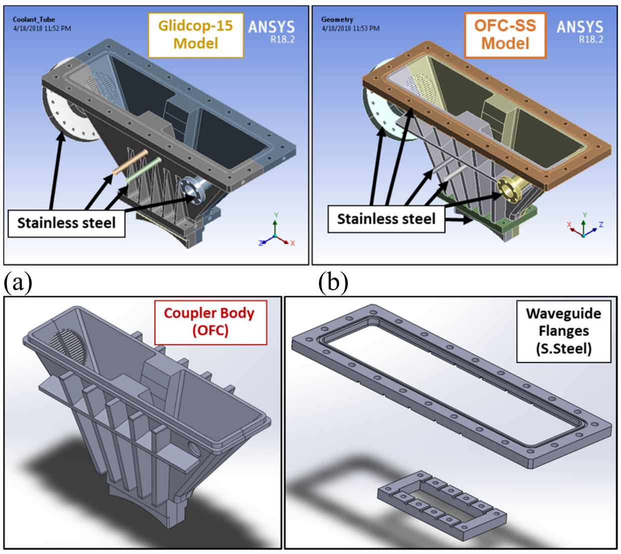

Figure 4: SNS DTL iris coupler models. (a) original GLIDCOP® model, (b) modified design, (c) OFC coupler body, (d) SS waveguide flanges [6].

Total deformations of the original GLIDCOP® design and the proposed OFC design with modification were calculated and compared using ANSYS [5]. In addition to the simulations for the vacuum pressure, the effects of gravity and mechanical load of the waveguide window and other parts that are needed to be mounted to the coupler were considered. The SNS DTL Iris coupler is attached to the cavity at a 45-degree angle, and the coupler, waveguide, and ceramic RF window assembly add approximately 400 lbs. to it. The simulation results are summarized in the Table 2 and depicted in Figure 5. The new iris coupler design employing OFC body with SS waveguide flanges and extended struts is more rigid against the mechanical stresses compared to the original design with GLIDCOP®. Gravity and weight have only a slight difference between the two designs as shown in Table 2.

Table 2: Comparison of Maximum Deformation Between Original Design of SNS DTL Iris Coupler and New Design Using OFC Coupler with SS Waveguide Flanges

Maximum Deformation (mils)	**SNS DTL Coupler GLIDCOP®-15**	**New Design OFC + SS flanges**
Vacuum Pressure (16 psi)	1.88 mils (47.8 microns)	1.75 mils (44.5 microns)
Gravity & Weight (waveguide 400 lbs.)	1.78 mils (45.2 microns)	1.72 mils (43.7 microns)

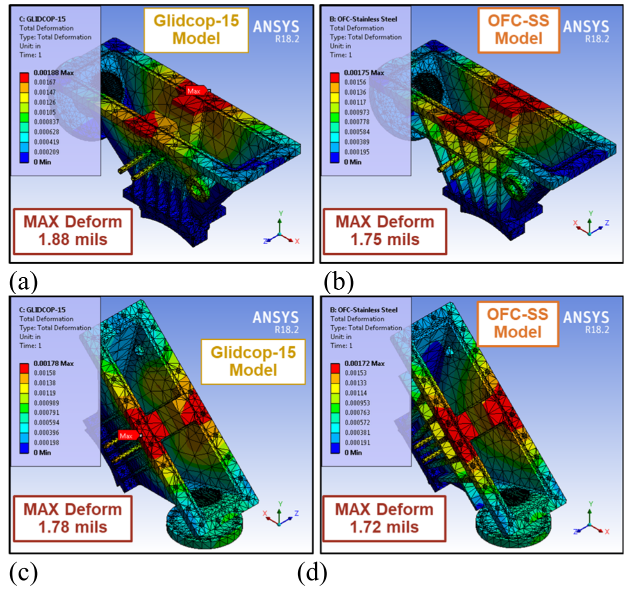

Figure 5: Mechanical simulations on SNS DTL iris coupler and new design. Structural deformations calculated for vacuum pressure on (a) original design and (b) new design, the gravity and weight effects on (c) original design and (d) new design.

SUMMARY AND DISCUSSION

Good thermal conductivity, mechanical robustness, cost effectiveness, and easy manufacturing are important in designing of waveguide iris couplers for high power RF operation of DTL cavities. Built with GLIDCOP®-15, original SNS DTL iris couplers are still in operation for over 12 years with reasonable electrical and mechanical reliability. The existing system for baseline operation or the RF system upgrade for the PPU project may need new spare couplers in the future. New manufacturing may be accomplished for the original design or modifications as shown above. OFC couplers with strengthening modification will perform as well as the original GLIDCOP® design based on thermal and mechanical considerations.

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