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DESIGN AND FABRICATION OF THE WAVEGUIDE IRIS COUPLERS FOR THE SPALLATION NEUTRON SOURCE DRIFT TUBE LINAC*

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Abstract

The Spallation Neutron Source (SNS) employs six cavities in the Drift Tube Linac (DTL) section to accelerate the H- ion beam to 87 MeV. Each cavity is energized by a klystron at 402.5 MHz up to 2.5 MW peak power using rapidly tapered waveguide iris couplers. All six original iris couplers have been in operation without replacement for over two decades. The increased RF power demands of the Proton Power Upgrade (PPU) project and operational problems, including arcing, temperature excursions, and vacuum bursts, have prompted the development of new spare iris couplers. The original iris couplers were made of GlidCop® material, which is known to be mechanically strong and thermally stable, but is expensive, and difficult to use in fabrication. The new spare couplers use Oxygen-Free Copper (OFC) and stainless steel (SS) materials to overcome these problems. This paper will discuss the mechanical, thermal, and RF design aspects and the challenges faced in the final coupler fabrication process.

INTRODUCTION

The original waveguide iris couplers were installed in the SNS DTLs and have been in operation since the commissioning of SNS in 2006. There are two different designs of iris couplers to match the DTL tanks in two different diameters: DTL1, 2, and DTL3 through 6. The DTLs have been running for decades, with only a few RF ceramic windows replaced, but no spare iris couplers available. Due to the increased RF power requirements of the PPU project and the operational risks associated with the lack of spare iris couplers, procurement of new iris couplers has become necessary.

The GlidCop® material was used for the original iris couplers. However, due to the high material cost and fabrication difficulties, the use of OFC and SS materials was considered for manufacturing spare iris couplers. Benchmarking design studies and thermo-mechanical simulations were performed [1]. The mechanical strength of the iris couplers is critical to withstand the high vacuum and gravity forces, especially on the broad side of the ridge waveguide. Additionally, the high thermal conductivity of a material is important for efficient cooling of the iris opening area. Careful engineering oversight and decision-making during the manufacturing process were required, especially in brazing the copper body, such as selecting brazing materials, temperatures, number of brazing steps, etc. Several discussions and fabrication iterations took place between vendors and mechanical designers to ensure the successful production of the iris couplers.

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DESIGN

The design of the spare iris coupler utilized OFC and SS materials, with modifications made to account for the softer nature of OFC compared to GlidCop® used in the original iris coupler (illustrated in Fig. 1). To address this, the supporting ribs on the broadside waveguide walls were extended, and SS material was used for the top and bottom waveguide flanges, which were brazed onto the OFC waveguide bodies, as shown in Fig. 2. Thermo-mechanical simulations were performed to compare the designs, with a focus on RF heating and deformation caused by vacuum pressure and gravity force during operation. The simulation results were detailed and summarized in reference [1].

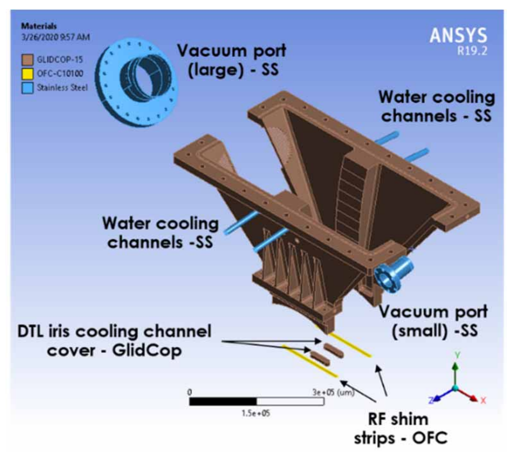

Figure 1: The original SNS DTL iris coupler. (GlidCop® body).

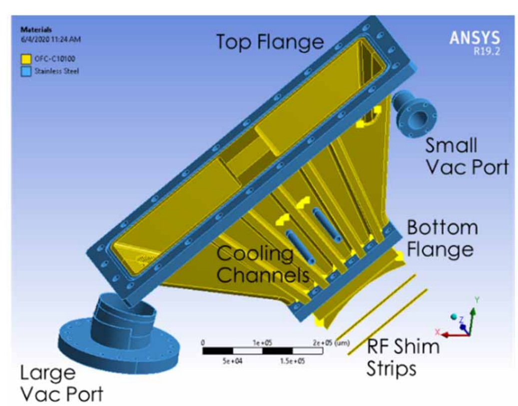

Figure 2: New design of iris coupler. (OFC body with extended vertical ribs and SS flanges, vacuum ports, and water-cooling tubes).

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FABRICATION

After a few iterations of reviewing drawings, designs, and brazing plans, the vendor fabricated the parts and proposed the initial brazing plan. Figure 3 shows the initial brazing setup on the copper waveguide bodies for the spare iris coupler Type A (DTL1-2). A three-step brazing procedure was planned as outlined in Table 1.

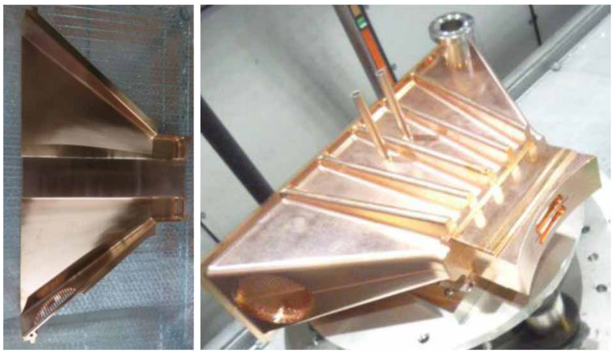

Figure 3: Manufactured part and initial brazing setup.

Table 1: Three-Step Initial Brazing Plan

Step	Material	Approx. Temp.	Parts
First	Cu/Au (62.5/37.5%)	1000°C	Cu bodies, water pipes, small vac port
Second	Cu/Ag/Au (20/20/60%)	880°C	WG flanges, large vac port
Final	Cu/Ag (28/72%)	800°C	

During the initial brazing process, there was significant deformation of the copper body parts, resulting in a large gap in the iris area and the tapered ridge waveguide touching and closing, as depicted in Fig. 4. The copper material became soft due to the high brazing temperature and did not regain its stiffness even after cooling to room temperature. This raised concerns about potential further deformation during operation under vacuum pressure. As a result, the Type A iris parts were scheduled for re-manufacturing.

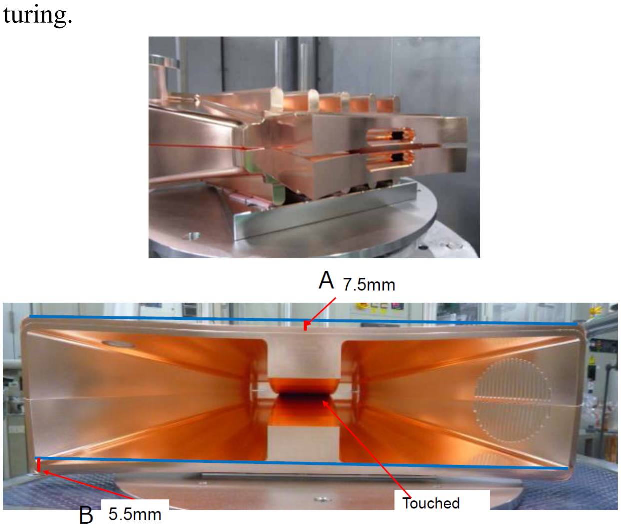

Figure 4: Deformation on copper bodies during the 1st brazing horizontal brazing setup on the Type A iris coupler.

Before proceeding with the fabrication of the Type B iris (DTL3-6), a thorough review of the brazing temperature and materials was conducted. Additionally, the vendor and SNS made parallel efforts to simulate and investigate the brazing failure of the Type A iris. The weight and expansion of copper at high brazing temperatures were identified as potential concerns during the brazing process from simulation shown in Fig. 5.

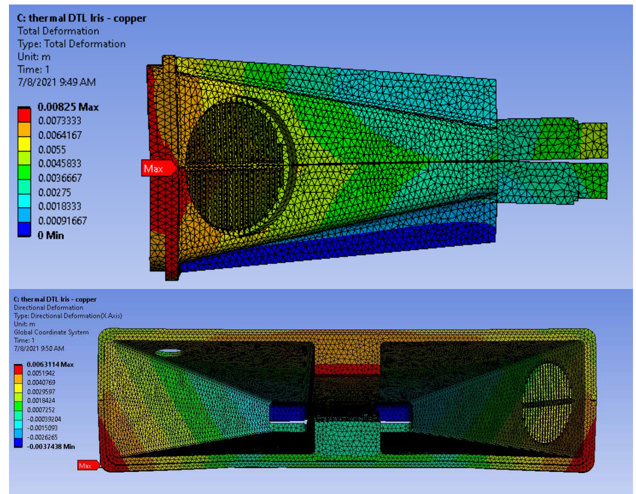

Figure 5: ANSYS analysis on the deformation during the 1st brazing of the Type A iris coupler.

Some literature [2-5] reviews on the brazing of copper RFQs, along with mechanical simulations, have revealed the following recommendations:

Brazing Process Recommendations

- Brazing Temperature: It is recommended to braze Oxygen Free Copper (OFC) at around 800°C and to heat the joint slowly at a ramp rate of about 100°C/hour.
- Brazing Material: Due to the lower recommended brazing temperature, using less Copper (Cu) and more gold (Au) as the brazing material is recommended.
- Brazing Orientation: Although a horizontal position is desirable for achieving uniform brazed joints, the thin brazing contacts of the iris coupler may cause severe deformation. Numerical simulations suggest vertical brazing with internal supports at a lower temperature (< 800°C) as a more suitable approach.
- Reduced Number of Brazing Steps: It is suggested to reduce the number of thermal cycling and to perform brazing at lower temperature goals with a slow ramping rate to minimize stress and avoid deformation on the broadside walls during the brazing of the copper body.

Table 2: Three-Step Initial Brazing Plan

Step	Material	Approx. Temp.	Parts
First	Cu/Au (28/72%)	800°C	Cu bodies, SS waveguide flanges, SS water pipes
Second	Cu/Ag/In (27/63/10%)	750°C	SS large and small vac ports

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In addition to the two-step brazing plan outlined in Table 2, the vendor created a vertical brazing setup, as depicted in Fig. 6. To keep the copper waveguide bodies together and press down the stainless-steel waveguide flanges during brazing, jigs were utilized. Space-holding jigs were inserted inside the waveguide from the bottom to support the body and prevent vertical deformation. Two thermocouples were also installed along the central rib to monitor the temperature difference during the process.

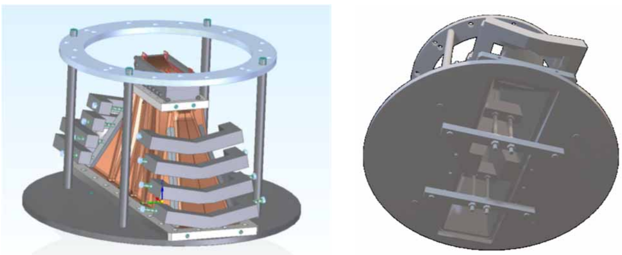

Figure 6: Vertical brazing setup. Two thermocouples were installed on each broadside wall.

The RF power coupling (β) into the DTL cavity is affected by the dimensions of the iris gap and dumbbell radii. The dumbbell radius needs to be machined at a fixed iris gap to achieve the desired RF coupling. A parametric RF simulation of the iris with SNS DTL5 (Fig. 7) showed that the maximum deformation resulting from brazing should be limited to 0.01", which deviates from the design value of 0.077". As a result, the gap between the iris and the dumbbell must be greater than 0.067" to prevent issues with RF coupling.

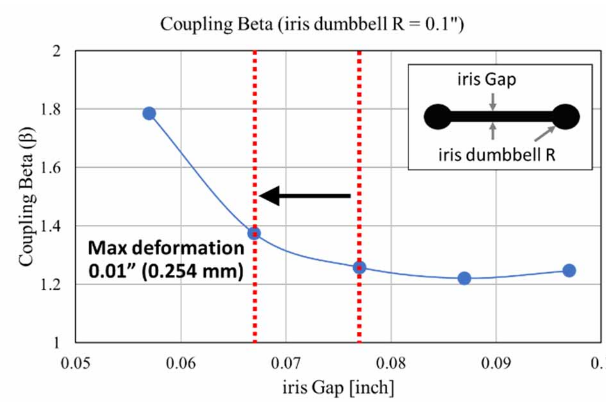

Figure 7: RF simulation (CST MWS) on the iris gap with a fixed dumbbell radius of 0.1".

The first brazing of the Cu bodies and the SS waveguide flanges was conducted at a carefully monitored temperature of 800°C. Subsequent procedures included surface machining, followed by the second brazing of water pipes and vacuum ports at around 750°C, and joining of vacuum flanges. Dimension verification confirmed that the iris gap was deformed within the acceptable range of 0.005", and vacuum leak tests and water pressure drop tests confirmed the successful fabrication of the Type B coupler (Fig. 8). A new Type A coupler was also built using the same procedure, and both couplers have been delivered to SNS.

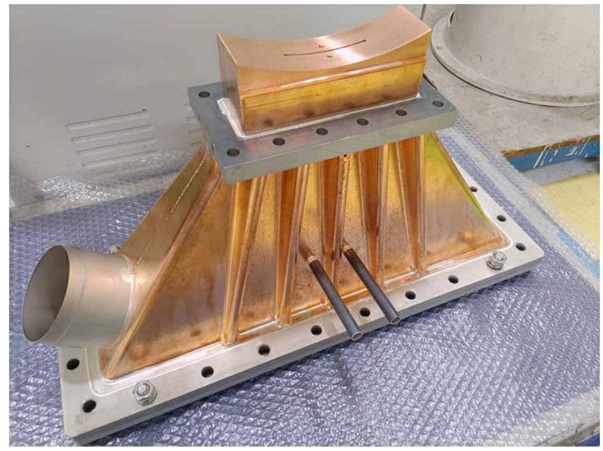

Figure 8: Type B iris coupler.

CONCLUSION

Spare couplers for the SNS DTL were built, consisting of two types of ridge waveguide tapered iris couplers. Unlike the original couplers, which were designed with GlidCop® material, the new couplers were constructed with OFC and SS, which are more conventional materials with reduced material and manufacturing costs. To ensure high-quality brazing joints and minimal deformation of copper, vertical brazing was carried out at a slow ramping temperature with jigs.

ACKNOWLEDGEMENT

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