ALTERNATIVE FABRICATION METHODS FOR THE ARIEL e-LINAC SRF SEPARATOR CAVITY

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Abstract

The ARIEL e-Linac RF deflecting cavity is a 650 MHz superconducting deflecting mode cavity that will allow simultaneous beam delivery to both the Rare Isotope Beam program and an Energy Recovery Linac. The cavity will be operated at 4 K and with deflecting voltages of up 0.6 MV, resulting in a dissipated RF power of less than 1 W. Due to the modest performance requirements, alternative methods are being employed for the fabrication of this cavity. These include fabricating the entire cavity from reactor grade Niobium and welding the cavity using tungsten inert gas (TIG) welding in a high purity Argon environment. A post purification heat treatment will be performed in an RF induction oven to increase the cavity performance.

INTRODUCTION

An SRF deflecting cavity is being designed and constructed for use as a beam separator at the end of the ARIEL e-Linac [1]. The 650 MHz cavity will provide a nominal 0.3 MV deflecting voltage, while up to 0.6 MV is being considered to allow for flexibility of the final design.

This is a modest deflection voltage and results in low dissipated RF power on the cavity surface and low peak surface fields. For the nominal voltage of 0.3 MV and operation at 4 K, the dissipated power is only 0.2 W and is < 1 W for up to 0.6 MV. The peak electric and magnetic fields are also low, reaching 9.5 MV/m and 12 mT at 0.3 MV. Given the previous high performing results of cavities fabricated from reactor grade Niobium, [2–4], we believe this lower grade Niobium will still exceed performance requirements for this application. Material costs are an important consideration since the inner ridges will be machined from a roughly 30 kg Niobium ingot.

Additionally, we will be fabricating the cavity using high purity TIG welding. Previous weld studies on Niobium samples at MSU in collaboration with FNAL have achieved very minimal degradation of Residual Resistance Ratio (RRR) though the use of TIG welding in a high purity Argon environment with Argon torch purging [5]. Finally, high temperature heat treatments in an RF induction oven will be performed to increase cavity performance.

THERMAL STUDIES

An integrated RF-thermal study was performed using ANSYS APDL to ensure the sufficient cooling of the RF surfaces. Of particular concern was the solid inner ridge which results in a large separation of the ridge's inner surfaces and the LHe cooling bath, particularly since reactor grade Niobium will have a lower thermal conductivity than typical cavity Niobium.

Since the heat load depends on the surface temperature through the surface resistance, an iterative technique was used to determine the cavities operating temperature distribution. The outside walls of the cavity were held at 4 K and a heat load was applied to the cavity surface by calculating the local dissipated RF power on the cavity walls from the magnetic field and temperature dependent surface resistance, $R_s(T)$. The RRR of the cavity walls was assumed to be 50 for a thermal conductivity at 4 K of roughly 13 W/m K. The results of several cavity fabrication options are shown in Table 1.

Table 1: Maximum Cavity Temperature due to RF Heating

Cavity	$V_\perp = 0.3$ MV	$V_\perp = 0.6$ MV
4 mm cavity walls on both body and ridge.	4.01 K	4.03 K
3 mm walls with solid ridge.	4.08 K	4.32 K
3 mm walls, solid ridge with cooling channel.	4.07 K	4.30 K

With a solid ridge, the peak temperature that the cavity reaches under nominal operation is 4.08 K, as shown in Figure 1. The addition of a cooling channel to the ridge to move the LHe closer to the RF surfaces causes an insignificant reduction in ridge temperature and was deemed unnecessary.

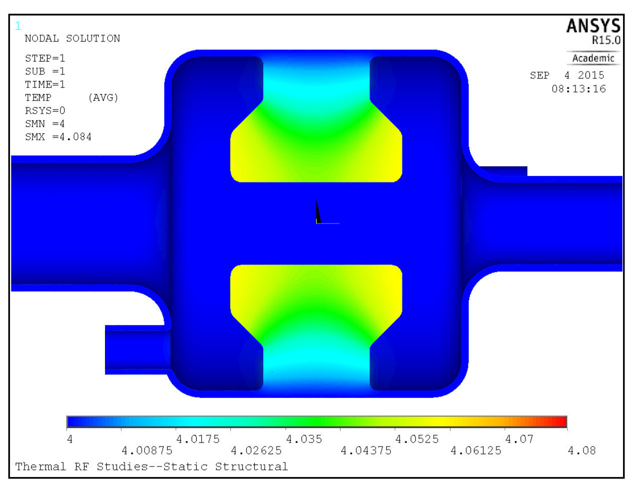

Figure 1: The cavity temperature distribution with a deflecting voltage of 0.3 MV and solid reactor grade ridges.

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FABRICATION

The cavity will be fabricated from both sheet and bulk Niobium material. An exploded view of the cavity is shown in Figure 2. The beam pipes, coupler ports, and cylindrical body will be formed from 3 mm sheet, and the endcaps and ridges will be machined out of solid Niobium.

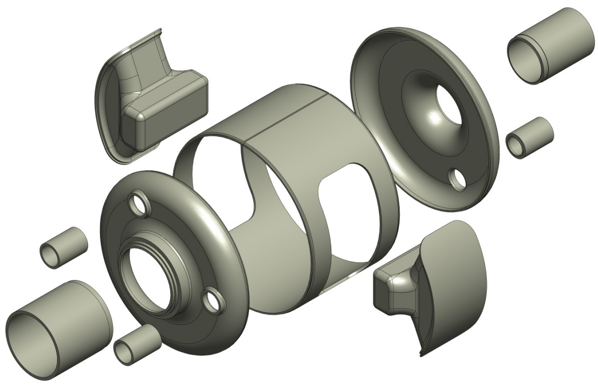

Figure 2: An exploded view of the individual Niobium components that will be welded together to form the cavity.

The cavity will be welded using TIG welding inside a high purity Argon filled chamber. A sealed weld chamber with an Argon filtration system is required to provide an inert weld environment to limit the introduction of contaminants into the welds. The TRIUMF machine shop is undergoing development of this process. They have successful experience welding Niobium from the fabrication of a Niobium susceptor for an RF induction oven, although for that application RRR degradation was not a concern and therefore was not monitored. A RRR measurement system is being developed for the characterization of weld samples to qualify the weld procedure.

The resonant frequency of the cavity was found to be most sensitive to the spacing between the ridges, with a sensitivity of about 4 MHz/mm, while the sensitivity to the cavity length is about 1 MHz/mm. The cavity length will be used as the final tuning step during fabrication before welding, trimming the body length to reach the target room temperature frequency. To do a final tuning of the assembled cavity, the cavity will be elastically deformed to move the ridges inwards or out to reach the goal frequency.

Welds, when possible, will be performed first by a continuous weld along the inner seam followed by a stitch weld on the outside surface of the cavity. The inner ridges will be first welded to the cylindrical cavity body and the beam and coupler ports to the endcaps. After frequency tuning and trimming the cylinder to length, the final welds between endcaps and cavity body will close up the cavity body, requiring full penetration welds from the outside of the cavity. The material around this final weld will be thinned to about 1.5 mm around the weld joint to ensure a satisfactory weld, as shown in Figure 3. Investigative weld studies are being performed to ensure reliability of the welds.

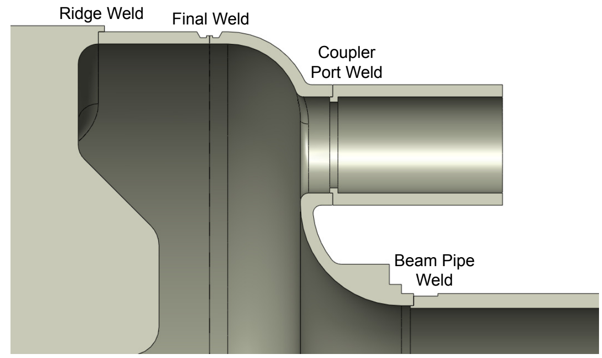

Figure 3: Details of the weld preparations for the cavity welds. The final weld will require a full penetration weld using a TIG welder from the outside of the cavity.

In order to avoid contamination of the oven in the post fabrication high temperature heat treatments, the cavity will be first fabricated with Nb flanges for testing which will be replaced with Titanium flanges after the treatments are complete. After the bare cavity cold tests, a titanium jacket will be welded to the cavity on a step machined onto the endcaps. The jacket will include titanium bellows to allow for longitudinal tuning of the cavity, as well as bellows between the coupler port flanges and the jacket to avoid twisting of the cavity due to the asymmetric locations of ports.

CONCLUSION

Due to the modest performance requirements of the ARIEL deflecting cavity, fabrication of the cavity using alternative methods is being pursued as a means of reducing costs and fabrication time. The individual methods described here have been successfully applied in the fabrication of other cavities, giving us confidence in achieving the required performance. Evaluation of welding methods are being undertaken to ensure the high quality and reliability of the welds, and minimal reduction in RRR of the material.

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