ANALYSIS AND COMPARISON TO TEST OF $AlMg_3$ SEALS NEAR A SRF CAVITY

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Abstract

The Energy Recovery Linac (ERL) presently under construction at BNL is being developed as research and development towards eRHIC, an Electron-Heavy Ion Collider. The experimental 5-cell 703.75 MHz (ECX) cavity was recently evaluated at continuous field levels greater than 10 MV/m. These tests indicated stored energy limits of the cavity on the order of 75 Joules. During design of the cavity the cold flange on one side was moved closer to the cavity to allow the cavity to fit into the available chemical processing chamber at JLAB. RF and thermal analysis of the $AlMg_3$ seal region of the closer side indicate this to be the prime candidate limiting the fields. This work presents the analysis results and compares these results to test data.

INTRODUCTION

Testing of the ECX cavity has shown that the cavity as presently designed is limited to a stored energy of about 75 Joules. This is a little more than half the stored energy, 127 Joules, that is generated from the design fields. The temperature of the flange that connects the cold section to the transition section runs significantly above the critical temperature of both niobium and niobium -55 titanium. RF analysis shows that the magnetic field penetrates the gap between the flanges causing RF losses on the surfaces of the flanges and RF seal. These losses drive the flange and seal temperatures up and as the RF through power increases the temperature of the NbTi flange and the RRR niobium approach their respective critical temperatures. As their temperature increases so does the local RF surface resistance. This combination results in thermal runaway that is evident in test data and thermal analysis.

GENERAL LAYOUT

Fig. 1 shows the CAD model of the end group and transition section. The transition section includes the helical helium cooling channels to absorb the room temperature heat leak, the bellows set that helps isolate room temperature from helium temperature, a flange on the left of the lower figure that is assumed to be at room temperature, and at the top of the figure, the copper plated stainless steel flange that connects to the NbTi flange. All stainless steel surfaces that are facing RF are copper plated. The copper plating on the cold stainless steel flange runs up the side of the flange to the seal groove as shown. Within the seal groove there is no copper plating.

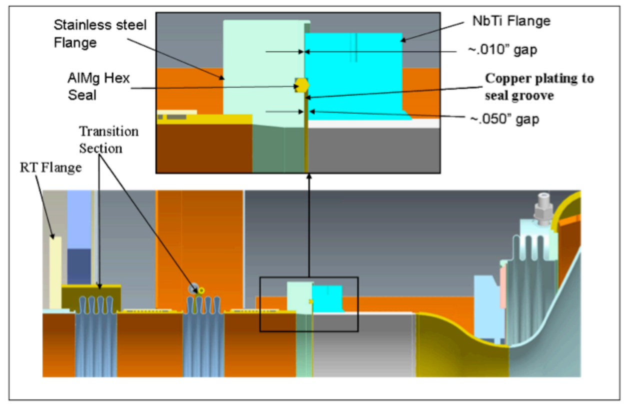

Figure 1: ECX Hex seal geometry.

Fig. 2 shows the finite element model that represents the region. The flange on the left is set to 300K. The inlet helium values are shown, .06 g/s at 4.9K and 1.56 atm. Thermal radiation from all outer surfaces interacts with a liquid nitrogen cooled thermal shield. 2K Kapitza resistance is applied inside the helium vessel. Stainless steel surfaces up to the seal groove are plated with 4.5 µm thick copper plating. The model includes temperature dependent material properties for RRR 250 Nb, NbTi-55, AlMg3, the copper plating and stainless steel.

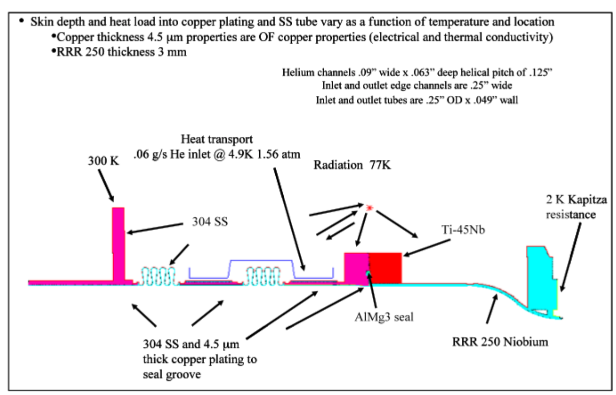

Figure 2: Finite element model of seal region and transition Section.

RF ANALYSIS

A SUPERFISH analysis was run to determine the depth of RF penetration into the seal region and the associated conduction currents on the region surfaces. Fig. 3 shows

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the SUPERFISH results of the cavity and beam pipe with the small areas representing the seal groove region. A very dense mesh was used to capture the effects within the seal region. The arrows in the lower graphic point to the locations of two seal grooves. The seal groove on the left is closer to the cavity than the seal groove on the right. The fields within the groove on the left were used in the analysis that is further described below.

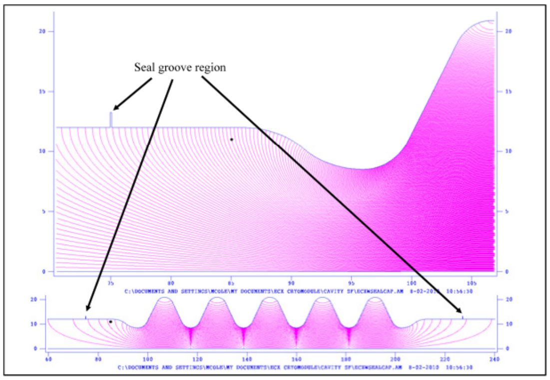

Figure 3: SUPERFISH analysis of the cavity with the seal groove regions.

Thermal solutions were completed at different cavity stored energy levels to determine the limits of stored energy and the stored energy just below thermal runaway. Fig. 4, shows the magnetic fields at a stored energy of 56 Joules. These field levels along with the local material resistance were used to determine the heat loads in the seal region.

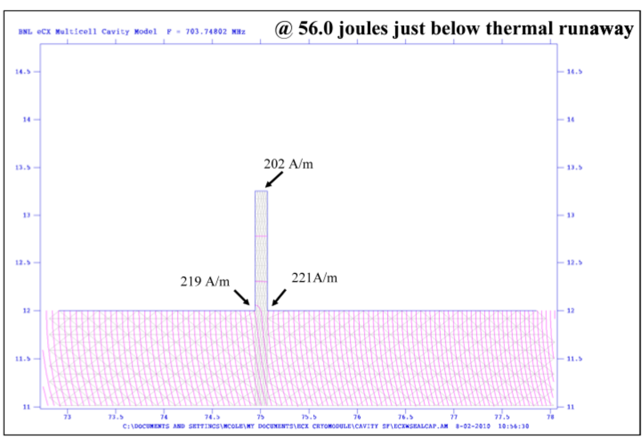

Figure 4: Seal groove magnetic fields at 56 Joules.

The SUPERFISH results are used to map the magnetic fields on to the thermal model. The fields are scaled by the stored energy of the cavity and transformed to heat loads after calculating the resistance of the temperature dependent surfaces. This requires an iterative solution where the updated resistance is calculated each iteration. The magnetic fields used for this are shown in Fig. 5. Inside the bellows the fields are assumed to penetrate without attenuation. Details at the AlMg3 seal were not included in the SUPERFISH run, the fields are applied by determining the closest RF surface, i.e. from Fig. 3, to the surface of the thermal model.

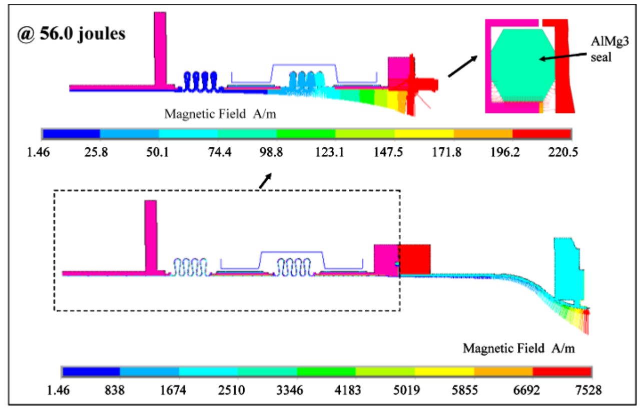

Figure 5: Magnetic fields mapped from SUPERFISH to the thermal model.

THERMAL ANALYSIS

The thermal analysis results completed to date are for steady state solutions. Thermal results for the 56 Joules of stored energy are shown in Fig. 6. Increasing the stored energy above 56 Joules results in thermal runaway where the temperatures increase to where the RRR niobium is no longer superconducting. The 5K transition section helium absorbs 8.58 watts and heats up to 29.5 K. The contours on the top of the figure show the temperatures in the Nb-Ti flange, the RRR niobium beam pipe and the helium vessel flange. The peak temperature on the Nb-Ti flange is 19.4K and occurs at the AlMg3 seal connection. The temperature of the Nb beam pipe is at 9.16K where it is welded to the Nb-Ti flange as shown. On the left of the figure are the heat loads into the different materials. The heat load into S.S. refers to the bare S.S. in the seal groove. The heat load into the copper includes all the copper surfaces and any heat generated in S.S. behind the copper plating. These values refer to this "short" side of the cavity, the other side has lower magnetic fields and results in different temperatures and has not been analyzed.

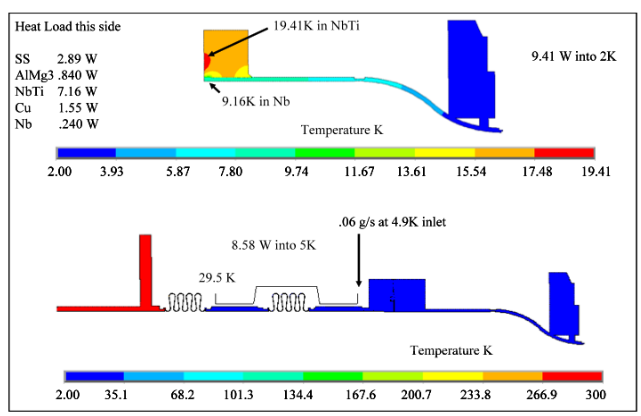

Figure 6: Thermal results at 56 Joules cavity stored energy.

The results that have been completed to date show the following. Stainless steel losses in the seal groove drive the temperatures of the NbTi flange and the RRR Nb. When the temperatures in the NbTi flange go above NbTi

Tc the losses become larger than the S.S. losses. Thermal conductivity of NbTi is similar to S.S. and has a large effect on temperatures in the NbTi and RRR Nb.

Fig. 7 shows the results of a BNL test, run on July 22, 2010[1]. On the right of the figure is a run for which the stored energy is 75.5 Joules. The temperature of the tuner side NbTi flange is near 30K and is still rising although at a slow rate. On the left is a run for 14 Joules. The 14 Joules case clearly shows the temperature of the tuner side flange has peaked and is at steady state. The steady state analysis does not show the flange to be at the temperature levels of the test runs for either 14 or 75.5 Joules. There may be a component, such as a shield, that may be in contact with the flange that is not included in the analysis and could lead to higher temperatures in the flange. Nevertheless, if we use the model to develop a way to "fix" the joint region the fix will be "conservative" relative to the test data.

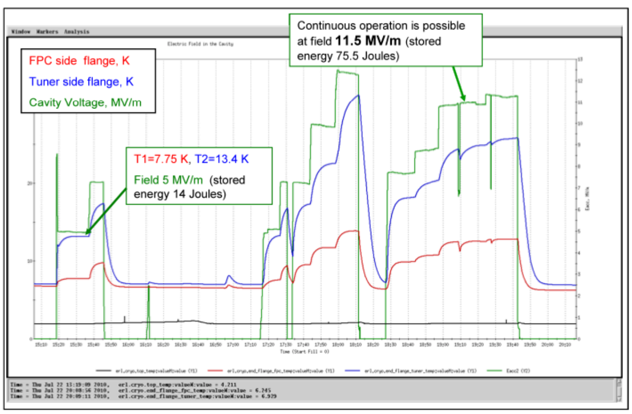

Figure 7: BNL test data from July 22, 2010.

The simplest method was to look at the addition of first cooling on the outside surface of the NbTi flange, then to add cooling to the outside of the adjacent stainless steel flange. This could be done relatively simply with a copper band and a cooling tube attached to the copper band. The first step was to look at cooling of the NbTi flange by setting the outside of the flange to 4.5K. This additional cooling increases the thermal runaway from 56 Joules to 77.5 Joules, still significantly below the design stored energy. The second analysis that was done was to add cooling to the stainless steel flange in a similar manner. This increased the thermal runaway condition to 98 Joules still below the design level.

The seal on the other side of the cavity is further from the cavity than the side that has been analyzed and runs cooler in test. This shows a clear relationship with the local magnetic field. Analysis shows that at about 56 joules of stored energy the magnetic field in the beam tube at the seal location is 220 A/m with an adjacent cooling transition section. If the seal were moved away from the cavity to a location where the fields were 220 A/m with a cavity stored energy of 127 Joules the cavity would operate successfully.

A set of temperature solutions were run for stored energy of the cavity between 5 and 56 Joules. The magnetic field at the seal and the temperature of the niobium beam tube at the seal were determined and plotted in Fig. 8. These results give a rough idea of the temperature dependency of the niobium with local field level for this cavity. For similar geometries and cooling schemes, this analysis can be used as a guide for locating the seal with respect to local magnetic field. In a location where the magnetic field is about 100 A/m the maximum niobium temperature would be near or less than 5K.

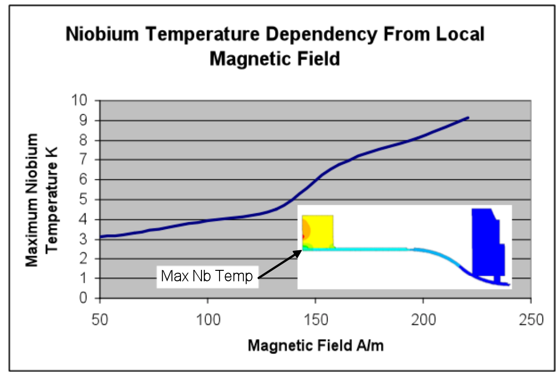

Figure 8: Niobium temperature dependency from local magnetic field.

CONCLUSIONS

By moving the location of the AlMg3 seal closer to the cavity so it would fit into JLAB's BCP cabinet, the magnetic fields in the region of the seal increased to a level that reduced the operating stored energy of the cavity. Simple cooling modifications increase the stored energy that the cavity can operate at but more complicated cooling near the flanges i.e. closer to the seal are required to operate at the design fields. The magnetic field regions that this type of seal can be operated in depend on the local cooling. For this geometry where there is an adjacent transition section to cool the seal, fields of less than 200 A/m would result in temperatures below the critical temperature. For other designs the combination of cooling and local fields should be analyzed. When lowering of the fields by moving the seal location away from the cavity and local cooling is not possible, a different seal configuration such as one that does not allow field penetration should be considered.

ACKNOWLEDGEMENT

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