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DESIGN, CONSTRUCTION AND TESTS OF THE COOLING SYSTEM WITH A CRYOCOOLER FOR CAVITY TESTING

P. Pizzol, J. W. Lewellen, E. R. Olivas, E. I. Simakov, T. Tajima
Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Abstract

Cryogenically cooled normal-conducting cavities have shown higher gradients than those operated at room temperature [1]. We are constructing a compact cooling system with a cryocooler to test c-band normal-conducting radio-frequency (NCRF) cavities and 1.3 GHz superconducting radio-frequency (SRF) cavities. This paper describes the design, construction and cooling test results as well as some low-power cavity Q measurement results.

INTRODUCTION

Large accelerating gradients are nowadays achieved by the use of normal-conducting copper cavities, like for example in LCLS at SLAC. The advantage of normal-conducting structures is of course their cost, since they are considerably cheaper than SRF structures, although they suffer from the inability of sustaining a CW operational mode due to excessive heating on the surface at high gradients. Also, electrical breakdowns have been the limit for short pulse operations. Research is being conducted on trying to reduce the number frequency of breakdowns by cooling copper to cryogenic temperatures, where the surface resistance decreases while the thermal conductivity and yield strength increase.

Cryocoolers can be used to reach such temperatures: they offer the advantages of being a close circuit system, intrinsically safe and very easy to operate once setup, with no need for expensive liquid cryogens handling.

SRF cavities operation could also be made considerably cheaper to operate if the cooling was provided by a cryocooler.

In this study we present the progress made on a test facility for cooling NCRF and SRF cavities via cryocooler, with some preliminary results obtained on a 5.1-GHz NCRF cavity.

EXPERIMENTAL SETUP

The facility has been developed using an already existing vacuum chamber as a starting point – a decision driven by the practicality of having already a large enough vacuum vessel available eliminating the need to design and fabricate a new chamber capable of accepting different cavity sizes. The vacuum chamber is made of three separate parts: a bottom and a top lid and a body. Vacuum is achieved via a scroll pump for the roughing down to <50 mTorr followed by a cryogenic pump that brings down the chamber to ~ 5E-7 Torr.

The core of the experimental system is the Sumitomo RDK-415D, a two-stage cryocooler capable of extracting 1.5 W of heat at 4 K. This component is connected to the lid of the vacuum chamber, so when the lid is removed and placed on a custom made stand it is possible to install the different accessories and samples.

Figure 1 shows a 3D model of the vacuum chamber that was constructed to help the designing of the different components and adaptors required to test the different sized cavities planned for this experiment.

The project will see the following cavities tested:

1. 5.1 GHz copper NCRF cavity provided by LANL.
2. 5.7 GHz C-band copper NCRF cavity provided by SLAC.
3. 1.3 GHz Nb SRF cavity provided by LANL.

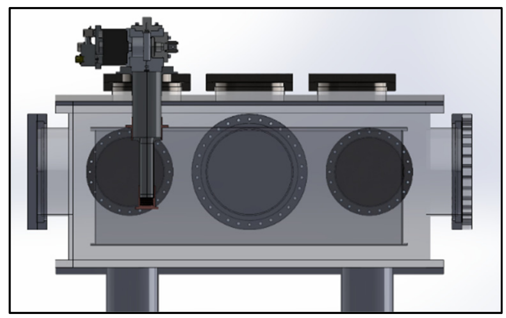

Figure 1: Side view of vacuum chamber with cryocooler and Al thermal shield (shaded).

5.1 GHz and C-band Cavity Adapters Design

The 5.1 GHz cavity and the C-band cavity are relatively small (Fig. 2) so the cryogenic simulations were only performed qualitatively and are not reported in this paper. A more thorough cryogenic FEA simulation was performed for the Nb cavity and its support structure due to its size and complexity. As the time of writing this paper, the 5.1 GHz cavity is the only cavity that is undergoing testing. The SLAC 5.7-GHz cavity tests are planned for late May - June, while the Nb cavity will be tested during the months of July and August 2021.

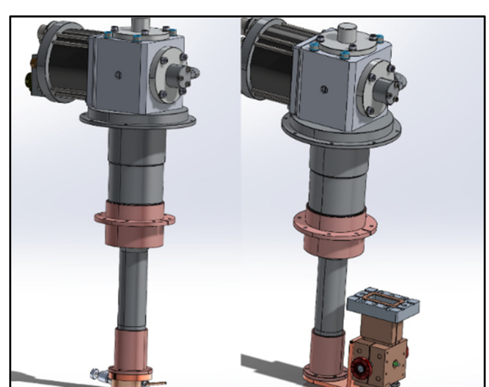

Figure 2: Cryocooler with (left) 5.1 GHz cavity and (right) SLAC cavity.

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1.3 GHz Nb Cavity Frame Design

The 1.3 GHz Nb cavity presents two extra challenges compared to the NCRF cavities: the cavity has to be cooled to $T<T_c$ to perform any valuable Q measurement as a superconductor, e.g. 9 K for Nb, 18 K for Nb_3Sn and 39 K for MgB_2, and its size is much larger than the copper cavities. Therefore it was necessary to design and simulate the frame that effectively cool down the cavity with conduction cooling.

The design was inspired by the work conducted by Dhuley *et al.* [2-4]: in their work the SRF cavity is anchored to the cryocooler second stage via Al 99.999% flanges connected to a ring e-beam welded to the equator of the cavity. This approach is not feasible for our study, so a different clamping mechanism was designed.

Figure 3 shows the thermal frame design and FEA analysis results.

Al 99.999% was chosen to fabricate the thermal frame (will be ready by mid-June). Due to its ductility the frame will not be capable of supporting the Nb weight without yielding so the cavity will be supported on each sides of its beam pipe using two half clamps connected to the thermal shield via G-10 threaded rods, not shown in the figure.

The simulation takes into account the use of indium film on every clamp as a method to improve thermal contact.

According to the FEA study the niobium cavity should be able to reach 7.7 K at its warmest spot, which is below the critical temperature of Nb at 9.2 K even when there is a 1W hot spot on the equator interior surface. This temperature should be sufficient for the cavity to be fully in its superconductive state, so it should be possible to perform Q measurements. The yellow dot on the cavity in Fig. 3 represents a 1 W hot spot, which will be recreated in practice by using a small resistor. This will allow us to test how well the thermal frame simulations match the real case.

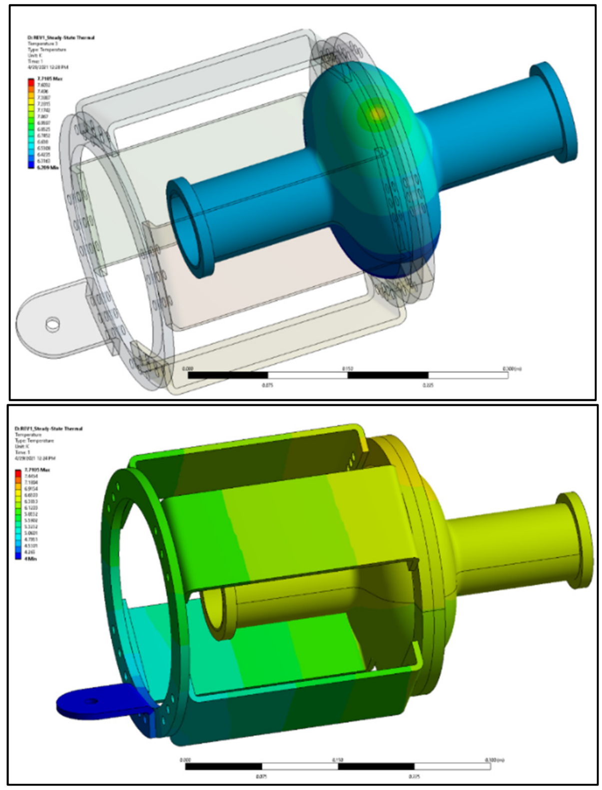

Figure 3: FEA thermal simulations for Nb 1.3 GHz cavity. The yellow dot simulates 1 W of heat on the inner cavity wall.

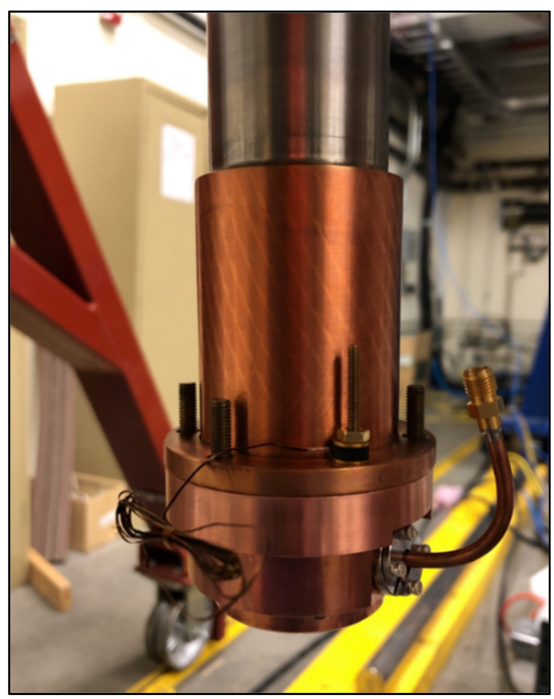

Figure 4: 5.1 GHz cavity mounted on cryocooler.

PRELIMINARY RESULTS OF A 5.1 GHz CAVITY

Cooling Test

The cavity was mounted on the cryocooler using the adaptor shown in Fig. 2. Two Cernox thermometers were mounted on opposite sides of it and were compared with the one mounted on the 2nd stage of the cryocooler. Figure 4 shows the cavity attached to the 2nd stage of the cryocooler. The cavity was then cooled down and tested.

Figure 5 shows the temperature trend of the second stage of the cryocooler and of the cavity temperature sensors. It is clear to see that the cavity cooling rate is comparable to the second stage one, with both cavity and second stage reaching the same temperature after 50 minutes from the start of cooling. The lowest temperature achieved was 3.5 K.

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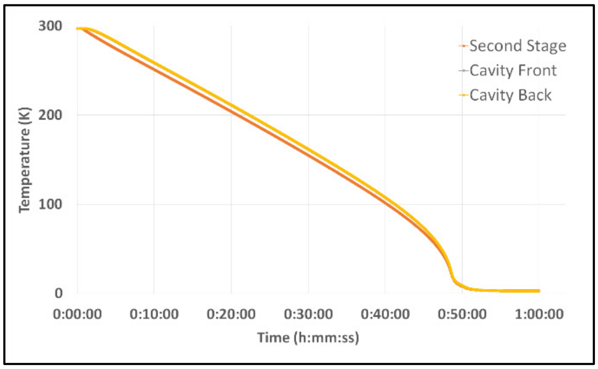

Figure 5: Cooldown curve for 5.1 GHz copper cavity.

RF Test

The cavity was connected to a network analyzer to perform reflection and transmission measurements.

Figure 6 shows the loaded Q (Q_L) measurement obtained by measuring the cavity in transmission.

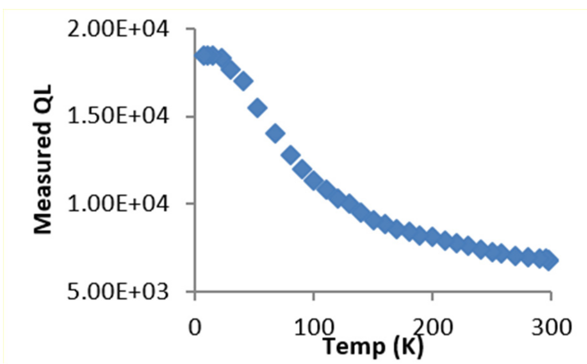

Figure 6: Q_L for 5.1 GHz cavity vs temperature.

To estimate accurately the Q_0, the aim of this measurement, it is important to know the losses due to cables, the coupling factor and any other effect that may influence the measured Q_L. As of now these values are still being measured hence why we can only present the measured Q_L.

It is worth to notice though that, as per literature, the Q_L increases considerably with the decrease in temperature. This is due to the decrease in the copper surface resistance, which is inversely proportional to the Q_L.

Once all the losses and factors will be accurately measured we will be able to obtain the value of Q_0. Moreover the 5.1 GHz cavity is being used as a benchmark for the thermometry and RF measurement system, so to allow us to fine tune our facility and develop a measurement methodology and procedure.

CONCLUSION

We have successfully designed and developed a cryogenic test bed for differently sized accelerating cavities. A 5.1 GHz copper NCRF cavity measurement has started. We will soon be able to obtain the cavity Q_0 and surface resistance at different temperatures down to <3 K for the small NCRF cavities.

Future tests will be performed with the remaining 5.7-GHz NCRF cavity and 1.3-GHz SRF cavity that, if successful, will confirm the flexibility of the testing facility and will allow us to reliably perform Q_0 measurements on accelerating cavities without the need of expensive cryogens.

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