CONTINUOUS-WAVE HORIZONTAL TESTS OF DRESSED 1.3 GHz SRF CAVITIES FOR LCLS-II

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Abstract

Fermilab's Horizontal Test Stand has recently been upgraded to provide CW RF testing capabilities in support of the LCLS-II project at SLAC. Several cavities have been tested in this new configuration in order to validate component designs and processes for meeting the requirements of LCLS-II. Areas of study included gradient and Q0 performance and their dependence on extrinsic factors, thermal performance of the input coupler and HOM feedthroughs, and microphonics and RF control. A description of the testing and the results obtained are presented.

INTRODUCTION

The Linac Coherent Light Source (LCLS)-II project [1] features a 4 GeV superconducting radiofrequency (RF) electron linac operated in the continuous wave (CW) regime. The ILC/XFEL nine-cell 1.3 GHz cavity serves as the basis for the LCLS-II dressed cavity design, with a number of elements modified to meet the needs of LCLS-II:

- A new cavity processing recipe optimized to achieve $Q_0 = 2.7 \times 10^{10}$ at a gradient of 16 MV/m [2]
- HOM feedthroughs with better heat conduction [3,4]
- Fundamental power couplers (FPC) with a higher Q_{ext} (4×10^7) and improved thermal conductivity
- Improved magnetic shielding to keep fields at the cavity < 5 mG
- A new helium vessel design to accommodate larger dynamic heat loads and meet mechanical and cooldown requirements
- A new tuner system for excellent resonance control and microphonics compensation

All of these design modifications need to be validated as they become available; the first two items were in hand relatively quickly and are the focus of this paper.

HORIZONTAL TEST STAND (HTS) UPGRADES

Fermilab's HTS [5] is currently dedicated to providing the testing necessary to support the above validation work. It was initially designed to test high gradient dressed cavities with high power pulsed RF. In order to measure Q_0 accurately it is necessary to use an RF coupling close to unity as opposed to a strongly overcoupled high power coupler. Therefore a number of upgrades to HTS were necessary to support low-power CW testing, including:

- A blank-off flange for the FPC port with a coaxial feedthrough and heat-intercepted cable in lieu of a high power coupler
- Installation of a low-level RF (LLRF) system with phase-locked loop control based on the system described in [6]
- Repurposing a 200 W solid state amplifier as a primary power source rather than a klystron preamplifier
- Installation of a set of Helmholtz coils around the HTS cryostat to provide three-axis cancellation of the Earth's magnetic field

The latter item is critical due to HTS's stainless steel cryostat, which provides minimal magnetic field attenuation. The average ambient field inside an ILC helium vessel and its single layer of magnetic shielding while inside HTS was measured to be approximately 45 mG at room temperature, well above LCLS-II specifications. With the addition of the cancellation coils, the room temperature magnetic field inside the helium vessel was reduced to 6 mG; see Fig. 1.

These upgrades were commissioned using cavity TB9RI026, an electropolished/120°-C-baked cavity in an

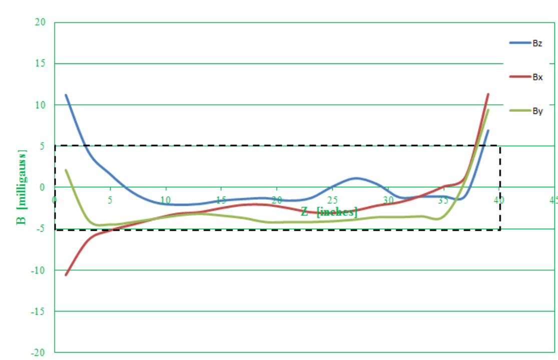

Figure 1: Room temperature magnetic field profile along the length of an ILC helium vessel/magnetic shield installed in HTS with cancellation coils turned on. The z-direction is along the cavity axis (north-south in HTS), the y-direction is vertical, and the x-direction is transverse. The dotted outline represents the LCLS-II target and the extent of the helium vessel/shielding.

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ILC helium vessel outfitted with a variable high-Q_{ext} input coupler and DESY high-thermal-conductivity HOM feedthroughs.

TB9RI026 RESULTS

The most important commissioning task was to establish reliable Q_0 and gradient measurements with the new RF systems. Figure 2 summarizes the measurements. The magnetic field cancellation coils work extremely well, providing up to a factor of two increase in Q_0. The Q_0 vs. E_{acc} curve taken at 2 K with the cancellation coils on is the data set most directly comparable to the data taken at Fermilab's Vertical Test Stand (VTS), where ambient magnetic fields are low. The VTS and HTS data agree quite well; the fact that the VTS curve is slightly lower is likely explained by the fact that the VTS data were taken in 2010, when the magnetic field environment at VTS had not yet been optimized to the sub-5-mG levels of its present-day configuration. The fact that the HTS curves all end at 20 MV/m or less is the result of the "chimney limit" of the ILC helium vessel; the cross-sectional area of the chimney from the vessel to the helium two-phase header limits heat transport from the liquid helium above approximately 25 W, leading to quenching of the cavity.

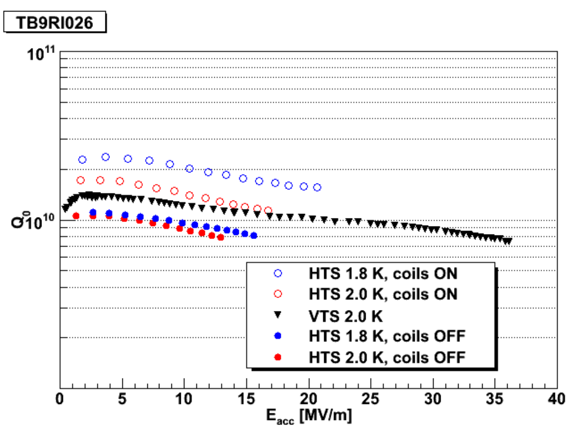

Figure 2: Q_0 vs. E_{acc} curves for HTS and VTS. "Coils ON/OFF" refers to the state of the magnetic field cancellation coils when the cavity was cooled through the critical temperature T_c.

Future cavity tests at HTS will be conducted in the strongly overcoupled regime, where Q_0 can only be measured from the dynamic heat load to the cryogenic system. Therefore it is important to demonstrate that cryogenic-based measurements reproduce the Q_0 measured from the RF system. At HTS dynamic heat load measurements are performed by measuring the change in steady-state helium mass flow at the discharge of the vacuum pump and calibrating these measurements against an internal heater. The dynamic heat loads for TB9RI026 were measured at several different gradients and compared to the cavity losses measured with the RF system (the losses are inversely proportional to Q_0). The

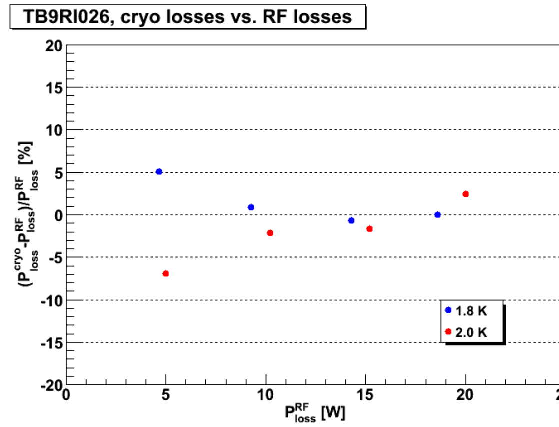

Figure 3: Percent difference between RF measurements of cavity losses P_{loss} and cryo measurements of same, at various values for P_{loss}.

results are shown in Fig. 3; the disagreement is no worse than 7% and improves to a few percent at values of P_{loss} > 10 W.

The other objective of the test of T9RI026 was to assess the thermal performance of the DESY HOM feedthroughs. Figure 4 shows one of the feedthroughs and its cooling scheme in HTS. In order to maximize the power dissipated on the feedthrough antenna tips the cavity was excited in the $8\pi/9$ mode where the fields in the end cells are boosted. Data were taken at 1.8 K with the cancellation coils on to maximize Q_0 and hence stave off the chimney limit. With an end-cell field of 22.6 MV/m (well above LCLS-II spec), about 0.5 W power was measured on the HOMs and the maximum temperature rise observed on the feedthroughs was 0.5 K.

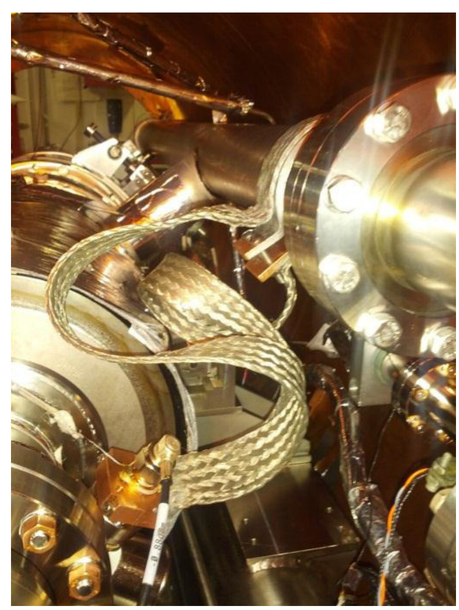

Figure 4: A DESY HOM feedthrough connected via copper braid to the two-phase helium header.

TB9AES011 RESULTS

The nitrogen-doped high-Q_0 cavity TB9AES011, which was welded into an ILC helium vessel and tested in VTS before arriving at HTS, had a non-standard configuration at HTS. In order to mimic the conditions of VTS as closely as possible, it remained under vacuum during the transfer between facilities and was not actively pumped during the HTS test. It also did not have any tuners or HOM feedthroughs.

Recent work [7] has shown that the expulsion of trapped magnetic flux and hence the Q_0 performance of high-Q_0 cavities is sensitive to the rate-of-change and uniformity of the cavity temperature as it cools through T_c. Therefore the cavity was equipped with four fluxgate magnetometers and four temperature sensors mounted near the equator of cell 1 (top and bottom) and the equators of cells 5 and 9 (top only).

Table 1 shows the parameters of four different cooldowns performed with TB9AES011. Several different rates and start temperatures were investigated, but it proved difficult to achieve a significant thermal gradient across the length of the cavity at T_c. Indeed, the cell 1 (top) and cell 9 temperatures were always at nearly the same temperature, with cell 5 colder by the amount shown in the last column of Tab. 1.

Table 1: TB9AES011 Cooldowns

Cooldown	Start T	dT/dt @ T_c	ΔT_y @ T_c	ΔT_z @ T_c
1	100 K	6 K/min	7.0 K	2.5 K
2	80 K	1 K/min	3.5 K	1.4 K
3	25 K	6 K/min	5.0 K	2.0 K
4	35 K	14 K/min	13 K	6.0 K

Possibly consequently, the differing cooldowns had very little effect on Q_0 as seen in Figure 5. Additionally, the Q_0 values observed are almost half of those measured at VTS. The source of this degradation is currently not understood. One theory being considered is heating of the end groups, but temperatures sensors on the beam pipes and HOM bodies show only a +0.5 K difference with respect to the cavity temperature. This difference of course increases with field (by about two degrees at most), but the degradation is present even at low field.

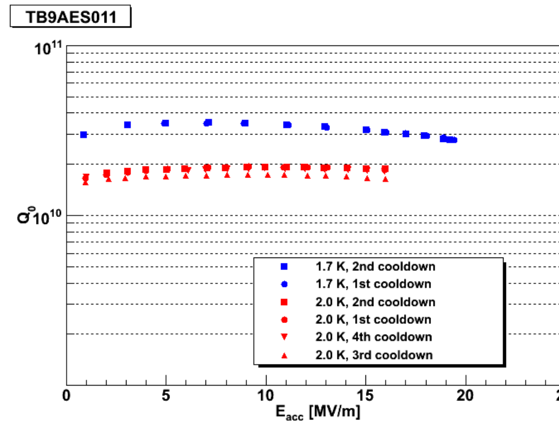

Figure 5: Q_0 vs. E_{acc} curves for TB9AES011 after the cooldowns described in Tab. 1.

CONCLUSION

HTS has been successfully upgraded for CW testing of cavities for LCLS-II. Two cavities have been tested so far to validate the choices of HOM feedthrough design and cavity high-Q_0 processing procedure. The DESY HOM feedthroughs tested showed only a very small temperature increase at fields far exceeding the LCLS-II requirements. Q_0 performance of the high-Q_0 cavity tested at HTS did not meet LCLS-II requirements. Tests of this cavity in the Cornell horizontal test cryostat are planned to help elucidate what the problem may be. Upcoming tests at HTS will serve to validate LCLS-II input coupler and helium vessel designs.

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