PERFORMANCE OF DRESSED CAVITIES FOR THE JEFFERSON LABORATORY LCLS-II PROTOTYPE CRYOMODULE - WITH COMPARISON TO THE PRE-DRESSED PERFORMANCE*

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Abstract

Initial vertical RF test results and quench studies for six of the eight undressed 9 cell cavities slated for use in the Jefferson laboratory LCLS-II prototype cryomodule were presented at IPAC2015[1]. For the final string 2 more cavities AES029 and AES030 (work done at Cornell) are being processed and tested for qualification before helium vessel welding. In addition, AES034 (initial R&D treatment) is being reworked with the current production protocol after a surface reset to improve the overall performance. After final qualification all 8 cavities will be welded into helium vessels and equipped with HOM couplers. In this paper we will present the final undressed and dressed vertical RF data comparing the changes in the surface resistance before their installation in the cryomodule string.

INTRODUCTION

The current doping protocol for the baseline design as well as for production is N2/6 + EP5 (nitrogen injection @ 800C for 2 minutes at an average pressure of 25mtorr, followed by 6 minutes under vacuum and then a 5µm electro-polish)[1-4]. The cavities used in the prototype module were already used in doping studies during the R&D phase. Because of this, all but one cavity was doped more than once. Two of the cavities used in the prototype string will not have the baseline doping. One is AES031 which was the only cavity to receive only one doping, and AES030 which was accidentally doped for 6 minutes rather than 2 and received a larger EP (14µm rather than 5 µm) which at the time was intended to compensate for the extra nitrogen. The final doping parameters and number of dopings for each cavity is shown in Table 1.

Table 1: Doping Parameters for 9 Cell Cavities and Total Doping Cycles

Cavity ID	Final doping	Times doped
AES029	N2/6 EP5	2
AES030	N6/6 EP14	2
AES031	N20/30 EP26	1
AES032	N2/6 EP5	2
AES033	N2/6 EP5	2
AES034	N2/6 EP5	3
AES035	N2/6 EP5	2
AES036	N2/6 EP5	2

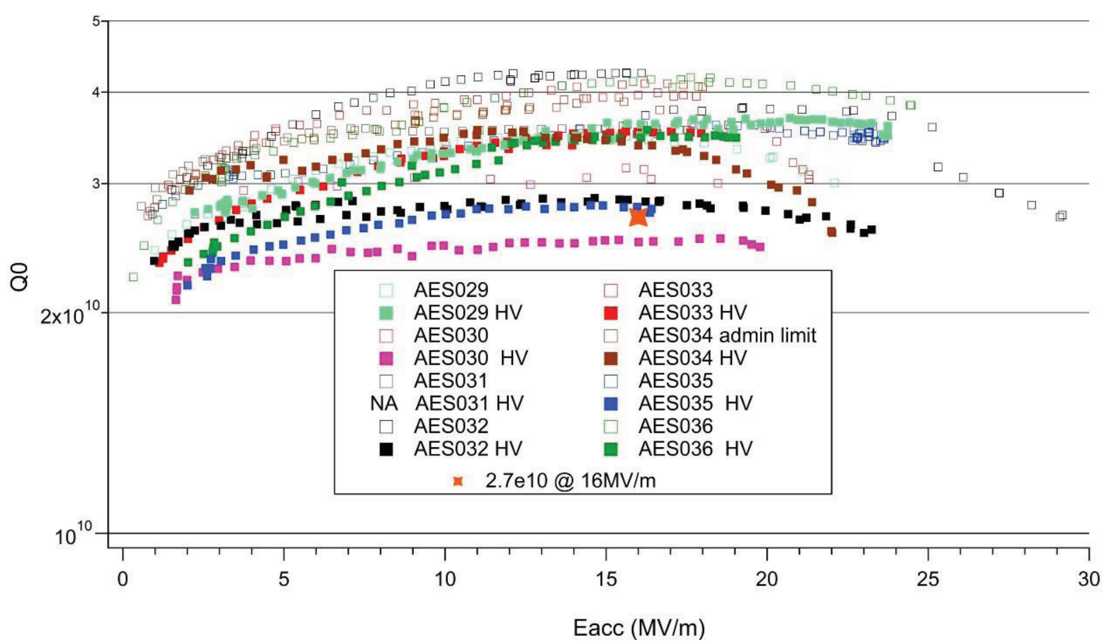

Figure 1: Q vs Eacc @ 2.0K before (solid squares) or after (open squares) HV welding and HOM installation. All data corrected to superconducting flanges if SS flanges were used.

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Q VS. EACC @ 2.0K

All cavity test before and after HV welding (except AES030 @ Cornell and AES034 @ JLab) were tested at 2.0K, 1.8K and 1.6K. The 2.0K data before and after HV welding is shown in Figure 1.

All data has been corrected for losses on the stainless steel flanges using a corrected factor of a field independent 1.4ηΩ, correction factor analysis was presented at IPAC2015 [1][3]. Without this correction the data before and after HV welding and between cavities is hard to compare because of the extra residual losses. The actual measurements and corrected values are shown in Table 2.

CAVITY STATISTICS

The LCLS-II project requires a Q0 @ 16MV/m of 2.7e10 (10Watts) to operate the LINAC with one cryo plant. Before dressing, the cavities produced an average Q0 @ 16MV/m of 3.78e10 (3.88e10 N2/6 only). There is an average degradation in the cavity performance of about 1.2 nano-ohms after welding, the average Q0 is still 3.3e10 and 3.15e10 for N2/6 EP5 cavities well above the required Q0. The full cavity statistics before and after HV welding/HOM installation are in Table 2.

RF FITTING DATA

For all vertical 9 cell tests except for the bare cavity test of AES034 (schedule conflict) and AES030 (tested @ Cornell during R&D phase) three Q vs. E curve were acquired at 2.0K, 1.8K and 1.6K. This data is then used to extract the temperature dependant and temperature independent portions of the surface resistance. The exact fitting and testing protocols for the 9 cell tests is presented in IPAC2015, with the fitting protocols similar to Romanenko, et al. and Dhakal et al [3, 5-7].

Separating the temperature dependant and temperature independent components of the surface resistance is the only way to separate the doping and environmental effects. Without the separation of the surface resistances we would be unable to ascertain if the HV welding is causing a change in the doping of the cavity (temperature dependant portion) or is the geometry and/or magnetic fields realized at the cavity during cool down causing the change is the Q vs. Eacc curve (temperature independent portion).

The temperature independent parameter fitting "A" for all cavities before and after dressing is shown in Figure 2. The first curve that stands out is AES030 after dressing, which turns out to have a doping that is different than the other cavities – very small slope and higher background, as well as AES031 with shallower slope. Second, for the cavities tested before and after dressing there is not significant change in the doping from the welding.

Table 2: Cavity Q0 @ 16MV/m before and after HV welding/HOM install. Average, % loss, and change in surface resistance also shown in coloured portion of table.

cavity ID	before HV welding nbti corrected	before HV welding ss corrected	after HV welding nbti	after HV welding ss
aes029	3.60E+10	**3.04E+10**	**3.62E+10**	3.05E+10
aes030	**3.40E+10**	2.89E+10	**2.48E+10**	2.20E+10
aes031	**3.50E+10**	2.96E+10	**TBD**	TBD
aes032	**4.20E+10**	3.45E+10	2.75E+10	**2.41E+10**
aes033	3.85E+10	**3.21E+10**	3.55E+10	**3.00E+10**
aes034	3.90E+10	**3.25E+10**	**3.48E+10**	2.95E+10
aes035	**3.60E+10**	3.04E+10	**2.87E+10**	2.50E+10
aes036	**4.15E+10**	3.42E+10	**3.62E+10**	*3.05E+10*
average	*3.78E+10*	*3.16E+10*	*3.2E+10*	*2.75E+10*
% -loss			*8*	*8*
Δ-Ω			*1.25E-09*	*1.25E-09*
N2/6_EP5 – average	3.88E+10	3.23E+10	3.32E+10	2.83E+10
N2/6_EP5 *% -loss*			8	8
Δ-Ω			1.2E-09	1.2E-09

The temperature independent Parameter "RS" for all cavities before and after HV welding is shown in Figure 3. The first item that stands out is that AES032 after HV welding has a much high residual than the other cavities. After all other cavities are tested, AES032 will be retested in a different dewar to verify the added surface resistance is environmental and not in the cavity (AES032 was the first dressed cavity tested in a different Dewar than undressed cavities and the cooldown stalled halfway through cooling). Second, all cavities tested after HV welding with HOM's installed have a higher temperature independent resistance than before HV welding. For the test of AES029, the cavity was placed in the same dewar (JLab dewar 7) used for the undressed cavities. JLab's Dewar 7 was fully degaussed before the test and the ambient field along the 9-cell was reduced to ~1mGauss vertical and ~1.5mGauss perpendicular; this is very close to the undressed state. As one can see, AES029 RS is close to the baseline test in the refurbished dewar, therefore we currently believe the doping before and after HV welding is intact and most of the added resistance is from the testing environmental only.

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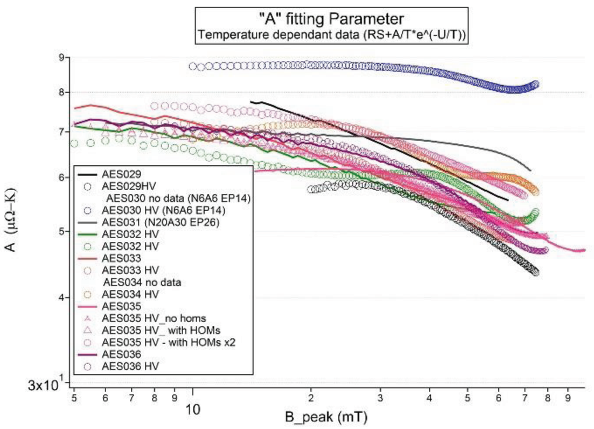

Figure 2: Temperature dependant fitting parameter "A" extracted from the Q vs. Eacc vs. T data, before (solid lines) and after (open circles) cavity dressing.

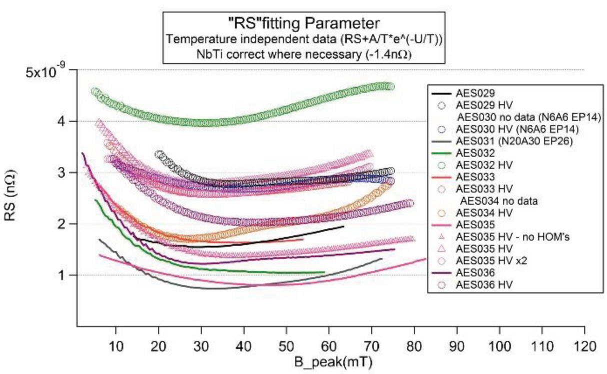

Figure 3: Temperature independent fitting parameter "RS" extracted from the Q vs. Eacc vs. T data before (solid lines) and after (open circles) cavity dressing.

POSSABLE OTHER CAUSES OF Q0 DEGRADATIONS

During the vertical testing of 9-cell cavities for LCLS-II all hardware and cavity components had a permeability spec of <1.1 on all welds and metal cuts, while the bulk material require a permeability of less than 1.03. In general this required test hardware that was made out the 316LN or annealed 316L stainless steel, titanium or superconducting NbTi. This made some of the standard hardware used for 9-cell testing unacceptable for testing (e.g. isolation valves and standard burst disks).

After dressing, multiple components that were not used for undressed cavities had to be used. These included an isolation value, and a burst disk which are not believed to cause the degradation with a standard cooldown, but not included in the undressed state. Also after welding, multiple stainless steel components on the helium vessel were permeable with some components having a permeability of 2.0. A dressed 9-cell cavity ready for vertical testing and its high permeability HV locations are pointed out in Figure 4. Also, the cut location on the return header "T" is permeable but no survey data is available at this time.

In the vertical test, inside a shielded dewar (nominal field <2mGauss), these joints can produce fields over 20 mGauss as measured by magnetic probes located within an inch. In addition, the same joints on AES035 measured in a shielded test cave (nominal field 40mGauss) produced 2 Gauss fields on contact. There is also a large variability between the welds/joint between cavities, but the correlation between the joint's permeability and change in the surface resistance has not been investigated to a degree where a correlation could be found or not.

One final difference between the vertical test before and after HV welding is the fact the cavity is now located off-axis of the dewar by ~ 6 inches. The magnetic fields do not change by more than ~20% from the axial measurements (one mGauss or two max). This offset may change the cooling dynamics in the Dewar, but there is insufficient data to suggest if this is an issue or not.

Figure 4: Left 9 cell cavity in helium vessel ready for vertical test showing permeable components on helium vessel (welds and exploded bonded joints) and their surveyed permeability range and locations on right.

CONCLUSION

7 of 8 nine-cell prototype cavities for use in the LCLS-II JLab nitrogen doping prototype cryomodule have been tested and qualified after dressing for installation in a string. The final cavity, AES031, will be tested during the week of the conference. All except one cavity (AES030) exceed the Qo @ 16MV/m of 2.7e10 required for the one cryo-plant baseline design. The average Qo @ 16MV/m

expected in the prototype from vertical tests is 3.2e10 and for the baseline recipe N2/6 EP5 average Q0 @ 16MV/m is 3.3e10.

All cavities after HV welding and installation of HOM's showed some degradation in their Q0, although some more than others. The average added resistance after HV welding in RF vertical tests is approximately 1.2ηΩ. At this time it is not fully known where the added resistance is coming from, but the current data suggests it is purely environmental effect from external magnetic fields and not a change in the cavity doping. One cavity, AES035, quench field is lower after dressing; this is the only unexplained quench change in any of the cavities.

The cavities will move forward to the prototype string assembly, and the unknown losses seen after dressing will be investigated further on spare cavities. Even with the extra losses after HV welding, the cavities Q0 @ 16MV/m does not drop below the baseline design specification of 2.7e10.

ACKNOWLEDGMENT

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