QUENCH STUDIES AND PREHEATING ANALYSIS OF SEAMLESS HYDROFORMED CAVITIES PROCESSED AT JEFFERSON LABORATORIES

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Abstract

One of the alternative manufacturing technologies for SRF cavities is hydroforming from seamless tubes. Although this technology has produced cavities with gradient and Q-values comparable to standard EBW/EP cavities, a few questions remain. One of these questions is whether the quench mechanism in hydroformed cavities is the same as in standard electron beam welded cavities. Towards this effort Jefferson Lab performed quench studies on two 9 cell seamless hydroformed cavities. These cavities include DESY's - Z163 and Z164 nine-cell cavities hydroformed at DESY. Initial Rf test results Z163 were published in the proceeding of SRF2011. In this report we will present post JLAB surface retreatment quench studies for each cavity. The data will include OST and T-mapping quench localization as well as quench location preheating analysis comparing them to the observations in standard electron beam welded cavities.

INTRODUCTION

Traditionally, rotationally symmetric (elliptical) niobium accelerating cavities are fabricated by deep drawing half-cells, machined to the length dimension and completed by electron beam welding (EBW) at the irises and the equators. While these manufacturing procedures are able to produce multi-cell cavities which perform close the theoretical limit, there are many steps in the process that, when not well controlled can reduce the performance and yield. One of the alternative technologies being investigated to replace stamped/welded cavities is to use hydroforming from seamless tubes [1–3]. Since these cavities do not have equator weld they are theoretically cheaper to manufacture in large quantities, contain no heat effected zone in the high magnetic field region, and require fewer steps which can introduce contamination during manufacturing.

On the way to the realiztion of large scale use of seamless hydroforming as an alternative to welded cavities there are questions that remain. One is the viability of large scale industrialization. The other one is how, if any the quench location within the cell, quench characteristics(preheating behavior) and gradient/Qo after standard cavity processing are different than those of welded cavities. Towards this effort JLab/DESY has processed two ILC type 9 cell cavities (Z163 and Z164) using the standard surface treatment to ascertain where there are any differences in cavity performance between treated seamless and welded 9 cell cavities.

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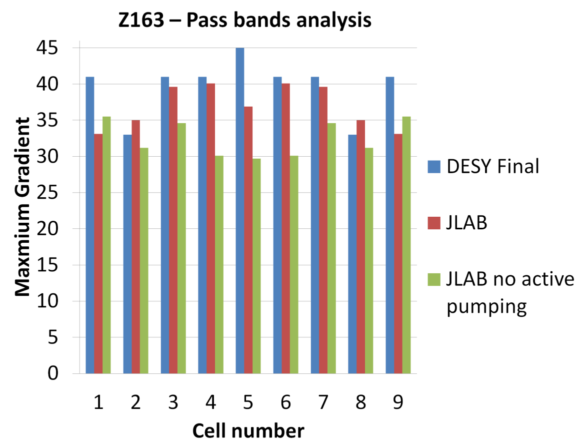

Figure 1: Compiled RF pass band analysis for three tests of Z163. Blue: final test at DESY π mode quench cell 8, Red: initial test at JLab π mode quench cell 9. Green: retest at JLab with no active pumping, π mode quench cell 5.

DESY - Z163

Z163 is a ILC 9-cell cavity made of three hydroformed 3-cell cavities. The 3-cell cavities were joined to one another and to the beam tubes by four electron beam welds at the irises. Besides iris welds, stiffening rings were added to each iris. The 3 three cell cavities were produced at DESY and the 4 iris welds performed at E. Zanon [4]. After 9 cell production the cavity went through the following treatments before initial test; 50 micron BCP, high temperature heat treatment at 800 ^{o}C for 2 hours, 144 micron EP, HPR, ethanol rinse and HPR. Initial RF tests were quite good at 33 MV/m and published in the proceedings of SRF2011 [5]. After the initial RF test the cavity was tested again with OST and temperature mapping in all modes to identify quench and maximum gradients in all cells [6]. The π mode quench location was found to be in cell 8 close to the stiffening ring in the lower half of the cell. Other quench locations were found in other modes in cells 1, 2, 4, 5 and 6 with the quench field in cell 5 going to 44 MV/m at DESY. The compiled pass band analysis

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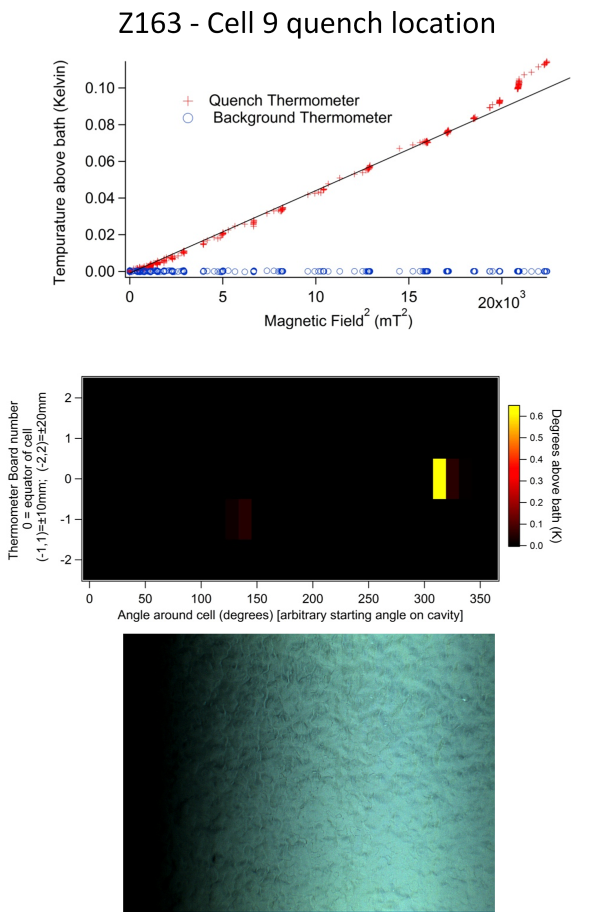

Figure 2: Quench location data for cell 9 in Z163, moving from top to bottom: temperature rise vs. magnetic field squared (field scaled to thermometer location field) for quench location thermometer in red, the background thermometer on the same board is shown in blue); unfolded temperature map from cell 9 after quench during cooling; inner surface optical inspection after disassembly showing no identifiable defect.

quench field vs. cell is shown in Figure 1 blue.

After testing at DESY the cavity was sent to JLab for reprocessing to see if additional EP would improve the cavity performance. After delivery the cavity went through JLAB standard second pass EP (30 micron) [7]. During the first RF test the cavity reached 34 MV/m; pass band analysis suggested the cavity was now limited in cell 1 or 9 in π mode. Mode analysis for the first RF test at JLab is shown in Figure 1 red. Following the first RF test the cavity was warmed up without venting and instrumented with JLab 2 of 9 temperature mapping system, OST's, as well as a 4x4 local temperature mapping array at the cell 8 quench location which was found at DESY. Because of conflict and test stand damage the cavity had to be valved off and tested without active pumping for the final test. During the final test the cavity was limited to 33 MV/ in cell 5 with quenches in other cell 6, 8, and 9 as well as

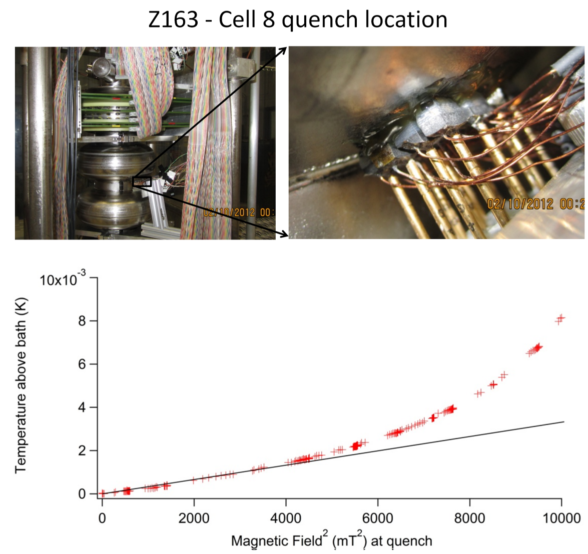

Figure 3: Quench location for cell 8 in Z163. Top: picture of top half of cavity in test stand, the right picture is a zoom in of the left picture showing the 4x4 temperature mapping array location at the quench location found at DESY. Bottom: temperature vs. magnetic field squares field scaled to quench location for the highest preheating temperature thermometer in the array.)

high preheating in cell 1. Mode analysis for the final RF test at JLab is shown in Figure 1 green. The interesting thing to note is that the quench field in each mode changed without venting the cavity. In general this only happen when there is either heavy field emission, or when there is trapped flux from the initial quench which changes the quench field between the first and second power rise [8]. In the case of Z163 neither is true, and to the knowledge of the authors this is the fist time such an event has been documented.

During the final RF test at JLab, quench location preheating temperature vs. field data was also measured for the cell 9 quench location as well as the cell 8 quench locations. No preheating data was taken for the cell 5 quench as cell 5 was not predicted to be the cavity limiting cell in the first RF test, so no thermometers were attached. For the quench location in cell 9 the preheating thermometer shows a linear temperature vs. magnetic field squared, suggesting the quench is most likely caused by a normal conducting inclusion on the inner surface (Fig. 2, top). There is a possibility that the normal conducting component comes from aluminum contamination similar to what was seen in Z161 which was made in the same batch and at the same time as Z163 [9]. Optical inspection on and around the quench location did not show any sign of a defect (Fig. 2, bottom). Preheating was also detected around the quench location in cell 8 (same quench location found by DESY). The preheating in cell 8 (Fig. 3) was drastically different than that of cell 9 where the curve suggests a magnetic and normal conducting components

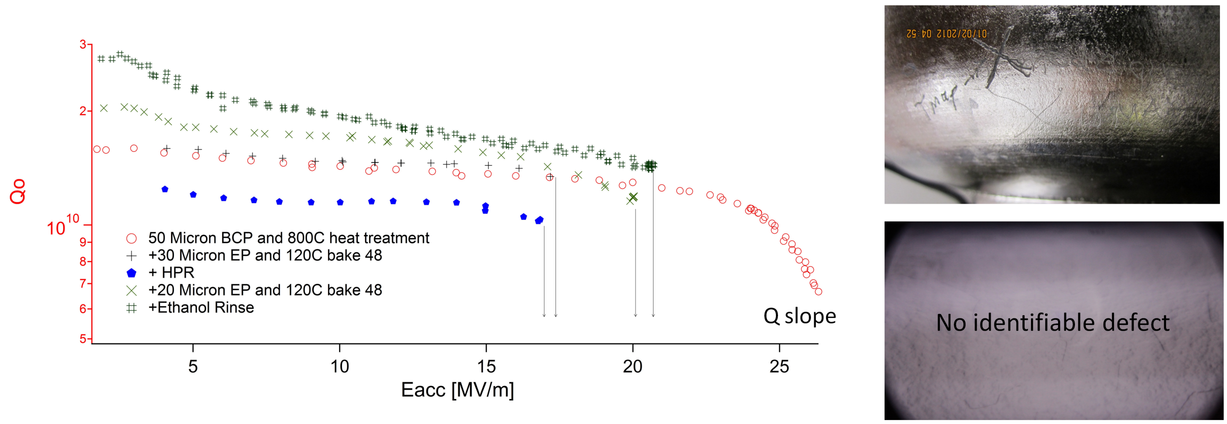

Figure 4: Compiled test data from Z164. Left: summary of 5 total cryogenic RF tests, the test results in the legend are in chronological order from top to bottom. For each test the legend contains the surface treatment added between each test. Right top: external quench location of cell 4 found by OST and temperature mapping. Right bottom: internal optical inspection location of quench site, the area around the quench site was also inspection. No identifiable defect was found, the large crystals in the image are from the 1250C heat treatment in the three 3-cell form.

[8, 10, 11]. Optical inspection around cell 8, quench location was not performed as the defect was outside the region of the inspection system at the time of imaging. In addition to cell 9 and 8, the quench location found by OST's in cell 5 was also inspected but no defect was found.

DESY - Z164

Z164 is a ILC 9-cell cavity made of three hydroformed 3-cell cavities. The 3-cell cavities were joined to each other and the beam tubes by four electron beam welds at the irises. Besides iris welds, stiffening rings were added to each iris. The 3 three cell cavities were produced at DESY and the 4 iris welds performed at E. Zanon [4]. Prior to welding the 3 three cell cavities were treated and tested at JLAB with BCP and 1250 ^{o}C titanium treatment, all cavities reached above 32 MV/m with Q slope limitations after multiple rounds of BCP [2]. After welding the cavity went through a total of 4 types of surface treatment and 5 RF tests, all performed at 2 K. Initially after the first 50 micron BCP and high temperature heat treatment at 800 ^{o}C the cavity was Q-slope limited to 26 MV/m (standard for this type of surface preparation). The cavity was limited by Q-slope, 30 microns of EP and a low temperature bake (120 ^{o}C for 48 hours) were performed following the JLab standard ILC EP surface treatment. The cavity was then limited by quench to 18 MV/m with moderate field emission (1 R/hr). Because of the field emission the cavity went through an addition HPR to remove possible contaminate which were possibly causing the field emission. After HPR the cavity was still limited to 18 MV/m with very light field emission (50 mR/hr). Following the ILC procedure the cavity went through a second pass processing EP of 20 microns. The additional chemistry plus ethanol rinse only improved the cavity performance to 21 MV/m. The RF test summary can be found in Figure 4 left. All other cells went above 33 MV/m with cell 5 going above 40 MV/m.

During the last RF test, passband measurements suggested the quench location must be in cell 4 or 6. The cavity was instrumented with Jlab's 2 of 9 high magnetic field region temperature mapping system and 8 OST second sound system. Both the t-mapping and triangulated OST data pointed to the lower half of cell 4 approximately 20 to 30 mm away from the equator as the single quench location between cell 3 and 4 (Figure 4 right top). After the instrumented RF test that cavity was disassembled for internal optical inspection [12]. An extensive inspection on and around the quench area was unable to identify any defect (Figure 4 right bottom). This is strange since most cavities limited below 100 mT have a correlated inner surface defect which can be found by optical inspection [13]. The only reasonable assumption to the degradation of the cavity was some how damaged during the iris and stiffening ring welding (between cell 4 and 3) but not found by optical inspection because of the hard to see location.

CONCLUSION

In this report we have presented RF tests with quench analysis on two EP'ed 9 cell seamless hydroformed cavity. The performance of the two cavities were quite different with one performing below 22 MV/m while the other reach approximately 35 MV/m. It appears in both cavities there might have been a problem with welding the iris and stiffening rings as quenches in both cavities were closer to stiffening ring welds than the equator. In either case no defect was found through standard optical inspection. The preheating nature of the quench defects in Z163 also suggest that seamless cavities contain both defect which appear to have either a purely normal conducting component as well as defects which appear to have a magnetic and normal conducting component.

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