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SHAPE EVOLUTION OF C75 LARGE-GRAIN NIOBIUM HALF-CELLS DURING CAVITY FABRICATION*

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Abstract

The largely anisotropic deformation of large-grain Nb discs during deep drawing into half-cells poses a challenge for achieving a desired shape accuracy. Two 5-cell cavities for the C75 CEBAF cryomodule rework program have been fabricated at Jefferson Lab from large-grain Nb discs directly sliced from an ingot. The shape of the inner surface of eight half-cells has been inspected using a FARO Edge laser scanner during the fabrication process and compared to the reference shape. On average, approximately 63% of the half-cell inner surface was found to be within 0.1 mm of the reference shape and ~90% to be within 0.2 mm, after the final equator machining. Several 5-cell C75 cavities have also been fabricated at Research Instruments, Germany, and measurements of the shape accuracy using a Zeiss 3D coordinate measuring machine gave similar results. One half-cell was measured both at Research Instruments and Jefferson Lab for comparison.

INTRODUCTION

Large-grain Nb technology is a viable alternative to the use of standard fine-grain, high-RRR, Nb material for SRF cavity production [1]. Nb discs are directly sliced from a Nb ingot and deep-drawn into half-cells of the required cell shape. Because of the presence of several cm^2-size grains, large-grain half-cells have a larger deviation from the ideal shape than fine-grain ones, after deep-drawing. Additional steps in the cavity fabrication, such as welding of stiffening rings, can also alter the cell shape.

Maintaining an accurate cell shape of the cavity is important to assure that the spectra of higher-order modes is consistent with what has been calculated using 3D electromagnetic solvers, at the cavity design stage. During the production of 1.3 GHz, 9-cell cavities for E-XFEL, a maximum deviation from the ideal cell shape of ±0.2 mm for 90% of the measured data and up to ±0.25 mm for the remaining 10% had to be maintained throughout the cavity fabrication steps [2, 3].

The availability of fast, non-contact, 3D coordinate measuring machines (CMM), allows for more detailed 3D shape measurements than it is possible with traditional CMM. In this contributions we present the 3D shape evolution of several large-grain Nb half-cells during the fabrication of two 1.5 GHz, 5-cell cavities for the C75 cryomodule rework program at Jefferson Lab [4]. The same type of cavities have also been built at RI Research Instruments GmbH, Germany, using the same type of material. The shape accuracy requested throughout the cavity fabrication was ±0.2 mm for 80% of the data within ±0.4 mm for the remaining 20%.

EXPERIMENTAL RESULTS

A FARO Edge ScanArm® laser line scanner [5] along with Geomagic® Control X 3D metrology software [6] were used throughout this study to measure the shape of half-cells and compare it to the ideal shape. The nominal accuracy of the laser line scanner is ±0.029 mm.

C75 Large-Grain Half-Cells

The large-grain discs of RRR ~ 165, 3.155 mm thick, were sliced from a Nb ingot produced by CBMM, Brazil. Figure 1 shows a shape comparison for the male and female dies used for deep-drawing C75 half-cells, showing that ~72% of the data points from the female die and ~48% of the data points from the male die are within ±0.1 mm from the ideal shape. About 96% of the data points and ~83% of the data points are within ±0.2 mm from the ideal shape for the female and male die, respectively. The die set, made of Al 7075, had been already used several times to fabricate C75 cavities in the past and was designed for 3.175 mm thick discs.

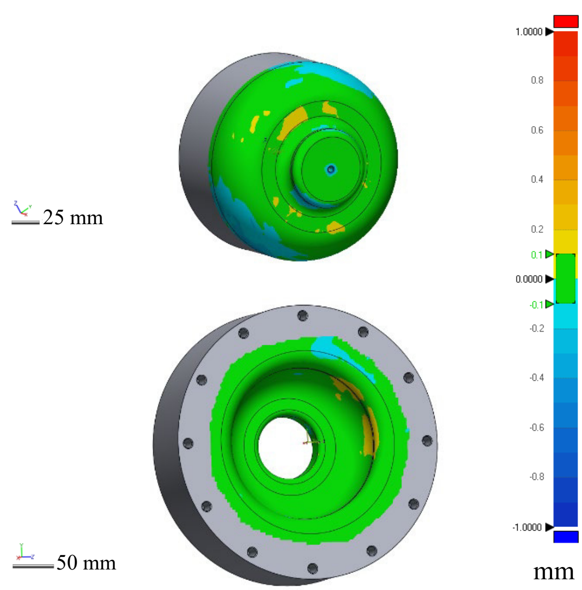

Figure 1: 3D shape comparison of the male (top) and female (bottom) dies used for the deep-drawing of C75 half-cells.

3D CMM data were acquired after the following fabrication steps:

1. First deep-drawing at 100 ton, iris coining at 25 ton, re-stamping at 100 ton

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2. 15 µm etching by buffered chemical polishing, vacuum annealing at 800 °C/3 h, 2nd deep-drawing at 100 ton, iris coining at 25 ton, re-stamping at 100 ton, machining of the iris weld-prep on a CNC mill.
3. Electron-beam welding at the iris to form dumb-bells and of the stiffening rings
4. Pressing of each half-cell of a dumb-bell with a re-shaping tool
5. Machining of the equator weld-prep on a CNC mill.

Figure 2 shows the fraction of data points within ±0.1 mm of the ideal shape for eight half-cells during the fabrication steps listed above. Figure 3 shows the circularity of the equator inner diameter (ID) of the same half-cells throughout the fabrication steps. Figure 4 shows the shape evolution of large-grain Nb half-cell HC 01-03 during the cavity fabrication.

Table 1 lists a summary of the fraction of points within a specified deviation from the ideal shape after each fabrication step, averaged over the 8 half-cells.

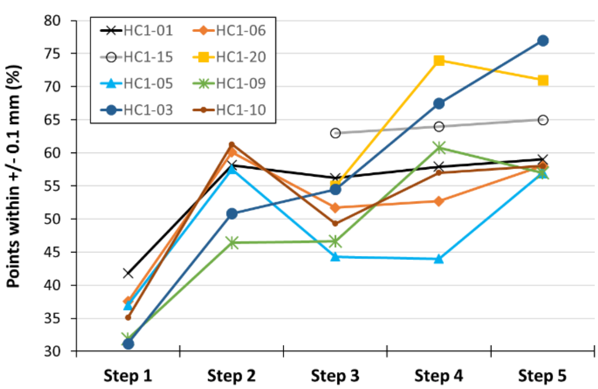

Figure 2: Fraction of data points within ±0.1 mm of the ideal shape for 8 C75 large-grain half-cells during the cavity fabrication.

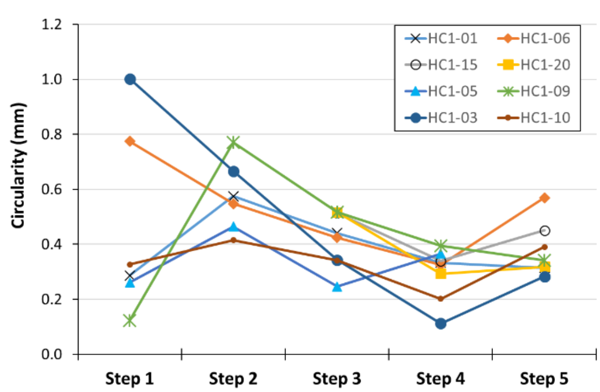

Figure 3: Circularity of the equator ID for 8 C75 large-grain half-cells during the cavity fabrication.

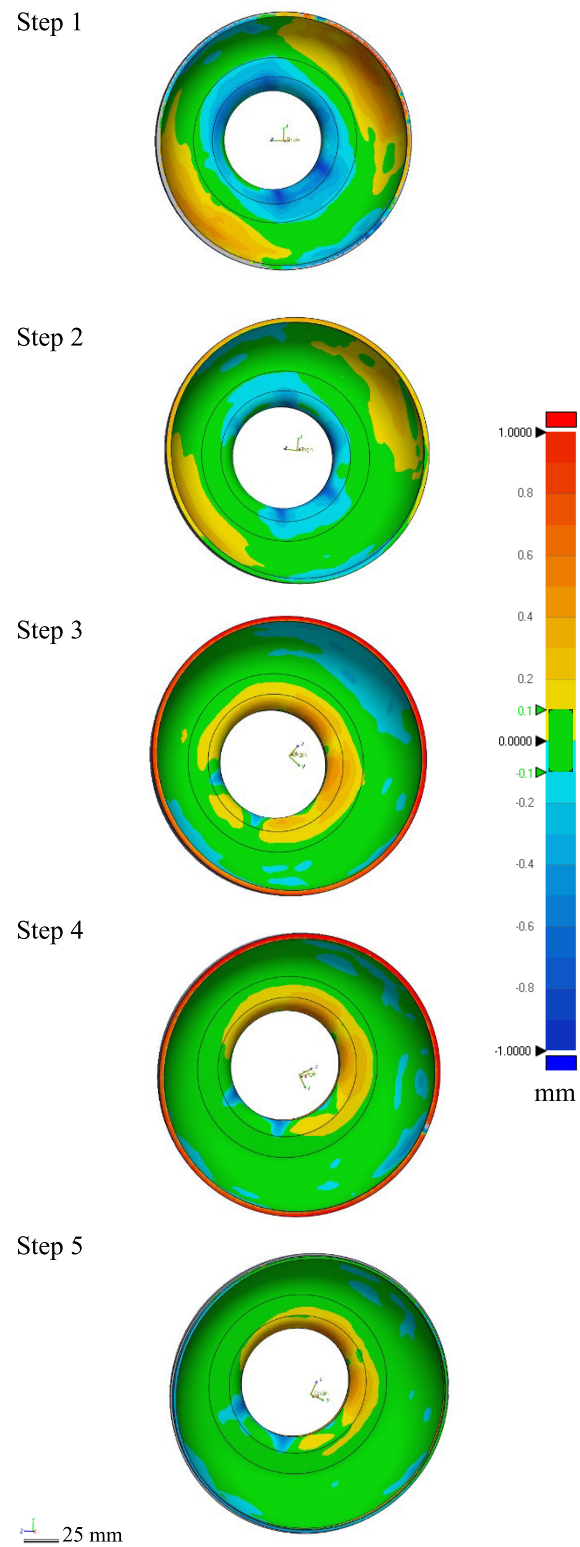

Figure 4: Evolution of shape accuracy of large-grain half-cell HC 01-03 throughout the cavity fabrication. Please refer to the text for details about each step.

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Table 1: Fraction of points within a certain deviation from the ideal shape measured on 8 large-grain half-cell deep-drawn at JLab, for different steps of the cavity fabrication. Please refer to the text for details about each step.

	±0.1 mm	±0.2 mm	±0.4 mm
Step 1	(34 ± 4)%	(68 ± 7)%	(92 ± 3)%
Step 2	(54 ± 6)%	(86 ± 7)%	(98 ± 1)%
Step 3	(53 ± 6)%	(82 ± 6)%	(94 ± 2)%
Step 4	(60 ± 9)%	(86 ± 4)%	(95 ± 1)%
Step 5	(63 ± 8)%	(89 ± 3)%	(98 ± 1)%

C75 Fine-Grain Half-Cells

To have a direct comparison on the shape accuracy between standard fine-grain and large-grain Nb discs after deep drawing, a 2.8 mm thick fine-grain, RRR = 480 disc was also deep-drawn at 100 ton, followed by iris coining at 25 ton. A 0.381 mm thick Teflon sheet was used to compensate the lesser thickness of the Nb disc. Figure 5 shows the shape comparison for the fine-grain disc after deep-drawing. The fraction of points within ±0.1 mm was 63%, 89% of the points were within ±0.2 mm and 97% of the points were within ±0.4 mm from the ideal shape.

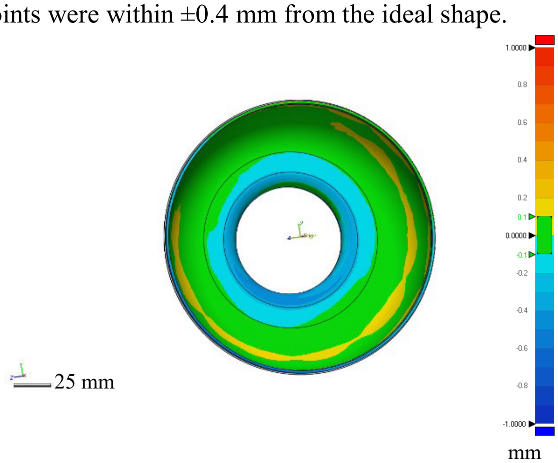

Figure 5: Shape deviation of fine-grain C75 Nb half-cell ATIFG2 after a single deep-drawing and iris coining at JLab.

Comparison with Shape Measurement at RI

CMM measurements of the half-cells' shape deviation are done at RI throughout the fabrication of C75 cavities from large-grain Nb discs, using a ZEISS CONTURA CMM with a ZEISS CALYPSO metrology software, with nominal accuracy of 1.8 µm [7]. Half-cell HC 02-24 was deep-drawn at RI and measured both at RI and Jefferson Lab and the shape comparisons using the systems at RI and JLab are shown in Fig. 6. 225 data points were taken at RI, whereas ~557,000 data points were acquired with the system at JLab. Table 2 shows a summary of the shape accuracy of half-cell HC 02-024 measured at RI and JLab: the lower number of points measured at RI seem to bias the fraction of data points towards ±0.1 mm.

The shape deviation of 15 large-grain half-cells was measured at RI after deep-drawing and the average of points within ±0.1 mm was (64 ± 4)%, which is consistent with the data measured at JLab on HC 02-024.

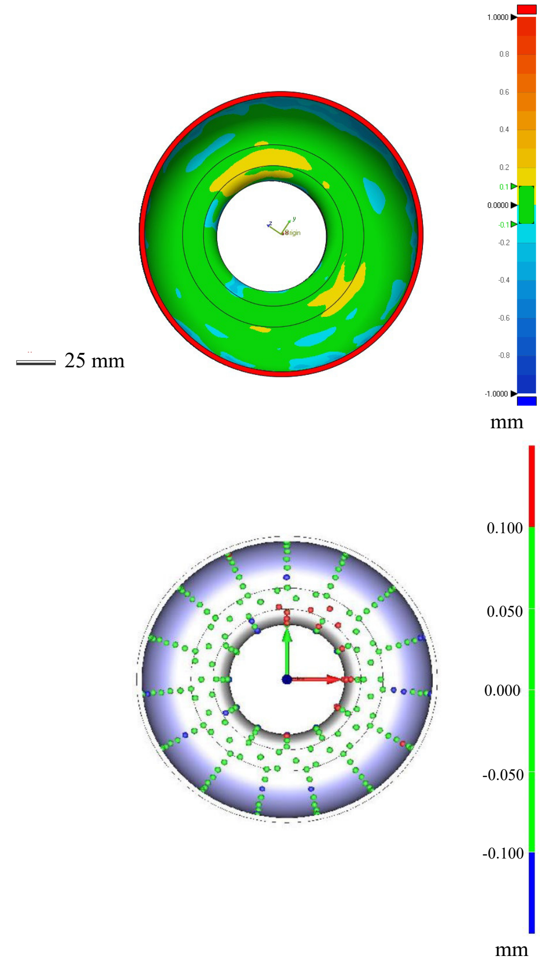

Figure 6: Comparison between the shape of large-grain half-cell HC 02-024 deep-drawn at RI, measured both at RI (top) and JLab (bottom) with different CMM systems.

Table 2: Fraction of points within a certain deviation from the ideal shape measured on one large-grain half-cell deep-drawn at RI and measured both at RI and JLab using different CMM systems.

	±0.1 mm	±0.2 mm	±0.4 mm
JLab	65%	87%	95%
RI	80%	95%	99%

DISCUSSION

The deep-drawing method in use at RI resulted in a better shape accuracy than achieved at JLab, after one deep-drawing step, whereas the results were comparable after the half-cells were annealed and re-stamped. Welding of the stiffening rings introduces a deviation of ~0.3 mm in the welded area. A reshaping tool used at JLab and RI allows to improve the shape accuracy after welding half-cells into dumb-bells and the stiffening rings. Table 3 lists a

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summary of the fraction of points within a specified deviation from the ideal shape after final reshaping and before the trimming and machining of the equator weld-prep, averaged over the 192 C75 large-grain half-cells produced at RI from 3 different ingots.

Table 3: Fraction of points within a certain deviation from the ideal shape measured at RI on 192 C75 large-grain half-cells deep-drawn at RI from different ingots, after final reshaping and before final dumb-bell equator trimming and weld-prep machining. 64 half-cells were produced from each ingot.

Ingot SN	**±0.1 mm**	**±0.2 mm**	**±0.4 mm**
02	65%	89%	99%
04	66%	90%	99%
05	63%	85%	96%

CONCLUSION

It is well-known that Nb half-cells deep-drawn from large-grain discs have larger shape deviation than those deep-drawn from fine-grain material. However, the shape can be corrected to be within ±0.2 mm for ~90% of data points acquired with a CMM prior to final equator welding of dumb-bells by using properly designed dies and reshaping tools. Reshaping tools are commonly used to correct the shape of fine-grain dumb-bells as well, particularly after welding of the stiffening rings, therefore the fabrication of cavities from large-grain material does not add a significant amount of steps, compared to that of fine-grain cavities.

ACKNOWLEDGEMENTS

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