PROGRESS TOWARDS Nb_3Sn CEBAF INJECTOR CRYOMODULE*

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Abstract

Operations at 4 K instead of 2 K have the potential to reduce the operational cost of an SRF linac by a factor of 3, if the cavity quality factor can be maintained. Cavities coated with Nb_3Sn have been shown to achieve the accelerating gradients above 10 MV/m with a quality factor around 10^{10} at 4 K. Because such performance is already pertinent to CEBAF injector cryomodule, we are working to extend these results to CEBAF accelerator cavities, envisioning coating of two CEBAF 5-cell cavities with Nb_3Sn. They will be installed in an injector cryomodule and tested with beam. The progress on this path is reported in this contribution.

INTRODUCTION

The cryogenic test facility (CTF) at Jefferson Lab provides sub-atmospheric liquid helium for testing purposes in the test lab. The vertical test facility (VTA) in the test lab hosts eight cryogenic dewars for SRF cavity testing with several dewars being often operated simultaneously. The test lab is also home for cryomodule test facility, where assembled cryomodules are RF tested at 2 K, before they are sent for integration into accelerators. The test lab will also soon feature an upgraded injector test facility (UITF), which will serve as a test bed for low energy beam tests in the test lab. All these facilities rely on 2 K helium delivered from CTF. With projected vertical test area and CMTF tests in support of CEBAF, LCLS upgrade work and R&D, as well as UITF beam tests, CTF is expected to be run at full capacity and testing times will be carefully coordinated to fulfill all commitments. Ability to run UITF, which hosts only one accelerating quarter-cryomodule, Fig. 1, at 4 K helium instead of 2 K may increase beam time available to users. Since Nb_3Sn cavities have recently been shown to achieve gradients suitable for this facility at 4 K [1, 2], we are working to demonstrate 4 K operation of a quarter-cryomodule with Nb_3Sn cavities. If cavity performance, demonstrated on single- and two-cell cavities, can be translated to the two CEBAF cavities in a quarter-cryomodule, the cryomodule can be efficiently run with 4 K helium. On the other hand, since long-term cryomodule operation with Nb_3Sn cavities has never been tested, such a run will provide valuable data towards operation of Nb_3Sn cavities in accelerators.

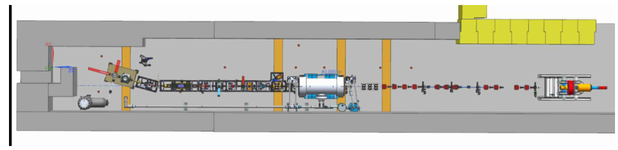

Figure 1: A draft layout of the upgraded injector test facility. The quarter-cryomodule is seen in the center of the picture and will be used to accelerate electron beams up to 10 MeV.

With these goals in mind we are working to upgrade our existing Nb_3Sn coating system to be able to coat CEBAF cavities from the spare CEBAF quarter-cryomodule. In parallel with the system upgrade, we conducted first coating tests of a CEBAF 5-cell cavity, which was modified to fit in our existing coating system. Test results and the progress in the coating system upgrade are reported here.

CAVITY DEPOSITION SYSTEM UPGRADE

The JLab Nb_3Sn coating system needs to be upgraded in order to fit a CEBAF cavity. Our present insert for Nb_3Sn coating, which was designed to coat single-cell R&D cavities, is about 11” ID and has a hot zone, which is about 22” long, [3], while a CEBAF 5-cell cavity is 28 1/4” long and can fit inside a 15” ID cylinder. Hence a new insert was design to allow for a 17” ID and 40” long coating space. The insert is being made out of 4 mm reactor grade niobium sheets. The sheets were cut and rolled to form half cylinders, which were then electron beam welded together. The cylinder is covered by a deep-drawn 4 mm niobium cover on one end, which will also be electron beam welded, and a double O-ring brazed SS flange on the other. In order to extend the hot zone, the furnace is modified to extend the heat shields up. The new heat shields are made out of 0.015” thick molybdenum and are similar in design to the existing ones. The heat shields are supported by a 0.125” SS can on the outside. In order to fit the heat shield extensions, a new door, which sits on the top of the furnace, must be made. The custom door was specified at JLab and is being purchased from Lesker. The door will interface with the existing furnace body on the bottom and will have a O-ring seal on the top, which will mate to a water-cooled zero-length reducer, also purchased from Lesker. The rest of the coating system will re-used. In Fig. 2, the sketch of the upgraded system is shown, where colored components

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are the new parts being built and grayed components are existing parts.

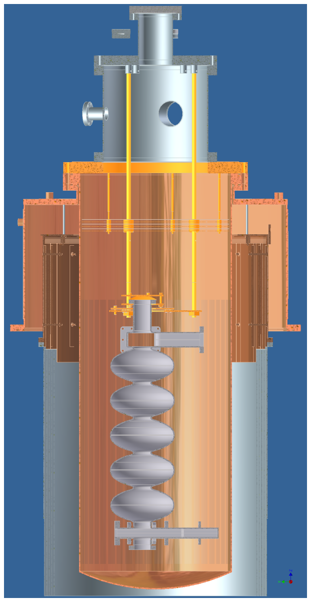

Figure 2: Sketch of Nb_3Sn system upgrade. The new components are colored, and the old components are gray. The new insert will provide 17" ID x 40" long coating space. For comparison, a CEBAF cavity is shown inside the new insert.

5-CELL CAVITY COATING

In order to test how our existing coating techniques translate to 5-cell CEBAF cavity coating, we modified IA007, one of the first CEBAF cavities. The end groups were removed from the cavity for C75 project, and 1" beam tubes with Nb flanges were electron beam welded instead. After this modification, cavity nomenclature was changed to CE5IA007. Numerical simulations showed that, if the beam covers are made out of niobium, a contribution of about 0.1 nΩ to the total loss can be expected from the beam tubes.

CE5IA007 received 50 μm BCP, was annealed at 800 °C for two hours, tuned for 96% field flatness, and received another 25 μm EP, before it followed the standard preparation steps for cavity testing. The cavity was then tested at 2 K as a baseline test before Nb_3Sn coating. During testing we encountered mild multipacting, probably, due to the short beam tubes, which was processed, and the cavity was limited by a quench at about E_{acc} = 10.5 MV/m.

After the baseline test, CE5IA007 was disassembled and HPR rinsed, before it was assembled for Nb_3Sn coating. In Fig. 3, CE5IA007 is shown drying in the clean room after HPR. The cavity was loaded with 9 gr of Sn and 3 gr of $SnCl_2$ and coated using the current JLab standard temperature profile [2]. Visual inspection, after the cavity was removed from the coating chamber, did not indicate any up-down coating asymmetry. Looking both from the top and the bottom of the cavity, we saw Nb_3Sn characteristic grayish color, and the cavity appeared to be uniformly coated without any obvious features, Fig. 4 [top]. Inspection with KEK camera of the equator regions also indicated complete and uniform coating in all cells. However, it also revealed multiple features on the weld seam, which were likely present in the substrate before coating, Fig. 4 [bottom]. After inspections, the cavity was degreased, HPRed, and assembled for the vertical tests. Quality factor as a function of accelerating gradient was measured at 2.0 and 4.3 K and is shown in Fig. 5. Low field quality factor was about $5{\cdot}10^9$ at 4.3 K, but degraded quickly with field. At 2 K, the low field quality factor improved to about $2{\cdot}10^{10}$,

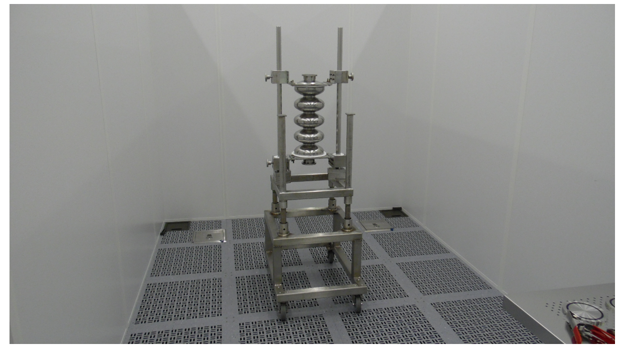

Figure 3: CE5IA007 is shown drying in the cleanroom before assembly for Nb_3Sn coating. The cavity was built from one of the first CEBAF cavities, IA007. The end group were removed from IA007 to be used for C75 project, and 1" beam tubes with niobium flanges were welded instead. The shorter beam tube necessitated the use of custom Nb covers for RF testing.

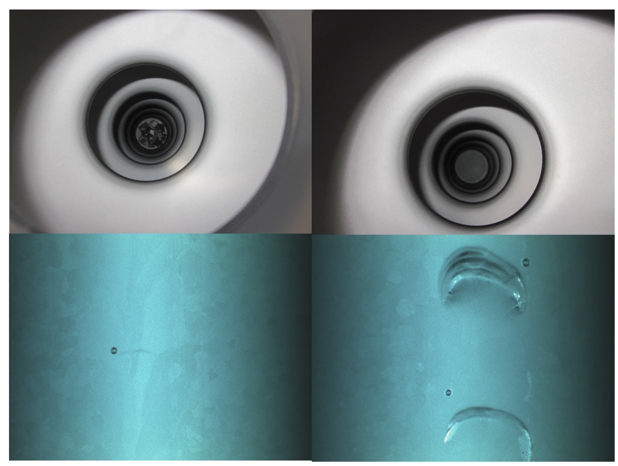

Figure 4: Optical inspection pictures of CE5IA007 after Nb_3Sn coating. The top left picture shows the inside of the cavity looking from the top after coating. On the bottom niobium packages, which contain Sn and $SnCl_2$ before coating can be seen. The top right image shows CE5IA007 surface looking from the bottom. The bottom left image shows an example of the equator region in the first cell from the top as seen with KEK optical inspection tool. The bottom right images shows an examples from the fifth cell.

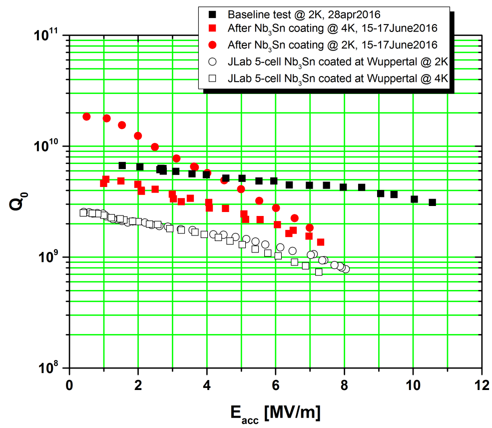

Figure 5: 5-cell cavity test results. Solid black squares show the baseline test result of CE5IA007. Solid red squares and circles show CE5IA007 test results at 4.3 and 2.0 K respectively. Open black square and circles show cavity test data at 4.3 and 2.0 K respectively for a 5-cell coated at Wuppertal, which is reproduced here from [tesla200].

but a strong Q-slope again limited the highest field to about E_{acc} = 8 MV/m. For comparison, in Fig. 5, we also show the baseline niobium cavity test result at 2 K.

A CEBAF-like 5-cell cavity was coated before at Wuppertal [4]. It was interesting to compare CE5IA007 results with those of a similar cavity coated at Wuppertal, Fig. 5 [black circles and squares]. Apparently, it was also a bare cavity without end groups, which was sent from JLab to Wuppertal for Nb_3Sn coating. CE5IA007 cavity has a better quality factor, especially, at 2 K, but, both cavities are limited, if we account for a different low field quality factor, by a very similar Q-drop.

Wuppertal suggested that the limitation in 5-cell cavity was due to the complexities of transferring single-cell coating techniques to a larger 5-cell. However, the coating that we did on CE5IA007 looked very similar visually to our single-cell coatings. Optical inspections that we did on CE5IA007 did not reveal any obvious up-down asymmetry. To check for surface resistance variation across the 5-cell cavity, we have measured quality factor as a function of field at 4.3 K in several passband modes. The analysis of the passband mode data suggests that the Q-drop largely comes from the center and one or both cells adjacent to it. The end cells on average performed better. Because of these observations we think that the strong Q-drop does not result from the coating itself, but rather is caused by the equator features, which were present in the substrate material before coating. Similar features have been observed in other CEBAF cavities, and, probably, were also in the cavity coated by Wuppertal, hence, a similar slope.

If the features are the cause of the Q-drop in CE5IA007, then we can expect a better performance from a better substrate. However, our present experimental plan is to use the existing CEBAF 5-cell cavities from the spare cryomodule for Nb_3Sn coating and cryomodule testing. CEBAF 5-cell cavities in the quarter cryomodule are likely to have similar features, in which case, even if Nb_3Sn coating using our present coating techniques results in a uniform and complete coverage on the cells and end groups, we will be limited by a similar Q-drop. If coated CEBAF 5-cell cavities will be proved to be limited by features in the existing substrate, we plan to replace the problematic material to address the problem.

SUMMARY AND FUTURE PLANS

Work is in progress to increase the coating volume of JLab Nb_3Sn coating system, so that CEBAF 5-cell cavities can be coated. The design is complete and all the component are being procured and manufactured.

First tests have been done with one of the existing CEBAF cavities, which was modified to fit into the existing coating system. Measurements show that the coated cavity performance was limited by a strong Q-drop, likely due to the pre-existing surface features in the niobium material. Even if the complete and uniform Nb_3Sn coating is achieved after the coating system upgrade, the coated CEBAF cavity is likely to be limited to similar gradients due to substrate imperfections.

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