29th Linear Accelerator Conf. LINAC2018, Beijing, China JACoW Publishing
ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO019

STUDY ON CLEANING OF COPPER PLATED BELLOWS FOR LCLS-II*

L. Zhao†, E. Daly, K. Davis, G. Eremeev, T. Reilly, A-M. Valente-Feliciano, K. Wilson
Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA

Abstract

Inter-cavity copper plated bellows are part of the LCLS-II cryomodule beamline components. Since the bellows are close to superconducting radio frequency (SRF) cavities during accelerator operation, it is desirable that these bellows have similar cleanliness as SRF cavities. Studies have been done to help evaluate bellows interior cleanliness after the standard bellows cleaning procedure at Jefferson Lab.

BACKGROUND

LCLS-II cryomodule design includes copper plated bellows between each cavity, similar to that of the European XFEL [1, 2]. During string assembly at JLab, bellows are assembled to the cavity vertically as part of the cavity sub-assembly. Connections made on the rail were done horizontally [3]. Bellows are cleaned in a manner similar to the standard hardware cleaning processes except that lower solution temperature and expedited drying are applied. Bellows present some challenges for cleaning, for example, the convoluted shape is more difficult to clean and dry, the adhesion quality of the plating added concerns during processing [4]. To help confirm our horizontal assembly practice as well as understanding bellows cleanliness, three cavities were tested with a bellows assembled to the top of each cavity. Particle samples were collected from one of the three cavity-bellows assembly after vertical testing for further study.

EXPERIMENTS

Processing of Cavities and Bellows

Bellows were cleaned in an ultrasonic tank with ultrapure water and Citranox®, thoroughly rinsed with ultrapure water, dipped in acetone, and blown dry with nitrogen. Previously field-emission-free cavities were selected for this experiment. CAV0116: cleaned bellows were assembled horizontally onto cavity; cavity was pumped down, and then attached to the test stand with bellows on the top. After vertical test, the bellows were stretched and squeezed 0.5 inch while staying on top of the cavity before the next vertical test. CAV0278 and CAV0286: Bellows were assembled vertically onto the cavity; the cavity was flipped and received the final HPR with the bellows on the top; after final assembly (the bellows were still wet), the cavity was pumped down and attached to the test stand with bellows on the top.

Vertical RF Test

The three cavities were tested vertically at 2.0 K to see if there was any early field emission onset. The cavity configuration during vertical testing is shown in Fig. 1.

Sampling of Bellows and Cavity

After vertical test, the interior of CAV0278 and bellows 2068 were sampled to help understand the source of field emitters. Sampling was performed by two operators using two types of tooling, to allow comparison of findings from the two sampling process. Particles found in both sampling processes are likely from the surface of interest, while those found in only one sampling process could be introduced by the sampling process. In the first method (L series), a cleaned Gore-Tex (Teflon, or PTFE) piece was used to sample the surface of interest and transfer any particles onto a carbon tape, and the carbon tape was preserved carefully until SEM analysis. Two samples were collected at each of three locations: the flat region and inside of one convolution of the bellows (L1, L2), the cavity beam tube next to the bellows (L3, L4), and the cavity beam tube on the other end (L5, L6). In the second method (S series), a piece of isopropanol soaked cleanroom wipe (TX®1082 QuanSat, polyester) was used to sample the surface of interest and transfer the sample to a carbon tape, which was preserved inside a commercially available standard SEM sample case [5]. Sample locations are shown in Figure 1. One sample was collected at each of eight locations: bellows top flat region (S0456), inside top first convolution (S0457), several iris (S0458), inside bottom first convolution (S0459), bottom flat region (S0460), shaking of bellows (S0461), cavity top beam tube (S0462), and cavity bottom beam tube (S0463).

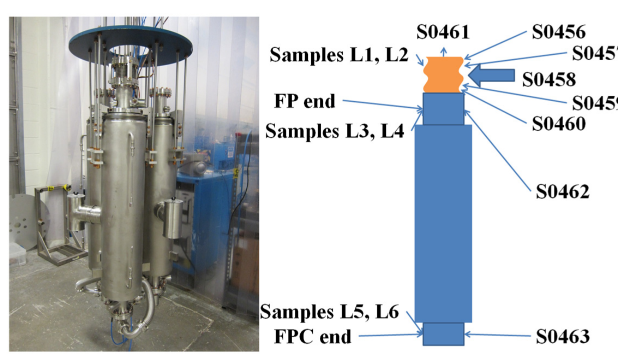

Figure 1: Bellows attached cavity on a test stand waiting to be loaded into the Dewar (left). Sampling locations on CAV0278-Bellows 2068 (right).

* Authored by Jefferson Science Associates, LLC under U.S. DOE Contracts DE-AC05-06OR23177 and DE-AC02-76SF00515 for the LCLS-II Project.
† lzhao@jlab.org

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Analysis Process

SEM/EDS analysis: The topography and elemental analysis of the particles are performed on TESCAN Vega3 SEM equipped with TEAMTM EDS System.

Interpretation and sizing: Based on the elemental ratio from EDS analysis, each particle is assigned as a compound or a mixture of several species. The sizes of particles are decided manually from the SEM image.

Categorize: Particles are categorized according to the interpretation of SEM/EDS data.

Count: The number of particles is counted in each category for each sample.

Separate distractions from suspects: Particles which are likely to be introduced from elsewhere rather than the sampled surface are considered distractions.

RESULTS AND DISCUSSION

VTA performance of each cavity is shown in Fig. 2. CAV0116 showed no early field emission onset during all three tests, indicating that the standard cleaning process and horizontal assembly procedure is providing satisfactory cleanliness. Exercising bellows mildly in-situ did not degrade the cavity performance. On the other hand, early onset of field emission was observed for both CAV0278 and CAV0286 after rinsing with bellows on top of the cavity, indicating that particulates were likely introduced into the cavities from the bellows during the HPR.

After sampling, 14 carbon tape samples were generated and a total of 219 particles were characterized in this study, as shown in Fig. 3. Particles from sampling media (Teflon and polyester) were not included. The number of particles on each sample varies between a few and 30. The number of particles in each category on each sample gives the distribution of particle categories inside the cavity and bellows.

A total of 24 categories were identified. A few categories of particles are described below, and their typical SEM images shown in Fig. 4. The average particle size in each category is shown in Fig. 5.

- Cu plating: From bellows inner surface, has a unique porous texture, possibly CuO, $Cu(OH)_2$, or $CuCO_3$ according to the atomic ratio;
- Precipitates, Ca: Mostly Ca and O, possibly CaO, $Ca(OH)_2$, or $CaCO_3$ according to the atomic ratio;
- Precipitates, mixed: Contains elements such as P, S, Cl, together with Na, Mg, K, Ca, and sometimes Fe, possibly metal and/or mineral particles that have been through chemical or cleaning process where they are mixed with salt or residue in the solution;
- Mixed metal clusters: Contains several metal elements such as Fe, Cu, Ti, Mn, Si, Cr, but no anions, likely resulted from cross contamination between different metal parts during handling;
- Mineral: Usually contains Si, Al, Mg, Ca, Na, K, and O, such as Talc, Kaolinite, and Dolomite); SiO_2 and Al_2O_3 are not included in mineral category, they are listed separately instead.

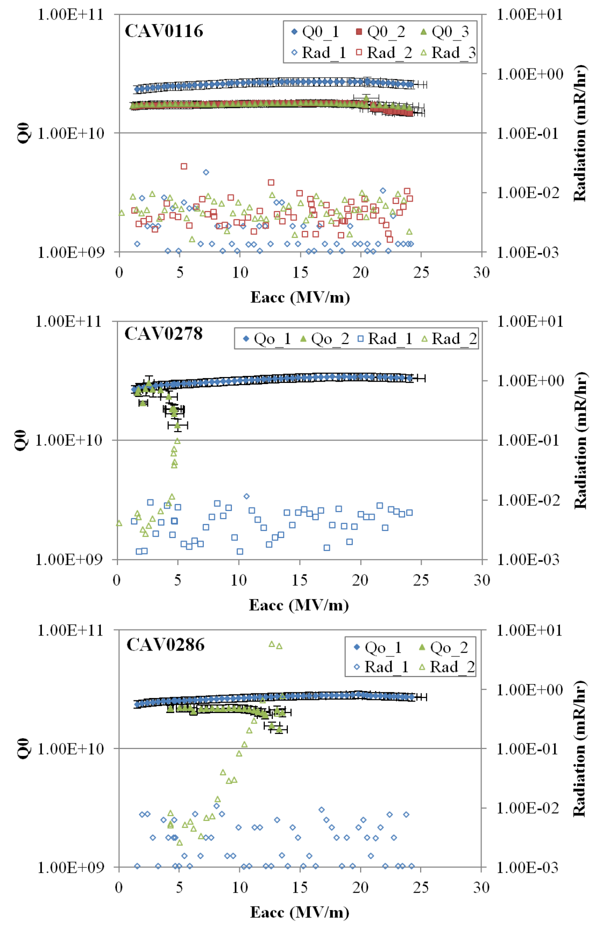

Figure 2: Vertical testing results of CAV0116 (without bellows, with bellows before exercising, with bellows after exercising), CAV0278 (without bellows and with bellows), and CAV0286 (without bellows and with bellows).

ID	Total	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
L1	2	1																						1	
L2	7	1	1	1	2		1		1																
L3	13		1	4			3											5							
L4	20	5		3			2	2			1		1					4						2	
L5	12	4	3	1			1						1					2							
L6	12		1	5			1	2	1									1				1			
S0456	17		2	3	2	2										6			2						
S0457	12	1	4	2	1			1	1		1								1						
S0458	18		4	3	7	1				1						1								1	
S0459	20	2	2	1	4	5			1	2	1							1			1				
S0460	29		7	2	5	3					1			5		1			1	2					2
S0461	16	6	2						1				1			2	3						1		
S0462	19		4	3	5				1	1							3	1						1	
S0463	22	1	3	1	1		1	1				1			9			2						2	

Figure 3: The number of particles in each category (C1-C24) on each sample. The color of each cell is scaled based on the number of particles in the cell (0~9). Darker color means more particles.

Several types of particles are decided to be distractions, due to their apparent source, distribution, or very low count: Particles introduced by tooling and sampling process, such as polymer material from the wipe (C-F, C-O), metal from scissors and tweezers (stainless steel, other types of steel, and Al-Mg), protein from operators (C-N-O-S), particles existing in the cleanroom from other processes (Sn, SnO, Ag, AgO, Al, Fe, Cu (non-plated copper)), and other stray particles (Zn-Al-O, Na_2SO4, NaCl,

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Cr). Species such as mixed metals, Fe oxide, and Talc were considered distractions because they appear only in one sampling process.

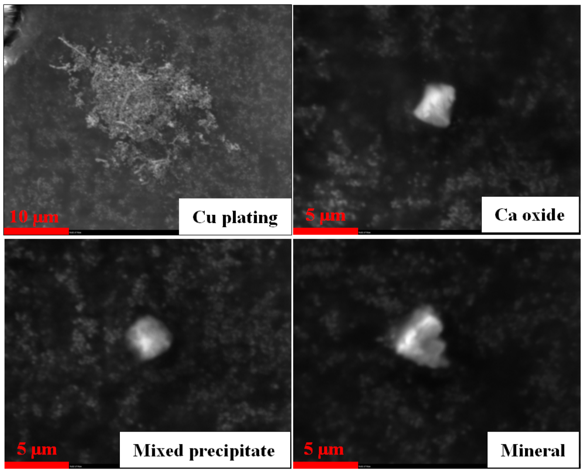

Figure 4: Typical particles of several main categories: Cu plating, Ca oxide, mixed precipitate, mineral.

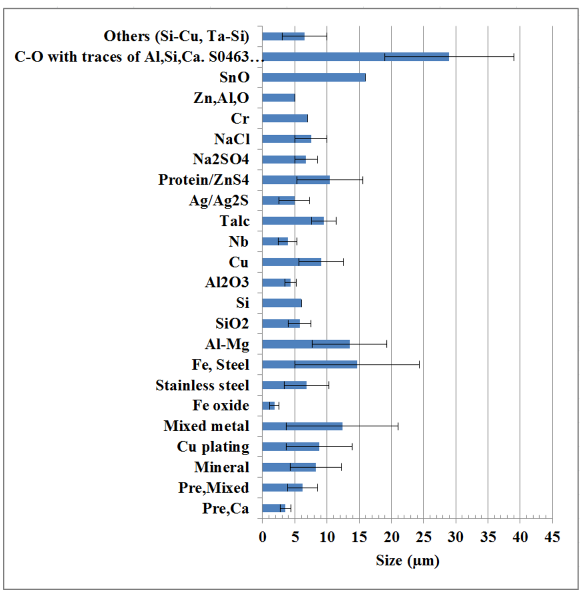

Figure 5: Size of different categories of particles, average and standard deviation.

Cu plating particles (C4) are seen in both sampling process, more on bellows than on cavities. Sample S0458 was from wiping several iris regions of the bellows, and it showed the most Cu plating particles, indicating that the plating particles tend to dislodge more easily on a surface under stretch. Interestingly, sample S0461 was from shaking bellows above a clean wipe then sampling the wipe; it showed no Cu plating particles, which could indicate that Cu plating does not come off bellows surface without strong force such as wiping.

Mineral particles (C3) also showed wide appearance. Many of precipitates (C1, C2) were observed in both the bellows and the cavity, even on the shaking sample (S0461). This indicates the precipitation particles dislodged easily from the bellows surfaces.

Figure 5 shows the size of particles in each category from both sampling methods. It should be noted that particles collected with two different methods showed slightly different characteristics. Even though assigned to the same category based on element presence, they can vary in sizing and topography.

CONCLUSION

Based on particle analysis, copper plating, mineral, and precipitates are likely related to the early onset of field emission in CAV0278. Extra cleaning steps have been added to reduce the chance of surface residue in bellows. Also, any changes to bellows cleaning need to be carefully assessed since aggressive methods can remove Cu from the plating.

As for the analysis process, it is noticed that a few factors could introduce bias. Since it is not practical to sample the entire inner surface of the cavity and bellows, therefore limited coverage of the interested surface during sampling could limit the information obtained from the surface. Not necessarily all particle collected is characterized in the SEM, although efforts were made to cover most of the particles on each carbon tape. Categorizing is subjective due to complication of particle history; particles with the same element may present in different forms (big particle vs. powder), which also affects size determination.

Despite the limitations, this study provided a procedure to analysis contamination and added knowledge to the understanding of particle species in our processing environment. Collecting more data to build up a database of particles would be beneficial in long term.

ACKNOWLEDGEMENTS

Authored by Jefferson Science Associates, LLC under U.S. DOE Contracts DE-AC05-06OR23177 and DE-AC02-76SF00515 for the LCLS-II Project. We thank Josh Spradlin and Olga Trofimova for helping with SEM/EDS analysis, Chris Dreyfuss for assisting with sampling process.

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