PRODUCTION OF COPPER-PLATED BEAMLINE BELLOWS AND SPOOLS FOR LCLS-II*

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Abstract

The SLAC National Accelerator Laboratory is currently constructing a major upgrade to its accelerator, the Linac Coherent Light Source II (LCLS-II). Several Department of Energy national laboratories, including the Thomas Jefferson National Accelerator Facility (JLab) and Fermi National Accelerator Laboratory (FNAL), are participating in this project.

The 1.3-GHz cryomodules for this project consist of eight cavities separated by bellows (expansion joints) and spools (tube sections), which are copper plated for RF conduction. JLab is responsible for procurement of these bellows and spools, which are delivered to JLab and FNAL for assembly into cryomodules. Achieving accelerator-grade copper plating is always a challenge and requires careful specification of requirements and application of quality control processes. Due to the demanding technical requirements of this part, JLab implemented procurement strategies to make the process more efficient as well as provide process redundancy. This paper discusses the manufacturing challenges that were encountered and resolved, as well as the strategies that were employed to minimize the impact of any technical issues.

DESIGN

Each cryomodule contains a short spool at the upstream end of the beamline, seven production (PrCM) bellows separating the eight cavities, a short bellows after cavity eight, and a long spool at the downstream end of the beamline. The quad magnet, which is split into two halves in the vertical plane, is assembled around the long spool after the beamline vacuum is sealed up (Fig. 1).

The cryomodule was designed by FNAL based on the original European XFEL design, with some modifications for this application [1]. The original specification called for the copper plating to cover the interior surface of the parts and wrap around 5 mm onto the flange face. After a request by the plating vendor, the requirement was modified to call for plating on the inside surfaces of the bellows and spools only, but not necessarily wrapping onto the flange face. This was to facilitate the plating, which is difficult on surfaces perpendicular to the plating cathode.

Simulations by FNAL show that the beamline bellows and spools are not exposed to high RF fields, but the power dissipation from beam-induced wakefields at higher LCLS-II design currents could place a significant heat load on the cryomodule 2K circuit unless these stainless steel components are copper plated [2]. The internal surface finish of these components (specified as 3.2 µm = 125 µin) has no impact on the thermal design, but resulted in complications for the platers, who resorted to hand polishing the interior surface of the spools to remove burrs. The surface finish also made quality control more problematic, due to the difficulty in differentiating between plating flaws and imperfections of the stainless steel substrate: For example, small blister-like bumps were visible on some of the plated parts, but as weld splatter was also observed on some unplated parts, it was unclear whether this was causing the small bumps in the plating.

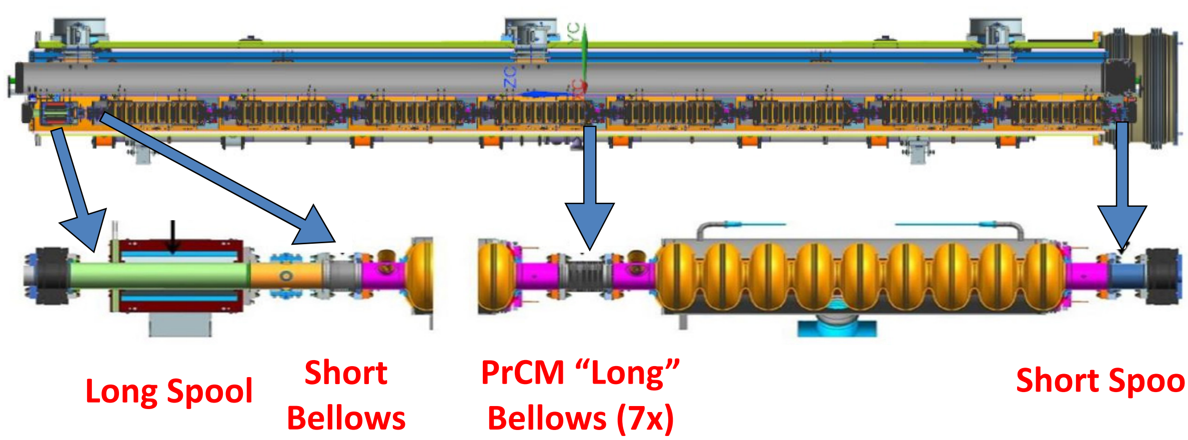

Figure 1: Location of beamline bellows and spools in the LCLS-II cryomodule.

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PROCUREMENT PLAN

For the LCLS-II project, redundant procurements were implemented for several critical components to mitigate delivery delays or technical failures. For the copper plating of the beamline bellows and spools, an effort was made to award plating contracts to two different vendors. In the first phase of the solicitation process, vendors provided technical and business information which was used to down-select to only those vendors that showed potential based on their experience and qualification, and who also offered a reasonable price. After an extensive outreach effort including contacting known vendors worldwide, and public postings of the request for proposal (RFP) containing the technical specification, only four vendors submitted paper proposals. Of those four vendors, only two qualified for phase two of the solicitation activity. The other two had a combination of non-compliance with the RFP, known performance issues or unreasonable pricing.

Phase two consisted of a copper plating demonstration using bellows provided by JLab that were identical to the production parts. Unfortunately, despite significant opportunities by JLab to qualify both vendors and make two awards, only one vendor successfully plated the qualification pieces, and therefore that vendor received a contract to plate the full production quantity of LCLS-II beamline bellows and spools.

COPPER PLATING QUALITY CONTROL

The LCLS-II project has outsourced quality control inspections on some procurements to reduce the workload at JLab and FNAL. For the beamline bellows and spools, the plater was asked to perform an array of standard quality control tests to verify the integrity of the copper plating. These include a cold shock, a compression/expansion test, a blister test at 400º C for one hour, and a visual inspection with a borescope. The vendor provided certification that these tests were performed with acceptable results.

The analysis from FNAL showing that the beamline bellows and spools see only weak RF fields implies that the thickness of the copper plating is not critical and, in fact, that gaps in the plating can be accepted (although none have been seen on these parts). Based on this, a decision was made that rejection criteria for plated parts are any features that could result in (1) flaking or (2) outgassing.

To verify the plating, the bellows and spools are inspected again with a borescope after arriving at JLab. In addition, the parts are leak checked and cleaned before installation on the cavity string. Some interesting features were observed on the plating. These were investigated in order to verify that the features observed are not detrimental to the plating.

Possible Inclusion

A few parts exhibited stains with unusual dark centers (Fig. 2). There was some concern that this might be an inclusion in the plating.

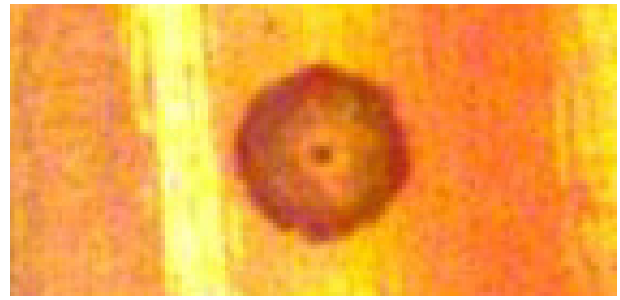

Figure 2: Spot with center before polish.

One part was lightly buffed at the location of the discoloration with a very fine Scotch-Brite cloth. With minimal plating removed, the dark spot at the center of the stain was removed, indicating that it was a very superficial discoloration (Fig. 3).

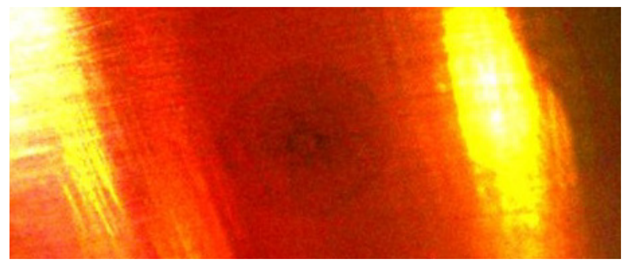

Figure 3: Spot with center after polish.

Dark Spots

Small dark spots, generally believed to be "water spots" or oxidation from moisture were commonly observed on the plating (Fig. 4). Some investigation was undertaken to determine the best way to remove the discoloration and verify that the spots were cosmetic and not indicative of contamination.

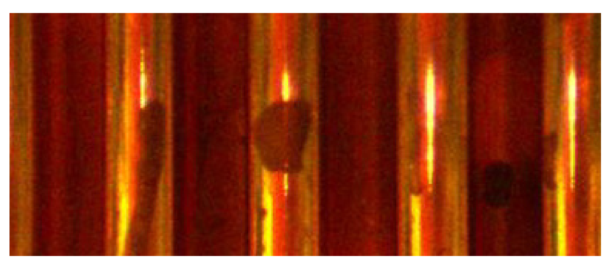

Figure 4: Typical spot at incoming inspection.

Several parts showing dark spots were baked in a vacuum furnace at 400º C for one hour, which is the recipe for a blister test on these plated parts. The spots showed variable levels of fading, but were generally lighter. Parts were baked again at 600º C and at 800º C for three hours. Spots faded progressively, and were considerably lightened by the end of the process (Fig. 5).

Similar results were obtained by cleaning with citranox: bellows and spools were wiped with a 100% citranox solution and then cleaned in an ultrasonic tank with 2% citranox and ultrapure water for one hour.

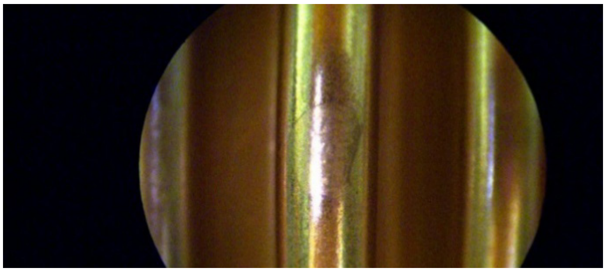

Figure 5: Same spot after 800º C bake.

Rough Plating near Edges

A few parts exhibited an unusual roughness in the plating near the flange; the roughness was usually striated along the part axis (Fig 6).

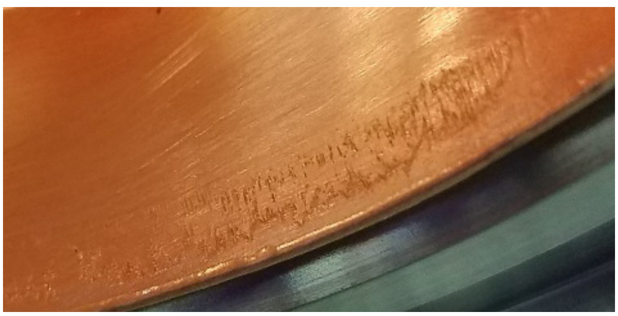

Figure 6: Striations in plating.

Conversation with the plater revealed that this was caused by water leaking past a seal during the strike process. An irregular weld between the body of the bellows convolutions and the flange made it difficult for the gasket used by the vendor during the strike and plating process to seal correctly. Water outside of the bellows was able to leak past the seal into the strike bath, causing uneven concentrations of the bath. This resulted in striations in the strike, which were then plated over. Because the bath is circulated during the plating process, the same effect was not seen with the plating itself.

Discoloration After Assembly

For reasons unrelated to the bellows and spools, the first three cavity string assemblies were disassembled after being pumped down to the beamline vacuum range. It was found after the first two disassemblies that several of the bellows had a purplish tint to them (Fig. 7).

As the prototype bellows had been plated by a different plater using a different procedure, it was theorized that the discoloration was unrelated to the plating process and instead caused by cleaning or handling [3]. Attempts to recreate the discoloration were only successful when the plating was dipped in water, bagged, and allowed to dry. The discoloration, which appears to be only oxidation, was completely cleaned off by a standard citranox rinse. For the third cavity string, the high-pressure rinse procedure was modified to ensure that water was thoroughly drained from the cavities. The benefit was seen after disassembly of the third string, when there was much less discoloration of the bellows.

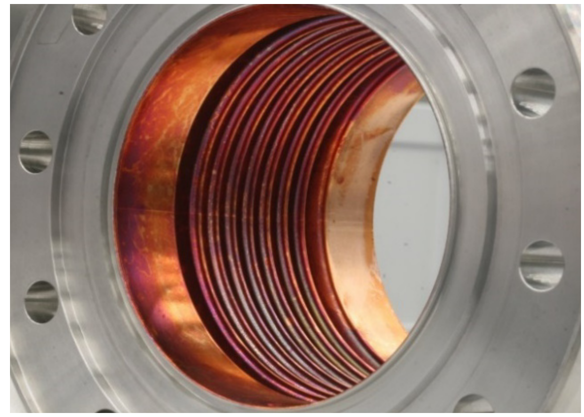

Figure 7: Oxidized bellows.

CONCLUSION

This project has provided the opportunity to investigate the requirements and quality of copper plating for accelerator applications. Future work includes investigating the effect of compression/expansion on the copper-plated bellows. One quality control test calls for compression/expansion of the bellows to its design stroke, +/- 6mm, to verify visually that there is no flaking. However, it has been found that installation of the bellows in the beamline sometimes requires compression beyond the design stroke. Tests are planned to flex a sample bellows up to full compression and perform a particle count to ensure that particulate does not flake into the beamline vacuum space during installation.

By understanding what we need to give the plater in terms of requirements and stainless steel parts, we can make future plating procurements more successful and efficient. Likewise, understanding what we are likely to receive in terms of plated product, as well as the causes and effects of any irregularities in the plating, allows us to reduce unnecessary quality control and ensure a high-quality product. Procurement of copper-plated components for accelerator applications is always difficult due to the stringent requirements and time required for process development, but the procurement of beamline bellows and spools for LCLS-II is proceeding very successfully, meeting schedule and technical requirements.

ACKNOWLEDGMENT

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