# DEVELOPMENT OF THE MANUFACTURING AND QA PROCESSES FOR THE LCLS-II INJECTOR SOURCE VHF ELECTRON GUN*

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*Abstract*

The Linear Coherent Light Source-II (LCLS-II), a new free electron laser currently under construction at SLAC, requires a high repetition rate, high brightness, continuous wave electron source. Lawrence Berkeley National Laboratory (LBNL) has developed a design for a normal conducting VHF gun in response to that need and is responsible for its production and that of the associated beamline, with much of the fabrication done in-house. The 186 MHz copper cavity dissipates approximately 90 kW of RF power while maintaining a vacuum pressure on the order of $10^{-10}$ Torr. The gun is a critical component that requires a very high level of operational reliability to ensure uninterrupted availability for future system users. A quality assurance system to instruct manufacturing and change control is vital to ensure production of a gun that reliably meets physics requirements over an extended period of usage. This paper describes the QA processes developed for fabrication and assembly of the Injector Source electron gun along with results and lessons learned from their current implementation.

## GUN DESIGN AND MANUFACTURING

The LCLS-II Injector Source electron gun is shown in Fig. 1 below.

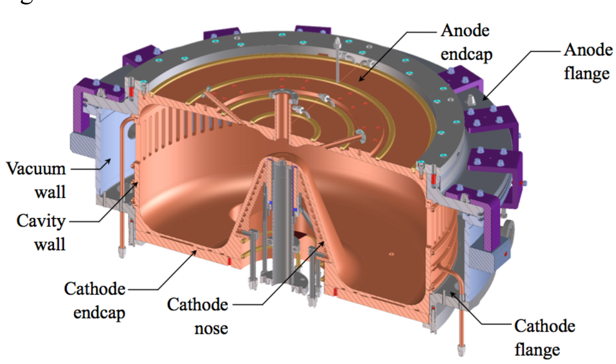


Figure 1: Cross-sectioned model of the electron gun.

The gun's internal copper resonating cavity is fabricated from four subassemblies: an anode endcap, a cathode endcap, a cathode nose, and a cavity wall. The cavity dissipates approximately 90 kW of RF power during operation, so all surfaces are water cooled with channels designed for predicted local surface power densities [1].

An external stainless steel vacuum wall and flanges attached to the cathode and anode supply structural rigidity and create a vacuum pumping plenum, with pumping ports provided on the cathode flange to maintain a $10^{-10}$ Torr UHV environment within the copper cavity [1].

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Electron beam and TIG welding and brazing are used for an assortment of vacuum tight, water tight, and structural joints. The gun has a multi-level fabrication structure with alternating rough machining, joining, and final machining steps to create an undistorted cavity profile.

## QUALITY ASSURANCE PLAN AND ON-SITE WORKFLOW

LBNL has established an LCLS-II Quality Assurance Plan (QAP) [2], which was first implemented for production of LBNL's LCLS-II undulators. Unlike the undulators, the gun is a one-off device; moreover, with the exception of cathode endcap brazement and e-beam joining, gun fabrication was contracted to LBNL's main machine shop, a facility with broad-based manufacturing capabilities. Thus, gun fabrication served as the first trial of on-site QA workflow, shown in Fig. 2 and described below.

Once a final design exists, three document types communicate the manufacturing processes needed to ensure that deliverables meet design specifications.

A Work Instruction (WI) describes how to build a particular assembly in detail beyond that provided in the drawing package, including hold points where certain actions must be performed and verified before continuing.

An Acceptance Criteria Listing (ACL) defines the tests and documentation required to accept components and move to the next-level assembly. An ACL gathers requirements from drawings, WIs, and other specifications.

If needed, a Verification Plan (VP) provides expanded instruction for validating a specific acceptance task.

Fabrication of the gun was divided into five WIs and five ACLs describing production of the nose, cathode, anode, cavity walls, and final assembly. Two VPs were written to describe cavity frequency testing and particle-free cleaning procedures. Added to the WIs were color-coded flowcharts, like that in Fig. 3, outlining the assembly stack-up, including all ACL line items. A summary of those items from the five ACLs is given in Table 1 below.

Table 1: Gun Acceptance Criteria

| Requirement | Quantity |
|---|---|
| Cleaning verification | 94 |
| Dimensional inspection | 78 |
| Vacuum leak check | 41 |
| Conflat knife edge check | 32 |
| Material certification | 12 |
| Electropolish/bright dip verification | 11 |
| Hydrostatic leak test | 7 |
| Torque value record | 7 |
| Other | 6 |


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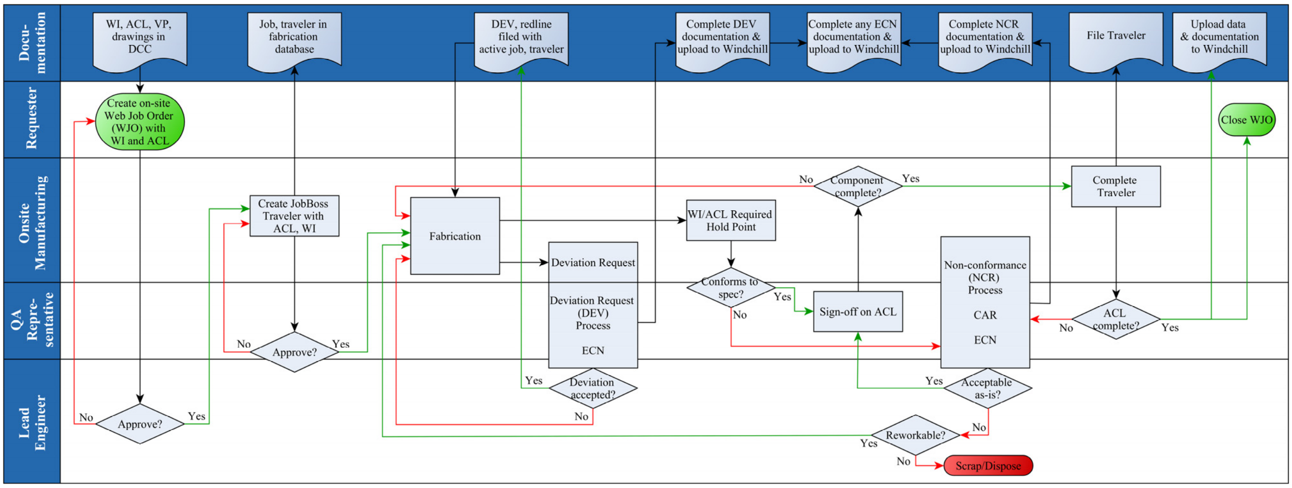


Figure 2: LBNL on-site manufacturing workflow. Based on charts in LBNL's Engineering Process Guide [3].

All components needed cleaning before any welding or brazing operations, yielding many cleaning requirements. Most components required inspection after any machining operation. Some tasks were repetitive to minimize risk as the gun moved through each level of assembly. For example, conflat knife edges were checked not only when first added to the assembly but also after each subsequent step of the build-up; braze and weld joints were leak checked immediately after joining but were also rechecked after any downstream machining of the joint.

Once completed, fabrication drawings, WIs, ACLs, and VPs were released into LBNL's Document Control Center (DCC). The Lab's internal Web Job Order (WJO) system was then used to route work to the main machine shop. WIs, ACLs, and VPs were attached to their associated job order to ensure their dissemination to the shop.

The Lab's main machine shop manages jobs using the JobBOSS software platform; shop travelers are created via JobBOSS to delegate work tasks. For the gun, references to specific WI steps and ACL line items were added at applicable points in the travelers and the travelers approved by a QA representative before work begun.

Once fabrication begins, any departures from the released manufacturing documents require documentation in order to have a document package fully representing the as-built device at project completion.

A Deviation Request (DEV) is used to deviate from specification(s), such as specified materials, tools, tolerances, or procedures, usually for a specific number of unbuilt parts. A Deviation Request identifies the affected part(s), describes the requested deviation(s), and documents the agreed-upon disposition to each request.

A Non-Conformance Report (NCR) documents characteristic(s) of a built part or assembly that do not meet specification. The report identifies the affected component(s), lists the non-conformance(s), and describes corresponding disposition(s). Non-conforming parts may be accepted as-is, reworked, or scrapped.

An Engineering Change Note (ECN) logs requested changes to documents. The note identifies the documents

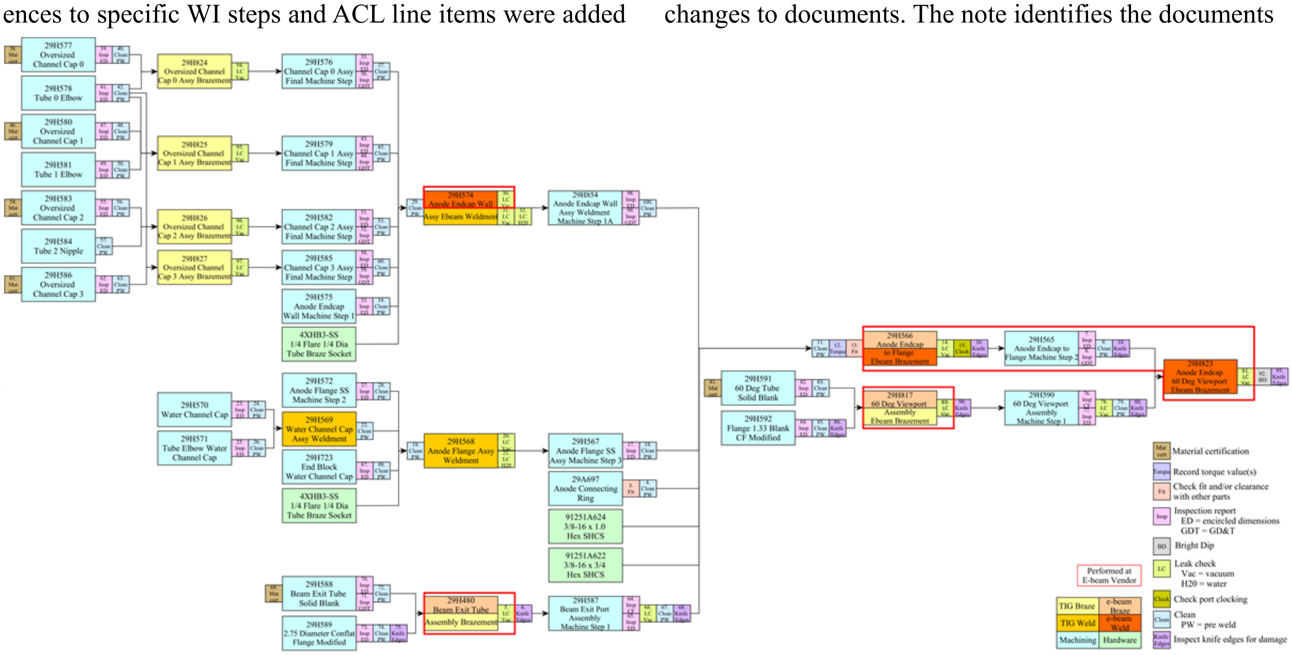

Figure 3: Manufacturing flow for the gun's anode, color-coded to indicate types of fabrication and QA operations. [4]

to be changed, and describes and justifies the desired change(s). An ECN is graded to evaluate potential risk of the change(s); significant schedule or cost impacts require review by higher-level project management.

It was decided that the QA representative should serve as a single contact between the engineering and fabrication teams for communication of QA actions, deviations, and non-conformances, to ensure proper documentation.

Documentation of various QA tasks was kept flexible to ease into the new system. For tasks requiring only evidence of completion, like cleaning, signoff on the paper traveler or in JobBOSS by the individual performing the work was acceptable. For data-driven tasks, like inspection, data entry could be via paper traveler, JobBOSS, email, or upload to a job-specific folder on the shop's network drive. Some tasks could also be witnessed by the QA representative and verified in person.

Shop management endorsed spontaneous visits to the shop, but a structured weekly meeting between engineering, QA, and shop management was also implemented.

## RESULTS AND INSIGHTS

As of mid-May 2017, the gun is near complete, with preparations for frequency testing and adjustment, dry ice cleaning, and final alignment and sealing of the gun underway. This first application of the LCLS-II QA system to on-site manufacturing has yielded a number of insights.

Having most production occur on-site at LBNL's multi-capability shop made managing quality easier. Significant risk was reduced not needing to transport precision components from site to site between operations. On-site manufacturing allowed for frequent in-person observation, consultation, even participation during the gun build. Impromptu visits were common and allowed for real-time awareness of component status. The weekly manufacturing meetings helped bring all parties up-to-date on progress and enabled joint input on issues encountered.

The Work Instruction flowcharts and their global view of all levels of the gun build was particularly useful for visualizing current shop activity and for organizing downstream work, especially as the number of active components increased. Annotating the charts during production also indicated trends in QA implementation, most notably with non-conformances. Some components had acceptable or reworked physical non-conformances; however, many non-conformances were "process" non-conformances, where the performance or documentation of an ACL item itself did not conform to specification.

For example, early vacuum leak checks were conducted according to LBNL's standard procedure, with no leaks detected; however, this procedure was found not to meet the more rigorous SLAC LCLS-II standard. Technicians were trained on a revised process to rectify the issue.

The shop has a set of standard operating procedures (SOP), including tasks like checking conflat flange knife edges for damage between manufacturing operations. These activities are usually not documented unless there is a non-conformance. Thus, when QA requirements aligned with the shop's SOP, requisite documentation was not always provided. In the future, greater emphasis should be given to the need to both complete and document tasks, when required to by the ACL.

Most QA required tasks were personnel- and location-specific: for example, dimensional inspection conducted by the inspector in the metrology room. There was a desire to not "handcuff" less constrained QA requirements, such as visual inspections, to a particular person or venue. However, these activities were best documented when performed in conjunction with a data-driven operation such as dimensional inspection or leak checking, which suggests that such a pairing may be optimal.

Some QA actions were completed and documented to specification, but the component or assembly continued to next-level manufacturing steps before the action was verified and signed off. In most of these cases, there were no non-conformances, but consequences could be significant in potential cases with critical non-conformances.

The QA representative was established as the single point of contact for QA communication between engineering and fabrication teams; however, both teams are used to directly communicating with each other, and it proved difficult to shift this pre-existing contact structure. With multiple channels of communication open, the shop may have received conflicting reports of a component's readiness to proceed through workflow.

Components could be held in a controlled area between operations, with re-release to the shop floor once QA has been verified; however, available space is limited, and repeated transport of large or delicate parts is risky. Alternatively, commercially available QA status tags could be introduced. A simpler option may be to add QA signoff on relevant operations to the paper travelers that already accompany each part. Providing access to a live copy of the ACL could also allow shop management to better know each line item's sign-off status.

That many non-conformances were process non-conformances rather than part non-conformances highlights the challenges in implementing changes into an established workflow and culture. The LBNL LCLS-II Injector Source team feels confident in their ability to deliver to SLAC an electron gun that meets functional requirements with a high degree of reliability. The lessons learned from this initial application of the on-site QA system will aid in its integration into future projects.

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