FABRICATION OF ILC PROTOTYPE CAVITIES AT ADVANCED ENERGY SYSTEMS, INC.*

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Abstract

Advanced Energy Systems, Inc. has recently completed manufacture of four standard 9-cell TESLA-style ILC cavities, six single-cell ILC prototype cavities, one 9-cell re-entrant cavity of the Cornell design, and is nearing completion of six 9-cell symmetric ILC cavities. This paper will present an overview of these fabrication projects and of the evolution of AES capability in cavity manufacturing. To date four of the 9-cell ILC cavities have been tested, the six single-cell cavities have been tested, and the 9-cell reentrant cavity has been tested. Preliminary results will be shown.

CAVITY FABRICATION AT AES

AES has been manufacturing superconducting cavities and components since 1998 and we have continuously been improving our manufacturing infrastructure to gain the necessary level of process control and schedule control while keeping production cost as low as possible.

To date we have internalized all processes necessary for cavity fabrication except for hydroforming of cells and brazing of cavity details. For these processes we continue to use specialized companies near our facility in Medford, NY. All niobium machining has always been performed within AES.

In-House Processes

The first specialty process we brought in-house was that of branch forming in seamless or welded tube. In 1999, under contract to Los Alamos National Lab, AES designed and built a specialized branch forming machine shown in figure 1.

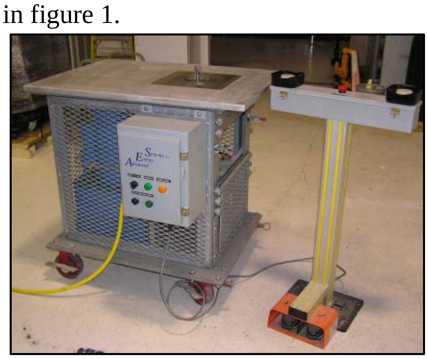

Figure 1: AES Designed & Built Branch Pulling Machine

While the technique of branch forming dates back 100 years, this machine utilizes a tooling package that results in identical parts being produced every time from machining of the elliptical holes right up through machining of the final weld preps for nipple welding. We have since built machines for Argonne and Cornell.

In early 2004 we installed pre-weld Buffered Chemical Processing and an Ultra-Pure water system at AES. Previously we had used facilities at National Labs and at some subcontractors however this was logistically very difficult. The AES BCP lab (figure 2) reduced cost, improved schedule, and improved process control.

Figure 2: Light BCP Lab at AES

In early 2005 we began deep drawing our own seamless tubing from flat sheet stock. We found that the cost and lead time required for small runs of custom tube sizes was prohibitive. Further, the use of rolled and welded tubing, while creating acceptable product, was undesirable because of the weld bead and the unavoidable out-of-round nature of the parts.

Finally, in early 2007, we installed a large EB welding system at AES (figure 3). This system has a 10' x 7' x 5'

Figure 3: EB Welding System at AES

vacuum chamber with a cryogenic Meissner coil for rapid pumpdown and low base pressure. It is a high voltage (150 kV), 15 kW system with full 5-axis CNC control.

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The machine has an attached 22' x 14' clean room for cavity assembly.

Hydroforming

At AES we use hydroforming as the forming technique for manufacturing half cells. This process is particularly well suited for SRF cavities because it is largely immune from small variations in material thickness that can cause problems with deep drawing. To get the best results however, we use coining and collaring dies to "set" the iris and to "iron" the equator. For ILC style cavities this yields cell profiles that are consistently better than .005" assuming the material has the necessary uniformity. For the dramatically re-entrant shape of the Cornell mid-cells we were able to hold the profile to about .008".

ILC CAVITY FABRICATION

The first ILC type cavities manufactured at AES were built prior to the installation of our EB Welding facility. This includes the 9-cell re-entrant cavity for Cornell and the first four DESY-Style 9-cell cavities for Fermilab. For these cavities the EB Welding was performed at EBTEC in Agawam, MA using a Hamilton Standard 36" x 36" x 50", 150 kV, 7.5 kW EB Welder with an LN_2 cold panel installed for improved pumping. Use of this equipment 170 miles from Medford required careful logistical planning. Pre-weld BCP operations were performed at AES on a Friday with parts packed in clean room nylon bags that were evacuated and backfilled with UHP, .05 μm filtered nitrogen. In all cases, except for final cavity assembly, the joints to be welded were assembled on a class 10 laminar flow bench prior to bagging to minimize handling at the welder. For final cavity assembly the dumbbells were assembled in special tooling to prevent any contact with the weld areas prior to bagging (fig. 4).

Figure 4: End Group & Dumbbell in Shipping Tools

Once packed in the backfilled bags the parts/assemblies were hand carried to the welder and welded within the next week. All parts were welded within 8 hours of being removed from the inert atmosphere.

In addition to special handling tools, special welding tools were developed for mass production. One example of such a tool is the rotary carousel (Ferris wheel) tool used for dumbbell assembly, iris stiffener welding, and end group final assembly. This tool shown in figure 5 has 10 positions and three orientations permitting welding the outside (normal incidence) and the inside of the dumbbell iris (+ and – 31° incidence) in a single fixture.

The AES EB Welding System was installed just after the completion of the four DESY-Style ILC Cavities and was used for manufacturing the Six Single-Cell ILC Cavities in the summer of 2007. It is also being used exclusively for fabrication of the six Symmetric 9-Cell ILC Cavities currently in process at AES.

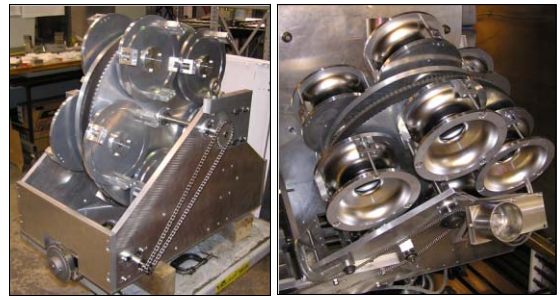

Figure 5: Rotary/Carousel Weld Fixture

Cornell 9-Cell Re-entrant Cavity

AES performed the engineering design and fabrication of a 9-cell cavity with a re-entrant cell shape designed by Cornell [1]. This was the first 9-cell structure built by AES and it immediately preceded the fabrication of four DESY-Style ILC cavities built for Fermilab. Because of the similarity of the structures the manufacturing plans were essentially identical with the only differences being in the end group details and iris stiffeners and the addition of an electropolishing step for the formed half-cells for the Cornell structure. The Cornell cavity had simple straight beam pipes rather than complex end groups.

Figure 6 shows the Cornell Dumbbells and End Groups just prior to machining of the equator weld preps for final assembly. The half-cells were all electropolished by Cornell immediately after forming.

Figure 6: Cornell Dumbbells and End Groups

Because of the re-entrant shape and lack of iris stiffeners this cavity is extremely flexible making it far more delicate than the standard DESY cavity. We performed significant finite element analysis to ensure that the cavity would be stable under vacuum load and to determine the behavior of the cells during RF tuning of the cavity. We also machined the cells to accept iris stiffeners and performed development tests to show that we can install stiffeners at a later date if required. Figure 7 shows the completed Cornell cavity during beadpull testing along with the as-welded beadpull profile (14.3% tilt, +/- 9.4% flatness) and the post-tuning profile (1.3% tilt, +/- 1.2% flatness).

The cavity has undergone some testing at Cornell and has demonstrated a hard quench with no FE at about 14.5 MV/m. Cornell is continuing testing and is investigating potential causes for this performance.

Four DESY-Style ILC Cavities

The first four DESY-Style cavities built by AES were delivered to Fermilab in early 2007. The primary issue associated with this production lot, aside from the difficult logistics of welding at a subcontractor's site, was an issue with the sheet material for the cells. As-delivered, the sheets were highly anisotropic resulting in egg-shaped cell forms. The material was returned to Wah Chang where a second heat treatment was performed substantially improving the forming behavior. With that issue resolved the remainder of the manufacturing was largely routine with the production tools working very well for the multi-piece welding as described earlier.

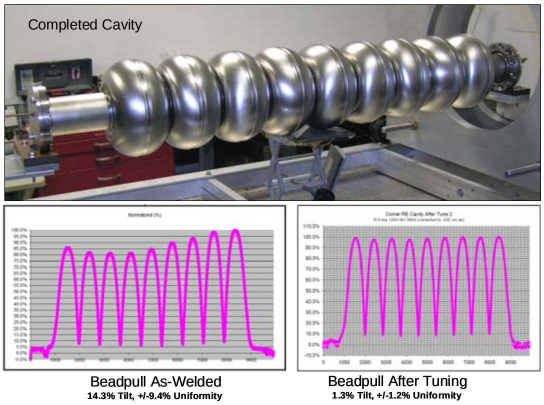

Figure 7: Complete Cornell Cavity with As-Welded and Post-Tuning Beadpull Test Results

All cavities were tuned at AES with average as-welded field tilt of 19.8% and flatness of +/- 9.9% and post-tuning field tilt of 0.9% and flatness of +/- 2.3%. Tuned frequencies were within 30 kHz of the target frequency. Figure 8 shows cavity AES-001 during beadpull with the as-welded and post-tuning beadpull results.

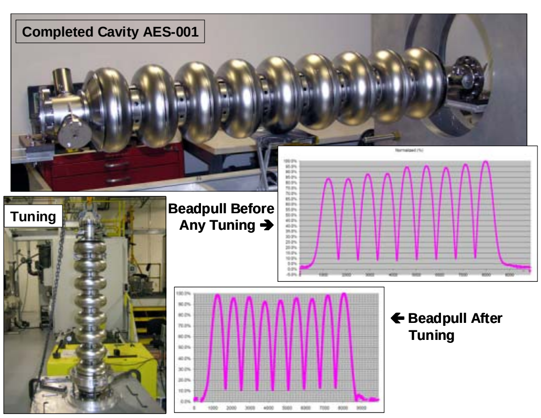

Figure 8: AES-1 During Beadpull with As-Welded and Post-Tuning Beadpull Test Results

Six Single-Cell ILC Cavities

In July of 2007 AES was given a contract to produce six, single-cell ILC type cavities for prove-out of the AES welding system. These cavities were built and delivered in September, undergoing testing at Cornell in November and December.

Testing at Cornell consisted of heavy BCP chemistry followed by high pressure rinse and VTA testing. There was no vacuum baking performed. Five of the six cavities exceeded 25 MV/m on first test with one reaching 28 MV/m [2]. One cavity experienced field emission at `17 MV/m but there was no attempt to re-clean and re-test.

Figure 9: Six, Single-Cell ILC Cavities

Six Symmetric 9-Cell ILC Cavities

AES is currently in the process of manufacturing six, symmetric ILC cavities for Fermilab. Since the budget cuts of late 2007 we have relaxed the schedule on these cavities in order to properly develop the various weld parameters on the new welder and to further develop production techniques. Unlike the previous 9-cell cavities we plan to weld these cavities from four double dumbbells and two end groups in a single pumpdown.

9-Cell DESY-Style Cavity Testing

All four of the DESY-Style cavities have seen some testing but none had fully completed testing prior to budget cuts at the end of 2007 [3][4]. Best performance has been cavity AES-2 reaching 32.6 MV/m (fig. 10)[5].

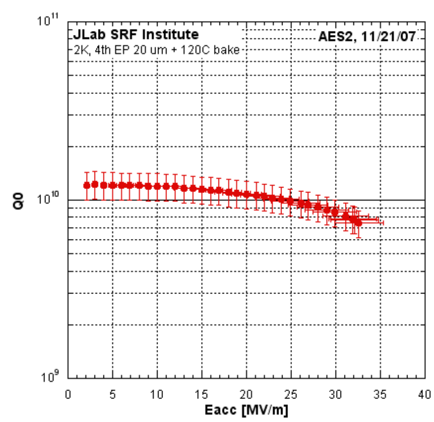

Figure 10: Test Results for AES-2

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