CEBAF CAVITY FABRICATION—A SUCCESSFUL TECHNOLOGY TRANSFER

M. Hiller, J. Dateo, W. Pruitt, W. Bensiek

Babcock & Wilcox - NNFD

P.O. Box 785

Lynchburg, VA 24505-0785

Babcock & Wilcox (B&W) has successfully completed an R.F. accelerator technology transfer with Cornell University for CEBAF, the Continuous Electron Beam Accelerator Facility. With this transfer of technology, B&W has commercially fabricated four niobium LE-5 R.F. cavities, 12 niobium spool pieces, and 12 niobium adaptors for CEBAF. The fourth niobium cavity was warm tuned to specification at the B&W test facility.

The industrialization of the accelerator technology benefits the scientific community because industry can provide large scale production resources, including standardized procedures, processes, and specifications, to assist in the construction of accelerator/collider projects. B&W has taken laboratory technology and developed standardized industrial procedures and processes for the fabrication of the CEBAF/Cornell R.F. cavity. B&W's industrialization of accelerator technology is discussed herein.

Introduction

The Babcock & Wilcox Naval Nuclear Fuel Division (B&W NNFD) has supplied high quality, advanced technology components to the U.S. Government for over 30 years. B&W NNFD has produced components for the nuclear Navy and the DOD, fuel elements for research reactors, Computer Integrated Manufacturing Systems (CIMS) for government and civilian facilities, and high precision nuclear components and systems for industry. These products constitute a successful and continuing technology transfer with national labs and other research oriented customers. Throughout all phases of the fabrication of these high technology products, Babcock & Wilcox has demonstrated a sensitivity to the unique and critical needs of the customer.

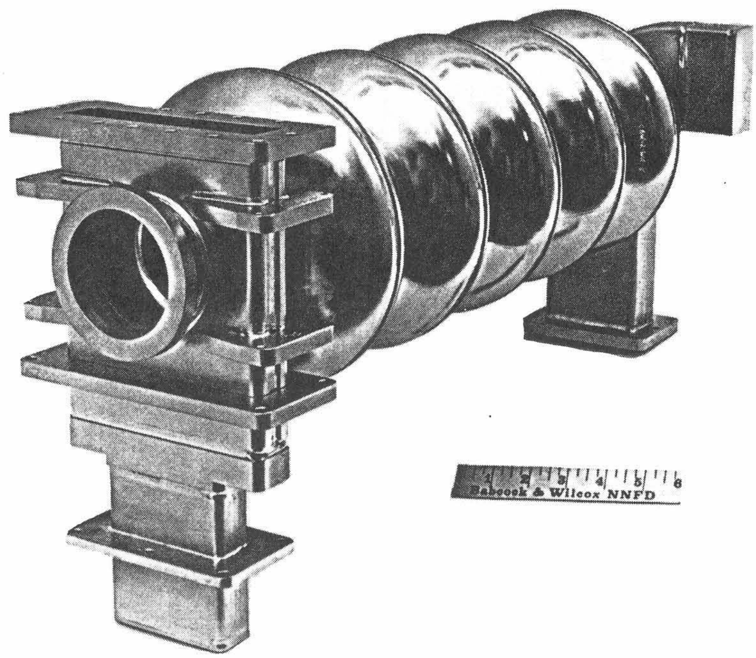
In the accelerator structures arena, the pursuit of higher particle energies has resulted in projected work scope sizes that are not manageable by the efforts of the scientific community alone. Larger projects such as the SSC, CEBAF, and RHIC can be completed economically in a finite amount of time through a combined effort. The dedication of industrial leaders, such as Babcock & Wilcox results in these projects being completed with improved manufacturing methods and materials.

B&W has established the first U.S. industrial warm tune facility for the CEBAF cavity. This facility was used to successfully warm tune CEBAF cavity No. 12, B&W cavity No. 4. Final machining of the fourth cavity was recently completed by B&W. The cavity was then re-checked in the warm tune facility to confirm that the final machining procedures had no adverse effects on cavity tune.

B&W has improved process efficiencies, developed production tooling concepts and a facilities plan, and improved manufacturing methods based on the learning derived from the fabrication of the niobium components.[1] Production process systems are currently being established for component flow and document control.

Manufacturing

Throughout the manufacturing of the first four CEBAF cavities, major emphasis has been placed on the transference of the accelerator knowledge and experience from the engineering group to the "shop floor". The transfer of this technology to standardized processes and procedures reduced the Engineering shop follow time.



CEBAF Cavity Fabricated by B&W

Electron Beam Welding

Experience with electron beam welding (EBW) of niobium was developed at B&W for the CEBAF cavity fabrication. B&W modified proven Cornell processes to work in the industrial environment.[2,3] Beam power energizing ramps were transformed to computer numerical controlled (CNC) EBW programs. The power ramp is now repeatable and operator independent. Each weld joint type/thickness was destructively evaluated prior to production—this quality assurance method ensured good weld integrity. Also, specialized repair procedures were developed and utilized for defective welds.

B&W has identified many cost saving alternatives during the CEBAF cavity development. Single pass welds have been developed to replace three pass weld sequences on the cup halves resulting in welding time reductions of approximately 50%. A successful defocused beam method was adopted as an alternative to Cornell's rhombic raster weld because defocused beam parameters were more readily adopted by the existing facilities at B&W. Using fully programmable EBW equipment (five-axis freedom and seam tracking), it was feasible to weld around corners when joining two rectangular sections end to end. This allowed the elimination of weld tabs in the radiused corners of certain components.

B&W has redesigned certain weld joints with the customers approval in order to move the beam-heated zone away from heat sinks. This improved weld penetration and quality without altering the dimensions of the final welded assembly. More simple weld prep geometries have also been investigated to reduce machining hours.

The production niobium welding will be done in B&W's industrial sized, numerically controlled EBW machine. The current EBW engineering effort is directed toward designing multiple component fixtures. The 12 feet of available length in B&W's welder will be utilized in order to fixture and weld multiple components in a single vacuum chamber pumpdown. Production weld estimates have been prepared and show that a savings of at least 30-40% will be realized in direct labor manhours. B&W has welded a central cell assembly in one pumpdown which provided the basis for qualification of this process for production cavities. Weld joint geometries which minimize machining and inspections, and a standardization of welding methods will also lead to decreased manufacturing time and cost.

Forming

The proven fabrication method for many CEBAF/Cornell cavity parts is the deep drawn forming of niobium sheet stock. Through analysis and development efforts, B&W is striving to minimize the number of discrete piece parts in cavity subassemblies. Present forming efforts include the development of HOMY (higher order mode coupler) halves with integrally formed legs—this will significantly reduce the HOMY subassembly fabrication costs. B&W has formed spool box halves using aluminum male dies and "Plasti-Cast" female dies. This method negates making custom female dies, produces acceptable results, and can be applied to a large variety of piece part sizes and shapes.

Machining

Through extensive development efforts B&W has developed industrial machining processes for niobium cavity fabrication. Manufacturing and Material Engineers at B&W have developed the optimum machining parameters (cutter types and material, feed, speed, coolant type, etc.) for the machining of niobium on industrial lathes and milling machines. At twice the previous cutting speed for niobium, the milling process perfected by B&W produces the specified surface finish and dimensional tolerances, yet maintains the niobium surface stock below 150° Celsius. A substitute for the coolant/cleaner trichloroethane was identified for the industrialized machining processes because the use of trichloroethane necessitates extensive environmental controls. B&W developed machining parameters to incorporate the "Accu-Lube" machining coolant into the processes. A multi-nozzeled spray mist system has been adapted to administer this coolant for use in cavity machining. A final machining process for the CEBAF cavities was developed by B&W and used for the fourth cavity. B&W developed a modular fixturing system which is capable of rigidly supporting the elastic and complex geometry of the finished cavity during the final machining. A computerized coordinate measuring machine (CCMM) survey was used to setup the cavity on a large horizontal boring mill (HBM). The cavity flange faces were successfully cut on the HBM, and these faces were then lapped for the final surface finish on the same machine (during the same fixture setup). B&W designed a spring loaded lapping tool holder, which moved in a programmed "figure-eight" pattern, to finish the flange surfaces on the completed cavity. This process produced the required flatness and surface finish which is critical to cavity operation.

The production machine shop is being designed to enhance product flow and minimize machine time. The weld preps on non-circular components will be machined on an NC Bridgeport using tracer templates, or a CNC vertical mill. Tooling has been fabricated to machine all circular (cylindrically symmetric) weld preps on a lathe instead of a programmable vertical milling machine. Production tooling is being designed for the complex shaped components to reduce setup time and facilitate inspection while still on the machine. This will reduce the number of quality control (QC) hours expended during manufacturing. These production cavity inspections will occur on a sampling plan determined by QC Engineering, while data generated during inspections will be analyzed for process control deviations or violations.

Cleaning

The ultimate performance of an RF cavity is limited significantly by its cleanliness. B&W engineers are sensitive to this issue and have followed the cavity throughout all phases of fabrication to transfer this sensitivity to shop technicians. For full scale CEBAF cavity production, B&W plans to use semi-automated cleaning processes with optimized fixtures. Improved agitation of the chemical solutions along with newly designed fixtures that handle multiple components with minimum part-to-fixture contact reduce the chance of chemical residue staining.

Tuning

Bench tuning of the cavity ("warm tune") is performed at room temperature to establish the resonant frequency and flat field profile for the five cells, and to obtain proper RF power coupling in the cavity. Cavities No. 1-3 were warm tuned at Cornell facilities. B&W cavity No. 4 was warm tuned to specification at B&W's new cavity tuning facility in Lynchburg, Virginia.[4] B&W Cavities No. 1-3 have equaled or exceeded all cryogenic (cold test) and warm test performance specifications (see Figure 1). The fourth cavity has been delivered to CEBAF where it is awaiting a cold test evaluation.

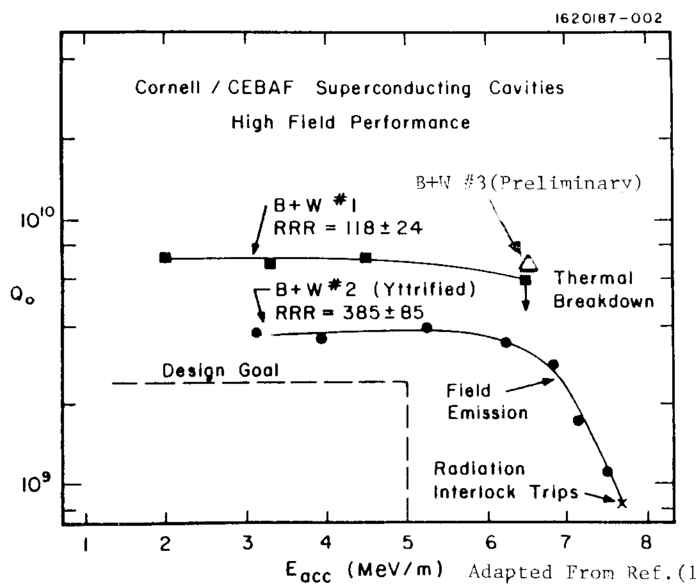


Figure 1. High Field Performance Results

A tuning fixture of Cornell design is presently being used by B&W. B&W will develop a tuning fixture which will tune the five cell array without necessitating the physical shifting of the cavity each time a new cell is addressed. If the production quantities justify the expense, an automatic control system will be incorporated into the tuning fixture and process. This control system will employ a linear travel feedback loop, the tuning program, and a statistical data base which predicts cavity response to mechanical tuning. This fixture could allow a timesaving simultaneous (5 cell) tuning for flat profile of the cell array. It would also reduce the likelihood of cavity damaged caused by (or during) excessive handling.

Transportation and Storage

Several methods were considered for the transportation and storage of final machined niobium CEBAF cavities. The axial stiffness, strength, and frequency sensitivity of a high RRR niobium CEBAF cavity has been identified.[5] B&W engineers specified an optimum environment for cavity handling and then researched current packaging practices and technologies. The packaging environment must be stable and inert to the niobium, while protecting the cavity from transportation and inertial loads. Previous cavity shipping designs were studied and found to be inadequate because of rigid cavity supports. The possibility existed for the development of highly concentrated loads which would act directly on the cavity possibly affecting the cavity tune and orientation of the flanges. B&W shipped the fourth cavity utilizing a "foam in place" process. This packaging method provides a safe, reusable, and structurally uniform and dampened support system for CEBAF cavities. The cavities can be foamed and safely transported and stored in a wooden crate or triple walled corrugated box.

Tolerances

Through open lines of communication between industrial participants and the customer (the science community), an identification of critical tolerances will lead toward lower manufacturing costs with no compromise to the performance of the product. Dimensional results of development parts and assemblies have been recorded. Correlating this information to the successful RF performance of the cavities has provided the customer with justification to relax tolerances on many noncritical dimensions.

For example, cold test results indicate that the tolerance on the internal dimensions of the elliptical cups need not be held to +/-.001" tolerance for proper RF performance. The cold forming deep drawing process that forms the cavity cups typically yields +/-.005" on most dimensions yet produces a cavity that meets or exceeds all performance specifications. Piece part weld prep tolerances of up to +/-.005" still provide quality welds with no discernible degradation in cavity performance. Similarly, the +/-.001" tolerance on other cold formed parts has not been achieved using certified dies.

Where proper fitup of mating parts was obtained, dimensional variations of as much as +/-.005" produced acceptable results. Since there is a direct correlation between tight tolerances and high manufacturing costs, a relaxation of tolerances would be beneficial.

Specifications

The standardization of specifications encourages broader participation from industrial contractors, subcontractors, and vendors. Since physical properties are quantified into understood industrial standards, the risks are minimized, the costs are lowered, and the resulting component performs as expected. B&W is in the process of standardizing all cavity specifications for production and has worked with the customer to identify the critical component qualities. B&W will strive to maintain this type of cooperative relationship.

CONCLUSIONS

The transfer of the accelerator fabrication technology to industry is crucial to the success of many "Big Science" projects. B&W worked with Cornell and CEBAF to transfer the technology that has resulted in the commercial fabrication of niobium cavities. During this process the benefit of B&W's experience was injected into the manufacturing plan to simplify the plan where possible and suggest cost saving approaches.

B&W has exhibited a sensitivity to the customer's needs and is the only remaining domestic industrial supplier of these components. B&W is qualified and committed to becoming a long term, major supplier of components and finished assemblies in support of this and other DOE projects.

ACKNOWLEDGMENTS

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