FABRICATION OF X-BAND ACCELERATING STRUCTURES AT FERMILAB

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Abstract

The RF Technology Development group at Fermilab is working together with the NLC and GLC groups at SLAC and KEK on developing technology for room temperature X-band accelerating structures for a future linear collider. We built six 60-cm long, high phase advance, detuned structures (HDS or FXB series). These structures have 150 degrees phase advance per cell, and are intended for high gradient tests. The structures were brazed in a vacuum furnace with a partial pressure of argon, rather than in a hydrogen atmosphere. We have also begun to build 60-cm long, damped and detuned structures (HDDS or FXC / FXD series). We have built 5 FXC and 1 FXD structures. Our goal was to build six structures for the 8-pack test at SLAC by the end of March 2004, as part of the GLC/NLC effort to demonstrate the readiness of room temperature RF technology for a linear collider. This paper describes the RF structure factory infrastructure (clean rooms, vacuum furnaces, vacuum equipment, RF equipment etc.), and the fabrication techniques utilized (the machining of copper cells / couplers, quality control, etching, vacuum brazing, cleanliness requirements etc.) for the production of FXB and FXC / FXD structures.

INTRODUCTION

The first structures built at Fermilab were proposed and designed by the SLAC RF group [1]. The initial goal of the Fermilab group was the industrialization of NLC type structures production [2]. Our mission expanded to include the above goal, plus as a higher priority, we were asked to supply test structures in support of the Eight Pack program at SLAC. With the creation of the RF Technology Development group and development of extensive infrastructure for our RF Structure Factory (clean rooms, RF QC Lab, vacuum furnaces, chemistry, tooling etc…) we started to participate more deeply in structure development. Beginning with the production of short 20-cm long FXA structures, we developed our capabilities and built six 60-cm long detuned structures (FXB series, or H60VG3) for the high gradient test program at SLAC. FXB-006 is the first structure ever built which satisfied the NLC design breakdown rate and it is currently being used for the Eight Pack test at SLAC. We also produced five FXC type 60-cm long damped, detuned structures (FXC series, or H60VG3S17) for the Eight Pack Test at SLAC. We are currently conducting R&D to fabricate FXD type structures. These structures will be similar to FXC type structures but will include input/output higher order modes (HOM) extraction and twofold interleaving [4] (FXD, or H60VG4S17). Our procedure is to verify SLAC’s cell dimension table, to design input/output couplers, to acquire high-precision machined parts from qualified vendors and to develop mechanical quality assurance and RF quality control at each step of production, including final structure tuning during bead-pull measurements.

STRUCTURE DESIGN

Fermilab’s Technical Division RF group has designed two different types of input and output power couplers: a conventional “fat lipped” coupler and a waveguide coupler. Results of simulation for input and output couplers and HOM simulations of trapped modes have been reported [3].

STRUCTURE FABRICATION

RF structures are fabricated in our RF Structure Factory (Fig.1), located in Industrial Building 4, a part of Fermilab Technical Division [4]. The FNAL Structures Group’s tasks include: RF Design, RF Disk Fabrication & Quality Assurance (QA), RF Structures Fabrication & QA, and Infrastructure Setup for all the above. The factory consists of two clean rooms (RF QC Clean Room - class 3000 and Assembly Clean Room - class 1000); two vacuum furnaces inside a soft-sided class 1000 clean room, clean room leak detector, turbo-pump station, residual gas analyzer, anaerobic chambers etc.

Fig.1. Assembly Clean Room and RF QC Clean Room

Structure production started with 20-cm long traveling wave structures. We produced three such structures: FXA-001, FXA-002 and FXA-003. The design was identical to a SLAC T20VG5 structure except for brazing grooves in the disks. These structures were all brazed; no diffusion bonding technique was used. The structure disks were precision machined; no diamond turning was done. Couplers were precision machined with some diamond turned RF surfaces (iris area). FXA-003 was the first structure, which was totally brazed and fabricated at Fermilab in our small and large vacuum furnaces. The FXA structures were not high power tested at SLAC. We also produced six 60-cm long, traveling wave, detuned, and constant gradient FXB type RF structures (Fig.2). The design was identical to a SLAC H60VG3 structure except for brazing grooves in the disks. Fermilab designed fat-lipped and waveguide couplers were used in order to reduce the pulsed heating [3]. The RF disks and RF couplers used in these structures were precision machined by Medco and LaVezzi Inc., our two major suppliers.

Fig.2. FXB-002

After the completion of the FXB series of structures, we produced five 60-cm long, traveling wave, damped, and detuned, constant gradient FXC structures (Fig.3). These structures are being used in the Eight Pack test at SLAC along with FXB structures. The FXC structures have Higher Order Mode (HOM) manifolds incorporated in the RF disks. We redesigned the brazing features (rosette shape dam) to accommodate the HOM manifolds in the disks. Fermilab waveguide couplers are used. The design was identical to SLAC H60VG3S17 structure except for the brazing grooves in the disks. A rotational alignment feature was added to the disks, and the tuning holes were increased from two to four. All the copper parts were machined at LaVezzi Inc.

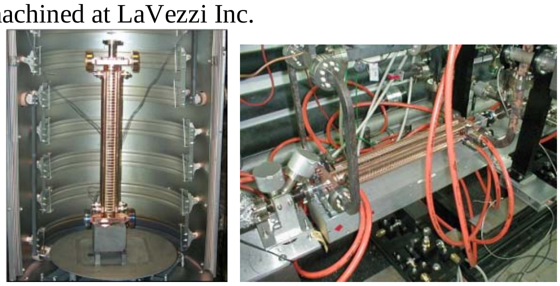

Fig.3. FXC-003 during fabrication and during high power testing at NLCTA / SLAC

Structure fabrication process flow can be outlined as follows:

Parts Acquisition:

All the RF parts are conventionally high precision machined at a local vendor. Peripheral parts are machined at in-house machine shops and/or at local vendors. Stress relieving of the rough machined parts is done in our vacuum furnaces. This process is required to achieve the tight dimensional tolerances during final machining.

Parts Preparation:

After the parts are received, a degreasing cleaning is done with detergents and citric acid to remove the machining oil. RF disks are then visually inspected under a 20X microscope for any scratches on RF surfaces. Micron level machining burrs around the HOM slots and rosette shape brazing dam are manually removed under microscope. The burrs in the RF volume could be a potential breakdown site. The burrs around the brazing dam could cause the brazing alloy to leak into the RF volume during disk stack assembly and cause a frequency shift.

Parts Quality Assurance:

All parts except the RF disks are mechanically measured by our QC department using a coordinate measuring machine (Fig.4). The RF disks are inspected using a single disk RF QC process. (See the RF Quality Control section).

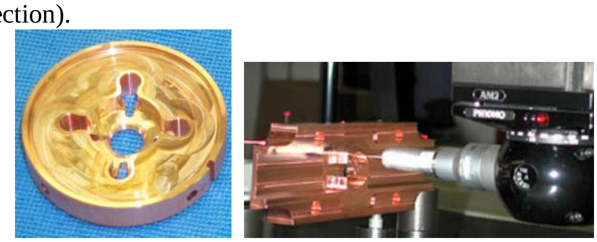

Fig.4. Slotted RF Disk and RF Coupler during QC

Parts Etching:

The RF disks and couplers are etched for 60 seconds using SLAC C01 procedure. [4] The etching acid is a mixture of nitric, phosphoric, acetic and hydrochloric acids. Approximately 2~3 microns of material is removed from all disk surfaces. Etching is necessary in order to reduce surface impurities and smooth rough features that could cause RF breakdowns.

Disks Baking:

The RF disks are baked at 1000 degree C under a 500-milliTorr partial pressure of argon for 60 minutes in order to increase grain sizes in the copper. It is believed that there is a correlation between grain boundaries and breakdown locations. By increasing the grain size, there are fewer grain boundaries, and thus a reduction in the number of potential breakdown sites.

Sub-Assemblies Brazing:

Sub-assemblies are constructed using a number of different brazing alloys. Each consecutive assembly brazing step uses a lower melting point braze alloy than the previous step so that the mechanical and vacuum integrity of the previously brazed sub-assembly is not compromised. Cooling water tubes, couplers, and disk stacks are assembled and brazed in our vacuum furnaces (Fig.5). All the sub-assemblies are leak checked after each braze cycle as part of the quality control assurance process.

We braze the parts in our vacuum furnaces under 500 milliTorr of argon gas. The gas source is boil-off from a liquid argon dewar. We use carbon and stainless steel materials for the assembly fixtures. Disk stack straightness during brazing is achieved with a V-block carbon fixture. 52 individual RF disks are carefully stacked into the fixture under a Class 10 clean room hood. The gap between each disk is checked for any problems with nesting, the gap between the fixture and disk outside diameter is checked for any problems with longitudinal alignment. The carbon V-Block is straight to 15 microns and we regularly achieve the same straightness on the disk stack.

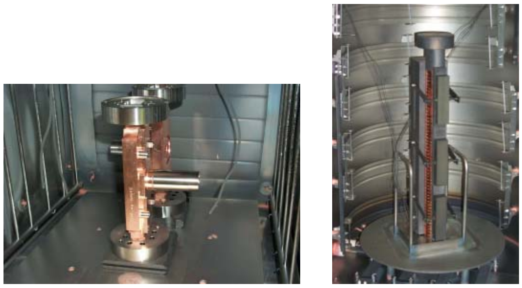

Fig.5. Coupler sub-assembly in the small furnace and disk stack assembly in the large furnace

Structure Final Assemblies Brazing:

After all the sub-assemblies are brazed and leak checked, the components are brazed in our large vacuum furnace together to form the RF structure (Fig.6). We use gold/copper braze alloys for sub-assemblies brazing. We use lower melting temperature silver/copper brazing alloys for structure final assemblies brazing.

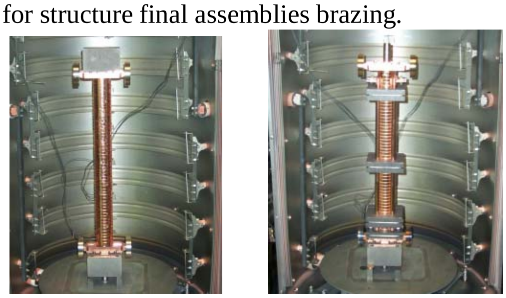

Fig.6. Couplers to Disk Stack Brazing and Water Tubes to Structure Brazing

Structure Bead Pull Measurements and Tuning:

After the couplers are brazed to the disk stack, the structure is tuned to the working frequency. Bead-pull measurements are made for determination of the accelerating field amplitude and phase distribution along the structure axis.

Structure Final Bake:

After the completion of the final brazing and vacuum flange welding, the structure is leak checked one last time. Then the structure is baked at 550 degree Celsius under 1-Torr partial pressure of 3% hydrogen + 97% argon for 2 hours. Then the hydrogen gas mixture is pumped out and the baking continues under full vacuum at the same temperature for 72 hours. At the end of this final bake, the structure is immediately backfilled with nitrogen, sealed and installed on its strongback for support. The structure is then crated and shipped to NLCTA/ SLAC for high power testing.

RF QUALITY CONTROL

To verify the quality of the high precision machined RF parts, we conduct a “single disk microwave QC” [5]. The particular design of our single cell QC set-up has been determined by the fact that the cells are machined in the form of “cups” to allow room for tuning holes. So, we need an additional half-cell to measure the frequencies of “0”-like and “π”-like modes. The “cup” shape of cell parts and tapering of structures precludes the possibility to perform direct absolute frequency measurements. We have to make a large number of very fine simulations of set-up, prepare and verify master cups for comparison, and perform control measurements of short stacks every time we get a different cell design in order to avoid possible systematic errors. Basically, the set-up consists of two flat ground blocks with a cup and a half-cell in between them. We decided to use a replaceable half-cell part despite the additional contact surface in order to facilitate the use of different half-cells for different cup designs. During measurement our network analyzer is operated and controlled by a PC. The program has a simple and convenient interface, which permits the online control of all parameters being measured. The characteristics of the measurement system can be summarized as: Low-pressure contact measurements, pneumatic actuator, applied force 300±5 lb; fully automated measurements of frequency (±500 kHz) and Q (5%); fundamental modes and HOM up to 40 GHz; single disk, disk stack (up to 10 disks) and coupler assembly QC (Fig.7).

Fig.7. Single Disk RF QC and Sub-assembly Coupler QC

SUMMARY

Our structure production factory was built up in 2-1/2 years from concept to a facility with a production rate of 2 structures per month. Excellent results have been achieved in reproducibility of single cells as well as flat field and phase profiles for entire structures. Structure cell-to-cell alignment and overall straightness routinely meets or exceeds mechanical requirements for NLC structures. Fermilab fabricated 5 of the 8 structures currently undergoing high power testing at NLCTA/ SLAC.

REFERENCES

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