DEVELOPMENT 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 JLC groups at SLAC and KEK on developing technology for room temperature X-band accelerating structures [1] for a future linear collider. We have built a few 60cm 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 60cm long, damped and detuned structures (HDDS or FXC series). Our goal is to build many structures for the 8-pack test at SLAC by the end of 2003, as part of the JLC/NLC effort to demonstrate the readiness of room temperature RF technology for a linear collider. This paper describes the design, fabrication techniques, RF measurements and tuning, as well as the initial results from high gradient testing of an FXB structure.

INTRODUCTION

The first structures built at Fermilab were proposed and designed by SLAC RF group [2]. The initial goal of the Fermilab group was industrialization of NLC type structures. Subsequently, the RF group was formed and we developed extensive infrastructure (clean room, RF Lab, vacuum furnaces, chemistry, tooling etc…), and we have started to participate more deeply in structure development. We developed initial production techniques by making short 20cm long FXA structures, and we further honed the technology by building numerous 60cm long detuned structures (FXB series, or H60VG3S18) for high gradient testing. Two FXB's were successfully tested at SLAC/NLCTA. We are now developing the FXC structure, which will incorporate damping and thus will have every feature needed for an NLC ready structure. Our goals include: verification of SLAC's cell dimension table, design of input/output couplers, development of mechanical quality assurance, and RF quality control on each step of production including final tuning. Also, some effort will be spent on R&D on movable supports (girders), which constitute the basic cell in the main linac. Temperature stability and vibration measurements together with FEA simulations are ongoing activities on the subject.

STRUCTURE DESIGN

For the FXB structure we designed two different types of couplers: the conventional "fat lip" coupler, and a waveguide coupler. Results of simulations of the input and output couplers and HOM simulations of trapped modes are reported elsewhere at this conference [3].

STRUCTURE FABRICATION

The RF structures are fabricated in the "RF Structure Factory", an infrastructure built at the Fermilab Technical Division [4]. The RF structures group's goals for the RF Factory are: RF Design, RF Disk Fabrication & Quality Assurance (QA), RF Structures Fabrication & QA, and Infrastructure Setup for all of the above. Major infrastructure of the factory consists of two clean rooms (Room A is class 3000 and Room B is class 1000); two vacuum furnaces inside a soft-sided clean room, a clean room leak detector, a turbo pump station, a residual gas analyzer, anaerobic chambers etc.

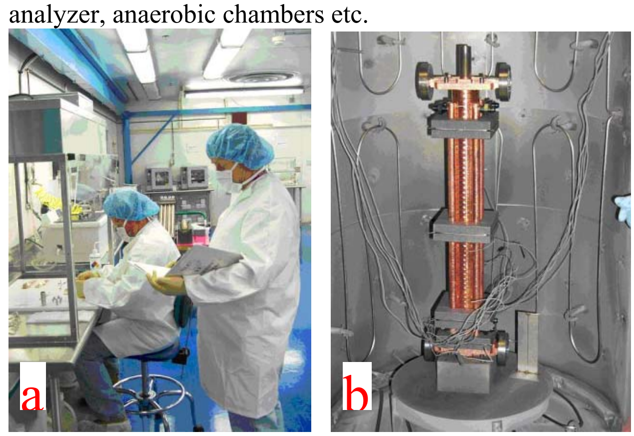

Fig.1. Clean room B (a), and an FXB structure in the large vacuum furnace (b).

The structures group's original mission was to develop industrialization of the structure manufacturing process. This included developing vendors to supply structure component parts and developing vendors to supply assembled structures. The mission has evolved into the above, plus as a higher priority, the group is to supply test structures in support of the Eight Pack Program at SLAC.

Structure production started with 20-cm long traveling wave structures. We have produced three structures: FXA-001, FXA-002 and FXA-003. The RF design is identical to the SLAC T20VG5 structure. However, FXA structures are all brazed; no diffusion bonding used. The RF disks are precision machined; no diamond turning is done. Couplers are precision machined with some diamond turned RF surfaces in the iris area. FXA-003 was totally brazed and fabricated at Fermilab using the small and large vacuum furnaces. FXA structures were not high power tested.

We are currently producing 60-cm long traveling wave FXB structures. The design is identical to SLAC H60VG3N structure except for brazing grooves in the

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disks. Disks and couplers are precision machined at Medco and LaVezzi Inc., our two major suppliers. The outer diameter of FXA disks is 45 mm, and that of FXB disks is 61 mm. The 60-cm structure length for FXB's required new tooling. Fat-lipped and wave-guide couplers were designed in order to reduce pulsed heating. Disks and couplers were chemically etched with the SLAC C01 procedure to remove any surface impurities. FXB-002 and FXB-003 were high power tested at the NLCTA at SLAC. The FXB-002 accelerating gradient was acceptable, although the processing of this structure was not finished. FXB-003's breakdown rates are lower than FXB-002. FXB-004 was totally fabricated in the RF Factory using proper clean room handling and furnace procedures. It is currently at the NLCTA and it will be tested in June 2003. We will produce two more FXB structures. All successful FXB structures can be used for the Eight Pack Test.
After completing the FXB structures, we will produce five 60 cm long FXC structures. These will have High Order Mode (HOM) manifolds on the RF disks and HOM couplers on the RF structures. Fermilab waveguide design (FWG) couplers will be used. The successful FXC structures will also be used for the Eight Pack Test. The design is identical to SLAC H60VG3S17 structure except for the brazing grooves in the disks. We will continue with the "all brazed" assembly approach. We redesigned the braze groove due to HOM manifolds in the disks.

RF CELL QUALITY CONTROL

To verify the accuracy of machining the cell parts, we do a so-called "single cell 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 the tapering of structures have resulted in the impossibility of performing direct absolute frequency measurements. We have to make a large number of very fine simulations of set-ups, 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. The ground blocks have offset antenna axes that permit the measurement of both the fundamental modes and the HOM frequencies. Fig.2 shows the set-up.

During the measurements the network analyzer is operated and controlled by a PC, or more precisely, by a program written in LabView. The program has a simple and convenient interface, which permits the online control of all parameters being measured and saves the result as a file, which can be opened by Excel.

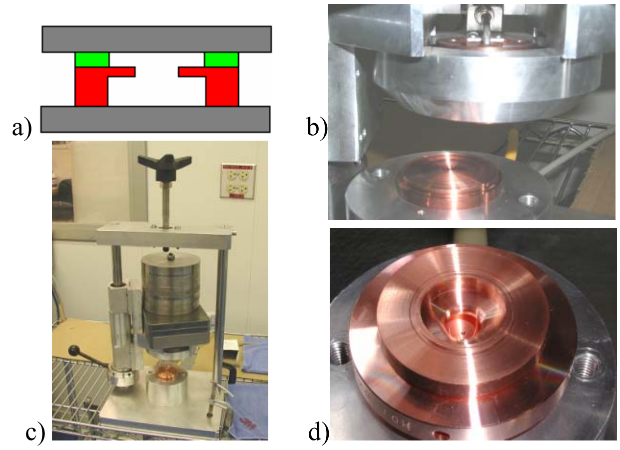

Fig.2. a) Schematic view. b) Bottom block and upper floating block. c) General view of set-up. d) Cup and half-cell installed on bottom block.

We have achieved an accuracy ± 0.2 MHz (random errors) for frequency measurements and ±3% for Q-factor measurements. One cup can be measured (four modes) in 35 seconds, but the necessity of careful handling and visual inspection of cups increases the time to 1-1.5 minutes per cup.

Fig. 3 shows the typical results of cell quality control.

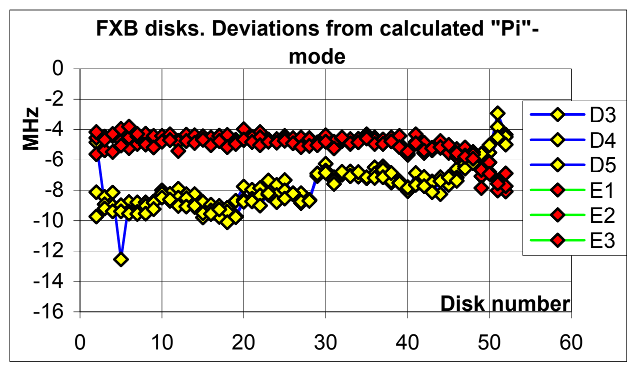

Fig.3. The cell quality control of six disk sets from two vendors. D3-D5 - machined at Medco, E1-E3 - machined at LaVezzi Inc.

BEAD-PULL MEASUREMENTS AND STRUCTURE TUNING

After final brazing, the structure needs to be tuned to the working frequency. Bead-pull measurements, which are based on the non-resonant perturbation method [6], are used for measurements of the accelerating field amplitude and phase distribution along the structure axis. Continuous nitrogen flow through structure is applied during whole tuning process; Fig.4 shows the bead-pull setup. Operating frequency calculations take into account air pressure, structure temperature and frequency shift due to the fishing line, which holds the metal bead. To minimize the error due to fishing line nonuniformity, we used the difference of two measurements: with and without the bead.

Fig. 5 shows the results of the Lab View program, which acquires the Network Analyzer data and displays

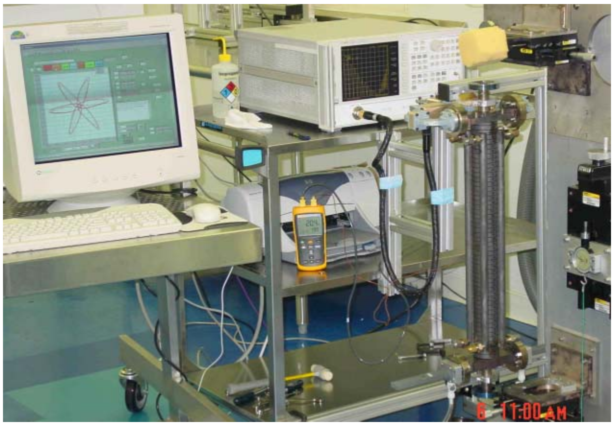

Fig.4. Bead-pull set-up in clean room A.

The reflection coefficient S11 during the pulling of the bead along the structure axis. The structure tuning technique [7] calculates forward and backward waves in different parts of the structure. For output coupler tuning we use minimization of the backward wave in the last cells. As the last step we tune the input coupler and 1-st cell to minimize the power reflected from the structure. After tuning, the SWR in the structure is less than 1.06 (Fig. 6) and the phase error is less than 2 degree (Fig.7).

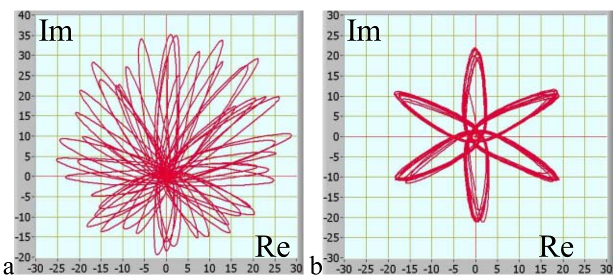

Fig.5. S11 trajectory during bead-pull before (a) and after (b) RF tuning of FXB-004.

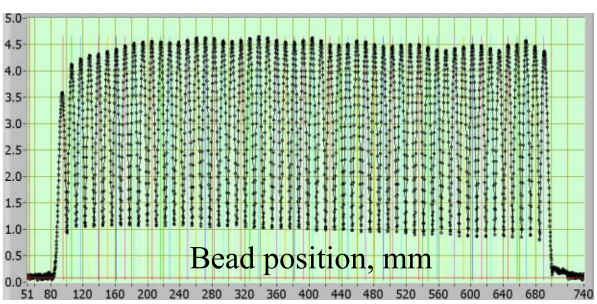

Fig.6. Amplitude distribution along tuned FXB-003.

HIGH GRADIENT TEST

Two FXB structures were high power tested at the NLCTA at SLAC. The first structure (FXB-002) reached a 65 MV/m accelerating gradient with a 400 nsec pulse length after 300 hours of processing. After testing, a visual boroscope inspection showed small breakdown spots in the surface of irises 2 to 20 but nothing in the input and output couplers. Bead-pull measurements did not show any degradation in the accelerating field distribution after the high power (HP) test as shown in Fig.7.

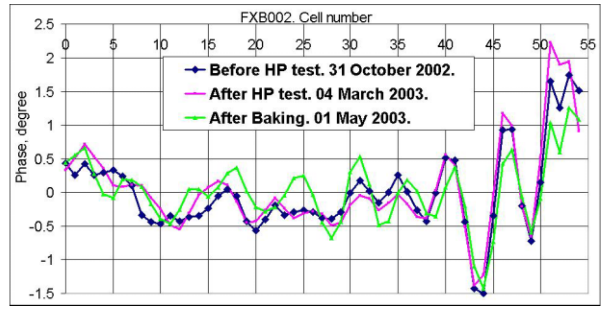

Fig.7. History of the phase distribution in FXB-002.

Fig. 8 shows the first 50 hours of high power testing of the second structure (FXB-003) and it looks pretty good [8]. Further FXB-003 HP processing is continuing with a pulse length of 400 nsec and accelerating field of 70-75 MV/m, which meet the NLC specifications.

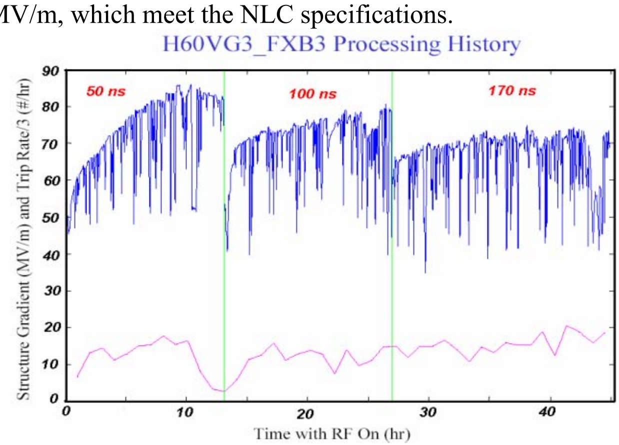

Fig.8. FXB-003 High Power processing. First 50 hours.

SUMMARY

We have developed at Fermilab the infrastructure and design and fabrication capabilities to allow us to built one accelerating structure per month for R&D toward the NLC. We have produced many 60-cm detuned structures and have started fabrication of 60-cm detuned damped NLC ready structures for the 8-pack test. High gradient tests at the NLCTA have demonstrated very good performance of the Fermilab built structures.

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