NORMAL CONDUCTING RADIO FREQUENCY X-BAND DEFLECTING CAVITY FABRICATION AND VALIDATION*

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Abstract

An X-band Traveling wave Deflector mode cavity (XTD) has been developed at Radiabeam Technologies to perform longitudinal characterization of the sub-picosecond ultra-relativistic electron beams. The device is optimized for the 100 MeV electron beam parameters at the Accelerator Test Facility (ATF) at Brookhaven National Laboratory, and is scalable to higher energies. The XTD is designed to operate at 11.424 GHz, and features short filling time, femtosecond resolution, and a small footprint. RF design, fabrication and RF validation and tuning will be presented.

INTRODUCTION

Some of the most compelling and demanding applications in high-energy electron beam-based physics, such as linear colliders[1], X-ray free-electron lasers[2], inverse Compton scattering (ICS) sources[3,4], and excitation of wakefields in plasma for future high energy physics accelerators[5,6] now require sub-picosecond pulses. Thus, improvement in resolution and capabilities of fast longitudinal diagnostics is needed.

To this end, RadiaBeam has developed an X-band Traveling wave Deflecting mode cavity (XTD) to be utilized for direct longitudinal phase space measurements of compressed electron beams. The XTD takes advantage of the greater efficiency and compactness of X-band RF structures; which naturally allows extension of the technique to very high energies, necessary for next generation light sources and linear colliders.

RF DESIGN

The RF design was carried out with the 3D electromagnetic code HFSS v12. The final design parameters are shown in Table 1.

Table 1: XTD Design Performance

Parameter	Value
Field amplitude, $\sqrt{E/P^{1/2}}$	8.48 kV/mW$^{1/2}$
Group velocity, v_g	0.0267c
Attenuation factor, α	0.66 m^{-1}
Cavity length, L_T	0.46 m
Number of cells, N	53
Power ratio, P_{out}/P_{in}	0.55

FABRICATION

The XTD is fabricated from OFE 101 F68 Class1 Cu, with the exception of the SS tuning pins, water fittings, SLAC crush seal style RF flanges and vacuum flanges.

Detailed manufacturing guidelines, handling, storage and cleaning procedures, critical to the successful realization of any RF cavity, have been established and internally documented. Travelers have been utilized to document the fabrication of the device, from raw material to final leak testing.

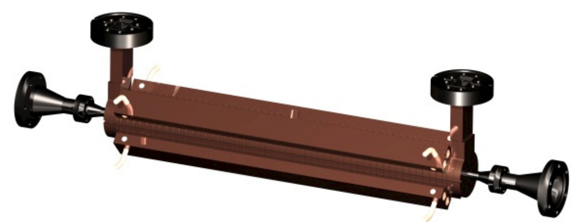

Figure 1: Model of the final XTD configuration.

The mechanical design and fabrication of the XTD structure was informed and guided by tolerancing studies performed in HFSS. All dimensional deviations encountered in the manufacturing of the device will be overcome by the incorporation of tuning pins. These pins allow for a total of 15 MHz of resonant frequency modification per cell by means of dimple tuning. Each cell includes 'mode separation' geometries whose alignment is accomplished with the incorporation of a clocking grove on the outer diameter of each cell. Axial alignment of each cell is also built into the cell geometry.

All fabrication will be performed at Radiabeam Technologies with high-speed CNC lathes and mills. Non-sulfur containing cutting fluids will be employed to ensure UHV compatibility and simplify the chemical cleaning processes.

All UHV copper and stainless steel components are subjected to a version of the SLAC C01 and C02a cleaning procedures, custom tailored in consultation with the SLAC MFD, prior to braze. These cleaning processes will be executed at the Radiabeam Technologies' cleaning facility, newly constructed specifically to address the UHV requirements of the particle accelerator community.

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VALIDATION

Two test stands are used to evaluate the state of the cells. The single-cell test stand (SCTS) measures the properties of a single resonant cavity and the bead-pull test stand (BPTS), significantly more complex, measures the properties of this same cell (and all the others) but within the context of the structure's properties. The SCTS allows us to put an upper bound on acceptance criteria for the BPTS, is a relatively fast and simple test to monitor for outliers and allows for prompt feedback to manufacturing.

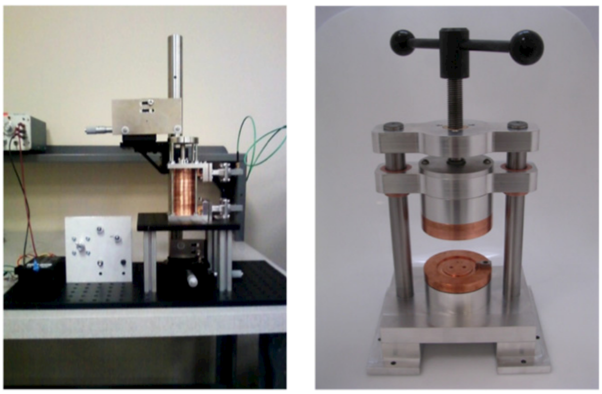

Figure 2: The BPTS (left) and SCTS (right).

The current BPTS has a repeatability of 500 kHz standard deviation and has been improved in several stages from an initial configuration of 1.6 MHz. If successive scans are run without any change in conditions, then we see a standard deviation on the order of 40 kHz. Additionally, we can change the RF input port and/or scan in the opposite direction. These effects contribute a similar amount of uncertainty, 40 kHz standard deviation, and are small compared to 500 kHz.

For example, our two primary contributors to the variance in the repeatability are the rigidity in the clamping structure (and clamping technique) and the bead alignment with respect to a datum. Tests indicate our sensitivity to alignment is approximately 850 kHz per 0.025 inches translation. Our present alignment method is estimated to be repeatable to ¼ of a revolution, or about 0.006 inches, so that we may attribute roughly 200 kHz of our repeatability error to bead alignment. At present we have no automated techniques to address this controllability. Additional considerations are wobbling in the drive and pulley system, HVAC drafts, and vector network analyzer settings.

TUNING

In the BPTS small metallic cylinder attached to a nylon thread is moved in ½ millimeter increments along the length of the stack while a network analyzer (and data acquisition system) measures the reflected signal of specified frequency. Repeating this procedure for a range of frequencies allows for the generation of the dispersion curves for both the structure and the individual cells. This analysis provides us with the individual cell's resonant mode frequency.

Based on our modeling, we then determine how much, if any, copper material to remove to hit the desired target value. We use this test to again look for additional outliers, as a large trim cut can interfere with the integrity of our fine-tuning mechanism. If a trim cut is needed on the cells, the structure is again tested in the BPTS. If the cells fall within tolerance, we hold them until all the cells are validated and utilize these cells for the final structure brazing. Once this is completed, the entire structure is then placed back in the BPTS and tested for comparison with a subsequent post-brazing bead pull.

Prior to any trim cuts however, the cells must be removed from the BPTS, cut, and then re-assembled for the final validation test. Thus it is critical to our process control that the repeatability of the BPTS be well understood; statistically characterized with the contributing components to the variance quantified. In this manner, solutions can be addressed to improve performance by isolating effects attributed to various subsystems of the test stand.

Fundamentally, the repeatability defines a bound on the accuracy to which each cell comprising the structure can be controlled, and provides the basis for establishing a cut schedule, choosing the outlier criteria, and verifying the expected result from simulation

This analysis suggests we should be making trim cuts with a resolution of approximately two standard deviations in repeatability, or 1 MHz. Our simulations suggest this cut is well within our machining capabilities and we have chosen 3 cells for small trim cuts to validate our simulated expectations. These cuts will take 0.001”-0.0016” off the radius and 0.050” into the cell cavity to compensate for ~3.5-5 MHz of deviation and to bring the cells within fine tuning range. The candidate cells can be seen in Fig. 3.

Verification of the final fine tuning procedure and algorithm will be performed on the final prototype under the contract with SLAC, utilizing the experience and infrastructure developed for the NLC X-band accelerating structures R&D program. Prior to this final structure characterization at SLAC, we will perform characterization in-house as a means to quantitatively compare the results from both beadpull setups.

CONCLUSION

Radiabeam Technologies has fabricated all the initial turned geometries for the XTD structure. Small lots of from this set are currently having their mode holes and timing slots milled into them and immediately characterized with our in-house BPTS. This BPTS is providing us with guidance as to whether particular cells within the lot will be suitable for utilization into the final brazed structure. In some cases, final trim cuts are implemented on cells in order to assure that they will resonate within the tuning range of the fine push-pull type tuning pins. Upon completion of this iterative process, the structure will undergo final cleaning and preparation for brazing. The structure will be brazed in a hydrogen atmosphere and then brought back for characterization at RBT using our BPTS. This will be followed by repeating the measurement process and performing final tuning at SLAC under an established collaborative agreement. Final vacuum bakeout to assist in gas desorption will be undertaken prior to shipment to the Accelerator Test Facility at Brookhaven National Laboratory.

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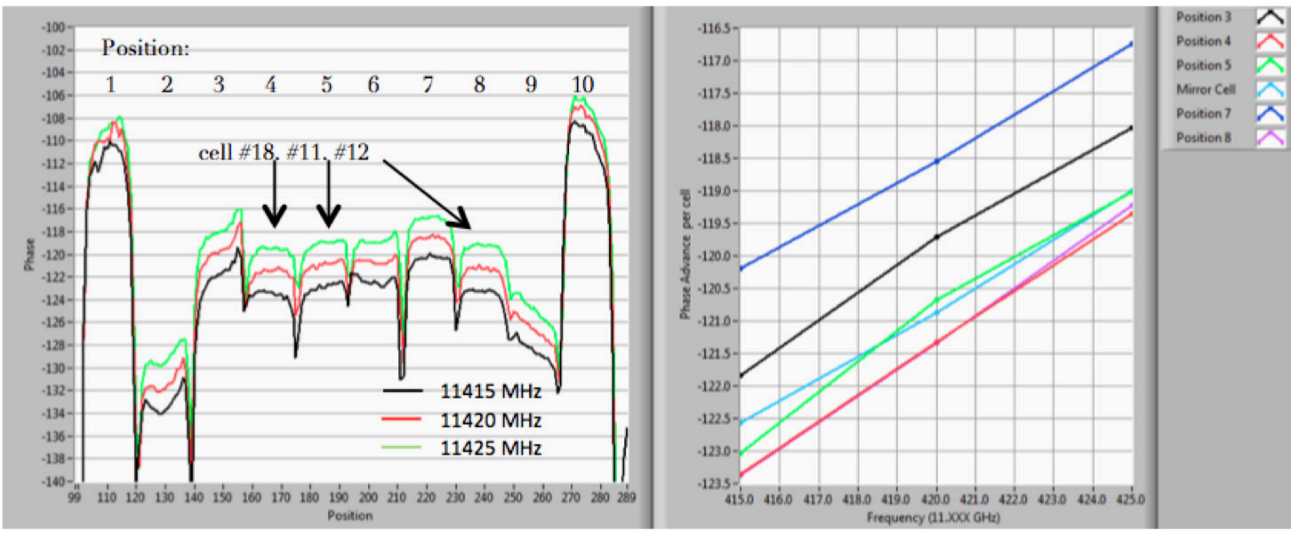

Figure 3: Above is a typical output from the BPTS used to analyze the state of the XTD cells. At right, a collection of dispersion curves.