

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.

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.

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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	0.40 m
Number of cells, N	45

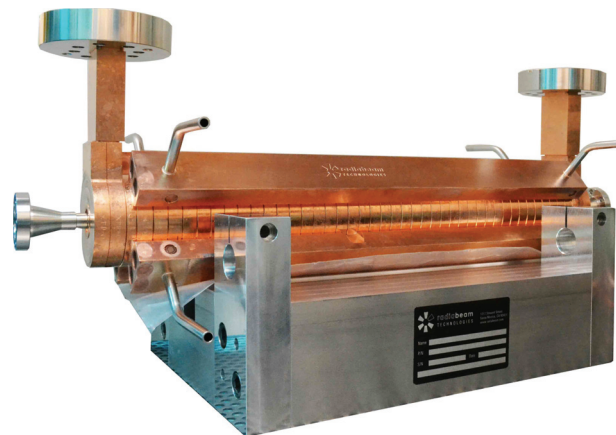


Figure 1: Brazed XTD prototype ready for tuning.

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 groove on the outer diameter of each cell. Axial alignment of each cell is also built into the cell geometry. All fabrication was 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 were 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

were be executed at the Radiabeam Technologies' cleaning facility.

Pre-Braze assembly of the components were undertaken at Radiabeam's Class 100 cleanroom and transported to a local vendor for brazing. Brazing of the XTD structure was performed with multiple cycles utilizing Au/Cu braze alloys in a vacuum oven. The oven was burnt out prior to each cycle to ensure clean operation and minimization of cross contamination. Final helium leak check of the entire structure was performed to 10^{-10} std cc/sec.

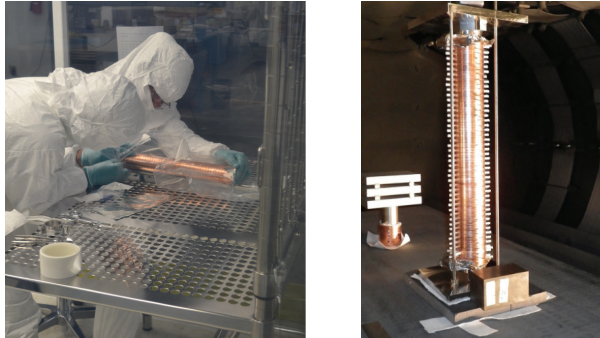


Figure 2: Cleanroom assembly (left); cell stack in furnace (right).

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.

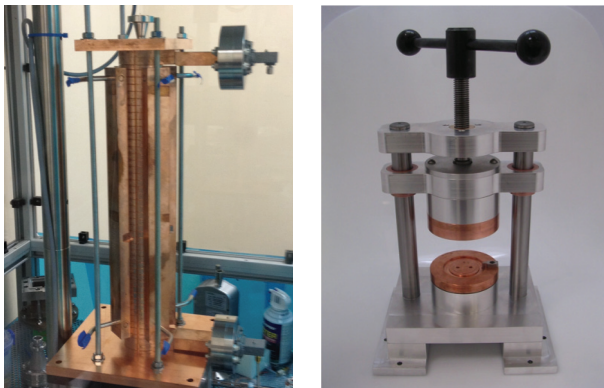


Figure 3: The BPTS located within a Class 100 hood (left) and SCTS (right).

The current BPTS has a repeatability of 500 kHz standard deviation and if successive scans are run without any change in local 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.

Our two primary contributors to the variance in the repeatability are the 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 $\frac{1}{4}$ of a revolution, or about 0.006 inches, so that we may attribute roughly 200 kHz of our repeatability error to bead alignment. Additional considerations are wobbling in the drive and pulley system, HVAC drafts, and vector network analyzer settings.

Utilizing the BPTS, the amplitude and phase of the axial electric field was measured by using a small dielectric spherical bead (about 1mm in diameter) attached to a silk string, shown in Figure 3, and moved in 300 micron increments. The method that we used is referred to as Steele Method and it is a perturbative non-resonant method.

The electric field amplitude, Figure 4, is measured along the axis of the structure and shows the expected profile (from simulations with HFSS). Due to the dipole operation mode, the field peaks are located at the irises location. The non-flatness of the field is due to the fact that the XTD has not been tuned. The field phase, Figure 5, shows perfect monotonic behavior along the whole structure and the cell-to-cell average phase shift is about 120deg.

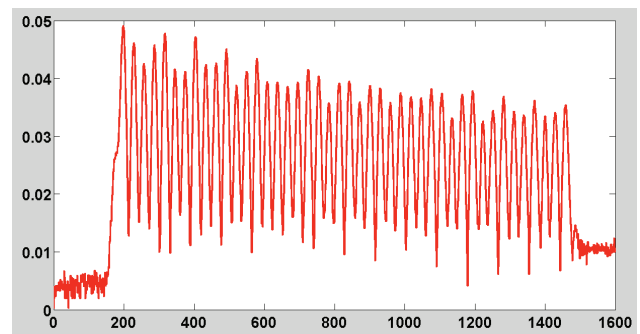


Figure 4: Electric field [a.u.] measured along the axis [step number].

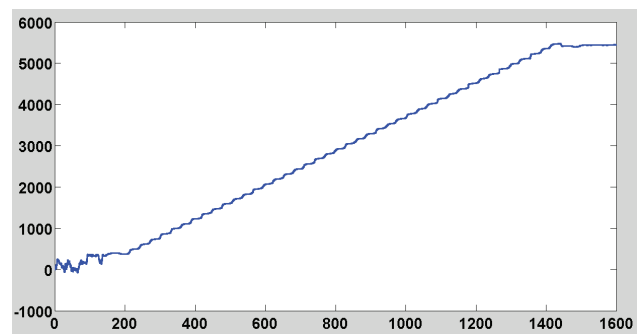


Figure 5: Cumulative field phase [degrees] measured along the axis [step number].

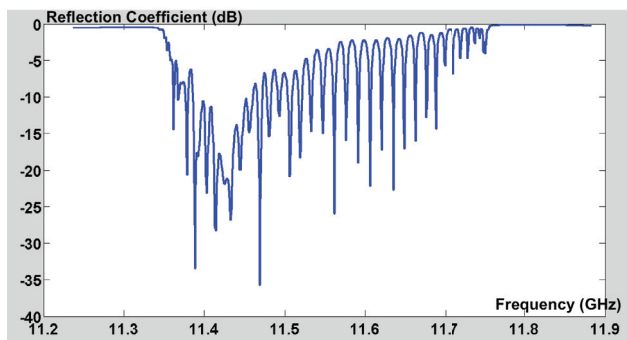


Figure 6: The reflection coefficient (S11), measured with the VNA (Vector Network Analyzer), results to be about 25dB at 11.424 GHz.

The Kroll or 3-point method, shown in Figure 7, gives a clear way to plot the phase advance per cell, showing the exact detuning of each cell. We are at a pre-tuning stage, but already the average value is close to 120 deg ($2\pi/3$). The first and last humps have a different appearance from the profile in the main cells and that is because the input and output of the structure cannot be described adequately by this method.

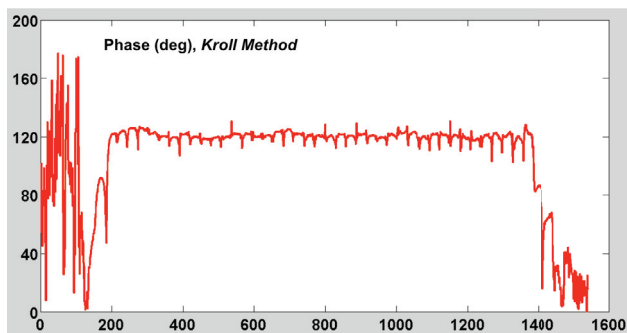


Figure 7: Phase along the structure extracted from the BPTS utilizing the Kroll Method.

TUNING

In the BPTS small dielectric or metallic cylinder attached to a nylon thread is moved in 300 micron 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. Then, by utilizing fine tuning pins brazed onto the structure, each individual cell frequency can be mechanically tuned both up or down in frequency within a range of approximately 15MHz.

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.

CONCLUSION

Radiabeam Technologies has completed fabrication, brazing and validation of the XTD structure. All braze joints have been leak tested to 10^{-10} std-atm cc/sec. The final XTD S11 is about 25dB, with average phase advance per cell very close to 120 degrees. The next step will be to finalize all ongoing measurements at Radiabeam Technologies prior to performing final tuning at SLAC under an established collaborative agreement. Final vacuum bakeout to assist in gas desorption will be undertaken prior to nitrogen backfilling and shipment to the Accelerator Test Facility at Brookhaven National Laboratory for installation.

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