

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

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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.

Table 1: XTD Design Performance

| Parameter | Value |
|-------------------------------------|----------------------------|
| Field amplitude, $\sqrt{E/P^{1/2}}$ | 8.48 kV/m/W ^{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 and fully tuned XTD prototype.

The mechanical design and fabrication of the XTD structure was informed and guided by tolerancing studies performed in HFSS. Dimensional deviations encountered in the manufacturing of the device will be overcome by the incorporation of tuning pins. All fabrication was performed at Radiabeam Technologies with high-speed CNC lathes and mills.

All UHV copper and stainless steel components were subjected to a version of the SLAC C01 and C02a cleaning procedures. These cleaning processes were 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 clean vacuum furnace. Final helium leak check of the entire structure was performed to 10⁻¹⁰ std cc/sec.

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VALIDATION

Two test stands were used to evaluate the state of the cells. The single-cell test stand (SCTS) measured the properties of a single resonant cavity and the bead-pull test stand (BPTS), measured the cell properties and their relationship to other cells nearby. 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 located within a Class 100 hood (left) and SCTS (right)

Utilizing the BPTS, the amplitude and phase of the axial electric field was measured by using a 1mm dielectric spherical bead attached to a silk string, shown in Figure 2, and moved in 300micron 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 3, is measured along the axis of the structure and shows the expected profile (from simulations with HFSS) soon after the final brazing and before the tuning of the structure. Due to the dipole operation mode, the field peaks are located at the irises location. The field phase, Figure 4, shows perfect monotonic behavior along the whole structure and the cell-to-cell average phase shift is about 120deg.

The Kroll or 3-point method, shown in Figure 5, gives a clear way to plot the phase advance per cell, showing the exact detuning of each cell. The average value is close to 120 deg ($2\pi/3$), however the first and last humps have a different appearance from the profile in the main cells as the input and output of the structure cannot be described adequately by this method.

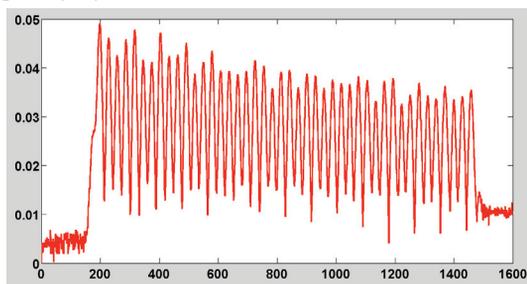


Figure 3: Electric field [a.u.] measured along the axis [step number], before tuning.

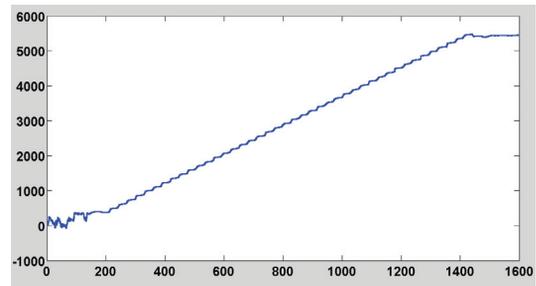


Figure 4: Cumulative field phase [degrees] measured along the axis [step number], before tuning.

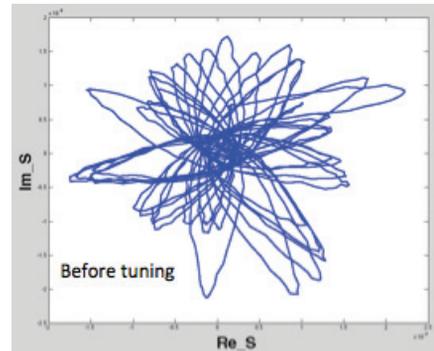


Figure 5: Polar plot of the S11 (real and imaginary part), before tuning.

TUNING

Tuning was accomplished at SLAC by pulling a metallic rod, stepwise, along the axis of the structure. Each step is equal to the cell length and the phase of the reflection coefficient is monitored. Pushing or pulling the tuners brazed around each main cell adjusts the phase value to the desired 120 degrees. The coupler cells cannot be tuned by using this technique and were managed separately.

A thermocouple was used on the structure to keep track of the temperature that overall showed a range of half a degree Celsius throughout the whole day. The reflection coefficient at port 1 will be the S11 while the transmission coefficient at port 2 will be the S22. In order to measure the S11, the RF is fed through port 1 of the XTD while port 2 is attached to a waveguide adapter, connected to the VNA, which acts as a matching load. The reflection coefficient at the port 1 (S11) was in the -20dB range while port 2 (S22) was shown to be slightly higher but still good enough for practical purposes so coupler tuning was deemed unnecessary at this initial stage. From the phase distribution of the reflection coefficient on a polar plot, it was evident that the optimal frequency of the pre-tuned deflector was around 11.430 GHz. This served as confirmation of the final bead-pull measurements carried out at RadiaBeam before shipping the structure to SLAC. It was then decided to aim for a tuning frequency of 11.427 GHz (in air at 19C) that would exactly lead to the eventual operating frequency of 11.424 GHz (in vacuum at 50C). From a practical point of view, tuning at a lower frequency meant mainly pulling of the tuning pins.

All the main cells were successfully tuned at 11.427 GHz. Nevertheless, it was not possible to tune the coupler corresponding to port 2, as pointed out earlier, because the corresponding plunger position inside the beam pipe would not provide a reference phase value. The S22 measured at -22dB since the coupler at port 1 was adequately tuned, while the S11 value was a few dB higher. In practice, to adjust the S11 value to obtain a comparable value to the S22, the port 2 coupler would require tuning. However, tuning port 2 could have deteriorated the recently successful tuning of all the main cells. Therefore, it was concluded that the RF input port of the XTD would be port 2 for beam operation. For the sake of completeness, we also measured the transmission coefficient to be -0.02dB at 11.427 GHz, demonstrating sufficient RF coupling and matching with the Klystron source.

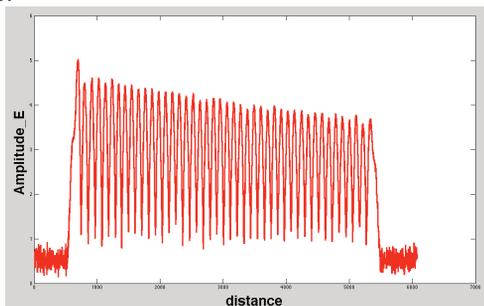


Figure 6: Electric field [a.u.] measured along the axis [step number] after tuning.

The on-axis electric field profile and phase, measured after the tuning, are plotted in Figure 6 and Figure 7, respectively. The electric field peaks are located at the iris positions, as expected from the measurement using a small dielectric bead. The slope in the peaks is due to the field attenuation along the structure, as expected from a constant-impedance cavity, but taking this factor into account, the flatness is <1%. Also, the phase of the field presents the correct monotonic behavior with an average value of 120degrees. The polar plot of the reflection coefficient at port 2 (S22) is shown in Figure 8. The flower-like manifold distribution shows a phase shift between each cell of 120deg with minimal cumulative phase errors, as compared to Figure 5.

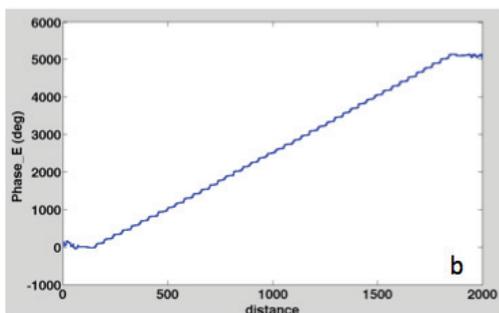


Figure 7: Cumulative field phase [degrees] measured along the axis [step number], after tuning.

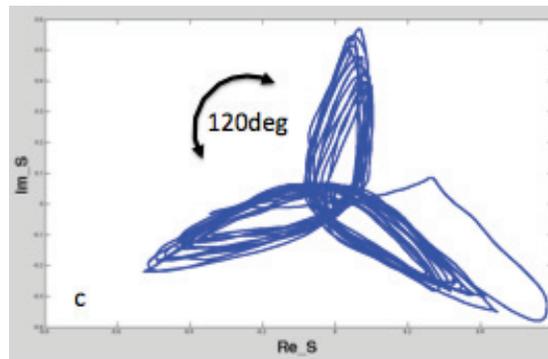


Figure 8: Polar plot of the S11 (real and imaginary part), before tuning.

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 22dB, with average phase advance per cell very close to 120 degrees. The structure has been shipped to the Accelerator Test Facility at Brookhaven National Laboratory and is awaiting installation and commissioning.

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REFERENCES

- [1] International Linear Collider Technical Review Committee Second Report, SLAC Technical Publications Department, Chapter 2, 15 (2003).
- [2] Linac Coherent Light Source (LCLS) Conceptual Design Report, SLAC-R-593, Chapter 1, 9 (2002).
- [3] I. V. Pogorelsky, et al., Phys. Rev. ST Accel. Beams 3, 090702 (2000).
- [4] S.G. Anderson, et al., Velocity Bunching Of High-Brightness Electron Beams, submitted to Phys. Rev. ST AB.
- [5] P. Muggli, et al., Phys. Rev. Lett. 93, 014802 (2004)
- [6] J.B. Rosenzweig, N. Barov, M.C. Thompson, R.B. Yoder, Phys. Rev. ST AB 7, 061302 (2004).