X-BAND TRAVELLING WAVE DEFLECTOR FOR ULTRA-FAST BEAM DIAGNOSTICS*

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Abstract

The quest for detailed information concerning ultra-fast beam configurations, phase spaces and high energy operation is a critical task in the world of linear colliders and X-ray FELs. Huge enhancements in diagnostic resolutions are represented by RF deflectors. In this scenario, Radiabeam Technologies has developed an X-band Travelling wave Deflector (XTD) in order to perform longitudinal characterization of the subpicosecond ultra-relativistic electron beams. The device is optimized to obtain a single digit femtosecond resolution using 100 MeV electron beam parameters at the Accelerator Test Facility (ATF) at Brookhaven National Laboratory; however, the design can be easily extended to be utilized for diagnostics of GeV-class beams. The XTD design fabrication and tuning results will be discussed, as well as installation and commissioning plans at ATF.

INTRODUCTION

Some of the most compelling and demanding applications in high-energy electron beam-based physics, such as linear colliders, X-ray free-electron lasers, inverse Compton scattering (ICS) sources, and excitation of wakefields in plasma for future high energy physics accelerators now require sub-picosecond pulses.

Thus, improvement in resolution and capabilities of fast longitudinal diagnostics is needed.

To achieve sub picosecond pulses, advanced photoinjector facilities employ compression techniques such as magnetic chicane bunch compressors [1] or velocity bunching [2] schemes. Nevertheless, these methods require intricate transverse and longitudinal diagnostics in order to successfully compress the beams without degrading their quality. Hence, a better experimental utilization of fast beams relies on improving resolution and capabilities of fast longitudinal diagnostics.

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 surpasses the state-of-the-art in deflecting cavities by taking 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. The capabilities of this type of measurement system can be straightforwardly extended to the measurement of longitudinal phase space, when a bend dipole is placed downstream of the deflector to disperse the momenta of the beam along the non-deflecting axis. Thus, one may expect that the longitudinal phase space will be displayed, subject to uncertainty introduced by the finite betatron beam size, at the post-dipole detector.

In the following sections, we briefly discuss the RF design. Also, we expose the fabrication procedure and cold test results.

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 AND TUNING

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.

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 (Figure 2). 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

* work supported by the U.S. DOE SBIR grant DE-FG02-05ER84370
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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 Ali Farvid of 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.

All brazing of the XTD structure will take place in a Hydrogen furnace, using preformed braze filler when possible. Cu Coupons will travel with the assembly during furnace braze for future metallographic analysis. Following structure brazing and tuning, we will treat the structure to a 48 hour vacuum oven bake out and immediately back fill with positive pressure nitrogen for storage and shipment.

A machined copper cell, 'main' cell, and a coupler cell are hown in Fig. 2.

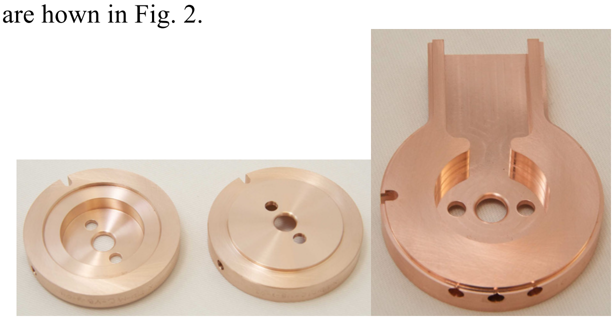

Figure 2: left, XTD main cell; right, XTD coupler cell.

Single cell test stand

The main structure of the XTD device is composed of 50 identical cells. Thus, to verify cell geometries by conventional metrological means such as with a CMM, would be expensive and time consuming. Therefore a more cost effective, time effective and informative QA process of measuring each cell frequency has been developed. This single cell RF test stand, shown in Fig. 3, is precisely measured only once by a CMM and simulated with HFSS. All of the repeating 'main' cells in the structure will then be measured to verify its resonant frequency and overall conformance to fabrication tolerances.

A number of 5 main cells have been tested. A max frequency shift of 800 kHz is observed for each cell over a few measurements, while the max frequency difference between different cells was about 5 MHz.

XTD COLD TEST

The XTD prototype is made out of copper and consists of 8 main cells and two coupler cells, see Fig. 2.

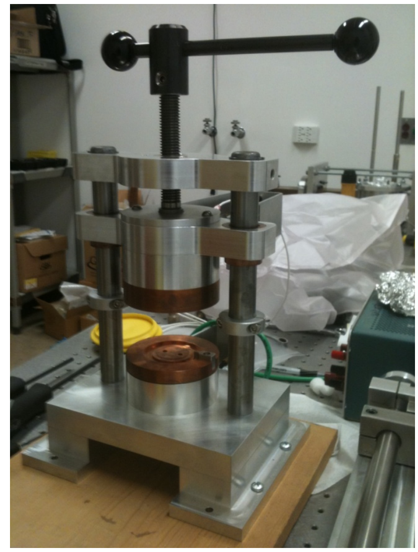

Figure 3: single cell RF test stand

The cells are tightened together by means of a stainless-steel clamping system. The input low RF power is fed through a standard X-band waveguide, while a matching load is located at the output port. The reflection coefficient of the structure has been measured via Vector Network Analyzer and it is shown in Fig. 3. A coupling of about -30dB is achieved at the operation frequency of 11.424GHz, ensuring good matching between the power source and the device.

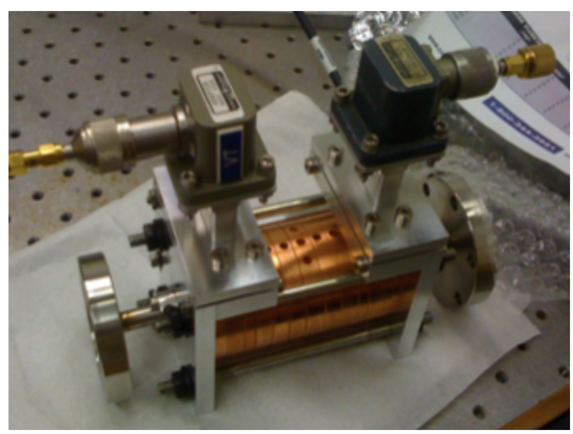

Figure 4: XTD copper prototype

XTD bead-pull measurements

Cold test measurements have been performed at SLAC. Figure 4 shows the bead-pull setup. A small metallic bead, 1 mm in length and 1 mm in diameter, attached to a fish lens is pulled through the XTD structure using a automatic motor. Changes in the reflection coefficient for different values of the field frequency are stored in a PC via GPIB device. After analyzing all data, it has been possible to obtain a plot of the axial field and phase advance per cell (see Fig. 6). The amplitude has shown good agreement with simulations carried out with HFSS v12. The project phase advance per cell of 120° was shifted about 15GHz down in frequency.

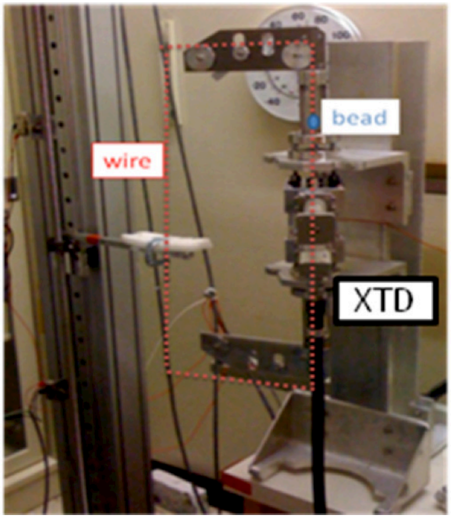

Figure 5: Bead-pull measurement setup

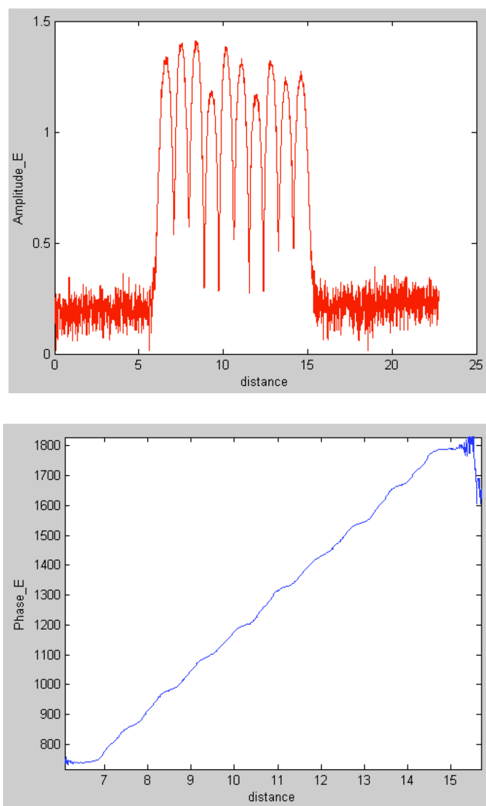

Figure 6: above, on-axis field; below, cell-to-cell phase advance

Cell stack

In order to address the frequency shift obtained from the bead-pull measurements, a cell stack setup has been machined. The stack is resonant set-up that allowed us to reproduce the effective frequency of the desired mode frequency and determine whether the measured frequency shift is due to mechanical errors. The frequency shift of 15 MHz obtained from the bead-pull measurements if confirmed. This detuning is beyond the range of tunability of the deflector as discussed above. Nevertheless, this was a result of cell fabrication discrepancies and currently new manufacturing strategies and equipment have been put in place to ensure tighter adherence to design parameters.

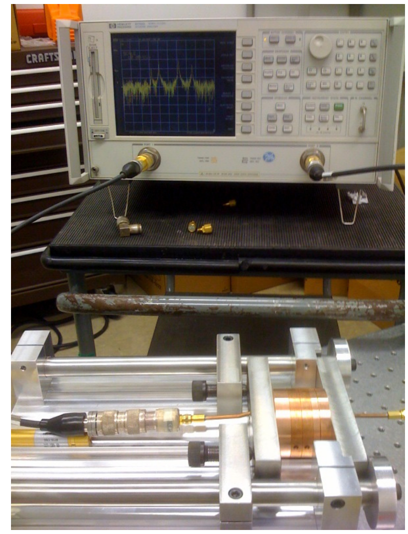

Figure 7: cell stack setup

CONCLUSIONS

We have presented here the RF design, engineering and fabrication of a travelling wave deflector (XTD) for ultra-fast beam diagnostics. The device use can be extended to very high energies due to compactness and efficiency of the X-band approach.

Also, the complete RF characterization of the XTD has been performed allowing confidence with this new class of compact deflecting structures.

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