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COMPACT 3D ELECTRO-OPTIC SAMPLING BEAM POSITION MONITOR*

T. Hodgetts†,1, L. Amoudry[1], G. Andonian[1], C. Hansel[2], A. Knetsch[3], M. Litos[2], D. Matteo[1], E. Ros[2]
[1]RadiaBeam, Santa Monica, CA, USA
[2]University of Colorado Boulder, Boulder, CO, USA
[3]SLAC National Accelerator Laboratory, Menlo Park, CA, USA

Abstract

RadiaBeam and University of Colorado Boulder have developed a 3D beam position monitor based on the well-established electro-optic sampling (EOS) technique, enabling non-interceptive, ultrafast position monitoring of high-intensity femtosecond beams. Based on the initial prototype of the 2D EOS-BPM, using 1 pair of crystals, installed at SLAC FACET-II, this 3D design has undergone several iterations. A fully functional prototype was manufactured and bench tested using Off-Axis Parabolic (OAP) mirrors to focus the laser on 2 sets of 2 crystals. However, due to the difficulty of working with OAPs and the offset of the crystal pairs, a new EOS-BPM was developed using an axicon lens to shape the laser into an annulus at the crystal plane. This dramatically simplifies the setup, reduces its footprint, and provides full 3D information from a single laser beam. Once installed, the EOS-BPM can yield the full 3D centroid positioning of two bunches in a wakefield accelerator, or the tilt of a beam used to power a light source. Under ideal conditions, simulation-based estimates show temporal and transverse resolution for the beam centroids of a two-bunch wakefield accelerator beam of order 50 fs and 1 μm, respectively.

INTRODUCTION

The EOS-BPM technique [1,2] offers a non-invasive method of measuring beam position without sacrificing beam quality (Fig. 1). We previously developed a 3D EOS-BPM prototype (Fig. 2) using 4x independently synchronized lasers and 2x pairs of crystals offset from each other. Due to the difficulty of aligning OAP mirrors, each mirror needed to be mounted on a stage with five degrees of freedom (DOF). In addition, all stages were motorized to allow for alignment in-vacuum. Each crystal assembly was also motorized in two directions to allow the user to change the position of the laser on the crystal should the crystal exhibit localized damage. Here we report on mechanical upgrades to the 3D EOS-BPM design based on axicon focusing of the probe laser, resulting in a more compact and less complex device.

Since the laser arrives at an angle, as seen in Fig. 1, the temporal dimension of the electron beam is mapped to the laser beam's spatial dimension (spatial encoding). A camera detects the polarization changes, providing relative temporal spacing of a two-bunch electron beam and transverse spatial offset. See Ref. [2] for more details.

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† tara@radiabeam.com

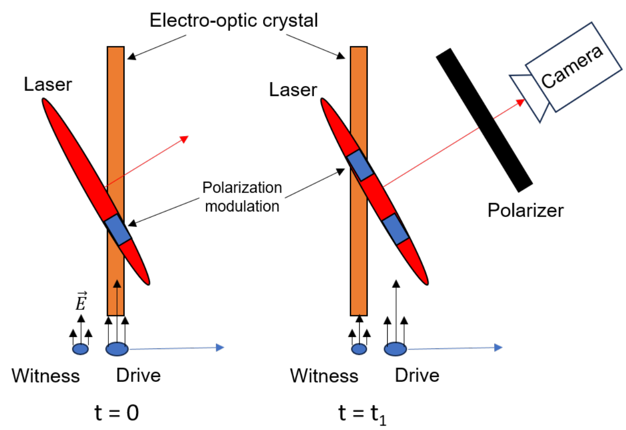

Figure 1: EOS-BPM operating principle. An ultrafast laser pulse has its polarization modulated via the electro-optic effect, with strong THz fields originating from the electron beam.

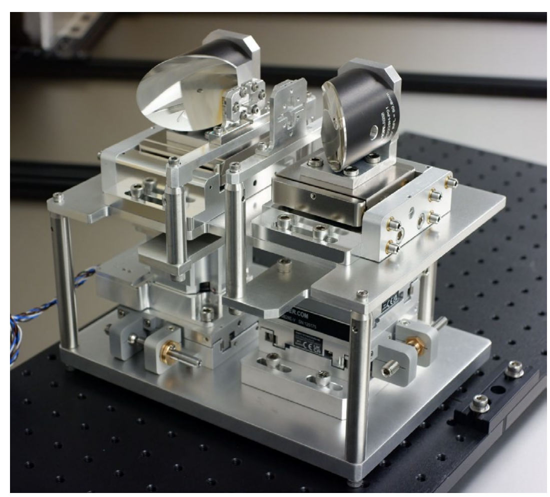

Figure 2: Phase I EOS prototype.

DESIGN IMPROVEMENTS

In the upgraded design, the focusing element is an axicon lens, replacing off-axis parabolic mirrors (OAPs) in the previous iteration. This change provides multiple technical and practical benefits over the OAPs. The axicon shapes an incident gaussian or flat-top laser beam into an annulus in the far field, with divergence angle defined by the axicon geometry. This automatically enables the spatial encoding at the nonlinear crystal plane required for high time-resolution of the EOS-BPM. The extended "donut"

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beam [Fig. 3(left)] allows for an entire arc of the laser to temporally overlap with the radial electric fields of the e-beam. Compare to the OAP-based design, where the focused laser beam only covers a small area of each crystal [Fig. 3(right)]. The benefits here are two-fold. First, the signal can be averaged over the entire arc length, theoretically improving signal to noise ratio (SNR) by a large factor. In simulations with added random noise, the SNR was increased by a factor of ~40 from this averaging. Second, the larger beam in the radial direction allows for a shallower incident laser angle while maintaining a wide temporal overlap window to assist in initial synchronization. Our design uses a 5-degree incident angle, which enables simulated temporal resolution below 5 fs and an overall temporal window close to 2 ps. An additional benefit of the shallower angle is reduction of signal "ringing" due to group velocity mismatch of the laser and THz pulses.

From a practical point of view, the axicon-based setup has significantly reduced complexity compared to the OAP-based design. The OAP design requires four individually delayed and synchronized pulses, compared to only a single synchronized pulse for the axicon setup. The alignment and optomechanical requirements before the electro-optic interactions are therefore dramatically simplified.

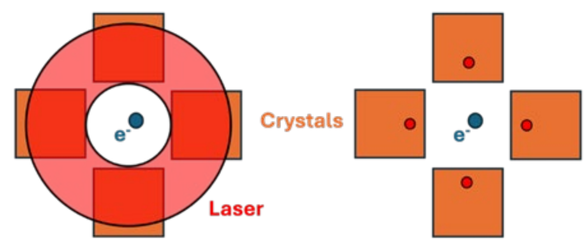

Figure 3: (left) New axicon design. (right) Previous OAP design.

In Fig. 3(left) the large surface area of the nonlinear crystals are exposed to laser light in the axicon-based design. An entire arc of the laser beam corresponds to the spatially encoded time of arrival of the electron bunch. Compare this to the previous, OAP based design in Fig. 3(right), where only a small portion of the ~mm scale laser beam is used.

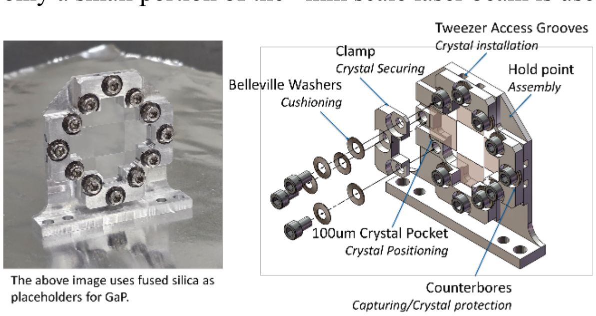

Figure 4: (left) holder with fused silica placeholders installed. (right) exploded view of holder.

The crystal holder design was modified from the prototype to hold all four crystals at once (see Fig. 4). The holding method was largely unchanged. By eliminating the OAPs, we were able to create an assembly that could be aligned completely on the benchtop using manual adjusters. The flat mirrors remained motorized for adjusting once inside the chamber. The assembly is then inserted into the chamber on a motorized transverse stage that will retract and insert the assembly into the beam path.

Each optical component, with the exception of the flat mirrors, is mounted on an x-y stage and has a vertical adjuster. The height of the flat mirrors is aligned to the beam, and all components are aligned to the mirrors. The completed axicon assembly can be seen in Fig. 5.

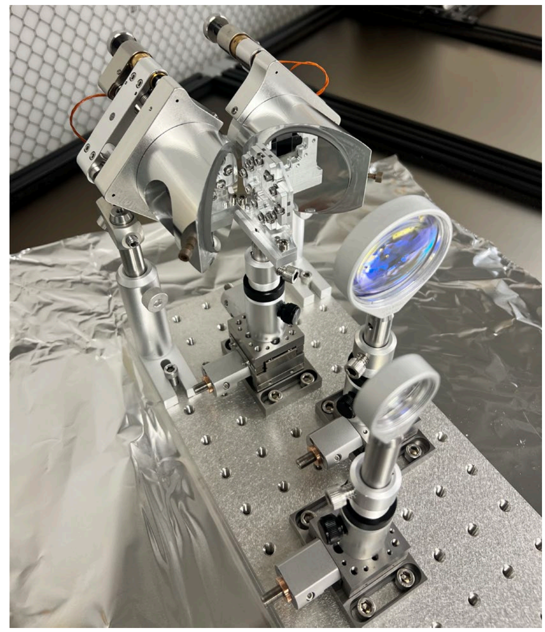

Figure 5: Axicon EOS-BPM assembly.

CONCLUSION

By implementing the changes mentioned, we were able to reduce the footprint of the EOS-BPM from 177.8 mm along the beam direction down to 152.4 mm. The complexity of alignment and assembly were also greatly reduced. Further improvements could be made with additional tooling and modifications to the holder for easier assembly.

ACKNOWLEDGEMENTS

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