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RECENT DEVELOPMENTS OF THE IDEAS-HALO DETECTOR*

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Abstract

Non-Gaussian beam distributions around the Gaussian core in an accelerator in both the transverse and longitudinal directions are generally referred to as beam halo. Many techniques had been developed to measure the beam halo. Most non-destructive techniques require complex setups, like a gas sheet monitor, or a digital micromirror array, while destructive measurements unavoidably interfere with the beam core such that beam operations are interrupted. In this paper, a novel device, named IDEAS-halo, that adopts a camera "iris diaphragm" structure for transverse beam halo measurement and collimation is described. It has advantages such as high-portability, cost-effectiveness, high-configurability and so forth. Several beam-based experiments have been conducted at the Argonne Wakefield Accelerator (AWA) facility of Argonne National Laboratory (ANL). In this paper, we present the recent design of the IDEAS-halo detector and experimental results.

INTRODUCTION

Beam halo structures are formed from various mechanisms, such as dark currents in an accelerator, or beam scattering with residual gas molecules in beamline, etc. The hazards it presents to the machine operation and the users are common concerns for accelerator beamlines. The halo beam can deposit overwhelming energy and generate radiation that damages the infrastructures.

Researchers have been exploring methods to measure the beam halo, using non-destructive, partially-destructive, or completely-destructive techniques. Among the non-destructive methods, the usage of synchrotron radiation light with a digital micromirror array [1], gas sheets monitor [2] are novel techniques that are being actively investigated. Among the destructive methods, wire scanner [3] is one of the most commonly adopted.

Inspired by the structure of a camera iris diaphragm, Euclid Techlabs started to develop an iris diaphragm e-beam apparatus series ("IDEAS-halo") detector from Feb, 2019. A conceptual logo for IDEAS-halo is shown in Fig.1. An IDEAS-halo uses metal iris blades to intercept and absorb the beam, for which the deposited charges are extracted as current signals. The beam core passes through the iris aperture. The iris is driven by an actuator to close in to intercept more halo until the blades reach the core. Each iris blade is insulated from the adjacent ones and generates an independent beam current signal and the insulation layer is a novel non-conductive thin-film [4] with nano-particle lubricant. The iris structure can be mounted on a X"-to-2.75" CF reducer where "X" can be any standard CF sizes not smaller than 6. The whole IDEAS-halo can be contained in a standard 6-way or 4-way CF cross that is no smaller than 6". The pulsed current signals from the blades are delivered to the air side through vacuum feedthroughs. It has the advantages to be *cost-efficient*, *highly-configurable*, *dual-purposed*, and *linearly-responsive*. Furthermore, it can work *both as a transverse profile detector, and as a collimator with an adjustable aperture*.

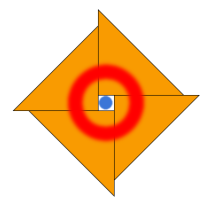

Figure 1: A conceptual logo for an IDEAS-halo detector. The beam halo is characterized by the red ring and the beam core is shown in blue at the center. The four triangles represent the iris blades.

PROOF-OF-PRINCIPLE VERSION-ALPHA

The version-alpha of the IDEAS-halo was tested in 2019 at the AWA Cathode Testbed (ACT) [5]. Version-alpha was designed to demonstrate a few principles. Firstly, pulsed current signals are generated in iris blades and can be transferred to the air side, which can then simply be read by an oscilloscope. Secondly, when the beam has enough energy to penetrate a blade, current signals can still be generated as long as the blade is thick enough to partially stop the beam. Lastly, the signal isolation between adjacent iris blades can be achieved by using thin ceramic plates, such that the extracted signal on each blade is independent of the others.

The CAD model of the version-alpha is shown on the right in Fig. 2. A holder that has multiple slots for holding plates made of different materials with different thicknesses is mounted on a linear actuator on the top. The holder is insulated from the actuator. A 45°-angle YaG screen is mounted at the bottom of the holder. A Kapton-insulated cable is used to connect the holder and an SMA feedthrough. A contactor with two vertical pillars is mounted on but also insulated from a rotary feedthrough on the bottom. Ceramic sheets are fixed on the sides of the pillars. The top holder has a special design, such that when the YaG holder drops down in the contactor and the contactor is rotated, the YaG holder could either directly touch the Aluminum contactor (Al-on-Al, i.e. Al/Al), or touch it with the ceramic plates in between them (Al/Ceramic/Al). Another cable was used to connect the contactor and another SMA feedthrough connector.

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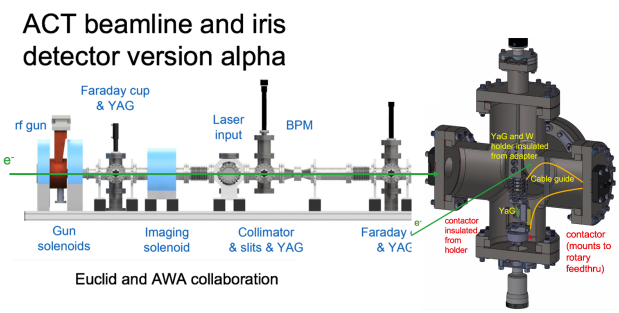

Figure 2: Left: ACT beamline schematics; Right: CAD model of the IDEAS-halo version-alpha.

The slots were filled with W or Al plates with different thicknesses. The least and most stopping power were provided by a 0.040”-thick Al plate and a 0.125”-thick W plate, respectively. The Geant4 [6] simulations of a 1.5 MeV e^- beam bombarding the two different targets were done. The beam is mostly back-scattered by the W plate while a portion of it stops in the plate. For the Al plate, the majority of the beam penetrates the Al plate.

Version-alpha was tested for mechanical integrity and vacuum compatibility with $< 10^{-8}$ Torr before being delivered to AWA. It was installed at the downstream end of the ACT beamline of AWA. The schematics of the ACT beamline and the installed version-alpha is shown in Fig. 2. There is an integrating current transformer (ICT) before version-alpha for measuring the total beam current delivered to the location of Version-alpha.

The data taking were compressed to two days. The IDEAS-halo version-alpha experiment was the *first time* that the ACT beam is used in an experiment not for cathode studies. At the time of the experiment, the electron beam had big jitters in size, position, and intensity. Nevertheless, the signal from the plate holder was significantly stronger than that from the ICT. The beam configuration that was used in this experiment had $\approx$ 1 ps length and 2 Hz repetition rate.

A short Gaussian pulse, which can be considered as the superposition of signals at various frequencies, experiences reflections at the SMA feedthrough. High frequency noises can come from scattered electrons hitting the cables and the vacuum cross. Besides, our recent studies indicate that dielectric insulation layers can be treated as capacitors, for which the signal attenuation drops rapidly with signal frequency [4]. Therefore, a low-pass (LP) filter was applied to the raw signal for signal analysis. Fig. 3 shows the raw, the high-pass (HP) filtered, and the LP filtered signal from the plate holder and the contactor when the beam is fully intercepted by the YaG screen and Al holder, which touches the contactor with ceramic insulation in between.

The beam current signal strength versus the ICT signal strength for a number of beam pulses is shown in Fig. 4, which agrees with the G4 beam-matter simulations where the YaG holder most effectively absorbs the beam. A large portion of the electrons are back-scattered when bombarding the W plate, while a smaller portion of them penetrate the target when bombarding the thin Al plate.

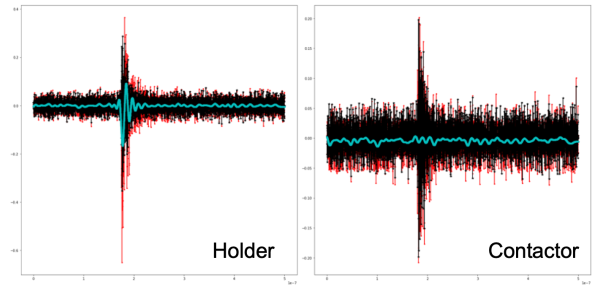

Figure 3: The raw, HP-filtered and LP-filtered signals from the top blade holder and bottom contactor. Red: raw signal, black: HP-filtered signal, cyan: LP-filtered signal. The short pulsed current and scattered electrons generate high frequency noises that can be filtered out by the LP filter.

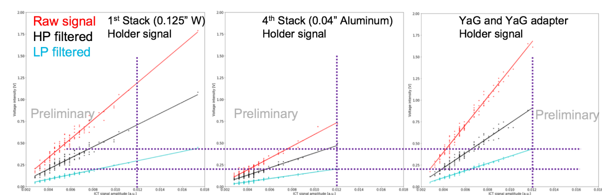

Figure 4: Comparison of signal strengths from the three beam interception configurations.

THREE VERSION-BETA’S

In late 2019, we made the version-beta1, which is the first IDEAS-halo version that had an iris structure. The iris is mounted on a 6” to 2.75” CF zero length reducer (ZLR) and whole apparatus is contained in a 6” CF 6-way cross. Iris blades (leaves) are insulated from adjacent ones via ceramic plates. A wire is connected independently to each blade. Due to the housing design and the ceramic insulation mechanisms, the version-beta1 suffered from precision assembly and iris mobility issues. In order to prevent damages to the iris due to immobility during the experiment, we disconnected the actuator and left the iris half open. The current signals from the blades confirmed that the blade-to-blade signal coupling is negligible at low frequencies.

The IDEAS-halo project continued with a Phase II SBIR award starting in Apr 2020. A prototype of an upgraded version *version-beta4* was made to introduce the following concepts:

- Integrating the linear actuator and the UHV SMA feedthrough into one 2.75” CF tee, such that the iris can be inserted from one of the 6 ports of the cross;
- Using four pillars to hold and locate the “iris sandwich” structure;
- Adding a detent design to the iris blades to eliminate moving wires during iris actuation;
- Using non-conductive thin-films as the insulation layers between adjacent blades instead of mounting ceramic plates.

Version-beta4 was tested in mid Nov 2020 at AWA for beam-based tests. The iris was kept half opened and the actuation

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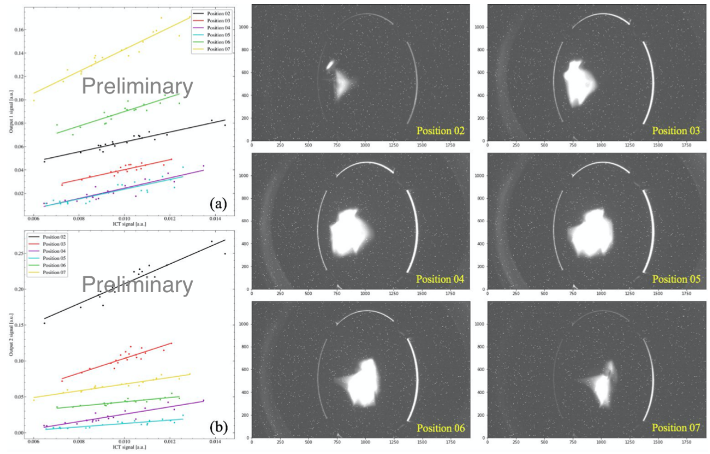

Figure 5: Signals from the right blade (a) and the left blade (b) at different beam positions, indicated by the beam images recorded on the YaG screen at the downstream of the version-beta4.

was disabled like in the version-beta1 tests because of some mechanical instabilities discovered during the assembly. We swept the beam from left to right to mimic the blades intercepting the beam from the halo. Signals from the left and right blades were analyzed for thin-film insulation evaluations. The ICT was used as a calibration of the total beam current. Because of the strong space charge effect the beam size was much larger than the iris and the shot-by-shot beam variation in both its size and charge was much larger than 50%. Therefore, careful synchronization among the Version-beta4 signals, the ICT signals and the YaG images was done to enable shot-by-shot analysis and calibration. Nevertheless, the beam current signals on the blades shifted from the left to the right. Both signals were at their minimums when the beam was passing through the iris aperture. The beam images on the YaG mounted at the downstream of version-beta4 agreed with the signal analysis. The preliminary results are shown in Fig. 5.

The most recent version that has been designed and fabricated is the *version-beta5*. In this version, we further optimized the mechanical stability of the iris and added ball bearings to improve the actuation smoothness. The pillar design was also improved to allow for more convenient assembly. The version-beta5 was tested at 5e-8 Torr for iris mobility and the iris compatibility with high vacuum. The iris was successfully opened and closed with the linear actuator at low 10^{-8} Torr. The beam-based experiment at the ACT beamline is scheduled for Aug 2021.

CONCLUSION AND FUTURE WORK

IDEAS-halo is a novel, cost-effective and dual-purpose (collimator) charge current detector. Proof-of-principle designs of multiple versions of the IDEAS-halo were fabricated and tested using the MeV e^- beam at the ACT beamline of AWA at ANL. The signal analyses indicate that independent pulsed current signals can be obtained from the iris blades and the iris in the most recent design was able to be opened and closed in high vacuum. The IDEAS-halo can be used both as a halo or profile detector and also as an adjustable beam collimator.

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