6th North American Particle Accel. Conf. (NAPAC2025), Sacramento, CA, USA JACoW Publishing
ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-MOP078

PROPOSAL TO MEASURE BUNCH LENGTHS USING A PULSE DILATION PHOTOMULTIPLIER TUBE*

K. P. Wootton†, Argonne National Laboratory, Lemont, IL, USA

Abstract

Electron bunches in storage rings are typically short (~100 ps) and separated by long periods of time (≥2 ns). A pulse dilation photomultiplier tube offers a new way of measuring high bandwidth optical pulses using low bandwidth oscilloscopes. Experiments performed by others have demonstrated a temporal resolution of 12 ps, meeting requirements for electron bunches expected for the Advanced Photon Source Upgrade. Compared to electrooptical streak cameras, we think that this may be a preferred technique for measuring the longitudinal profile of bunches in electron storage rings.

INTRODUCTION

Measurements of electron beam temporal profiles in storage rings are typically performed using streak cameras [1,2]. We are interested in considering alternative techniques of measuring electron beam bunch length other than a streak camera. We have identified a novel diagnostic device that we feel could be usefully applied to measure bunch durations in electron storage rings: a Pulse Dilation Photo-Multiplier Tube (PD-PMT).

In the present work, we evaluate the PD-PMT for measurement of electron bunches in the APS-U storage ring. We introduce the properties of the PD-PMT, and its background of use for experiments at the National Ignition Facility (NIF). We summarise properties of the nominal APS-U electron bunch profile and storage ring fill patterns.

BACKGROUND

Photo-Multiplier Tubes (PMTs) have been used extensively to measure beams of synchrotron radiation [3–6]. PMTs are typically operated with a direct-current (DC) voltage between a photocathode and the first (and subsequent) dynodes. PMTs are available with fast time resolution, however the fastest tubes available have a time response ~100 ps [7].

But a time response on the order of ~100 ps is insufficient for measuring the temporal profile of electron bunches in the APS-U storage ring, with rms bunch lengths on the order of ~100 ps [8, 9]. Ordinarily, this temporal profile is measured by a streak camera [10, 11]. By way of example, a synchroscan streak image of the electron beam temporal profile in the APS-U storage ring is reproduced in Fig. 1.

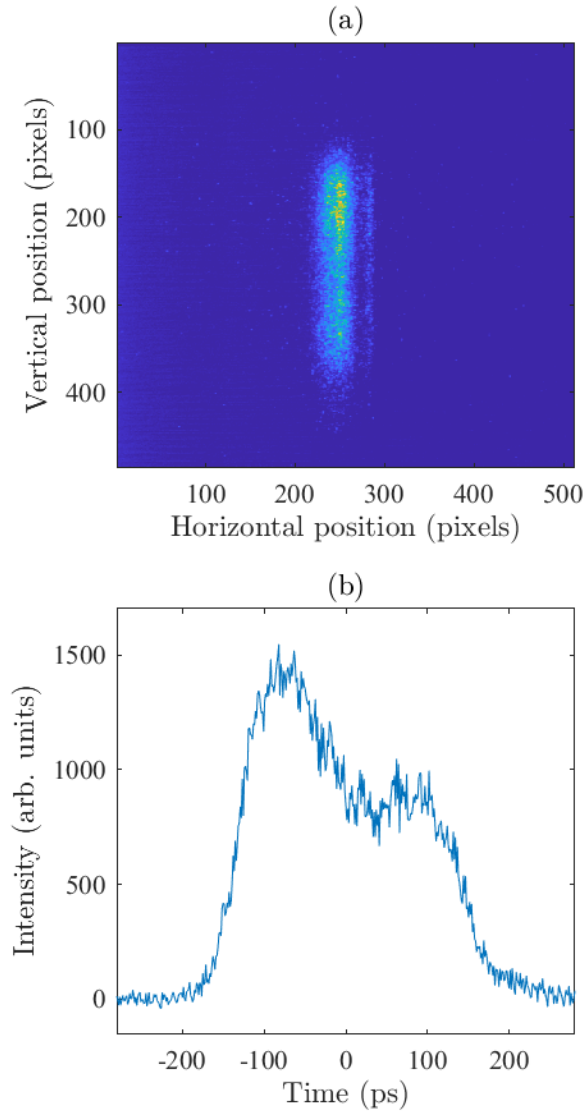

Figure 1: Measured electron beam temporal profile of bunches in the APS-U electron storage ring. A Hamamatsu C5680 dual sweep visible light streak camera was used at 35-BM beamline [12]. (a) Measured streak camera image. The beam was measured using a streak camera operating in synchroscan in the vertical direction, and unswept in the horizontal direction. The digitised image was acquired using a DataCube Max Video MV200 system [13–15]. (b) Measured temporal profile [projection of (a)].

In the special case of a PD-PMT, a long electron drift tube is positioned between the photocathode and the first dynode. By exciting the accelerating potential between the photocathode and dynode with an electrical pulse that falls in time, electrons departing the photocathode drift and are velocity-dispersed as they are accelerated towards the dynodes [16–19]. This is illustrated in Fig. 2 [19].

* Work was supported by the U.S. DOE Office of Science-Basic Energy Sciences, under Contract No. DEAC02-06CH11357.
† kwootton@anl.gov

ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-MOP078

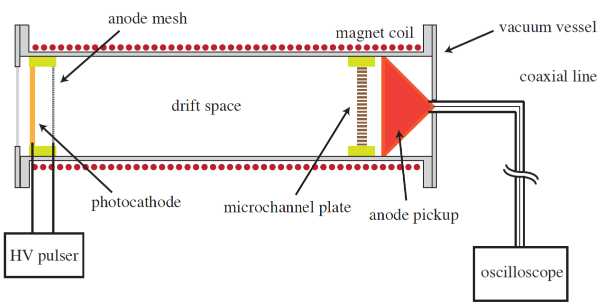

Figure 2: Conceptual illustration of a Pulse Dilation Photo-Multiplier Tube (PD-PMT). Reproduced under CC-BY 3.0 license from Ref. [19].

The effect of applying a fast voltage ramp from an external pulsed power supply is that the PD-PMT is able to provide a magnified temporal response to optical pulses.

DEMONSTRATIONS

An experimental demonstration of a PD-PMT was performed in 2016 [19]. Using a falling linear voltage ramp, pulse dilation by a factor of 25 was experimentally demonstrated. The results of that demonstration are reproduced in Fig. 3, adapted from the original [19].

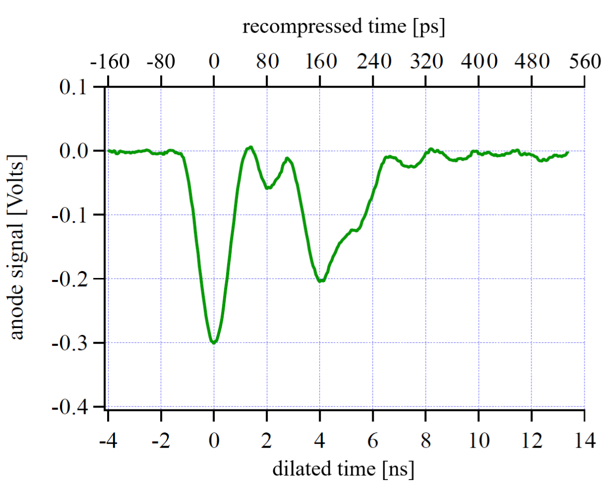

Figure 3: Measurement of two laser pulses separated in time by 160 ps. Photomultiplier tube anode signal was measured in dilated time, dilated by a factor of 25 from the original events. A corresponding horizontal axis of recompressed time indicates the laser pulse separation of 160 ps. Adapted under CC-BY 3.0 license from Ref. [19].

The Kentech PD-PMT makes use of two key components: a modified Photek PMT, and a Kentech fast pulsed high voltage power supply [20–23]. The device was demonstrated experimentally in 2018.

The temporal resolution of the Kentech PD-PMT was measured using a 0.2 ps laser pulse to represent an impulse function. Following compression and re-magnification, the 0.2 ps laser pulse was measured as 12 ps FWHM (5 ps RMS) [20]. This is comparable to many optical streak cameras, and also adequate for measuring the temporal profile of electron bunches in the APS-U storage ring [8, 9].

A PD-PMT has also been demonstrated by a group at Shenzhen University [24–26]. Device performance with resolution of 12 ps has been demonstrated [27].

DISCUSSION

Streak cameras are available for measuring short optical pulses, and as demonstrated in Fig. 1, they work. So are there advantages to using a PD-PMT instead of a streak camera? We contend that the PD-PMT offers advantages worth considering for future diagnostics of beams in electron storage rings.

The principal proposed advantage is the interfaces of the device. The device needs ethernet networking for control, and a fast rising trigger to initiate the pulser. But the output of the device is a low-bandwidth representation of a high-bandwidth optical pulse. We see that continuing investment in oscilloscopes to meet changing cyber security requirements makes it very desirable to be able to select low bandwidth (e.g. 1 GHz) oscilloscopes to measure high bandwidth (e.g. 20 GHz) optical pulses.

CONCLUSION

A pulse dilation photomultiplier tube offers a new way of measuring high bandwidth optical pulses using low bandwidth oscilloscopes. Previous measurements of short optical pulses using a dilated and recompressed signal suggests performance similar to a streak camera. It is desirable to be able to measure high bandwidth (e.g. 20 GHz) optical pulses using low bandwidth (e.g. 1 GHz) oscilloscopes. We contend that the PD-PMT offers advantages worth considering for future diagnostics of beams in electron storage rings.

ACKNOWLEDGEMENTS

KPW acknowledges assistance from Alex H. Lumpkin (ANL), Timothy Suzuki (MSU/ANL) and Weixing Cheng (ANL) in collecting the data shown in Fig. 1.

The submitted manuscript has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory ("Argonne"). Argonne, a U.S. Department of Energy Office of Science Laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan. `http://energy.gov/downloads/doe-public-access-plan`

ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-MOP078

REFERENCES

[1] D. J. Bradley, B. Liddy, W. E. Sleat, "Continuous-writing streak camera", *Nat.*, vol. 182, no. 4635, p. 564, Aug. 1958. doi:10.1038/182564c0

[2] G. S. Mavrogenes, C. Jonah, K. H. Schmidt, S. Gordon, G. R. Tripp, and L. W. Coleman, "Optimization of isolated electron pulses in the picosecond range from a linear accelerator using a streak camera–TV diagnostic system", *Rev. Sci. Instrum.*, vol. 47, no. 2, pp. 187–189, Feb. 1976. doi:10.1063/1.1134587

[3] W. W. Moses and S. E. Derenzo, "A method for measuring the time structure of synchrotron X-ray beams", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 291, no. 1–2, pp. 435–437, May 1990. doi:10.1016/0168-9002(90)90101-b

[4] A. Lumpkin *et al.*, "Initial diagnostics commissioning results for the APS injector subsystems", *AIP Conf. Proc.*, vol. 333, pp. 181–187, May 1995. doi:10.1063/1.48068

[5] M. Labat, L. Cassinari, M.-E. Couprie, R. Nagaoka, and D. Pédeau, "Streak camera measurements of the SOLEIL Bunch Length", in *Proc. DIPAC'07*, Venice, Italy, May 2007, paper WEPB05, pp. 241–243.

[6] A. L. Romanov *et al.*, "3D tracking of a single electron in IOTA", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 3708–3713. doi:10.18429/JACoW-IPAC2021-THXB01

[7] Y. Kim *et al.*, "Aerogel Cherenkov detector for characterizing the intense flash x-ray source, Cygnus, spectrum", *Rev. Sci. Instrum.*, vol. 87, no. 11, p. 11E723, Aug. 2016. doi:10.1063/1.4960541

[8] M. Borland, T. G. Berenc, R. R. Lindberg, and A. Xiao, "Tracking studies of a higher-harmonic bunch-lengthening cavity for the Advanced Photon Source Upgrade", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 543–545. doi:10.18429/JACoW-IPAC2015-MOPMA007

[9] M. Borland *et al.*, "The upgrade of the Advanced Photon Source", in *Proc. IPAC'18*, Vancouver, Canada, Apr.–May 2018, pp. 2872–2877. doi:10.18429/JACoW-IPAC2018-THXGBD1

[10] A. Lumpkin, B. Yang, W. Gai, and W. Cieslik, "Initial tests of the dual-sweep streak camera system planned for APS particle-beam diagnostics", in *Proc. PAC'95*, Dallas, TX, USA, May 1995, paper MPQ11, pp. 2476–2478. doi:10.1109/PAC.1995.505589

[11] A. H. Lumpkin, F. Sakamoto, and B. X. Yang, "Dual-sweep streak camera measurements of the APS user beams", in *Proc. PAC'05*, Knoxville, TN, USA, May 2005, paper RPAT086, pp. 4185–4187. doi:10.1109/PAC.2005.1591759

[12] K. P. Wootton, W. X. Cheng, G. Decker, N. Sereno, and F. Westferro, "Beamline for time domain photon diagnostics at the Advanced Photon Source Upgrade", in *Proc. IBIC'23*, Saskatoon, Canada, Sep. 2023, paper WEP016, pp. 363–367. doi:10.18429/JACoW-IBIC2023-WEP016

[13] G. L. Ahearn, "MaxVideo 200: A pipeline image processing architecture for performance-demanding applications", in *Proc. SPIE*, Washington DC, USA, vol. 2368, pp. 225–228, 1995. doi:10.1117/12.200800

[14] N. Arnold *et al.*, "Implementation of improved interactive image analysis at the Advanced Photon Source APS Linac", in *Proc. LINAC'98*, Chicago, IL, USA, Aug. 1998, paper TH4058, pp. 899–901.

[15] J. R. Vallino, "Datacube MV200 and ImageFlow user's guide", Department of Computer Science, University of Rochester, Tech. Rep. CS-TR 590, June 1995. http://hdl.handle.net/1802/396

[16] R. D. Prosser, "An electron-dispersion tube for the observation of subnanosecond transient signals", *Proc. IEEE*, vol. 60, no. 5, pp. 645–646, May 1972. doi:10.1109/proc.1972.8717

[17] R. D. Prosser, "Electron-dispersion technique for observation of fast transient signals", *J. Phys. E: Sci. Instrum.*, vol. 9, no. 1, pp. 57–59, Jan. 1976. doi:10.1088/0022-3735/9/1/018

[18] T. J. Hilsabeck *et al.*, "Pulse-dilation enhanced gated optical imager with 5 ps resolution", *Rev. Sci. Instrum.*, vol. 81, no. 10, p. 10E317, Oct. 2010. doi:10.1063/1.3479111

[19] J. D. Hares *et al.*, "A demonstration of ultra-high time resolution with a pulse-dilation photo-multiplier", *J. Phys. Conf. Ser.*, vol. 717, p. 012093, May 2016. doi:10.1088/1742-6596/717/1/012093

[20] S. G. Gales *et al.*, "Characterisation of a sub-20 ps temporal resolution pulse dilation photomultiplier tube", *Rev. Sci. Instrum.*, vol. 89, no. 6, p. 063506, Jun. 2018. doi:10.1063/1.5031110

[21] H. Geppert-Kleinrath *et al.*, "Pulse dilation gas Cherenkov detector for ultra-fast gamma reaction history at the NIF", *Rev. Sci. Instrum.*, vol. 89, no. 10, p. 10I146, Oct. 2018. doi:10.1063/1.5039377

[22] A. K. L. Dymoke-Bradshaw *et al.*, "Development of an ultrafast photomultiplier tube for gamma-ray Cherenkov detectors at the National Ignition Facility (PD-PMT)", *Rev. Sci. Instrum.*, vol. 89, no. 10, p. 10I137, Oct. 2018. doi:10.1063/1.5039327

[23] C. Trosseille, S. R. Nagel, and T. J. Hilsabeck, "Electron pulse-dilation diagnostic instruments", *Rev. Sci. Instrum.*, vol. 94, no. 2, p. 021102, Feb. 2023. doi:10.1063/5.0128802

[24] W. Fu, H. Cai, D. Wang, Y. Lei, and J. Liu, "Time resolved x-ray image of laser plasma interactions using a dilation framing camera", *Opt.*, vol. 186, pp. 374–378, Jun. 2019. doi:10.1016/j.ijleo.2019.04.093

[25] W. Fu *et al.*, "Development of an ultra-fast photomultiplier tube with pulse-dilation technology", *IEEE Access*, vol. 8, pp. 47533–47537, Mar. 2020. doi:10.1109/access.2020.2979756

[26] W. Fu, C. Hu, P. Chen, R. Zhou, and L. Li, "The development of an electron pulse dilation photomultiplier tube diagnostic instrument", *Sens.*, vol. 24, no. 23, p. 7497, Nov. 2024. doi:10.3390/s24237497

[27] H.-Z. Cai, Q.-Y. Luo, K.-X. Lin, D. Wang, J.-K. Huang, and J.-Y. Liu, "Development of an ultrafast detector and demonstration of its oscillographic application", *Nucl. Sci. Tech.*, vol. 33, no. 6, p. 72, Jul. 2022. doi:10.1007/s41365-022-01055-5