ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-TU1AB3

THE OPTICAL DISSECTOR BUNCH LENGTH MEASUREMENTS AT THE METROLOGY LIGHT SOURCE

D. Malyutin†, A. Matveenko, M. Ries, Helmholtz-Zentrum Berlin, Berlin, Germany
O. Anchugov, V. Dorokhov, S. Krutikhin, O. Meshkov, Budker Institute of Nuclear Physics, Novosibirsk, Russia

Abstract

The bunch longitudinal profile measurements using an optical dissector are introduced in the paper. The principles of the dissector operation are briefly discussed. The first measurements using the optical dissector at the Metrology Light Source are presented. Results are analyzed and compared with the bunch profiles from the streak camera measurements. Measurement errors and limitations of the both methods are estimated. Possible applications for the presented technique are discussed.

INTRODUCTION

Practically all present synchrotron radiation sources and electron-positron colliders use streak cameras as an important diagnostic tool, which may provide high spatial resolution (up to tens of micrometers) as well as ultimate temporal resolution up to hundreds of femtoseconds [1, 2]. In the seventies of the last century, the LI-602 dissector [3, 4] was developed at BINP to measure the longitudinal beam profile at circular accelerators. This electron-optical device is based on a stroboscopic approach and is designed for measurement of periodic light pulses of sub-nanosecond and picosecond duration. This dissector is used now for permanent control of the bunch length at the VEPP-2000, VEPP-4M electron-positron colliders and SIBERIA-2 synchrotron light source [5, 6]. However, the LI-602 dissector provides a limited temporal resolution of 20 ps, which is at least one order of magnitude higher than required for modern accelerator diagnostics. Later a new generation of picosecond dissectors was developed based on the PIF-01/S1 picosecond streak-image tube [7, 8] designed and manufactured at the GPI Photoelectronics Department [9, 10]. The experimentally determined temporal resolution of such dissector approaches 3.5 ps [11]. This value was obtained illuminating the tube-input photocathode with femtosecond laser pulses at 800 nm wavelength [12]. In this paper, we describe the test of this new dissector under real experimental conditions at the Metrology Light Source (MLS) [13]. A comparison between the dissector and a Hamamatsu streak camera C10910 [14] was undertaken.

DISSECTOR

The dissector is a device similar to the streak camera. The main difference is in the detector part. The basic schematic layout of the dissector is shown in Fig. 1 and a photo of the dissector vacuum tube is shown in Fig. 2.

† dmitriy.malyutin@helmholtz-berlin.de

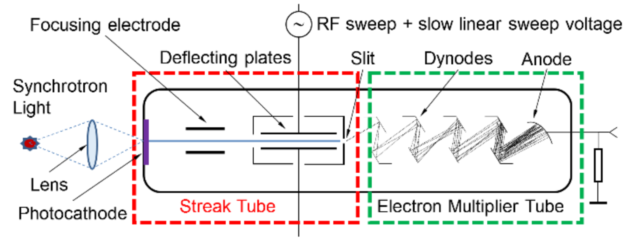

Figure 1: Dissector basic layout.

Figure 2: Dissector vacuum tube.

The synchrotron light pulse is focused on the photocathode and produces photoelectrons. These electrons are accelerated, focused and deflected transversely in a linear dependence of their longitudinal position. As a result, the vertical profile of the electron image at the slit plane will give directly the initial synchrotron light temporal profile, like in a streak camera. In the dissector a narrow slit cuts a small fraction of the electron image and this fraction of electrons is amplified in the electron multiplier tube. The amplified signal is measured by an oscilloscope or an ADC module.

Introducing a slow linear sweep voltage to the deflecting plates allows to scan the full electron image through the slit. The vertical profile is then measured as a function of time on the oscilloscope trace.

With a permanent light source like a flashlight the dissector can be calibrated: a typical signal from the dissector output will have the following appearance, Fig. 3.

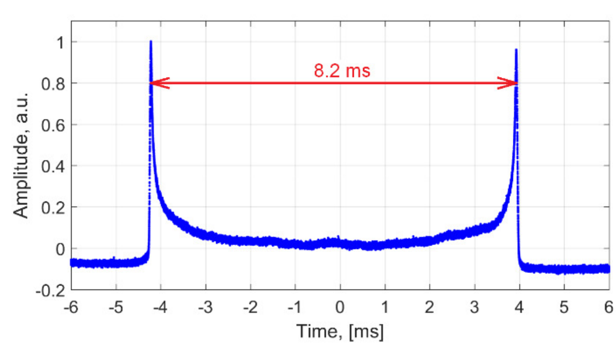

Figure 3: Dissector calibration. Signal from the dissector output for the permanent light source as an input.

6th International Beam Instrumentation Conference IBIC2017, Grand Rapids, MI, USA JACoW Publishing
ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-TU1AB3

The two peaks corresponds to the time points when the photo electrons have maximum deflection due to the RF sweep – so the distance between two the peaks is the half period of the dissector RF frequency. For the MLS case, the dissector is operated at the 93.8 MHz – the fifteenth harmonic of the MLS revolution frequency, which is about 6.25 MHz (MLS RF frequency is 500 MHz). The measured distance between the peaks (Fig. 3) is 8.2 ms (mostly defined by the speed of the slow linear sweep voltage and RF sweep amplitude) and corresponds to the time distance for the photo electrons of about 5.3 ns (a half of a period of the dissector RF sweep).

Switching off the RF sweep and running only the linear sweep voltage, the point spread function of the dissector can be measured, Fig. 4 (dissector response to the light pulse with "zero" duration).

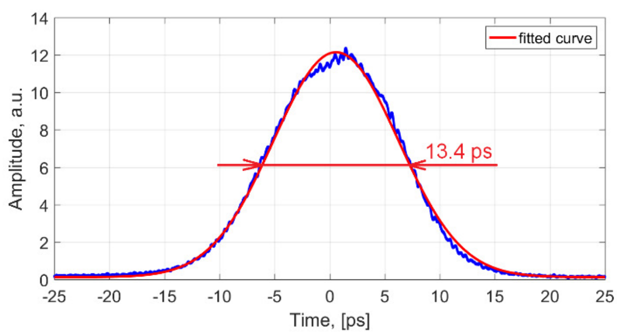

Figure 4: Point spread function of the dissector: dissector signal (the blue dots) and Gaussian fit (the red curve). The time axis is already scaled according to the calibration.

The FWHM from the Gaussian fit gives 13.4 ps. In other words, a bunch with "zero" bunch length will be measured by the dissector with a length of 5.2 ps. This number mainly depends on how well the alignment of the light path is performed and how small the light spot is at the dissector input. It also depends on how small the slit in front of the electron multiplier tube is and how well the electron optics is done, Fig. 1. For the used dissector vacuum tube, the slit width was about 50 µm.

MEASUREMENT RESULTS

Examples of the bunch profiles measured by dissector and streak camera are shown in Fig. 5 and Fig. 6 for 1.3 and 0.13 mA bunch current respectively. For the long bunch, about 24 ps FWHM, the bunch length measured by the both devices are similar, but the shape is different. Dissector cannot reproduce the fast change in the bunch current in comparison with the streak camera – point spread function of the dissector is bigger: 13.4 ps versus 2.6 ps for the streak camera. Also one can see not Gaussian profile of the bunch for the high charge.

For the short bunch, about 13 ps FWHM, dissector gives longer profile, which is about 18 ps. Subtracting the point spread function of the dissector one can get the bunch length close to the one obtained by the streak camera.

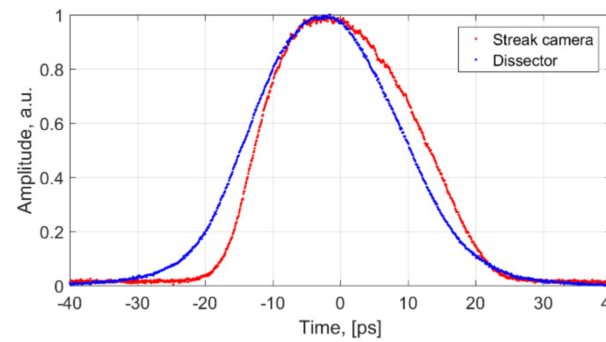

Figure 5: The bunch current profiles from the dissector and streak camera for 1.3 mA bunch current. Low alpha optics at MLS.

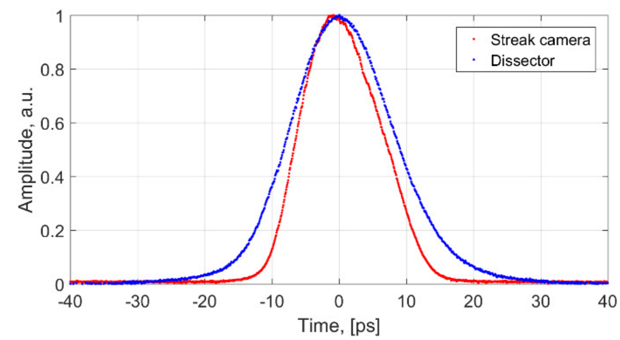

Figure 6: The bunch current profiles from the dissector and streak camera for 0.13 mA bunch current. Low alpha optics at MLS.

The result of the bunch length measurements as a function of the bunch current using dissector is shown in Fig. 7.

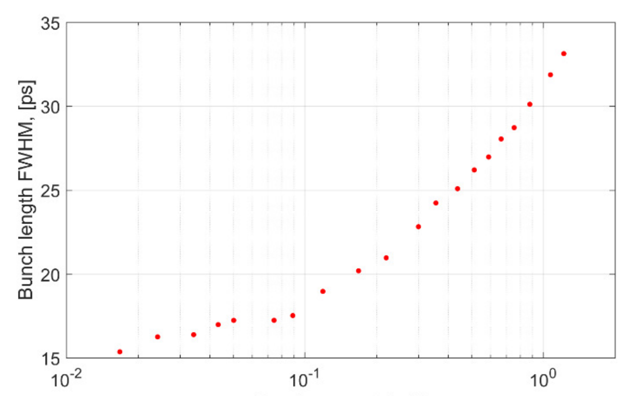

Figure 7: Measured bunch lengths as a function of single bunch current. Low alpha optics at MLS.

The measurements of the bunch length as a function of the RF cavity voltage are shown in Fig. 8 and Fig. 9 for standard user and low alpha optics settings of the MLS respectively. Measurements were performed by the dissector and the streak camera simultaneously: the synchrotron light was shared between the both devices by the edge of a mirror. The bunch length from the dissector was obtained as the FWHM of the scope signal, and the bunch length from the streak camera was obtained as the FWHM of the

ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-TU1AB3

fitted Gaussian to the image profile. Point spread function of both devices is subtracted.

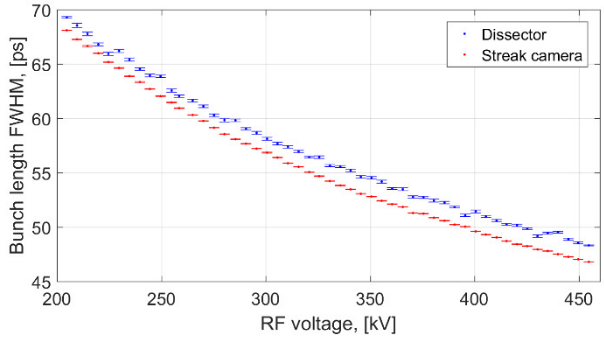

Figure 8: Bunch length at FWHM as a function of the RF cavity voltage measured with the dissector (the blue dots with error bars) and with the streak camera (the red dots with error bars) for the standard user optics at MLS and 0.9 mA bunch current.

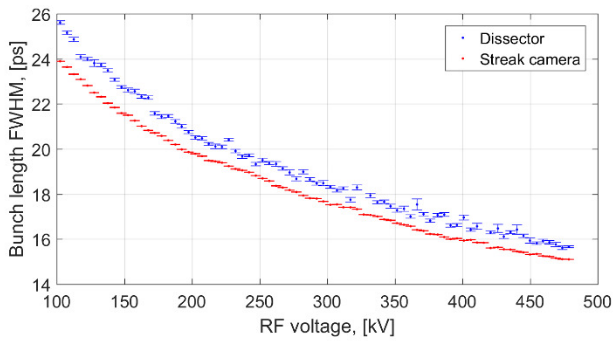

Figure 9: Bunch length at FWHM as a function of the RF cavity voltage measured with the dissector (the blue dots with error bars) and with the streak camera (the red dots with error bars) for the low alpha optics at MLS and 0.3 mA bunch current.

Error bars in figures represent the statistical errors: each voltage point corresponds to about forty measurements of the bunch length.

The dissector gives slightly larger values of the bunch lengths in comparison with the streak camera. Main reason is the error in the FWHM calculation: due to the noise of the dissector signal the scope calculates higher value of the FWHM than one can get from the Gaussian fit.

Another error comes from the calibration and can be estimated to be around 2%, Fig. 4. An additional error source is coming from the point spread functions of the devices. For the streak camera it was measured to be around 2.6 ps FWHM and for the dissector in the current set of measure-ments it was around 12.5 ps. Both values can be improved by a more careful alignment and fine tuning of the both systems. The best achieved value for the dissector was about 5 ps.

CONCLUSION

The bunch length diagnostic based on the optical dissector was successfully commissioned at the Metrology Light Source. The measured bunch profiles and the bunch lengths obtained by the dissector and the streak camera are in good agreement for the range from 70 ps down to 15 ps. Slight overestimation in the dissector data can be explained by the error of FWHM determination of the used scope: noise in the dissector signal yields a bigger value of the calculated FWHM than if one will get it from the smooth curve fit.

Next steps will be to perform a comparison of the devices for even shorter bunches down to 1 ps.

One of the possible application of the dissector can be bunch length measurement in the BESSY II booster where other diagnostics are not available up to now [15]. The dissector is simple and radiation hard device in contrast to the streak camera. In result is can be used for the permanent bunch length monitoring at the running facility.

ACKNOWLEDGEMENT

Experimental samples of dissectors with picosecond resolution were designed and manufactured at the Department of Photoelectronics of A.M. Prokhorov General Physics Institute, Russian Academy of Sciences. The authors wish to thank all the Department members and especially the members of its technological division, namely, G.P. Levina, V.A. Makushina, S.R. Ivanova, Yu.M. Mikhal'kov. The authors are grateful to P. A. Molyavin for technical assistance. We are very grateful to Physikalisch-Tech-nische Bundesanstalt (PTB) and Dr. Jörg Feikes for the possibility to perform the dissector commissioning at the MLS. We are very grateful to Dr. Roland Müller and Dr. Ji Li for masterful management of the MLS for our experi-ments. Also we would like to express our thanks to the all people who provide us the necessary equipment for the preparations, installations and the measurements: Arne Hoehl, Terry Atkinson, Ingo Müller, Hannes Stein, Bern-hard Schriefer and Andreas Heugel.

REFERENCES

[1] L. N. Vyacheslavov, M. V. Ivantzivskiy, O. I. Meshkov *et al.*, *Phys. At. Nucl.*, 43, 451 (2012).
[2] M. Ya. Schelev, *Physics-Uspekhi,* 55, 607 (2012).
[3] E. I. Zinin *et al., At. Energ.,* 20, 320 (1966).
[4] E. I. Zinin *et al., Nucl. Instrum. Methods,* 208, 439 (1983).
[5] O. I. Meshkov, V.F. Gurko, A. N. Zhuravlev *et al.,* "The Upgraded Optical Diagnostic of the VEPP-4M collider", in *Proc. (EPAC'04)*, Lucerne, Switzerland, 2004, pp. 2739 – 2741.
[6] O. Meshkov, A. Stirin, G. Kovachev *et al.,* "A new station for optical observation of electron beam parameters at electron storage ring SIBERIA-2". *Journal of Instrumentation* 12/2016; 11(12):P12015-P12015
[7] V. P. Degtyareva, Yu. V. Kulikov, M. A. Monastyrsky, *et al.*, in *Proc. SPIE*, 491, 239 (1984).
[8] A. M. Prokhorov, N. S. Vorob'ev, V. I. Lozovoi, *et al., Quantum Electron.,* 32, 283 (2002).
[9] S. G. Garanin, S. A. Bel'kov, G. S. Rogozhnikov, *et al., Quantum Electron.,* 44, 798 (2014).
[10] E.I. Zinin and O.I. Meshkov, "Optical dissector for longitudinal beam profile measurement", *JINST,* 2015 1748-0221 10 P10024 doi:10.1088/1748-0221/10/10/P10024.

ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-TU1AB3

[11] E.I. Zinin, O.V. Anchugov, V.L. Dorokhov *et al.,* "Direct temporal-resolution calibration of new-generation dissector", *JINST,* 2016 1748-0221 11 T03001 doi:10.1088/1748-0221/11/03/T03001.

[12] O. I. Meshkov *et al.,* "Development, Calibration and application of new –generation dissector with picosecond temporal resolution", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16)*, Barcelona, Spain MOPG60, pp. 205-208.

[13] J. Feikes *et al.,* in *Proc. 11th European Particle Accelerator Conf.* (EPAC'08), Genoa, Italy, pp. 2010.

[14] https://www.hamamatsu.com

[15] D. Malyutin *et al.,* "Injection and Bunch Length Studies at the BESSY II Storage Ring", presented at the 6th Int. Beam Instrumentation Conf. (IBIC'17), Grand Rapids, Michigan, USA, August 2017, paper TUPCC06, this conference.