

DEVELOPMENT, CALIBRATION AND APPLICATION OF NEW-GENERATION DISSECTOR WITH PICOSECOND TEMPORAL RESOLUTION

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Abstract

A dissector is an electron-optical device designed for measurement of periodic light pulses of subnanosecond and picosecond duration. LI-602 dissector developed at BINP SB RAS is widely used for routine measurements of a longitudinal profile of electron and positron beams at BINP electron-positron colliders and other similar installations [1-3]. LI-602 dissector is a part of many optical diagnostic systems and provides temporal resolution of about 20 ps. Recently a new generation of picosecond dissectors were created on the basis of the PIF-01/S1 picosecond streak-image tube designed and manufactured at the GPI Photoelectronics Department [4, 8-10]. The results of the measurements of instrument function of the new dissector based on PIF-01/S1, which were carried out in the static mode [5], showed that temporal resolution of the dissector can be better than 3-4 ps (FWHM). The results of temporal resolution calibration of the new-generation picosecond dissector carried out at the specialized set-up based on a femtosecond Ti:sapphire laser and recent results of longitudinal beam profile measurements at BINP damping ring are given in this work.

BASIC PRINCIPLES OF DISSECTOR OPERATION

The detailed description of the detector operation can be found in [3, 6]. We will remind just very common ideas of the device operation. The layout of a dissector is shown in Fig. 1. The image section of dissector consists of a photocathode, electron lens, deflection plates and slit aperture.

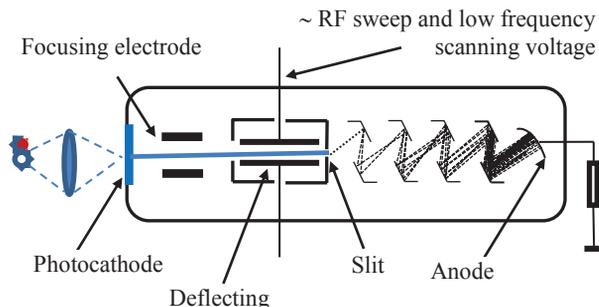
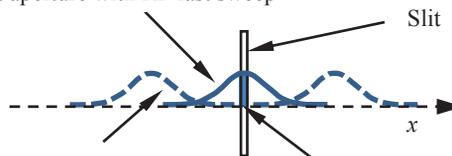


Figure 1: The simplified layout of the dissector.

Let the point-like image of a pulse radiation source be projected onto the photocathode of such a device. If radiation pulses and RF deflection voltage are strictly synchronized, then a stationary electron image $Q(x)$ appears on the slit plane (Fig. 2). The typical frequency of RF sweep voltage $U_{sw}(t)$ is tens of MHz. The image $Q(x)$ reproduces the time structure of the object under observation.

Beam longitudinal profile $Q(x)$ obtained at the slit aperture with RF fast sweep



Slow scanning of the beam longitudinal profile through the slit

q - Fraction of the electrons passing through the slit

Figure 2: The scheme of slow scanning of $Q(x)$ distribution transversely through the slit.

Only the electrons with charge q , which pass through the slit, reach the secondary electron multiplier. The average anode current of the secondary electron multiplier is proportional to this charge q and is proportional to the luminosity of the process at the given moment. The beam image is scanned transversely through the slit with velocity $V_{sl} \ll V_{sw}$. When distribution $Q(x)$ is scanned, the anode signal of the secondary electron multiplier repeats the shape of the observed signal.

TIME SCALE OF THE DISSECTOR

A simple way to define a time scale is an important advantage of the dissector. It is achieved with permanent point-like source of the light focused on the photocathode of the dissector. The space distribution $Q_p(x)$, as it is represented in Fig.3, periodically appears on the slit aperture plane and is read out during slow scanning. As a result, the space scale transforms into time scale. The space interval and the corresponding time interval T_l between two distinct marks at the calibration curve depend on U_0 at fixed RF frequency ν_{RF} . The same signal appears at the anode of the dissector if to scan slowly this distribution with linear ramp voltage applied to the deflecting plates.

The upper plot in Fig. 3 is an experimental curve obtained for temporal calibration of the dissector. The sweep velocity as well as the time scale of the dissector

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are obviously non-linear and varies within the period of RF sweep. The shape of the calibration curve depends on the relation between technical resolution of the dissector (see below) and the RF sweep span [3, 6].

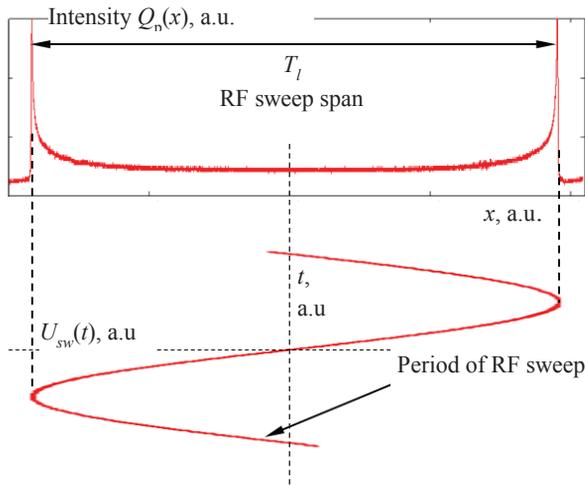


Figure 3: The temporal calibration of dissector with a permanent point-like light source.

The restrictions of accuracy of calibration caused by non-linearity of the scan are described in [6]. The temporal interval corresponding to the labels is $T = 2/\omega_{RF} = T_{RF}/\pi$, ω_{RF} is an angular velocity of RF sweep. We define a technical resolution as an instrumental function of the tube, which depends just on the quality of electron optics of the device.

The measured pulse should be placed at the center of the sweep where non-linearity is negligible. It is achieved with a change of a phase shift between the measured signal and the RF sweep.

FEATURES OF THE DISSECTOR OPERATION

The precise measurements of bunch length with LI-602 dissector can be done at single-bunch mode of operations of accelerator. A dissector must operate at N harmonic of revolution frequency ($N \gg 1$).

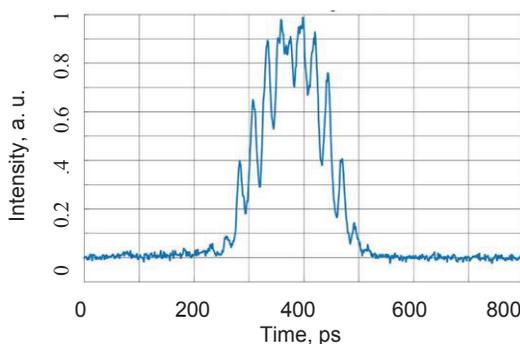


Figure 4: Distortions of the signal of the dissector caused by synchrotron oscillations.

It means that signals from different bunches will overlap for multi-bunch beam. For example, SIBERIA-2 stor-

age ring has 75 separatrices. The LI-602 dissector is applied for beam length measurements and operates at 15 harmonic of revolution frequency [7]. Due to that the signal of the dissector contains 5 peaks and each of them is a sum of signals from 5 separatrices. The new version of the dissector has an electrons shutter which may select a chosen separatrix.

Another feature of the dissector is a high sensitivity to the phase oscillations of the beam. Phase oscillations appear at SIBERIA-2 at the beam current less than 2 mA at the energy of injection. It takes place because of decrease of a feedback between the beam and accelerating RF cavity. It distorts an operation of the dissector (Fig. 4). On the other hand a Fourier transform of the dissector signal enables us to determine a synchrotron frequency (Fig. 5).

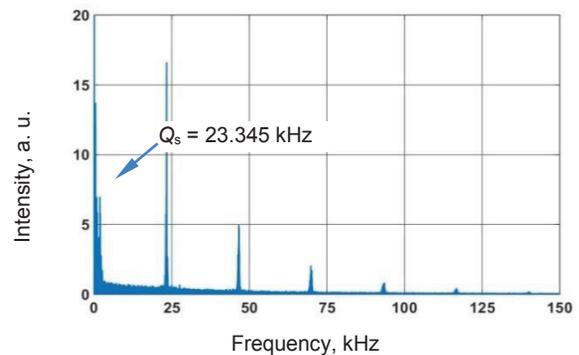


Figure 5: Synchrotron frequency obtained by Fourier transform of the dissector signal.

DIRECT TEMPORAL-RESOLUTION CALIBRATION OF THE DISSECTOR

The direct measurements of the dissector temporal resolution were carried out at the laser set-up (specially created at the GPI Department of Photoelectronics) for testing technical parameters of the picosecond dissectors being under development by means of synchronous electron-optical chronography method (Fig. 6), [11]. The Ti:sapphire laser generated light pulses at the wavelength of 0,81 microns with a 30-femtosecond duration at the frequency of 75,3 MHz.

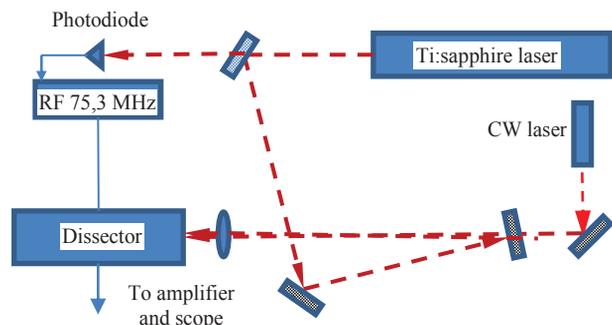


Figure 6: The scheme of the experiment for direct measurement of the temporal resolution of the dissector.

Thus, the pulse duration was much shorter than the expected temporal resolution of the dissector and can be neglected at measurements. Radiation of the laser, re-

flected from two surfaces of the plane-parallel glass plate, was focused on the dissector photocathode by a lens. As a result, a pair of pulses separated by the time interval $\tau = 2dn/c$ (where d is thickness of the glass plate, $n = 1,51$ is glass refraction index) came to the dissector with a frequency of 75 MHz. We used four plates with the thicknesses creating a time interval between pulses of 100; 52,1; 25,4 and 9,7 ps (Fig. 7).

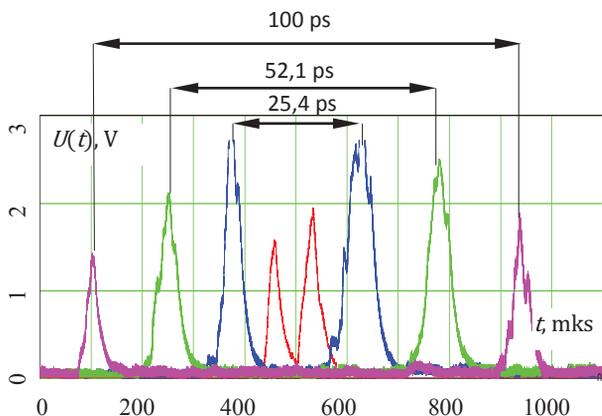


Figure 7: Pairs of the laser pulses acquired by the dissector at different time intervals between them.

RF voltage with a frequency of 75,3 MHz and with a total amplitude up to 1500 V and scanning saw-tooth voltage with a frequency of 50 Hz and with an amplitude up to 750 V were simultaneously applied to the deflecting plates of the dissector.

It should be noted that to achieve the ultimate temporal resolution, light should be focused on the dissector photocathode in a spot with a size not exceeding the width of the slit at the EMT input, which in our case is $s = 0,04$ mm. The expected value of temporal resolution is [4, 12]: $t_{tr}(s) = (s(\text{mm}) \cdot M) / (2\pi\nu_{RF}(\text{Hz}) \cdot U_{RF}(\text{V}) \cdot \xi (\text{V/mm})) \approx 3$ ps, where $\xi = 0.07$ mm/V is an efficiency of the deflecting plates for PIF-01/S1, $M = 1,5$ is coefficient of electron-optical magnification.

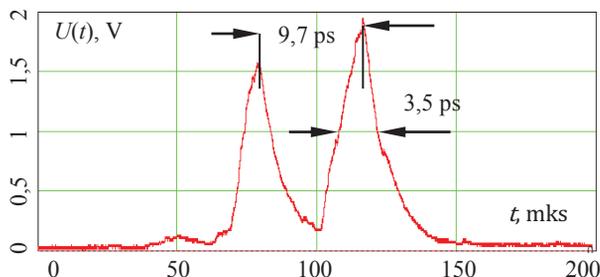


Figure 8: The two laser pulses separated by a 10-ps time interval acquired by the dissector.

The best temporal resolution of 3,5 ps (FWHM) was measured for the 10-ps interval, as shown in Fig 8. The average value for all pairs of pulses is $4,5 \pm 0,6$ ps.

APPLICATION OF THE DISSECTOR AT THE DUMPING RING

The dissector with temporal resolution of about 4 picoseconds has recently started operating at the BINP damping ring. The beam stored at accelerator contains several bunches separated by time interval of 1,2 ns.

The comparison of data obtained with streak camera PS-1/S1 and the dissector is presented in Fig. 9. A good agreement of two methods can be observed.

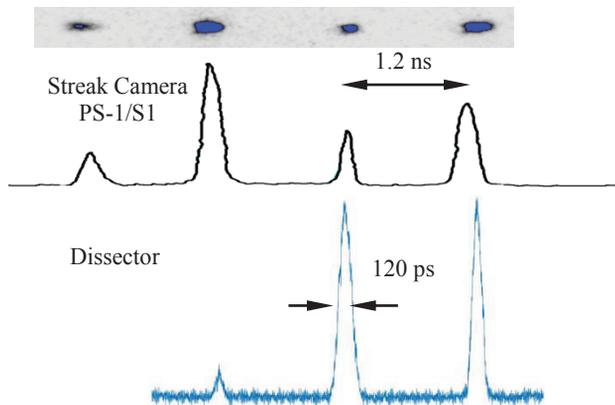


Figure 9: The longitudinal bunches profiles acquired by streak camera PS-1/S1 and the dissector.

CONCLUSION

We have showed the possibility to achieve temporal resolution within picosecond range by means of the dissector created based on the PIF-01/S1 picosecond streak tube developed earlier at GPI RAS. The set-up, created at the GPI Department of Photoelectronics for measurement and calibration of temporal resolution of new-generation picosecond dissectors, which uses radiation of the femto-second Ti:sapphire lasers, has showed efficiency and reliability at testing of the dissectors in the continuous scanning mode with the highly-stable 75-MHz generator, also developed by the participants of the present Russian Science Foundation Project. The dissector was successfully tested at damping ring of BINP.

ACKNOWLEDGMENTS

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