RECENT RESULTS FROM NEW STATION FOR OPTICAL OBSERVATION OF ELECTRON BEAM PARAMETERS AT KCSR STORAGE RING

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Abstract

The new station for optical observation of electron beam parameters at electron storage ring SIBERIA-2 is dedicated for measurement of transverse and longitudinal sizes of electron bunches with the use of synchrotron radiation (SR) visible spectrum in one-bunch and multi-bunch modes and for the study of individual electron bunches behavior in time in the conditions of changing accelerator parameters. The paper briefly describes the main components of the diagnostics and experimental results obtained with them.

OPTICAL OBSERVATION STATION

SR Beam Line

Fig. 1 represents the model of SR beam line and optical table. The beam line has two collimators forming round shape of a SR beam and supressing a stray light.

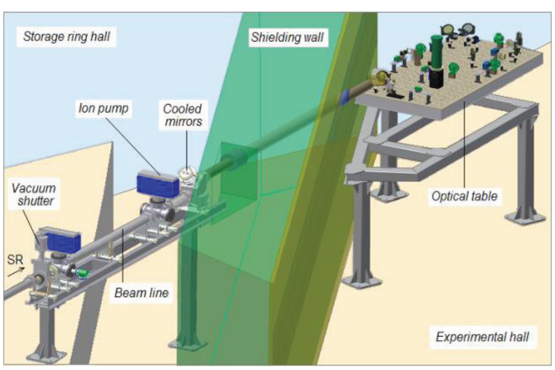

Figure 1: Model of SR beam line with the diagnostics devices placed on the optical table.

First collimator (cooled) is installed at SR beam line entrance. The second collimator (non-cooled) is installed after the quartz vacuum window. The inlet part of vacuum SR beam line (is not shown in Fig. 1) comprises SR absorber and ion pump. The optical part of SR spectrum is separated from the SR fan with two mirrors. The first optically polished cooled copper mirror is installed inside the vacuum unit at the distance about 6 m from source point. The mirror is coated with gold. The second Al – coated mirror reflecting the optical radiation is manufactured from the glass.

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Both mirrors can be mechanically adjusted for precise alignment of the light beam. Lead beam stopper is installed inside the part of beam line passing through the shielding wall for to absorb scattered X-rays. The complete length of the beam line from source point to the main lens of diagnostics placed at the optical table is about 10 m. The computed values of synchrotron radiation from bending magnet at $\lambda = 500$ nm are presented in Table 1.

Table 1: Computed Parameters of Synchrotron Radiation from Bending Magnet at $\lambda = 500$ nm

Divergence, $\sigma_{SR} = (3\lambda/4\pi R)^{1/}$	$1.8\cdot10^{-3}$ rad
Diffraction limit, $\sigma_D \approx (\lambda^2 R/12\pi^2)^{1/3}$	≈0.011 мм
Minimal radial size, $\sigma_R \approx R(\sigma_{SR})^2/2$	≈0.03 мм

Layout of the Optical Diagnostics

The measurement part of the optical diagnostics [1] consists of six independent devices with different functions located on the optical table outside the storage ring shielding wall. We use the STANDA optical table.

Transverse beam sizes precise measurement system is based on the double-slit interferometer serves to measure bunch vertical size with a resolution about several µm.

Bunch longitudinal sizes measurement system is based on the optical dissector tube with electrical focusing and deflection is also used for the diagnostics of longitudinal multi-bunch instability caused by electron bunches interaction with high modes of cavity electromagnetic field. The marker is used for determining and controlling the temporal scale of the dissector. Dissector tube temporal resolution is 40 ps FWHM [2]. The light reflects to dissector from the Edmund Optics 6’’ pellicle beamsplitter

TV camera is used for observation of the electron beam cross-section image on the video monitor in main control room.

The CCD camera is based on high resolution Allied Vision Technology 1280×960 pixels EG1290 CCD camera with a 100 Mbit Ethernet interface. The result of computer processing of signal from CCD-matrix is a visual two-dimension image of electron beam cross-section, x - and y - curves of electron density distribution within beam, FWHM of Gaussian curve on both coordinates and position of center of electron beam [4].

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Turn-by-turn beam transverse cross-section measurement systems records at 16 points y- and x-distribution of electron density within a chosen bunch, determines betatron and synchrotron tunes (defined by way of Fourier analysis of bunch dipole oscillations triggered by kick) as well as investigates y - or x - dynamics of a bunch shape. The diagnostics provides a one-turn distribution during tens of thousands turns of beam and is based on Silicon Sensor 16- elements avalanche photodiode array AA-16-0.13-9 SOJ22GL.

EXPERIMENTAL RESULTS

Transversal Beam Dimensions

We tested the double-slit interferometer s varying separation of slits D within 15 – 30 mm with step of 5 mm (Fig. 2) during routine run of SIBERIA-2. The visibility of interference patterns is correlated well with theoretical calculations.

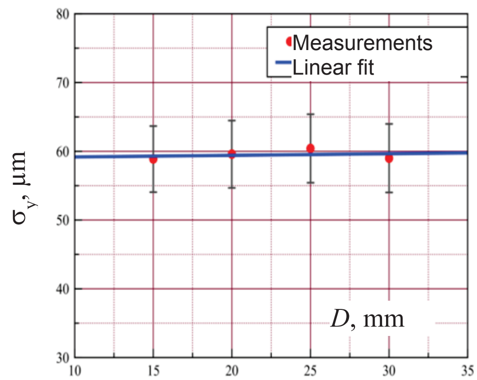

Figure 2: Vertical beam size determined with a different slit separation D.

Another method of measurements of transversal dimensions of a beam is provided by projection optics and CCD camera (Fig. 1). Calibration of spatial scale of CCD camera was done with controllable shift of the position of the beam.

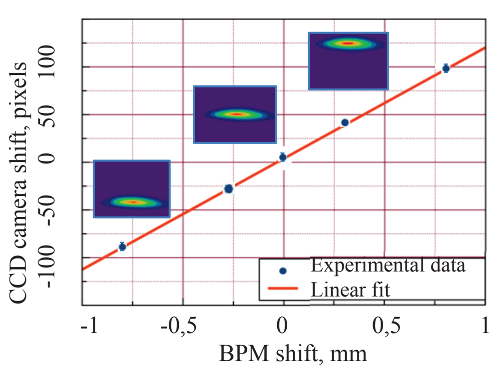

Figure 3: Shift of the beam image at the CCD camera vs BPM data.

The beam was vertically shifted by the magnet corrector and beam position was measured by Beam Position Monitors (BPM). The center of mass of beam image at CCD matrix was computed as well. The data of BPM had a good coincidence with values computed from numerical model of the accelerator. (Fig. 3). The spatial scale of one pixel of CCD matrix was determined as 9±0.2 µm. Taking into account the instrumental function, the measured horizontal beam size σ_x = 480 µm is in a good agreement with the expected value.

Measurement of Longitudinal Beam Size with Dissector and Streak Camera

The dissector LI-602 [2-4] is a traditional component of the optical diagnostics of the accelerators of Budker Institute of Nuclear Physics. It is a very reliable and sensitive device which can be applied for permanent control of longitudinal beam profile

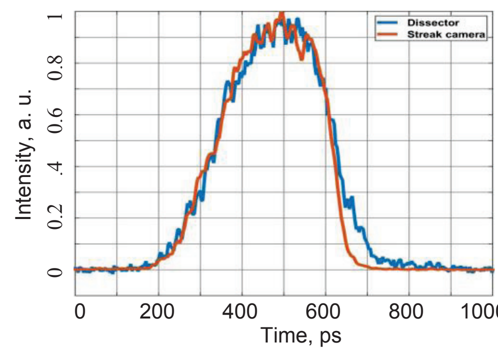

Figure 4: Comparison of the beam profiles acquired by the dissector and streak camera, $I_b \approx 12$ mA.

The disadvantage of the LI-602 is a relatively low temporal resolution τ, about 40 ps FWHM. Recently the new version of the dissector with τ ≈ 3 ps was developed [5,6].

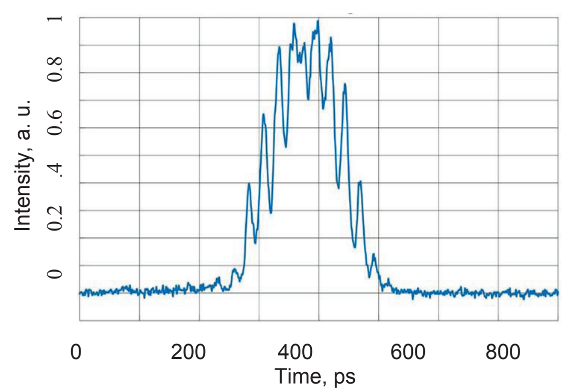

Figure 5: Distortions of the signal of the dissector caused by synchrotron oscillations, $I_b \approx 2$ mA.

The instrumental function of the dissector can be easily measured with a permanent light source [4], but a true temporal resolution of the device depends on the stability of the jitter of RF sweep voltage of the dissector relative to arrival time of electron beam to the observation point. The feature of the dissector is a high sensitivity to the phase oscillations of the beam (Fig.5). We have compared the measurements of the beam length by the dissector and by streak camera PS-1/S1 [7], Fig. 4, 6. Streak camera was temporary supplemented to the optical diagnostics.

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The experiments were done at single bunch mode of operation of SIBERIA-2 and at the energy of injection E = 446 MeV. The lengthening of the beam due to microwave instability is clearly seen (Fig. 6).

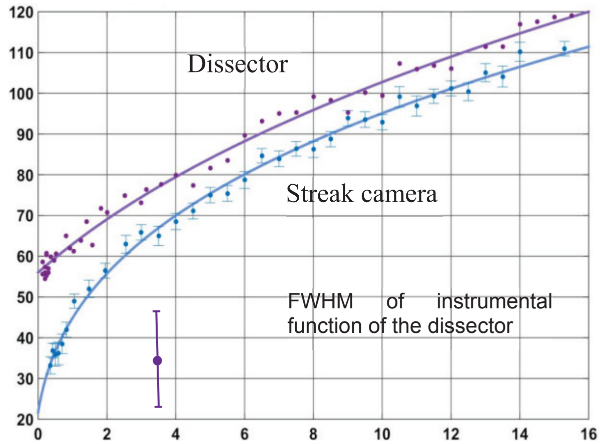

Figure 6: Beam length vs beam current measured by optical dissector and streak camera at E = 446 MeV.

The wideband impedance $Z_{\|}/n \approx$ 2,9±0.5 Ohm of vacuum chamber of SIBERIA-2 was computed from the results obtained with streak camera [8-10]:

$$\sigma_z^3 = \frac{R^3 \alpha \left|Z_{\|}/n\right|_{BB}}{\sqrt{2\pi} E Q_s^2} I_b$$

R – an average radius of the orbit, α - compaction factor, Q_s – synchrotron frequency, n – harmonic number of the revolution frequency.

The data of dissector are systematically exceeded the data of streak camera at the value about 10 ps. This discrepancy increases at the beam current less than 2 mA due to synchrotron oscillations which are distorted an operation of the dissector (Fig. 5). Synchrotron oscillations appear at this value of the beam current at the energy of injection because of decrease of a feedback between the beam and accelerating RF cavity. On the other hand a Fourier transform of the dissector signal enables us to determine a synchrotron frequency (Fig. 7).

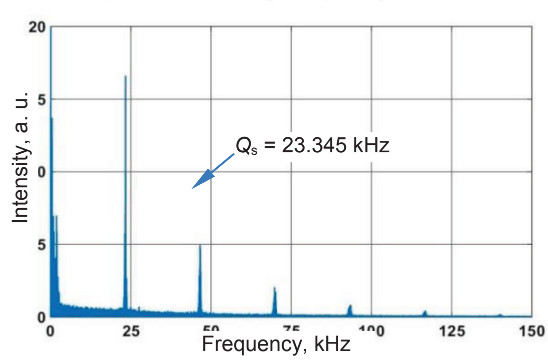

Figure 7: Synchrotron frequency obtained by Fourier transform of the dissector signal

Measurement of Transversal Beam Profile with Linear APD Array

Turn-by-turn beam transverse cross-section measurement systems [11] serves the purpose of measuring y- and x- distribution of electron density within a chosen bunch, betatron and synchrotron tunes (defined by way of Fourier analysis of bunch dipole oscillations triggered by kick) as well as investigating y- or x- dynamics of beam shape in a chosen separatrix. The diagnostics should provide a one-turn distribution during hundreds of thousands turns of a beam. The systems use a linear photo-detector based on 16 - element avalanche photodiode array. The device includes AA16-0.13-9 SOJ22GL photodetector unit and signal recorder. The photodetector unit is built on a photodiode strip consisting of 16 integrated avalanche photodiodes. Dimensions of the single sensitive element are 648×208 μm and a pitch between two elements is 320 μm.

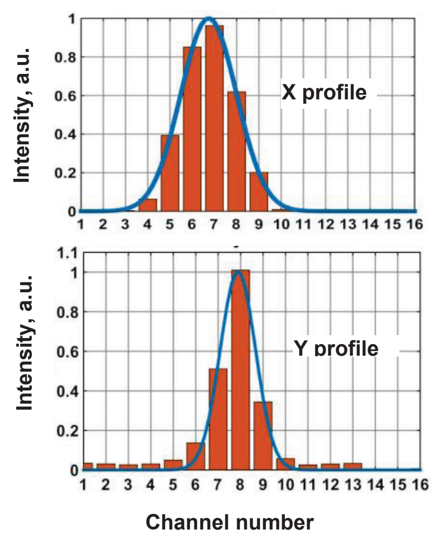

Figure 8: The vertical and radial beam profiles of a single bunch acquired with APD at a single beam turn.

Figure 8 represents the x, y beam profiles of a single bunch acquired with the APD.

CONCLUSION

The station of beam optical diagnostics is commissioned at SIBERIA-2 storage ring. The diagnostics is able to measure all the beam dimensions and meet the requirements of accelerator physics experiments and experiments with the use of SR related to the knowledge of parameters of separate electron bunches.

ACKNOWLEDGMENTS

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