THE NEW OPTICAL DEVICE FOR TURN TO TURN BEAM PROFILE MEASUREMENT

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Abstract

The electron beam quality determines the main synchrotron radiation characteristics therefore beam diagnostics is of great importance for synchrotron radiation source performance. The real-time processing of the electron beam parameters is a necessary procedure to optimize the key characteristics of the source using feedback loops.

The frequency of electron beam cycling in the synchrotron storage ring is about 1 MHz. In multi-bunch mode electrons are grouped into a series of bunches. The bunch repetition frequency depends on the total number of bunches and usually reaches hundreds of MHz. The actual problem is to study the separate bunch dimensions' behavior under multi-bunch beam instabilities.

To solve this problem a turn-to-turn electron beam profile monitor is developed for siberia-2 synchrotron light source. The linear avalanche photodiodes array is applied to imaging. The apparatus is able to record a transversal profile of selected bunches and analyze the dynamics of beam during 106 turns. The recent experimental results obtained with the diagnostics are described.

INTRODUCTION

We have developed the same device several years ago and successfully used it at VEPP-4M electron-positron collider [1-4]. The Fast Profile Meter (FPM) based on the Multi-Anode Photomultiplier Tube is a part of the VEPP-4M optical diagnostic system. We have successfully applied the FPM for determination of synchro-betatron resonances, phase oscillation monitoring, measurement of the beam spread and study of collective effects.

The device includes a MAPMT, a 12-byte ADC, a controller module, an internal memory of 4Mb and 100 Mb ethernet interface. It can record 2^{17} profiles of a beam at 16 points. Discontinuity of the records can vary within $1 \div 2^8$ turns of a beam. Revolution time of a beam in the VEPP-4M is 1220 ns and the recording time can last between 0.16 s to 20 s. As a result, the device can analyze the frequency oscillation of a beam in the range of 10 Hz — 1MHz. Fig. 1 represents a single beam profile fitted with Gaussian function.

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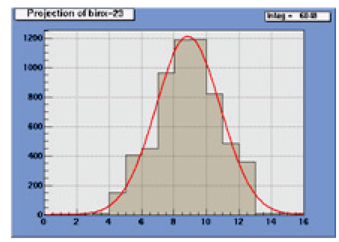

Figure 1: Example of the single beam profile fitted by the Gauss function.

The optical arrangement (Fig. 2) allows us to change the beam image magnification on the cathode of MAPMT from 6× to 20×, which is determined by the experimental demands. The set of remote controlled grey filters, included into optical diagnostics, allows selecting a suitable level of the light intensity with the dynamic range about 10^3.

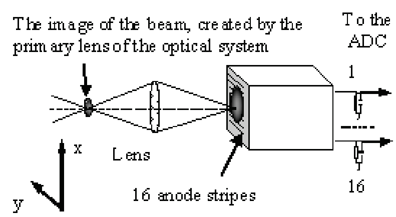

Figure 2: Optical layout of the diagnostics. The lens sets up a beam image on the photocathode of the MAPMT. The radial profile measurement is shown.

Fig. 3 presents the beam size and position behavior in the case of beam-beam instability, restored from FPM data.

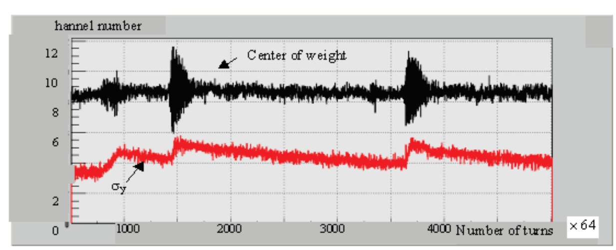

Figure 3: Beam dipole oscillations (black plot) and σy behavior (red plot) during the beams convergence at the interaction point. Duration of the single turn is 1220 ns. The channel constant is 0.12 mm.

The currents of the electron and positron beams were restricted by beam-beam effects (Ie = 3 mA, Ip = 3.4 mA), and the positron beam was the "strong" one. Both the di-

ISBN 978-3-95450-177-9

pole oscillations and the beam size increase during the evolution of instability. Every "flash" of oscillations is accompanied by beam losses.

Nevertheless, the FPM based on MAPMT had some disadvantages. At first, the photomultiplier is designed to operate in photon count mode and has a low value of an average anode current. We guess that it was a reason of statistical noise of measurements of beam position and beam transversal dimensions (Fig. 3). So, the fluctuations of Gaussian curve half-width were about ten percent at stable condition of a beam. At second, the approach applied for acquirement of anode signals [2] can't be used for multi-bunched beam. Besides it, we have recognized that "slow" beam instabilities with duration about period of synchrotron frequency can be accompanied by betatron oscillations and it is desirable to record both transversal beam profiles synchronously during hundreds of thousands of beam revolutions. We have designed a new version of FPM taking into account the operating experience of MAPMT.

FPM BASED ON LINEAR AVALANCHE PHOTODIODE ARRAY

Two new FPM became a part of new optical diagnostics of synchrotron radiation storage ring SIBERIA-2 at Kurchatov Institute [5]. Parameters of 2.5 GeV electron beam of SIBERIA-2 storage ring at the azimuth of station disposition are given in Table 1.

Table 1: Electron beam parameters at SIBERIA-2

Revolution frequency, MHz	2.4152
Bunch repetition rate, MHz	2.415 – 181.14
Bunch sizes, mm: σy, σx, σs	0.059, 0.45, 20
Bunch duration (FWHM), ns	0.16

Beam of the accelerator consists 75 bunches. Turn-by-turn beam transverse cross-section measurement systems 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 (APDA). 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 (Fig. 4).

The optical scheme similar presented in Fig.2 creates an image of a beam on APDA. It takes the radiation intensity distribution on the electron beam profile.

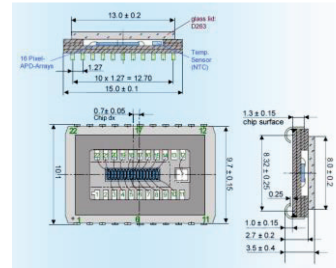

Figure 4: Package of AA16-0.13-9 APD linear array.

Electric pulses from the photodiodes are fed to inputs of analog integrators. The integrator operates continuously without reset between two adjacent pulses. Varying continuously the integrator output level consistently takes the value of every input pulse integral (Figure 5, 6).

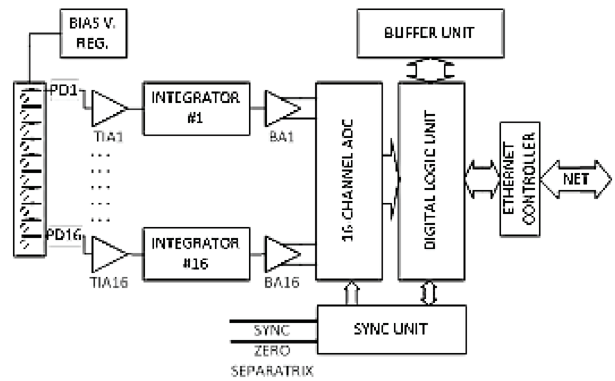

Figure 5: Functional diagram of the device.

This technique improves the integrator performance. The integrator is designed for input pulse repetition rate of 200 MHz. The 16-channel signal recorder fixes the integrals values, performs their 12-bit analog-to-digital conversion and buffering in the internal 3 Gb memory.

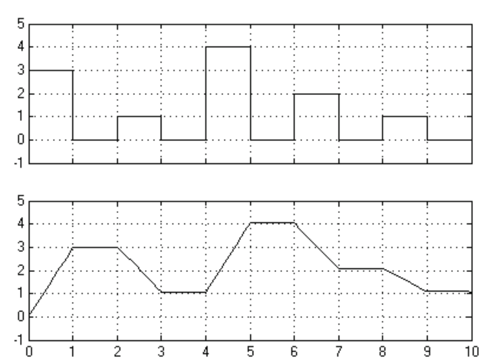

Figure 6: The integrator model in Simulink. Input signal (the 1st diagram) and output signal (the 2nd diagram).

The accumulated data is transferred via Ethernet 100BASE-T. The recorder also contains a synchronization unit consisting of a clock synthesizer with a phase-locked loop (PLL) and digital delay elements to adjust the clock phase of analog-to-digital converter (ADC). This unit synchronizes the recorder with a frequency of bunches and provides timing of the registration process to the zero separatrix. The device parameters are listed in the Table 2.

ISBN 978-3-95450-177-9

Table 2: Device parameters

Frame resolution, pixels	1x16
Frame rate, Mfps	50
Time resolution, ns	5
Dynamic range, bit	12
Memory, frames	15625000
Data transfer speed, Mbps	100
Spectral range, nm	450…1050
Pixel size, um	320
Max quantum efficient, %	85
Max avalan. multiplication	100
Max power consumption, W	25
Supply voltage, V	220
Module size, mm	100x100x400

Multi-channel registration of each bunch is possible but requires technically complex solution (16-channel ADC with 200 MHz sampling rate). The compromise solution is to record every 5th bunch with the ability to select a specific sequence of bunches (16-channel 50 MHz ADC with serial outputs is used). Any sequence can be chosen by configuring the synchronization unit via device GUI (Fig. 5).

EXPERIMENTAL RESULTS

The new version of FPM measures a complete charge of the signal corresponding to the separated bunch of a beam. The signal recorded into the internal memory during one turn of a beam of SIBERA-2 storage ring is presented in Fig. 7. It is a signal of one of 16 channels of APDA.

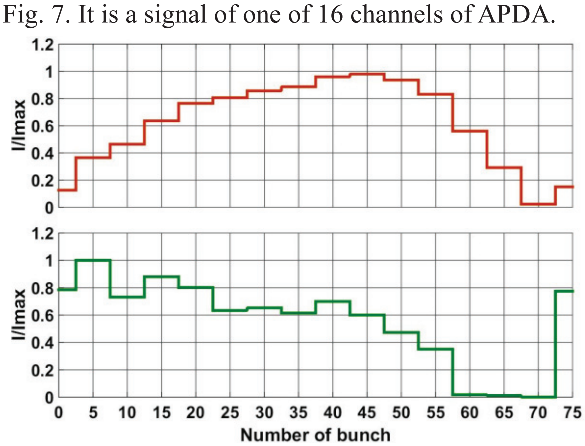

Figure 7: The integrated signal from the channel of APDA recorded by ADC.

The beam had about 70 bunches with a gap between 57th and 72nd separatrix. The signal of each 5th bunch was recorded. The upper curve represents a change in value of the signal at the exit of the integrator. The "steps" on the curve appears after the signal of corresponding bunch arrives. The lower curve represents the restored distribution of intensity of bunches. The value of the signal at the upper curve between 57 and 72 separatrix decrease due to feedback discharging the integrator.

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

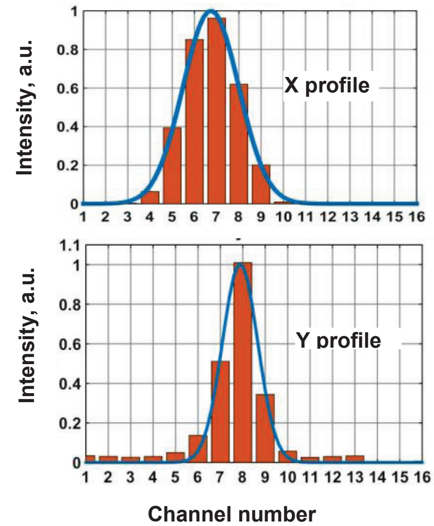

Figure 8: The vertical and radial beam profiles of a single bunch acquired with APDA at a single beam turn.

The spatial resolution of both versions of FPM is practically the same and depends on the magnification of the projection optics. But the average accuracy of the new version of the device is better significantly.

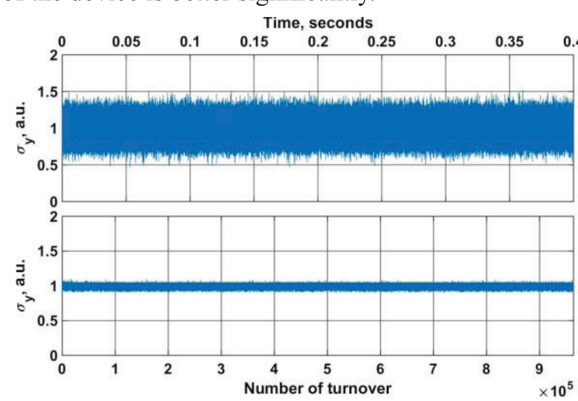

Figure 9: Comparison of an accuracy of the old (upper plot) and the new (lower plot) versions of FPM.

Figure 9 represents the ratio $\sigma_y^i / \langle\sigma_y\rangle$ for old and new FPM at the stable condition of the beam, where σ_y is a vertical beam size and i is a turn number. The number of SR photons per bunch acquired by the devices was the same. The decrease of the statistical noise of new FPM is connected with a high quantum efficiency of APDA as well.

The vertical profiles of the bunches recorded at one turn of the SIBERIA-2 beam are presented in Fig. 10.

ISBN 978-3-95450-177-9

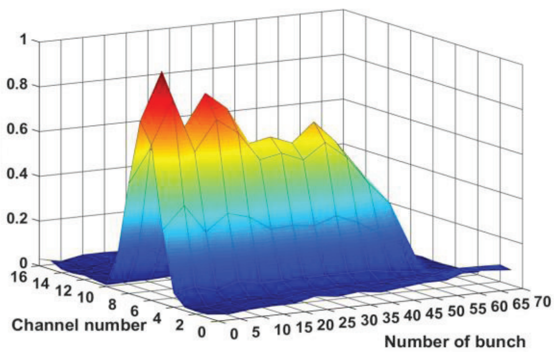

Figure 10: Vertical profiles of the bunches recorded at one beam turn.

The beam tunes can be measured with the new FPM as well. Figure 11 represents the measurements of the vertical betatron tune with frequency synthesizer. The synthesizer excites the vertical oscillations of the beam and frequency sweeps linearly in a time. The spectrum of beam oscillations computed from Fourier transform of coordinate of beam image acquired by FPM. It is seen that spectrum of beam respond contains two frequencies: frequency of excitation and vertical betatron tune. The amplitude of betatron oscillations is peaked at the moment of resonance, at about 0.35 seconds. This value of the frequency is determined as a vertical tune by software driving the synthesizer. The data of optical diagnostics are the same, but it provides also a behavior of vertical tune during a time. The temporal spectrum of betatron frequency contains an obvious 50-Hz harmonic which can be caused by noise of a power supply of quadrupole lenses.

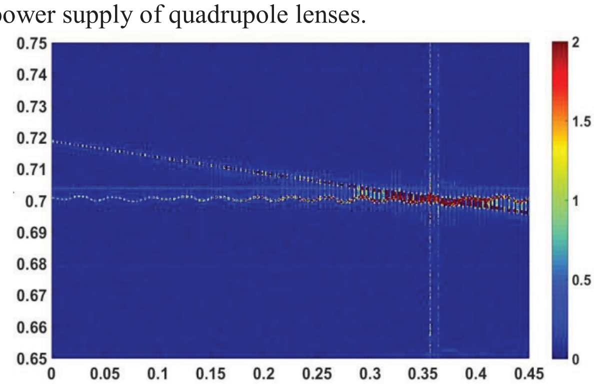

Figure 11: Measurement of the vertical betatron tune with FPM.

DISCUSSION

We have a restricted experimental experience with a new version of FPM yet, but believe that it has a better parameters and more experimental opportunities in comparing with the predecessor. The device was designed for the storage ring with RF frequency of 181 MHz. The temporal resolution of APDA restricts the possibility to apply it for accelerators operating at 500 MHz. The spatial resolution of the optical diagnostics is restricted by the diffraction limit, but this problem can be solved with X-ray optics, say, a beryllium lens. The phosphors with a response time about 3 ns can be manufactured now [6]. It allows acquiring the beam image created by beryllium lens with a proper temporal resolution. The FPM can be applied for routine runs of cyclic accelerators, but is more useful for experiments in the accelerator physics.

CONCLUSION

The Fast Profile Meter based on avalanche photodiode array is successfully tested at SIBERIA-2 storage ring. The device described must continuously implement 15625000 measurements of the vertical or horizontal electron beam profile at 16 points with a time resolution of 5 ns at 50 MHz rate. It will make possible to monitor single bunches of the beam and study multi-bunch beam instabilities.

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