A FAST BEAM SIZE DIAGNOSTIC SYSTEM USING HIGH-SPEED PHOTOMULTIPLIER ARRAY AT SSRF *

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Abstract

A fast beam size diagnostic system is developing at SSRF (Shanghai Synchrotron Radiation Facility) storage ring for turn-by-turn and bunch-by-bunch beam transverse oscillation study. The system is based on visible synchrotron radiation diagnostic, detected by a Hamamatsu H10515B 16-channel photomultiplier array with 0.6ns rise time. A telescope imaging system is developing for optical front-end process, with CCD camera as reference. A fast pick-up board and amplifiers are designed for analogue signal optimization. The data acquisition and analyse solution is Tektronix oscilloscope with 6GHz analogue bandwidth and 25GS/s sampling rate or four synchronized ADQ14 digitizers with 700MHz analogue bandwidth and 1GS/s sampling rate.

By now, we have finished the detector selection, system setup, data acquisition design and system response testing. The telescope imaging testing and 16-channels data acquisition based on synchronized digitizers are under development. A new photomultiplier array with less response time is in plan for strictly bunch-by-bunch diagnostic.

INTRODUCTION

Synchrotron radiation (SR) method based on visible light is widely used for transverse beam size measurement in synchrotron radiation light sources as SSRF. The operating beam size measurement system in SSRF are interferometer system and x-ray pinhole system, which shows high horizontal and vertical resolutions within 10μm [1-3]. However, they have limitations in fast temporal resolution. For turn-by-turn and bunch-by-bunch beam size measurement and transverse oscillation diagnosis, high-speed detectors is indispensable.

High-speed photomultiplier (PMT) is one of the solutions to capture turn-by-turn and bunch-by-bunch optical information and calculate beam size. An ultra-fast response photomultiplier array Hamamatsu H10515B was selected as the detector of the fast beam size diagnosis system, which contains 16 channels with 0.6ns rise time.

The visible-light beam size monitor (vBSM) at Cornell Electron Storage Ring (CESR) use a similar PMT array detector for turn-by-turn beam size measure combining with its interferometer system [4]. Fast Profile Meter (FPM) system of Siberia-2 synchrotron light source at Kurchatov Institute compared the PMT array detector and avalanche photodiode array, showed low current output and in multi-bunch signal acquisition limitations of PMT array [5,6].

In this paper, we review the configuration of the fast beam size diagnostic system with signal pick-up and acquisition solutions and discuss a single-shot response testing result of special filling pattern at SSRF storage ring.

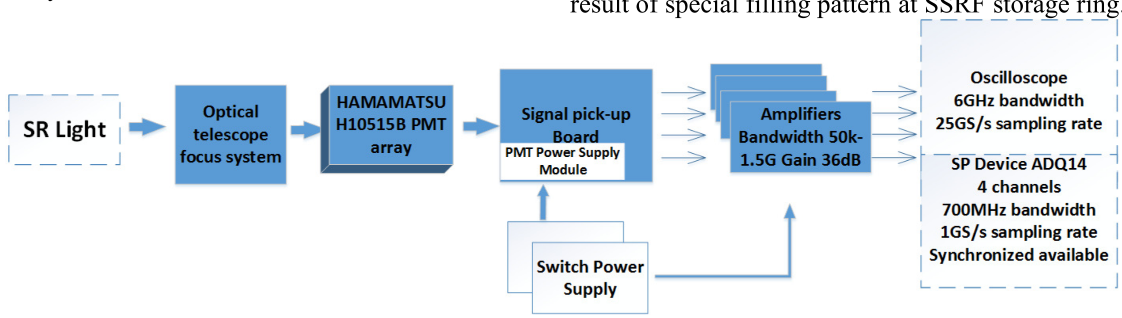

Figure 1: Overview of fast beam size diagnostic system.

SYSTEM SETUP

The fast beam size diagnostic system consists of three parts: optical telescope focus system, optical-to-electronic detection, fast signal pick-up and acquisition (see Fig. 1), which located at the optical diagnostic beamline at SSRF.

Front-end Optical Path

The front-end optical path is based on available visible radiation light extraction path of interferometer system switched by a plane mirror. An optical telescope system is installed in front of the PMT array detector for beam image amplification. The focal length of the objective is 500mm, and the focal length of the ocular is 14mm. The calculated magnification is about 35.71, which could cover about 3-4 pitches on the PMT array for horizontal size measurement.

Through an additional focus system, the beam light spot is imaged on the PMT detector. A CCD camera is assembled at the same place for focus imaging plane searching at the first step in stand of the PMT array. It is also a reference for the PMT array detection method.

The setup is shown in Figure 2 and Figure 3.

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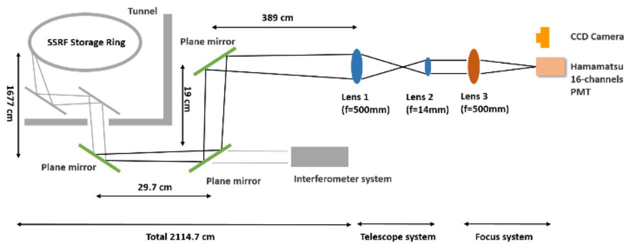


Figure 2: Layout of front-end optical path.

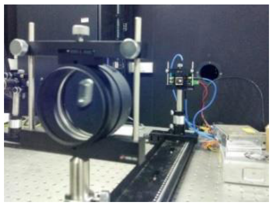


Figure 3: Focus system and PMT array detection setup.

Photomultiplier Array Detector

The Hamamatsu H10515B photomultiplier array was selected for high-speed photoelectric conversion as its fast rise time and linear electric transmission to the light intensity. The specification of the H10515B was listed in Table 1. We could also see the photo of H10515B in Figure 4.

The signal output pins will export the optical intensity detected on each channel area at the front face linearly, which could obtain a one-dimension intensity distribution.

Table 1: Hamamatsu H10515B Specifications [7]

Parameter	**Value**	**Unit**
Effective area per channel	0.8*16	mm
Channel pitch	1	mm
Spectral Range	300 to 880	nm
Peak Wavelength	420	nm
Gain	$1 * 10^6$	
Rise Time	0.6	ns
Fall Time	1.691	ns
Transit Time Spread (FWHM)	0.18	ns
Pulse Linearity per Channel (±2%)	0.8	mA
Cross-talk	3	%
Supply Voltage	-800	V dc

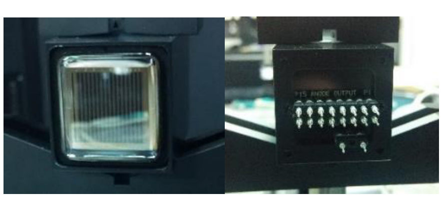


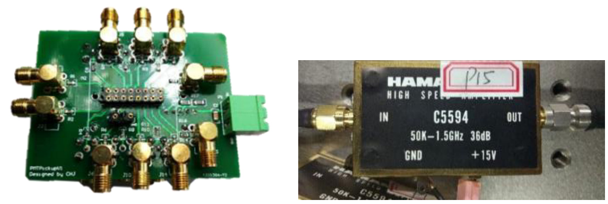
Figure 4: Photo of Hamamatsu H10515B detector

It is possible to use the Hamamatsu H10515B detector for our bunch-by-bunch application (SSRF operating frequency 499.654MHz).

Signal Pick-up and Acquisition

An analogue front-end board has been designed for fast signal pick-up of photomultiplier array detector, which consists of a 16-pins socket, a power supply module (Hamamatsu C4900-01) for PMT, 16 SMA connectors and matching resistors (see Fig.5 (a)).

Four high-speed amplifiers, we use Hamamatsu C5594 amplifier module as its wide bandwidth (50k-1.5GHz) and high gain (36 dB typ.) (see Fig.5 (b)) [8].



(a) Signal pick-up board (b) C5594 amplifier module

Figure 5: Setup of signal pick-up and amplifier.

There are two plans for data acquisition and processing and they will be processing together: one is 4-channels off-line data analyse based on oscilloscope and another is multi-channels on-line analyse based on synchronized digitizers and FPGA fast processing unit.

For off-line analyse, we use a Tektronix DP070604 Digital Phosphor Oscilloscope, which has four input channels with 6GHz bandwidth and 25GS/s maximum sampling rate. Data processing is based on Matlab code with resampling, interpolation, reshape and Gaussian fitting algorithms.

For online multi-channels analyse, the digitizer board is ADQ14DC-4C from SP Devices. It has four input channels with a 14-bit ADC, 700MHz analogue bandwidth, maximum 1GS/s sampling rate and multi-board synchronization. It also consists of a Xilinx Kintex 7 FPGA core, for online data optimization and beam size calculation based.

The pictures of these two data acquisition equipments are shown in Figure 6 and the specification comparisons are listed in Table 2.

(a) Tektronix oscilloscope (b) ADQ14 [8]

Figure 6: Pictures of data acquisition equipment.

Table 2: Specification Comparison between Tektronix Oscilloscope and ADQ14

Features	**Tektronix Oscilloscope**	**ADQ14**
Analog bandwidth	6GHz	700MHz
Maximum sampling rate	25GS/s	1GS/s
Operating channels	4	16
Standard memory	10MS	3200MS
Data analyse method	Matlab code	FPGA
Real-time capability	No	Yes

EXPERIMENT

Filling Pattern

A special filling pattern experiment was designed for system verification and system response testing, which was shown in Figure 7.

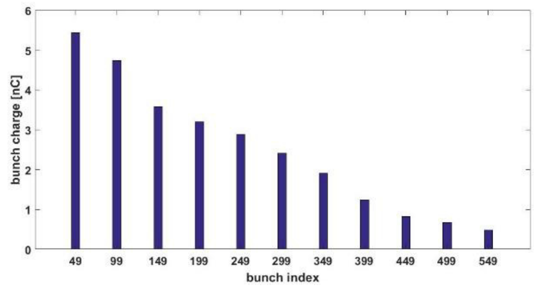


Figure 7: Diagram of special filling mode.

The bunch chain consists of 11 bunches with different bunch charge. The time space between two bunches was 100ns, which could sufficient for system single-shot configuration. The repetition rate of the bunch chain was 694 kHz. The bunch charges were from 5.4 nC to 0.16 nC.

System Single-shot Response

The single-shot response of beam size diagnostic system was tested with special filling pattern at SSRF. The selected bunch charge was 0.16 nC and four chosen channels were channel 3, 6, 9, 12, for collecting a large scale of light spot.

The result of single-shot response of four channels were shown in Figure 8 with PMT panel and calculated FWHM of 4 pulses.

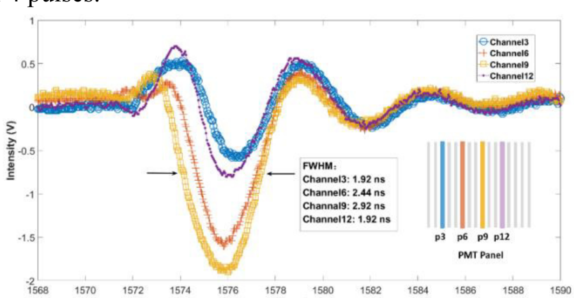


Figure 8: Single-shot response of four channels.

From figure 8, it shows a larger time response than its specifications, especially at Channel 6 and Channel 9 with high signal intensity (up to about 2V). It could be contributed by the bandwidth limitation of pick-up board and amplifier module, and high signal amplitude. At SSRF operating pattern, the intensity is about 100 mV, and the response could be short and sufficient for bunch-by-bunch diagnostics.

A new photomultiplier array detector with about sub-picosecond time response is in plan to replace this one as strictly bunch-by-bunch resolution.

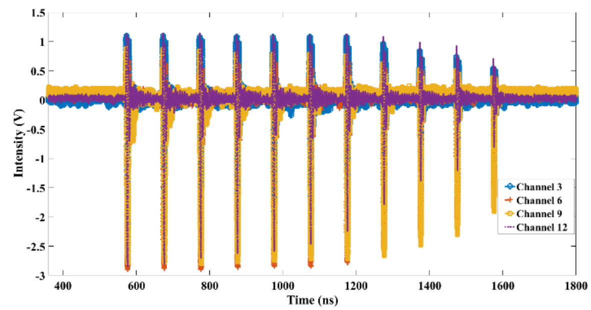
Data Resampling Method

One problem in data analyse from oscilloscope was the signal synchronization between real operating RF frequency and internal sampling clock from oscilloscope.

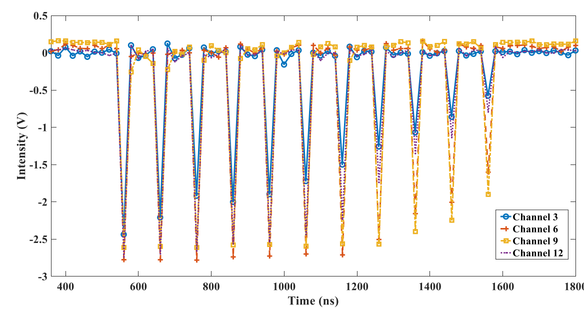
A software data resampling method was applied before beam size analyse for pulse peak pick-up and data alignment between different channels

The algorithm consists three parts: obtain the real period (T_{rf}) based on Fourier Transformation and zero-padding method; determine start point based on cubic spline method; data reconstruction using T_{rf} and start point [9][10].

The raw signal from oscilloscope and resampled result in special filling pattern were shown in Figure 9. The setting signal frequency was 50MHz and the sampling rate of oscilloscope was 25GS/s.



(a) Raw signal from oscilloscope



(b) Signal after resampling

Figure 9: Data resampling performance.

From Figure 9, software-resampling algorithm is good for negative peak capture of each bunch and time jitter optimization between different channels.

From Figure 9(b), the first six bunches with large bunch charge were saturated comparing with real filling pattern.

CONCLUSION

The design and assembling of fast beam size diagnostic system are complete. Signal pick-up, amplifier and analyse from oscilloscope had been tested, which shows enough signal amplitude and small broadening for bunch-by-bunch beam size diagnostic. With data resampling and Gaussian fitting processing in Matlab code, 4-channels beam size analyse from oscilloscope is feasible and facilitated.

The telescope image system is under testing and calibration. The 16-channles data analyse plan based on ADQ14 digitizer development is processing with multi-board synchronization design and beam size analyse on FPGA based on Look-up table methods.

We hope in the future, the fast beam size diagnostic system will be operated on-line for beam size measurement, transverse instability research and system alert of accelerator operation.

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