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RECENT PROGRESS OF BUNCH RESOLVED BEAM DIAGNOSTICS FOR BESSY VSR *

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Abstract

BESSY VSR is an upgrade project of the existing storage ring BESSY II to create long and short photon pulses simultaneously for all beam lines by installing additional superconducting cavities with harmonic frequencies of 1.5 GHz and 1.75 GHz. The storage-ring operation will be influenced by a transient beam-loading effect of all cavities and by the complex filling pattern due to the disparity in the current of long and short bunches. This, in turn, could introduce a variation of beam trajectory, transverse profile, and length for the different bunches. This stimulates the development of bunch-resolved monitors for bunch length, beam size, filling pattern and beam trajectory displacement. In this paper, we show new developments of crucial beam diagnostics including measurements of the bunch-resolved temporal profile with a resolution of less than 1 ps FWHM and bunch-resolved profile with a resolution of less than 10 µm rms. The upgrade of the booster beam-diagnostics will be discussed as well.

INTRODUCTION

The BESSY Variable-pulse-length Storage Ring (BESSY VSR) project was launched at the Helmholtz-Zentrum Berlin to provide the capability of user accessible picosecond pulses at a high repetition rate, up to 250 MHz [1, 2]. The installation of additional harmonic-frequency superconducting radio-frequency (SRF) cavities generates a beating of the voltages of two SRF systems, thereby creating alternating buckets for long and short bunches [3]. BESSY VSR preserves the present average brilliance of BESSY II by filling more beam current in the long bunch buckets since the short bunch buckets have relatively low bunch charge to avoid the longitudinal microwave instability that occurs above a certain threshold current. This results in the disparity in 6-D phase space particle distribution such as spatial distribution, angular spread, and energy spread. The implementation of the 1.5 GHz and 1.75 GHz SRF cavities for BESSY VSR enhances a relative phase shift along multi-bunch train due to combined effects of a transient beam-loading in the cavities and complex filling pattern. The relative phase shift can cause a variation of beam trajectory, transverse profile, and length for the different bunches. This stimulates the development of bunch-resolved monitors for transverse and longitudinal electron distribution, relative arrival phase, filling pattern and central beam trajectory. We are in the process of carefully evaluating and define all feasible monitors for BESSY VSR [4].

BEAM DIAGNOSTICS PLATFORM REFURBISHMENT

Due to confined space of our present beam diagnostics platform and the installation of a new cryogenic system for BESSY VSR cryomodule near the platform in section 3 of BESSY II, we need to move diagnostics to a new platform in the section 12 of the ring. Several modifications are requested for the new platform, as shown in Fig. 1. The main modifications are the installation of the dedicated hutch for keeping a clean environment and constant temperature, and preparation of the second optical beam line for separating the ports of the profile monitor and bunch length monitor, respectively. The third beam line for THz-based diagnostics will be also prepared inside the accelerator bunker. During summer machine shutdown, the extension of the stage and preparation of new optical beam line such as drilling a hole into the accelerator bunker was conducted. The installation of the hutch is scheduled for next year for a smooth transition will allow time for commissioning of all devices at the new platform.

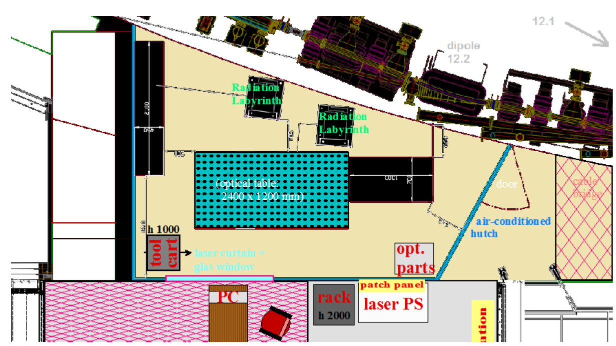

Figure 1: Schematic layout of new optical beam diagnostics platform for BESSY VSR with two beam lines and three separated optical tables.

In addition, we are putting in a great deal of effort into the evaluation and optimization of the optical transport system for timing experiments, which consists of a elliptical mirror with a hexapod 6-axis stage and toroidal mirror with a degree of freedom in angles. Based on a ray-tracing simulation and experimental results, we hope to improve the light output and the position sensitivity with less timing distortion. We are also preparing the isolation of optical tables from ambient vibration sources such as cryogenic compressors, vacuum

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pumps, magnet-cooling water, and internal cooling fans of electronic devices since the strong vibrations are observed on the optical table during long-term investigations. The measured result is shown in Fig. 2.

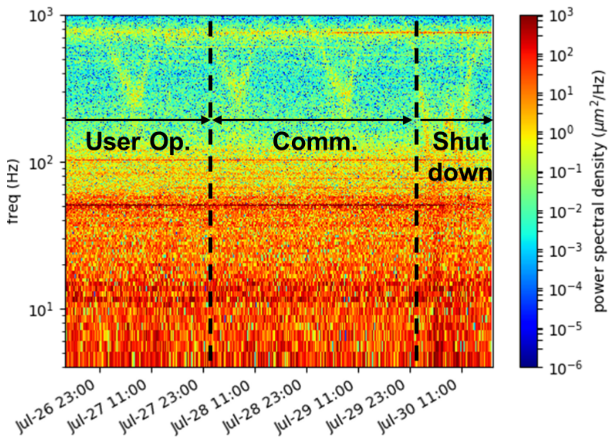

Figure 2: Power spectral density of vibration on optical table during 4 days.

The main peak at around 50 Hz and a long-term drift component are from the cryogenic compressor and internal cooling fan of a streak camera, respectively. This motivates the implementation of passive damped legs and separation of the devices onto different tables.

STATUS OF OPTICAL DIAGNOSTICS

Research and development of several optical monitors are on going for the measurement of bunch-resolved transverse distribution, temporal structure, and filling pattern. The beam-size monitor based on an interferometric technique with double and quadrature slit was investigated at BESSY II and the performance is verified by a careful comparison with X-ray pinhole monitors in several operation modes [5, 6]. For the bunch-resolved beam-size measurement, it needs a special charge-coupled device (CCD) camera, which applies a fast gating technique with the gate time of shorter than the bunch spacing of 2 ns, to select the light from a single bunch. However, the gating technique reduces the photon flux and therefore an intensified CCD (ICCD) with an iterative gating technology is practically necessary to compensate for the photon flux reduction. Since an ICCD can obtain shot-noise-limited operation by increasing the gain that causes the shot noise to overwhelm the noise generated by the camera electronics, the evaluation of the noise contribution on interferometric beam size measurement in a low photon flux mode (9.1×10^6 photons/shot) is performed using the Monte-Carlo method. The result is shown in Fig. 3.

Based on the numerical simulation, the minimum number of photons per single shot for a reliable resolution is about 10^5 which corresponds to the bunch current of 7 µA. By improving the optical transport system, we can enhance the operation range by a factor of 5 – 10 for the beam-size monitor.

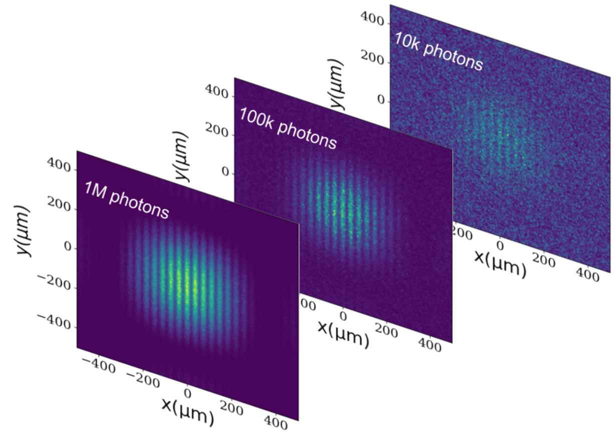

Figure 3: Monte-Carlo simulation-based approach to estimate minimum photon flux due to noise contribution on interferometric beam size measurement.

For bunch-resolved bunch length and phase measurements of BESSY VSR, a new streak camera (Hamamatsu C10910-05) with a synchro-scan repetition rate of up to 1 kHz was delivered and the evaluation of the temporal resolution is performed. We derive the resolution of 0.88±0.18 ps FWHM. In addition to the improvement of the horizontal scanning rate, the optimization of the new beam port enhances the photon flux by a factor of about 80. We also anticipate the minimum operating range of a few µA. We prepared a new high-accuracy translation stage with the position precision of a few µm and movable range of up to 80 cm, which corresponds to $\Delta t_{\mathrm{delay}} \sim 5.3$ ns. It allows the calibration of not only the vertical axis in specific time range but positive and negative slope in the streak camera with the accuracy of about 10 fs. The measurement result of relative synchronous phase evolution in BESSY II standard user mode is shown in Fig. 4.

Since the streak camera is not suitable device for continuous monitoring, a fast and reliable monitoring system using

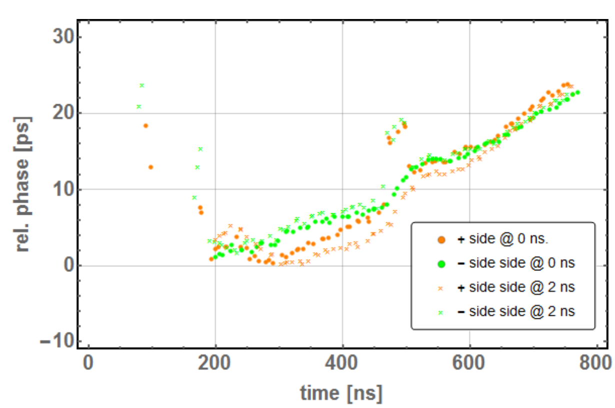

Figure 4: Measurement result of relative synchronous phase evolution in BESSY II standard user mode by using the streak camera calibrated by the high-accuracy translation stage.

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a GaAs metal-semiconductor-metal (MSM) photo-detector (Hamamatsu G4176-03) having 30 ps response time for both rise and fall while keeping a low dark current of 100 pA at T_a = 25 °C is prepared. The diode is calibrated by short pulses produced by synchrotron radiation and a careful comparison with the streak camera. The result of bunch length measurement after the deconvolution is shown in Fig. 5.

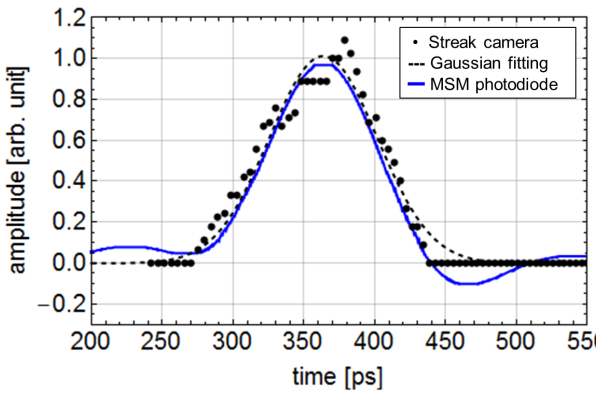

Figure 5: Temporal profile measurement using the streak camera and diode after applying the calibration in 15 mA high current single bunch operation. The measured bunch lengths using the streak camera and photodiode are 88 ps FWHM and 87.4 ps FWHM, respectively.

Apart from the development of major optical beam diagnostics stated above, the research of several feasible ideas is currently underway simultaneously.

STATUS OF RF DIAGNOSTICS

A sophisticated operation mode, such as transverse resonance island buckets (TRIBs) for spatial separation of photon pulses has been proposed and tested at BESSY II and is being prepared for BESSY VSR [7–9]. Furthermore, fundamental power coupler of BESSY VSR cavities provide additional transverse kicks, perturbing a closed orbit and effecting transverse beam dynamics [10]. The calculation has been confirmed that beam trajectory distortions of about 100 µm occur between the long and short bunches. This stimulates the development of a bunch-by-bunch beam position monitoring system and bunch-selective orbit feedback system. For a reliable and accurate bunch-by-bunch beam position monitor (BPM) system, the signal conditioning is required to improve position measurement quantitatively because the signal interference to the neighboring bunches by some pulse-reflections and long-range trapped mode inside the BPM electrode were observed.

Since typical LC low-pass filters produce long-range ringing due to logarithmic phase variation at the upper stopband, a linear-phase response low-pass filter is currently under investigation. In addition, a new methodology based on analog signal mixing with reflected pulses was tested and it is very promising for reducing long-time disturbances [4]. The preliminary test result of the signal conditioning with analog signal mixing with reflected pulses is shown in Fig. 6.

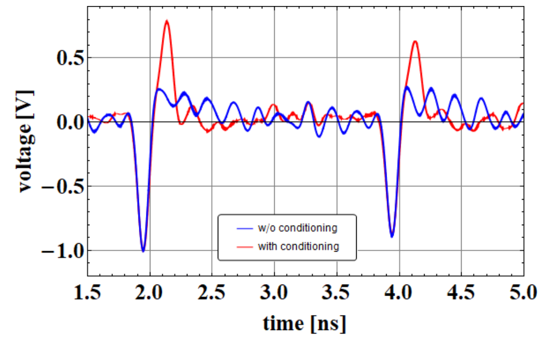

Figure 6: Preliminary test result of BPM signal conditioning with analog signal mixing with reflected pulses.

A new button-type BPM design is also under consideration to push the frequency of the trapped mode higher such that it is damped fully within 1 ns [11]. In parallel, the upgrade towards a digital BPM system for bunch-by-bunch position data acquisition is underway, particularly, involving tests with several wide-bandwidth digitizers with the analog bandwidth of more than 1 GHz and sampling speed of 1 GSa/s.

BOOSTER DIAGNOSTICS

The bunch length on injection into the storage ring may determine the injection efficiency, particularly, the short bunch bucket in the BESSY VSR. In order to keep the high injection efficiencies, additional RF cavities will be installed to reduce the bunch length [12]. The beam commissioning of the new cavities needs essentially the monitoring of beam parameters such as the transverse beam size, bunch length, and position for actively controlling the beam in all dimensions. For the bunch length measurement, the MSM photo-diode will be installed inside the bunker. To avoid any signal distortion in time-domain by the bandwidth of digitizer, a pico-sampler developed by Karlsruhe Institute of Technology (KIT) is proposed. It is based on the state of art in wideband digitization technology using a track-and-hold amplifier [13]. The development of the pico-sampler was conducted within the ST-3 ARD Helmholtz collaboration. A frequency beating scheme which intentionally offsets the operating frequency of the digitizer will be used, thereby naturally scanning the signal with 3 ps sampling over time and scanning all signals. The preliminary test of the beating scheme is shown in Fig. 7.

SUMMARY

Various research and development activities are currently underway in parallel to move towards BESSY VSR which is the upgrade project of the existing BESSY II ring. It is essential to improve the performance of the electron-beam diagnostics installed in the storage ring and booster. During the summer shutdown this year, the refurbishment of the floor of the new platform was successfully finished. From October this year, we plan to relocate and install existing optical diagnostics to the new platform with passive isolation

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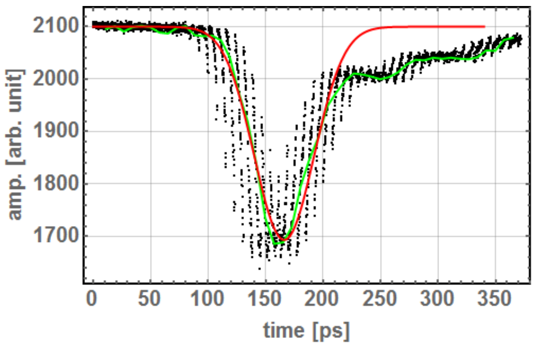

Figure 7: Preliminary test result of frequency beating scheme in the KIT pico-sampler.

legs. The test of a linear-phase response low-pass filter will be performed. A new button-type BPM design is finalized to mitigate unwanted effects caused by complex reflections and trapped modes in an insulator. It will be fabricated and installed at BESSY II next year. Other devices are still in the evaluation phase.

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