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TIME-SYNCHRONIZED BEAM DIAGNOSTICS AT SPEAR3*

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Abstract

The SPEAR3 timing system includes a 1.28 MHz beam revolution clock and a 10 Hz pulse train for charge injection into the main storage ring. In the past the 10 Hz pulse train was used to study transient injected beam dynamics using turn-by-turn BPMs and visible-light synchrotron radiation diagnostics. For this work the timing distribution system was configured to extract solitary pulses from the 10 Hz pulse train to synchronize bunch-by-bunch data acquisition with visible light diagnostics during transient beam events. The synchronous measurements are used to study controlled grow/damp and drive/damp beam physics.

INTRODUCTION

SPEAR3 nominally operates at 500 mA beam current with charge stored in 4 discrete bunch trains and an isolated timing bunch for pump/probe experiments. Top-up injection occurs every 5 minutes with charge deposited into single targeted bunches at a 10 Hz rate.

To stabilize the beam at high current, a transverse BxB feedback system was installed featuring DIMTEL processing electronics [1], 150 W RF power amplifiers acquired from the PEP-II project and a single transverse stripline kicker on loan from The ALS [2]. The kicker striplines are oriented at 45° to the beam axis with feedback control at separate betatron frequencies in the horizontal and vertical planes. The BxB feedback system is normally used in operations and can be used to study beam dynamics in the storage ring [3].

Modern BxB feedback systems operate by detecting the dipole moment q•Δx for each bunch and digitally processing the data with sufficient bandwidth to control each bunch independently. The BxB feedback bandwidth requirement for SPEAR3 is 238 MHz with an output power of only ~10 W for nominal beam delivery. For more challenging conditions such as bunch cleaning or resonant bunch excitation, instantaneous power requirements can exceed 100's of Watt at full bandwidth into the 4 kΩ ALS-style kicker.

For the study of beam instabilities, in many cases low-amplitude BxB motion can be decomposed into a linear combination of orthonormal 'modes' of oscillation. For higher-amplitude conditions the charge distribution can decohere in phase space rendering feedback performance less effective and data analysis difficult. For these situations it is useful to measure the transverse beam profile using visible-light synchrotron radiation to identify (a) the onset of charge decoherence, and (b) the impact of decoherence on the process under investigation.

To better instrument our ability to detect and analyse high-amplitude oscillation events, we developed a timing infrastructure to synchronize multiple beam diagnostics to a common trigger event. The main components at SPEAR3 include digital delay generators [4], DIMTEL iGp12 feedback processors [1], an Arbitrary Waveform Generator [5], a fast-gated image-intensified PiMax camera [6] and a Hamamatsu streak camera [7]. A single turn-by-turn BPM is also available. The hardware triggers make use of either the 10 Hz pulse train or a discrete pulse from the continuous 10 Hz pulse train. For faster data acquisition or turn-specific camera imaging, the 1.28 MHz beam revolution clock can be used. In this report the timing synchronization system and initial experimental results are presented.

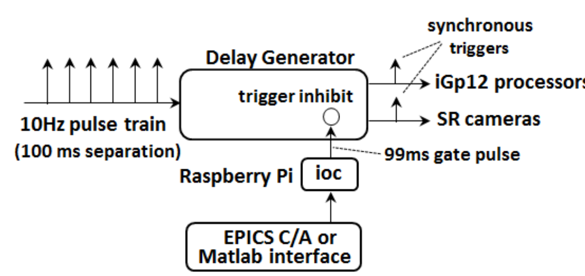

Figure 1: SPEAR3 synchronous trigger pulse system.

TIMING, SYNCHRONIZATION AND BEAM EXCITATION

As illustrated in Fig. 1, the 10 Hz injection pulse train provides a convenient signal to trigger the iGp12 feedback processors and diagnostic cameras. Separate delays are applied to the common 10 Hz hardware triggers in a delay generator to account for transmission line delays. For single-trigger events, a 'gate' pulse can be applied to the trigger inhibit port on the digital delay generator to select pulses on demand. The gate pulse allows a solitary 10 Hz hardware trigger to process through the delay generator. Data from the various diagnostics can then be saved to file and/or processed to evaluate the isolated acquisition event.

For the single-trigger system the inhibit gate pulse is generated from a Raspberry Pi microcomputer configured with EPICS channel access. At the top level, a Matlab-based iGp12 control interface (or any labCA client) instructs the Pi to issue the gate pulse resulting in synchronous data acquisition triggers from the delay generator [3].

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In order to study beam transients, there are several ways to excite the SPEAR3 beam. These include:

- injection kickers - discrete horizontal impulse on the beam for instrument timing and dynamic aperture studies.

- grow/damp events - at high beam current narrowband ID chamber resonances drive coupled-bunch instabilities.

- trapped ion instabilities - after venting the main vacuum chamber ion instabilities can be present.

- iGp12 beam drive - asynchronous chirped-frequency waveforms can be applied to specified bunch patterns.

- Arbitrary Waveform Generators (AWG) - synchronous baseband waveforms to drive the stripline kickers.

Grow/damp studies are important to determine the source and strength of coupling impedances. By synchronously triggering camera systems, images of the beam cross-section can be acquired at relatively high instability amplitudes. Similarly for drive/damp studies transient beam events can be captured synchronously on demand. This class of experiments is important for bunch cleaning and resonant crabbing research. Although the iGp12 internal drive pattern generator provides a convenient means to resonantly excite target bunches, the drive waveform is not currently synchronized with the SRAM data acquisition timing. Alternatively, the beam can be driven with the AWG which is synchronized but does not have the ability to target individual bunches. In the AWG configuration the drive is connected directly to BxB RF amplifiers so the feedback loop is open.

DIAGNOSTIC CAPABILITIES

The initial 10Hz timing triggers used for data acquisition arrive -321μs prior to the SPEAR3 injection kicker pulse. The lead time provides sufficient time for trigger transmission delays. In order to establish diagnostic synchronization, separate channels of the delay generator were adjusted to start data acquisition at or near the injection kicker trigger time. Individual delay times take into to account transmission line propagation, electronic latency and photon beam time-of-flight as needed.

Beam excitation events can be monitored with the following diagnostics:

- iGP12 - onboard SRAM can store 26ms of BxB data under external trigger command (33,000 SPEAR3 turns).

- turn-by-turn BPM receivers - SPEAR3 has TBT Echotek modules and tested Libera Brilliance+ units [8].

- fast-gated camera - 1024 x 1024 pixel Roper PiMax with an MCP amplifier.

- streak camera - Hamamatsu C5680 with vertical syncroscan and dual horizontal scan.

At the heart of the diagnostic complex are the iGp12 processors which control the feedback state and can acquire BxB transient data for up to 26 ms. As discussed in [3] a graphical user interface has been developed to control the iGp12's, plot the waveforms and numerically process the data. Fitting results are displayed in the interface. The interface also provides a pushbutton to send synchronous hardware triggers to different beam diagnostic systems via the Raspberry Pi. In this case, since the acquisition time is based on one 10 Hz trigger event, the measurements provide a self-consistent view of the beam dynamics from several different perspectives.

For transverse profile measurements, the fast-gated camera has a programmable amplifier gain and exposure time. By using the 'sequence' mode of operation, multiple exposures can be acquired in a single acquisition frame by processing a series of 10 Hz or 1.28 MHz revolution clock triggers. The sequence mode is particularly useful when a synchronous rotating mirror sweeps the beam image across the camera CCD [9]. Using this technique we plan to capture grow/damp and drive/damp beam dynamics over a period of milliseconds. One drawback of visible light diagnostics is that the image resolution is diffraction-limited by a point-spread function of ~75 μm.

For the streak camera we plan to use the slow time-scale sweep unit to 'streak' the entire bunch train along the vertical camera axis. For sufficiently large amplitudes the modal structure on the beam can be found using Fourier analysis on the data. By axially rotating the beam image with a periscope or Dove prism it is possible to view the motion as seen from the 'top' of the beam (horizontal motion) or from the 'side' of the beam (vertical motion). With the synchronous camera trigger the data can be compared with beam centroid data acquired with the iGp12 processors to assess time evolution of the mode structure.

For reference, Table 1 provides a list of betafunctions at key diagnostic locations.

Table 1: β_x/β_y Values for SPEAR3 Diagnostics

BxB BPM	8.25/9.4	m^{-1}
BxB kicker	10/2.8	m^{-1}
K1 injection kicker	8.87/ 4.90	m^{-1}
Echotek BPM	3.0/12.5	m^{-1}
SR camera source pt.	1.86/14.38	m^{-1}
Q_x/Q_y	110/225	kHz

PRELIMINARY RESULTS

One of the main goals of the synchronous data acquisition system is to correlate time-dependent transient beam dynamics from different diagnostics to provide a deeper understanding of the physical processes. The iGp processors and turn-by-turn BPM receivers, for instance measure bunch centroid displacement but cannot resolve charge distribution. Fig. 2 shows an example where measurement of a single bunch centroid has modulations during the damping phase of a grow/damp measurement. Investigation of the mechanism behind the apparent

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vertical amplitude modulation can provide insight into transverse beam dynamics and feedback operation. Similar behaviour has been observed during the rise and fall phase of grow/damp experiments.

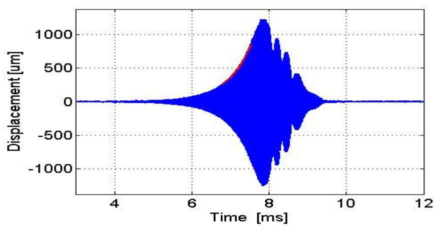

Figure 2: Non-linear response of a single bunch during 500 ma grow/damp measurement. τ_g=600 µs.

PiMax camera measurements of single bunch motion following a horizontal injection kicker event are shown in Fig. 3. For this case the camera exposure was single turn and we plot the first 20 turns. The images show rapid decoherence for the large-amplitude motion. The non-linear beam decoherence makes detection of the bunch displacement by BPM receivers complicated.

Figure 3: Turn-by-turn images of a horizontal bunch oscillation with BxB feedback on. Rapid onset of decoherence is evident. Time on the vertical axis.

Tests of a Libera Brilliance$^+$ BPM receiver triggered with the synchronous 10 Hz pulse train have also been performed. For these tests the beam was excited to progressively higher amplitudes with the horizontal injection kicker or resonantly excited with chirped-frequency AWG waveforms swept across the vertical betatron frequency.

SUMMARY AND PLANS

Synchronous measurements of transient electron beam motion in a storage ring can reveal important information field about non-linearities and chamber impedance. A similar, more sophisticated timing synchronization system operates at ANKE to study single-bunch bursting dynamics [10]. Of particular importance to SPEAR3, mechanisms leading to amplitude saturation during bunch cleaning procedures need to be better understood. Synchronization of the fast-gated camera with resonant bunch drive is also useful for studies aimed at ultrashort x-ray pulse production.

In terms of hardware updates, we plan to implement the 'rotating mirror' configuration for the fast-gated PiMax camera and synchronize streak camera measurements with transient beam events. The rotating mirror configuration can provide time-resolved measurements of the transverse beam profile during grow/damp or drive/damp studies in the millsecond range. At large excitation amplitudes, the camera images reveal the onset of decoherence in transverse phase space caused by non-linear fields.

Similarly, a streak camera operating in 'slow' sweep mode can capture transverse motion along the bunch train to reveal multibunch mode growth. With the aid of simulations, we plan to study what appear to be anomalies in the measured bunch centroid evolution as a function of time.

For nominal machine operations, synchronised diagnostics are useful to study beam-abort dynamics and potentially optimize BxB feedback system parameters.

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