ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF056

A GRAPHICAL USER INTERFACE FOR TRANSVERSE BUNCH-BY-BUNCH FEEDBACK AT SPEAR3*

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Abstract

A transverse bunch-by-bunch feedback system was recently installed in SPEAR3 to control beam instabilities, remove unwanted satellite bunches and test resonant bunch excitation schemes for short pulse x-ray production [1]. The DIMTEL iGp12 feedback processors also provide the potential for more advanced investigations of time-dependent electron beam dynamics. To streamline the process, a graphical user interface was developed to control the iGp12 processors and display the beam response in a variety of views with calculated metadata. In this report we outline first operation of the SPEAR3 BxB feedback system and describe the graphical user interface.

INTRODUCTION

SPEAR3 is a 3rd generation storage ring with relatively low impedance. To achieve this goal, the copper vacuum chamber has shallow transition tapers and copper plating inside many of the insertion device chambers. In order to minimize narrow-band impedance, PEP-II style mode-damped RF cavities were used resulting in passively stable electron beam operation at 500 ma without bunch-by-bunch feedback.

In recent years, however, the number of variable-gap ID chambers has grown which introduces resonant narrow-band impedances [2,3]. In addition, modern SR research methods are increasingly susceptible to top-up injection transients and bunch cleaning is needed for time-resolved pump/probe experiments. Studies are also underway to develop resonant crabbing techniques for ultrafast x-ray pulse production [4].

To meet these requirements transverse bunch-by-bunch feedback was installed. As illustrated in Fig. 1, input to the BxB feedback process starts with button-style BPM signals passing through a hybrid network to produce analog H/V bunch position waveforms. The analog output signals are then conditioned with DIMTEL FTE-LT front end electronics and further processed in DIMTEL iGp12 modules to generate the BxB feedback drive signals [5]. The positive and negative analog H/V feedback signals are then summed to drive a pair of stripline electrodes in a single feedback kicker module. The summed signals are amplified by 150W, 238 MHz bandwidth RF amplifiers recovered from the PEP-II project and transmitted over low-loss heliax cables.

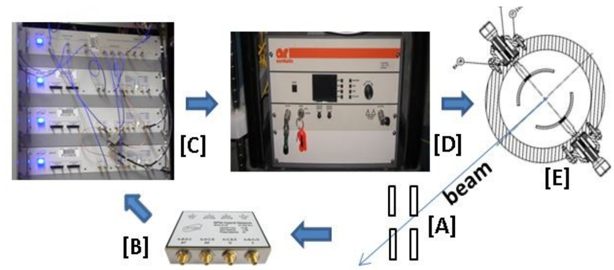

Figure 1: BxB feedback system at SPEAR3. (a) button BPM, (b) hybrid network, (c) DIMTEL FBT-LE and iGp12's, (d) AR amplifiers and (e) ALS-style stripline kicker rotated 45˚.

The feedback kicker is a 30 cm long impedance-matched stripline assembly on loan from the ALS with a shunt impedance of about 4 kΩ at 250 MHz [6]. Following the lead of the ALS, the kicker electrodes are rotated 45° relative to the beam axis to allow feedback in both planes. Since the beam responds at high-Q narrow-band betatron oscillation frequencies, the H/V feedback loops are well decoupled but the kicker rotation reduces the effective in-plane shunt impedance by a factor 2.

For low-order mode suppression (e.g. resistive wall, ion trapping) a modest drive power of 10's of Watts is necessary [7,8]. A new in-vacuum insertion device however produces higher-order instabilities at discrete gap settings [2]. In each case the feedback system supresses BxB beam instability with ease. A new beam-abort feature was also added to protect sensitive insertion device chambers by dumping the beam in the event of low-amplitude vertical bunch motion.

In order to further study impedance effects and test potential resonant crabbing schemes, the BxB feedback system is used for machine development studies. To address these needs, a Matlab interface was developed to consolidate iGp12 control with data processing in a flexible unified environment [9]. The functionality of the interface is presented in the following sections.

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DATA FORMAT

BxB data from the DIMTEL iGp12 SRAM (or BRAM) is acquired in vector form which can be re-formatted into the matrix structure seen to the left in Fig. 2. Each column of matrix M contains the time-evolution of a single bunch, with inter-bunch motion coupled by electromagnetic wakefields. In general, bunch motion along the time axis can be influenced by the bunch fill pattern, chamber impedance, background gas composition, total beam current, RF voltage and the action of feedback systems. Instability growth rates and damping times are calculated along the time axis. As shown below, the rows and columns of matrix M can be plotted in the software interface with the columns automatically fit to determine characteristic grow/damp times.

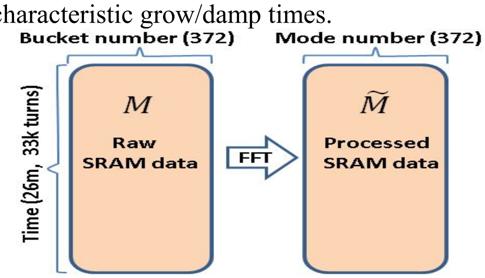

Figure 2: BxB data structure before and after modal analysis: SPEAR3 parameters shown.

The corresponding modal matrix $\widetilde{M}$ to the right in Fig. 2 represents the Fourier-transform of matrix M evaluated along the beam propagation axis. Matrix $\widetilde{M}$ reveals the beam displacement resolved into transverse modes as a function of time. Dominant modes point to sources of impedance - low frequencies for resistive wall impedance, intermediate frequencies for trapped ion instabilities and higher frequencies for discrete narrowband 'pillbox resonances' in the vacuum chamber. The mode spectrum and the corresponding time evolution of the mode spectrum often provide key ingredients to determine sources of impedance. The measurements can then be compared with theory and simulation to determine cause and cure.

SOFTWARE INTERFACE

After the initial feedback hardware commissioning phase we developed a graphical Matlab-based user interface to combine iGp12 control with data analysis in a unified environment. The interface software was hard-coded to improve program readability and allow users to modify interface functionality. EPICS communication with the iGp12's is made with native labCA commands. The graphical format of the interface seen in Fig. 3 is modelled after the Matlab Middlelayer program 'PlotFamily' which features a 'One Shot' option to acquire and display data on demand and a 'Continuous' data acquisition option. Similar to the standard iGp12 waveform interface, MAXRMS and the beam spectrum are displayed in Continuous mode for fast cycling time.

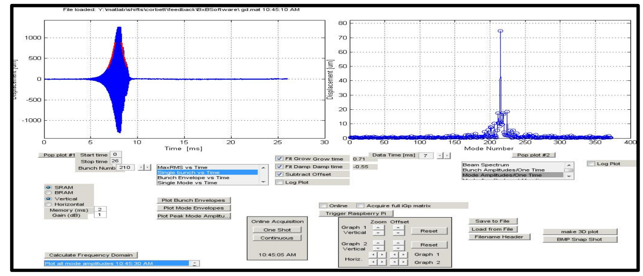

Figure 3: BxB software interface featuring display of single bunch time evolution (left) and mode spectrumevaluated at t=7.8 ms (right).

The main software interface contains two plotting windows which allow the user to simultaneously view data from different perspectives. In general, the left window displays time-dependent data and the right window displays data in the frequency domain. Graphics menus are available to select different display options for each window. Most of the data analysis routines are based on DIMTEL-supplied software. By updating a few machine-specific program parameters the interface can be used at other facilities rendering it 'machine independent'.

Internally the interface software stores data in three main structures containing (1) time-domain information, (2) frequency domain information and (3) program flags and graphics handles. Each of these structures can be manipulated in the main Matlab workspace for deeper analysis of the raw data. Users can save data to file from the interface in the standard DIMTEL file format and recall files for display and analysis at a future date. Due to the modular code structure, data acquisition and post-processing sequences can be 'scripted' to perform parameter scans or more detailed analysis.

Other significant graphics features include horizontal/vertical plane selection, SRAM/BRAM selection, and a checkbox to acquire only the MAXRMS and beam spectrum or acquire the full beam dynamic matrix M in One Shot mode. Once matrix M is available, frequency domain analysis can be performed on demand. Software flags keep track of data acquisition events and data processing sequences to avoid mixing information from separate data acquisition events.

Of interest, a button was added for SPEAR3 applications to instruct a Raspberry Pi single-board computer to output a TTL 'gating' pulse to select an isolated hardware trigger pulse from the 10 Hz injection trigger pulse train. The resulting trigger pulses are routed to the iGp12 processors and to visible-light diagnostics for synchronous data acquisition [9].

In the following sections we describe plotting options for the left- and right- graphic windows in more detail. Similar to PlotFamily, each window has a menu to select the data format of interest and the physical plots can be easily extracted from the main window into a more publication-compatible format. Pop-up figures containing *3-D* renditions of M and $\widetilde{M}$ are also available.

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Left Plot Window

The left plot window is dedicated to time-domain analysis based on matrix M. A data selection menu allows choice of information to display. The 'Single Bunch vs. Time' option, for instance, allows the user to plot

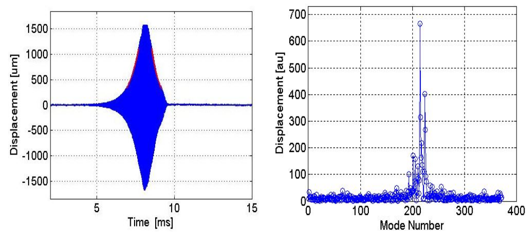

Figure 4: Left: bunch 201 grow/damp transient with exponential fit in red: τ_{grow}=0.75ms, τ_{damp}= -0.56ms. Right: BxB mode amplitudes evaluated at t= 7.8 ms.

individual columns of M to examine single bunch dynamics in time. Plotting options include offset subtraction, vertical logarithmic axis and numerical fitting of grow/damp behaviour. For the grow/damp case, the numerical Levenberg-Marquardt (L-M) algorithm is used to fit exponential curves to the raw data with results displayed in the interface. Other plotting options include 'MAXRMS vs. Time', results of a time-domain bunch 'Envelop' calculation and 'Mode Amplitude vs. Time'. For the latter case, the user can select mode number with the same L-M exponential fitting algorithm reporting exponential grow/damp time constants to the interface.

Figure 4 shows an example of a grow/damp transient for a single bunch in an unstable 500 ma beam. The red curves denote the exponential grow/damp fit to the data. In this view, the time axis can be expanded to reveal the betatron oscillation structure in time.

Right Plot Window

The right plot window primarily displays data in the frequency-domain. By default, this window shows the beam spectrum in decibels with frequency along the horizontal axis. By selecting 'Mode amplitudes/one Time', individual rows of matrix $\widetilde{M}$ can be viewed at one time. Figure 4 (right), for instance shows the mode spectrum for the same grow/damp event displayed to the left at time t=7.8 ms. The dominant mode corresponds to a narrowband ID chamber resonance known to cause instability at high total beam current [2]. Other plotting options include all mode amplitudes evaluated at the time when the peak single-mode amplitude occurs and all bunch amplitudes evaluated at one time (bunch number on the horizontal axis). A checkbox allows logarithmic scaling on the vertical axis.

CONCLUSION

A BxB feedback system has recently been installed on SPEAR3. The main components include digital DIMTEL processing electronics, 150 W RF power amplifiers and a single transverse stripline kicker on loan from LBNL. The ALS-style kicker is oriented at 45° to the beam axis and operates on the principle of separate betatron frequency response in each plane. To date the SPEAR3 BxB feedback system has been used for single-bunch drive/damp studies and high-current grow/damp studies to investigate ID chamber resonances. In operation BxB feedback systematically damps beam instabilities at 500 mA circulating current.

In order to unify BxB feedback control, data acquisition and analysis, a graphical interface has been hard-coded in Matlab. The interface communicates with the iGp12 processors via EPICS or can be configured for other communication protocols. Measured data can be analysed and saved or recalled later for post-processing. Two main interface plotting windows display data in the time-domain and frequency-domain, respectively. Due to the modular structure of the interface software, the program is 'machine independent' and open to development of scripted algorithms that can acquire and process data automatically. In principle the flexibility of the programming environment allows for machine control, automation, optimization and synchronized connectivity to complementary beam diagnostics.

ACKNOWLEDGMENTS

The authors thank P. Boussina, A. Krasnykh, J. Safranek, J. Shtalenkova, S. Wallters, K. Wootton and the SPEAR3 operations staff for technical assistance and the ALS for loan of the feedback kicker.

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