OPERATIONAL STATUS OF THE TRANSVERSE MULTIBUNCH FEEDBACK SYSTEM AT DIAMOND

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Abstract

A transverse multibunch feedback (TMBF) system is in operation at Diamond Light Source to damp coupled-bunch instabilities up to 250 MHz in both the vertical and horizontal planes. It comprises an in-house designed and built analogue front end combined with a Libera Bunch-by-Bunch feedback processor and output stripline kickers. FPGA-based feedback electronics is used to implement several diagnostic features in addition to the basic feedback functionality. This paper reports on the current operational status of the TMBF system along with its characteristics. Also discussed are operational diagnostic functionalities including continuous measurement of the betatron tune and chromaticity.

INTRODUCTION

The 3 GeV Diamond storage ring is currently serving photon beam for users with a current of 250 mA in a multibunch fill of 900 bunches. In addition, a hybrid mode where 3/4 of the ring filled with a multibunch and a high intensity single bunch sitting on the opposite side is run for certain experiments. Multibunch instabilities have been clearly observed and studied at Diamond from the early days of commissioning [1]. Indeed the operation with the nominal zero chromaticity lattice is prevented at multibunch currents as low as 10 mA in a uniform fill with 936 bunches. Therefore, it was necessary to create a transverse multibunch feedback system to combat the instabilities towards achieving our final target current of 300mA in multibunch mode.

OVERVIEW OF THE TMBF DESIGN

The Diamond TMBF System is a wideband feedback correcting the positions of individual bunches, spaced

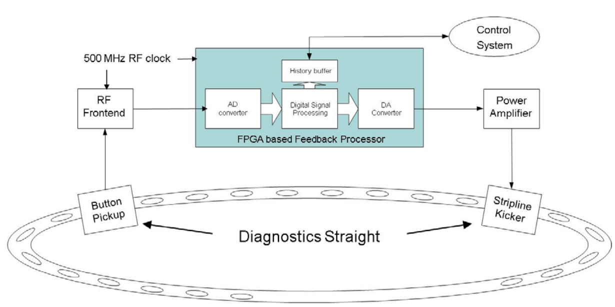

Figure 1: Block diagram of the Diamond TMBF system.

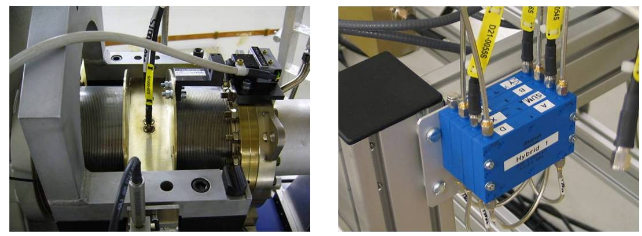

Figure 2: 4-button pickups and hybrids installations in the ring.

2ns apart. Figure 1 shows the system level structure of the TMBF system. It is composed of a detector in terms of pickup buttons, hybrids (Figure 2) and an in-house developed RF front end (Figure 3) inspired by an existing ESRF design, a commercial digital FPGA based feedback electronics called Libera Bunch-By-Bunch from Instrumentation Technologies [2], stripline kickers and 100W power amplifiers.

Wideband position signals are picked up by a set of four button pickups, and then passed through a set of hybrid combiners to generate the X and Y position signals. These wideband signals are passed to an RF front end, where the signal is mixed and filtered to 0-250 MHz baseband signal and then amplified to the correct level for the electronics.

The position signal is directly sampled at the RF frequency with 4 ADCs (f_{rf} = 500MHz and $f_{adc} = f_{rf}/4$). On the basis of the betatron motion measured for each bunch, FPGA-based electronics performs FIR (Finite Impulse Response) filtering to feedback the signal

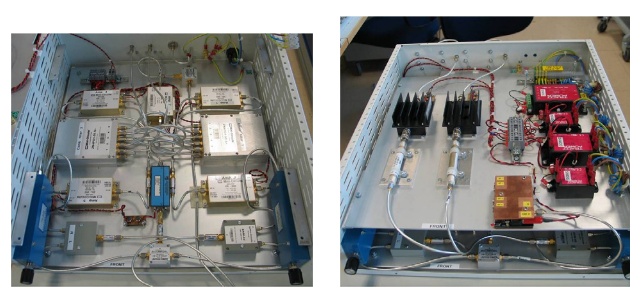

Figure 3: In-house developed RF front end occupies a 3U 19” rack and built over two layers. The bottom layer (left) houses the input comb filters and the mixer, while the the timing module, output filters, splitters and power supplies are located on the upper layer (right).

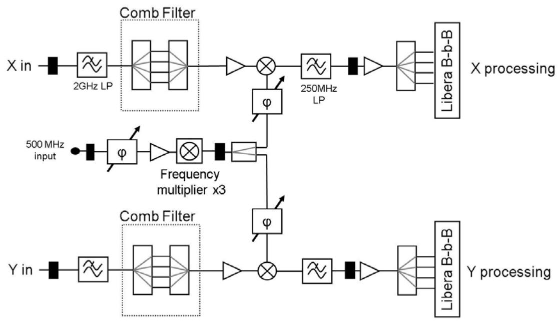

Figure 4: RF front end schematics. A phase shifter was added on the 500MHz RF clock input path to compensate electron beam phase shifts relative to the RF clock.

necessary for oscillation damping of a given bunch turn by turn. This information is passed to a power amplifier which, through some low pass filters, drives two sets of kicker striplines differentially (one in X and one in Y) to apply the corrections to the beam.

The details of the TMBF system and its FPGA-based digital feedback processing capability have previously been discussed [3, 4]. Since our last status report [5], the main modification on the system was the addition of a phase shifter operating at 500MHz to the local oscillator chain in the front end electronics as shown in Figure 4. This was required as the RF phase of the synchrotron drifts slowly relative to the 500MHz timing signal. This has the effect of moving the sampling point on the bunch. If the phase shift is too large, the sample point moves off the bunch completely and the tune signal disappears. As the drift is very slow (on the order of days or weeks), this new phase shifter is not in a control loop; rather the operators can adjust the bunch intensity as necessary.

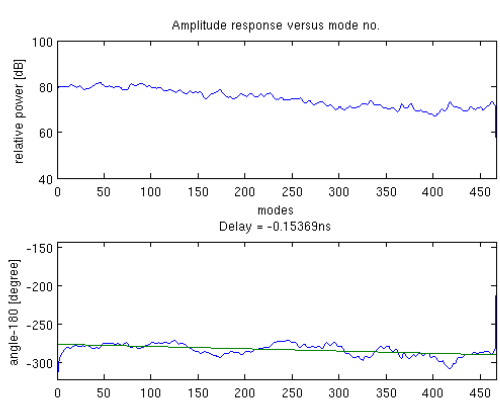

Figure 5: Variation of loop gain (top) and open loop phase response (bottom) as a function of mode number for the horizontal plane. The straight-line fit on the phase response reports 153ps of loop delay.

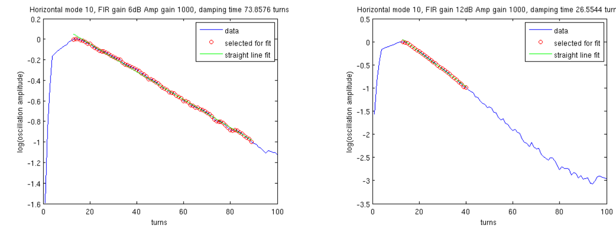

Figure 6: Damping time measurement for mode 10 in the horizontal plane. The fitting reports 73 and 25 turns damping time at FIR gains 0dB and 12dB, respectively.

PERFORMANCE

The stability of the feedback loop for all 936 modes is studied by exciting the beam at each mode frequency in turn using the internal Numerically Controlled Oscillator (NCO) and measuring the amplitude and phase response of the open loop at the output of the feedback FIR filter as shown in Figure 5. A straight-line fit on the phase response gives the overall loop delay, which guarantees a successful loop closure in terms of feeding back on to the right bunch in the train. The loop delay is tuned in 2ns steps in the FPGA, whilstt further tuning within the 2ns is achieved by modifying cable lengths in the loop.

To characterise the TMBF system, the feedback loop can be opened and closed momentarily in order to measure the growth and damping rate of individual modes. This measurement is carried out under the control of FPGA frequency sweep logic and internal timers. The routine to measure the damping time has been further automated to include post processing, including a straight-line fit on the decay. This produces a single number (the damping time) as an output. Figure 6 shows a typical damping time measurement.

Figures 7 shows a damping time scan for all modes in the horizontal plane at 250mA beam current with 2/3 fill and chromaticity set to 2. The damping time increases with rising mode number, as the gain of the feedback loop decreases with rising frequency. This is the conglomerate effect of the RF front end, the ADC, the drive amplifiers and the striplines. However, at low modes, where resistive wall effects drive instabilities more strongly, we achieve damping times of 73 in Horizontal and 82 turns in Vertical plane with FIR gain set to 0dB.

The feedback loop has been successfully closed to stabilise the beam up to 300mA with full fill, which is more challenging than the usual 2/3 fill. Figure 8 shows the transverse beam sizes as captured on a pinhole camera when the beam is stabilised by the feedback and when the beam is unstable without being lost.

In order to facilitate the measurement of the system characteristics and performance, a set of high-level graphical user interfaces has been developed using Matlab (Figure 9). It is our aim is to carry out these measurements routinely in order to understand the machine behaviour.

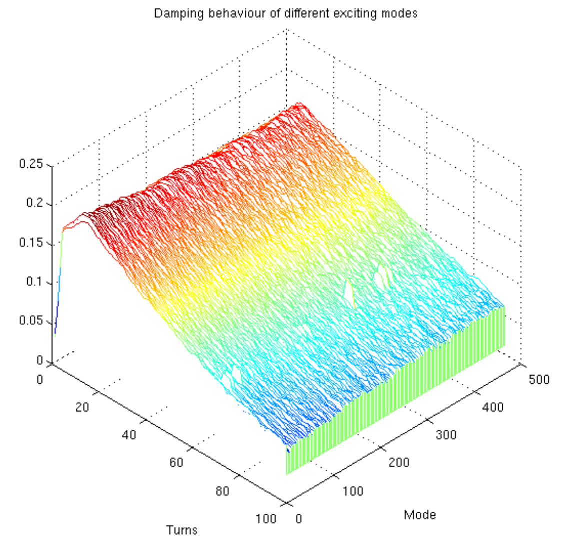

Figure 7: Damping time measurement for all instability modes in the horizontal plane.

FPGA DIAGNOSTICS APPLICATIONS

The ability of the FPGA design to act on a selected single bunch in terms of applying feedback or excitation, or simply doing nothing, has enabled us to develop techniques for online tune and chromaticity measurements with no visible disturbance to user beam [6].

Measurement of continuous betatron tune with no visible disturbance to the user beam is achieved by exciting only a single bunch at a frequency near the nominal tune. The bunch motion is then detected by mixing the measured bunch position with a sine and cosine output of the excitation frequency and accumulating the result for a certain period over 100 turns. The excitation sweep is repeated for 4096 different frequencies with small increments and completed in less than a second. The result is delivered by the FPGA as waveforms of I and Q value per frequency point through the control system interface as shown in Figure 10.

The frequency-sweeping-based excitation for the tune measurement also produces information about the synchrotron oscillation sidebands to the tune. From the relative magnitudes of the tune sidebands, the chromaticity (tune shift with energy shift) can be derived. This application is currently in the commissioning phase, and is used at machine start-up when the chromaticity is assumed to be constant. It will subsequently be employed during user operation and allow us to replace an invasive measurement with a passive one giving a measurement of the chromaticity from the tune spectrum available every second. In doing so it will both reduce the impact on machine operations and improve our understanding of the behaviour during run time. Work-in-progress test results recorded on our stripline tool are shown in Figure 11.

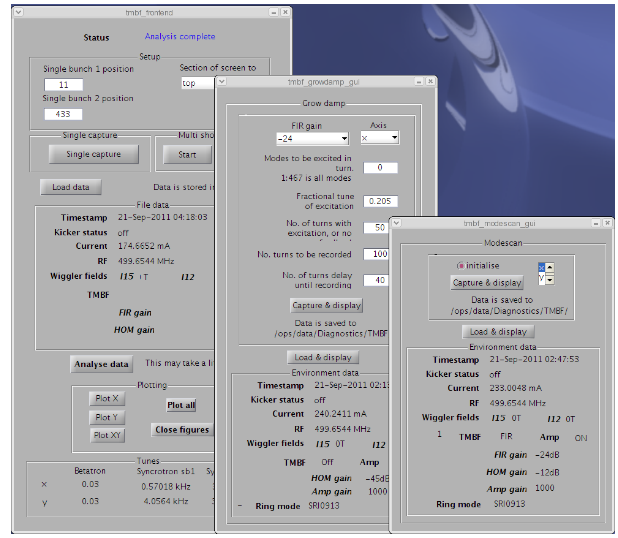

Figure 9: Matlab graphical user interfaces to launch diagnostic utilities. The main front end GUI for capturing and analysing raw data (left), grow/damp utility supporting measurement on multiple modes (middle), open-loop response measurement tool (right).

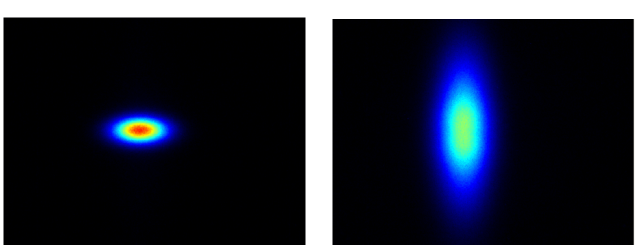

Figure 8: Pinhole screen captures of the electron beam with TMBF on (left) and TMBF off (right) at 250mA, 2/3 fill and chromaticity set to 0.

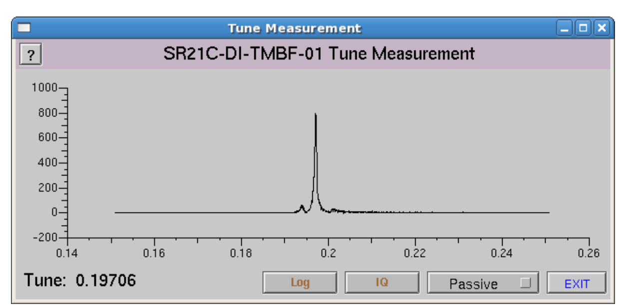

Figure 10: Online tune measurement (horizontal plane). The raw IQ data from FPGA can also available as Epics waveforms.

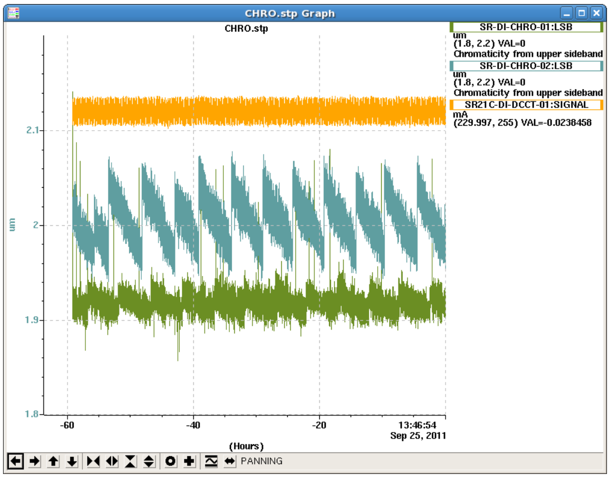

Figure 11: 60hrs of online acquired chromaticity data from the tune sidebands of a single bunch during top-up operation. Presently there is no bunch charge adjustment which explains the zig zag pattern.

CONTROL SYSTEM INTERFACE

The operation of the TMBF system is fully integrated into the Diamond EPICS control system. The user interface is divided into two modes of operation. The "Simple Mode" provides the higher level control interface in order to operate the TMBF system and reports basic status information such as feedback status, bunch amplitudes and the tune value (Figure 12 left). The "Expert Mode" provides a comprehensive control interface enabling access to all lower level control parameters on the FPGA (Figure 12 right). The expert mode is used mainly for commissioning and system debugging purposes.

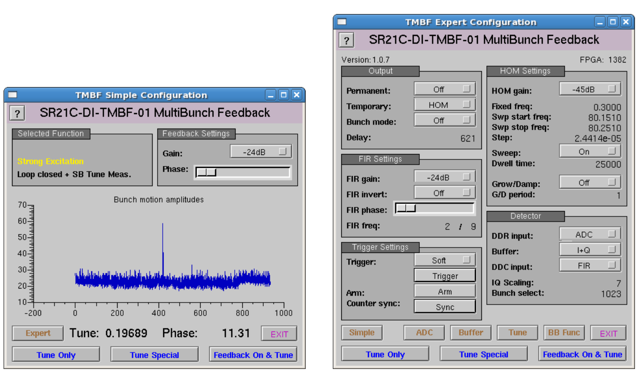

Figure 12: EPICS user interfaces. The selected function panel on the Simple Mode screen (left) shows that the feedback loop is closed and the single bunch tune measurement is activated as well. The spike on the bunch motion amplitude window confirms the excitation of a single bunch used for online tune measurement. The Expert Mode screen (right) provides access to all control registers.

CONCLUSIONS

The current status of the TMBF system at Diamond has been reported along with its performance. The feedback system has proven its ability to correct horizontal and vertical instabilities at 250mA with chromaticity set to 0. The feedback system is fully integrated into the EPICS control system for machine operation and supported by a useful set of Matlab applications for system analysis purposes.

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