Development of a Turn-by-Turn Beam Position Monitoring System for Multiple Bunch Operation of the ATF Damping Ring

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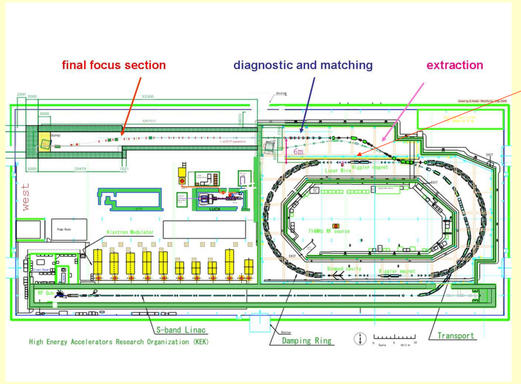
Abstract

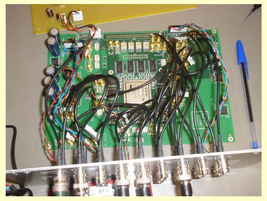
An FPGA-based monitoring system has been developed to study multi-bunch beam instabilities in the damping ring (DR) of the KEK Accelerator Test Facility (ATF). The system utilises a stripline beam position monitor (BPM) and a single-stage down-mixing BPM processor. The system is designed to record the horizontal and/or vertical positions of up to three bunches in the DR with c. 150ns bunch spacing, or the head bunch of up to three trains in a multi-bunch mode with bunch spacing of 5.6 ns. The FPGA firmware and data acquisition software allow the recording of turn-by-turn data. An overview of the system and performance results will be presented.



Two stripline BPMs in DR

Properties of ATF DR

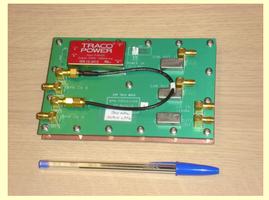
- **Energy: 1.3 GeV**
- **Circumference: 138 m**
- **Revolution frequency: 2.16 MHz**
- **Machine repetition rate: 1.56 Hz**
- **Up to 3 trains injected per cycle**
- **Up to 10 bunches per train @5.6 ns bunch spacing**
- **Store time per cycle: ~10^6 turns**



FONT5 FPGA-based digital processor

Used for DAQ for DR monitoring system. FPGA firmware and DAQ software modified for turn-by-turn operation

System Design & Hardware



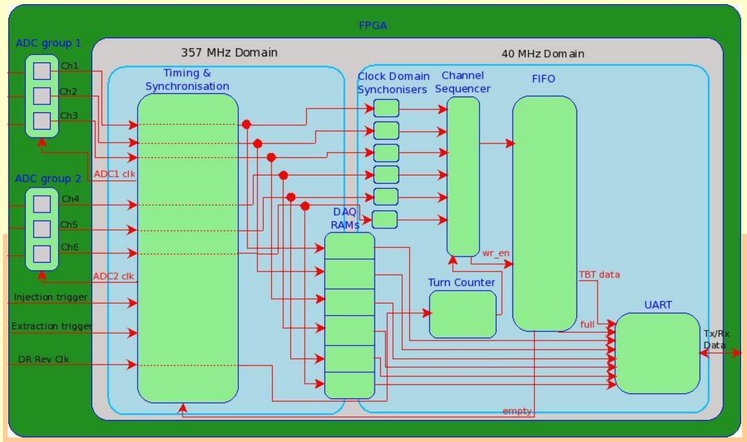
FONT5 digital processor board

Unmodified from extraction line feedback system – differential attenuation added to measure large position offsets in DR

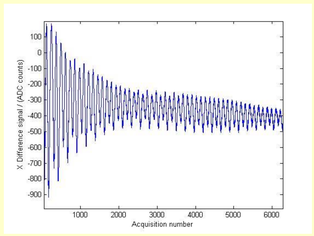
Key Design Features:

- **Re-uses existing hardware with modified firmware/DAQ software**
- **Records turn-by-turn data for up to three bunches per turn**
- **Record data from up to 6 channels (2 BPMs – horizontal and vertical difference, & sum)**
- **Single large FIFO memory stores 131071 samples (Maximum of ~15 % of store time for consecutive turns single bunch, single channel)**
- **Can vary time window and time resolution to record every *n* turns in *m*.**
- **Data returned in ~6s – can record data from every 1 in 3 machine cycles in multi-train mode.**
- **Position resolution ~1.3 ❍m (with 8 dB attenuation) , phase resolution ~ 0.1 ° (no attenuation)**

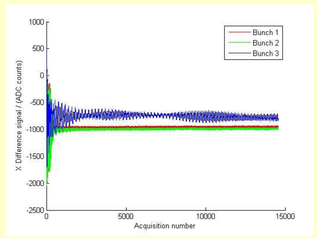
Schematic overview of the FPGA firmware for turn-by-turn monitoring



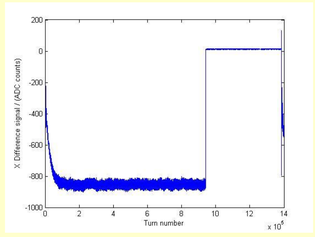
Initial Results



X difference signal for first few thousand turns of single bunch beam. Note injection occurs at turn number 6.

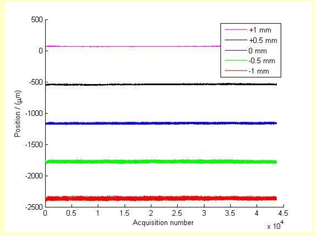


X difference signals for first few thousand turns of multi-train beam.



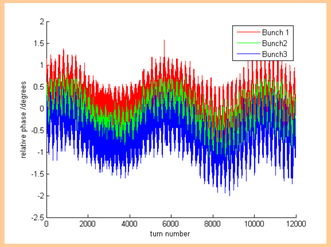
X difference signals for every 1 turn in 32 of single bunch beam. Note that injection occurs at turn 0 and extraction around turn number 940000. On the far right of the figure a subsequent injection can be seen, at a time of 0.65 s after the first, corresponding to the next machine cycle.

Vertical position for c. 45000 turns of single bunch beam, for five different vertical orbit bump settings.

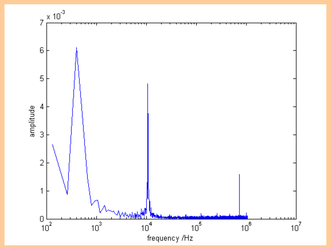


Bunch phase measurements with respect to LO

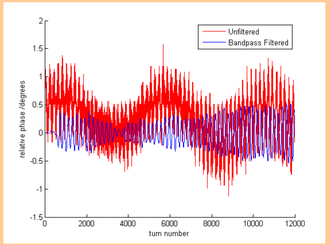
The turn-by-turn system was used in November 2011 to investigate the performance limitations of the down-mix stripline BPM processors used for the beam-based feedback system in the ATF extraction line. This study identified several frequencies in the spectrum of the bunch phase with respect to the local oscillator, including the synchrotron oscillation at 10.8 KHz, and contributed to the understanding of the effects of the longitudinal bunch motion on the apparent BPM resolution as measured in the extraction line.



Bunch phase with respect to the LO, for the last c.12000 turns before extraction for three bunches separated by 154 ns.



Fourier transform of the relative phase of bunch 1. Bunches 2 and 3 show very similar behaviour.



Comparison of unfiltered (red) and band-pass filtered (blue) data for bunch 1. The bursting nature of the synchrotron oscillation can be seen clearly in the filtered data.

Last 200 turns (one synchrotron period) before extraction for band-pass filtered data for bunch 1. Data for 43 successive pulses are overlaid, showing that the phase at extraction is random.