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New Fast Orbit Feedback System using MicroTCA-Based BPM Electronics for the PF-ring

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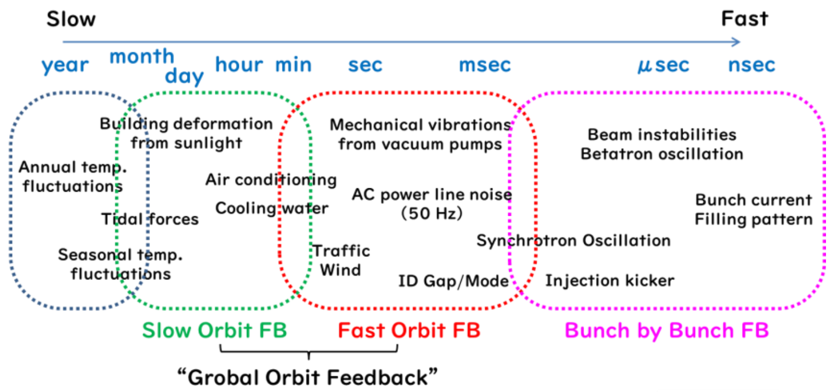
Abstract

The upgrade to the fast orbit feedback (FOFB) system for the PF-ring is currently in progress. The new FOFB system features MicroTCA-based BPM electronics and a feedback control (FBC) unit. The BPM electronics are matched in number to the BPMs and synchronously transmit beam position data at a 10-kHz rate to the FBC unit via an optical data link. The FBC unit promptly calculates closed-orbit distortion from the received positional data and performs a matrix operation to correct it. The results are then converted to analog signals by fast D/A converters and applied to the power supplies of the fast-steering magnets. The immediate goal of the new FOFB system is to achieve a closed-loop bandwidth of 50 Hz, exceeding the current system performance by more than 100-fold. This paper will present the details of the new BPM electronics and the upgraded FOFB system, along with initial results obtained during beam tests.

1. Introduction

➢ Causes and Countermeasures for Orbital Fluctuations

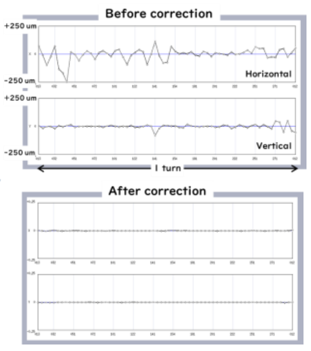


➢ Global Orbit Feedback (GOFB)

Feedback Loop

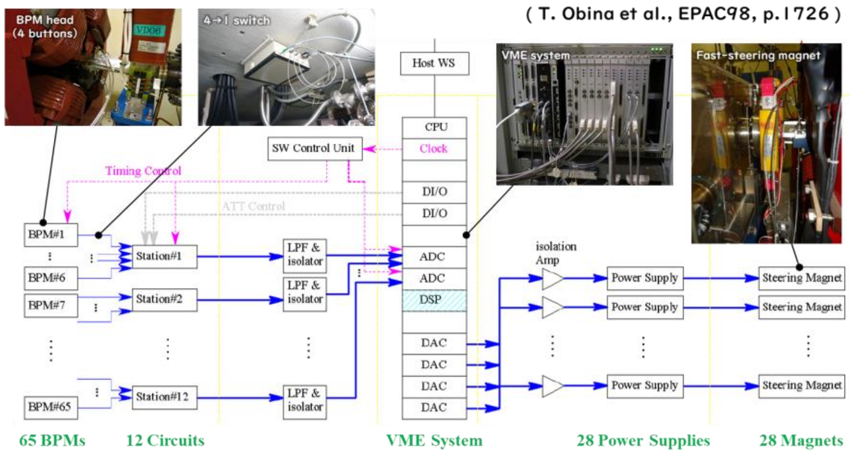
1. Measure the closed orbit by BPMs
2. Calculate deviations from the ideal reference orbit
3. Calculate kick angles to minimize the deviations
4. Apply the PID compensation
5. Change current settings of fast-steering magnets

Faster FB cycle results in wider FB bandwidth !



➢ Current Fast Orbit Feedback (FOFB) System for the PF-ring

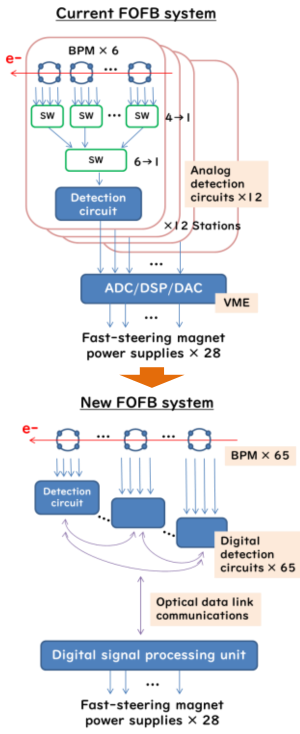
(T. Obina et al., EPAC98, p.1726)



- Serial signal processing with 12 analog detection circuits for 65 BPMs
- Measurement accuracy: 2–3 μm@1 Hz
- Feedback cycle: 12 ms (80 Hz), Feedback bandwidth: 0.3 Hz
- Since its introduction in 1997, hardware failures due to aging have frequently disrupted user operations.

Since FY2020, the KEK PF-ring has been planning an upgrade to the FOFB system. To achieve a faster feedback cycle and wider bandwidth, serial signal processing of the current system with few analog detection circuits has been replaced by parallel processing with digital circuits matching the number of BPMs.

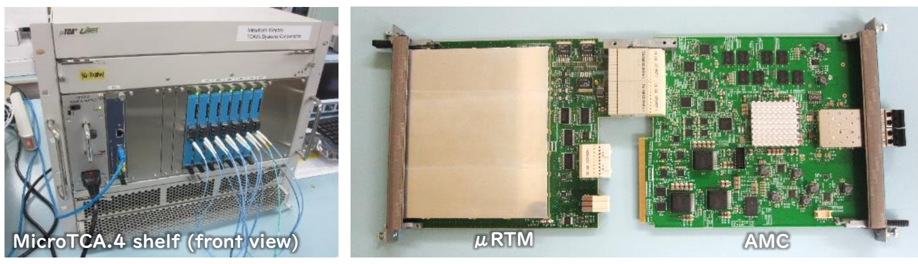
➢ Upgrade Policy



2. New BPM Electronics

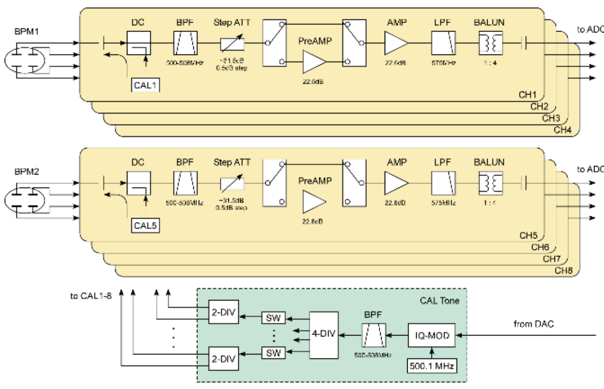
➢ MicroTCA.4-Based BPM Electronics

- Micro Telecommunications Computing Architecture + Scientific applications
- High availability and redundancy, High-speed data communication, High-precision timing, Remote management, Compact form factor, Wire saving
- Manufactured by Mitsubishi Electric Defense And Space Technologies Corporation
- These modules were originally developed for BPMs in the SPring-8 upgrade project and have been adapted for use in the PF-ring.



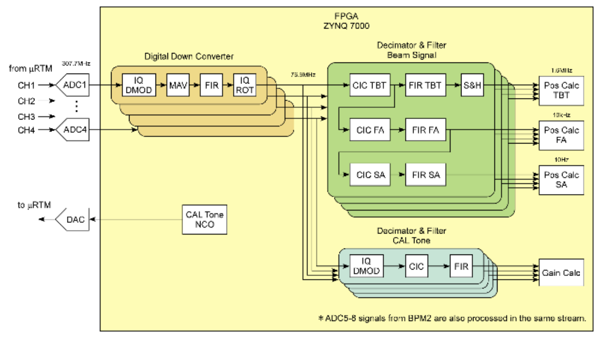
➢ Micro Rear Transition Module (μRTM)

- Analog front-end circuit that extracts beam-related components from raw BPM signals and adjusts their levels for compatibility with subsequent ADCs
- Two-stage amplifier for a wide dynamic range
- Calibration function using tone signals

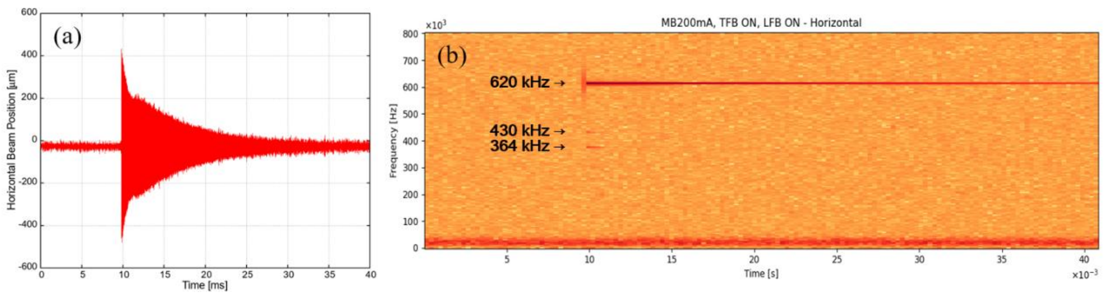


➢ Advanced Mezzanine Card (AMC)

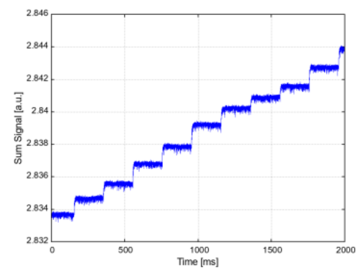
- Digitizer and digital signal processor, features high-speed ADCs (8 channels, 16-bit, 370 MSPS max.) and FPGA (Xilinx: Zynq XC7Z045-1FFG900C)
- EPICS IOC running on the FPGA's CPU
- Three datasets: TBT (1.6 MHz), FA (10 kHz), SA (10 Hz)
- Position calculation with a fifth-order polynomial



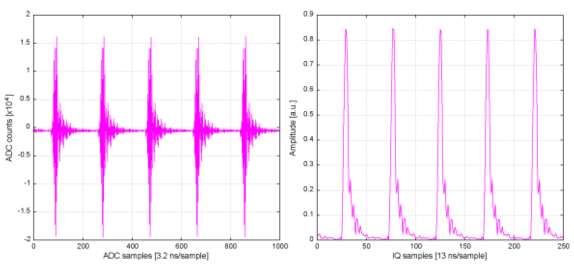
➢ Beam Test Results



Horizontal injection oscillation captured by the TBT data during multi-bunch storage: (a) time domain waveform (b) its spectrogram.



Sum signal of the FA data obtained during beam injections at 5 Hz.

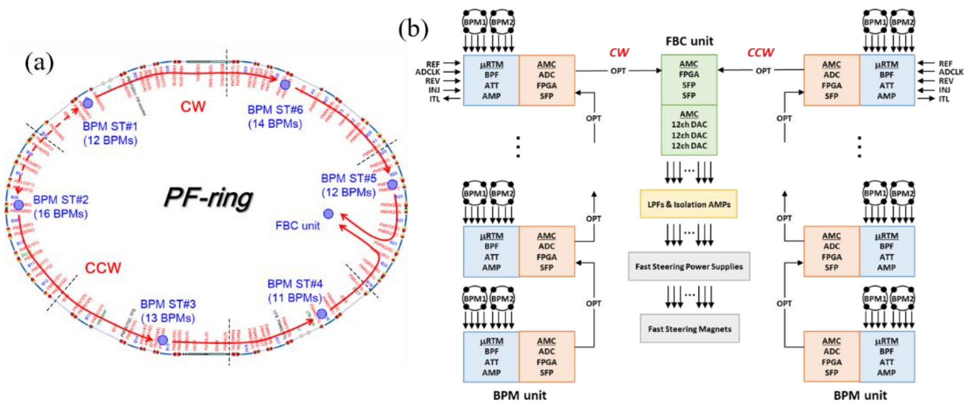


ADC raw data and its amplitude reconstructed from the IQ data during single-bunch storage.

3. New FOFB System

➢ Distributed BPM Stations and Optical Data Link

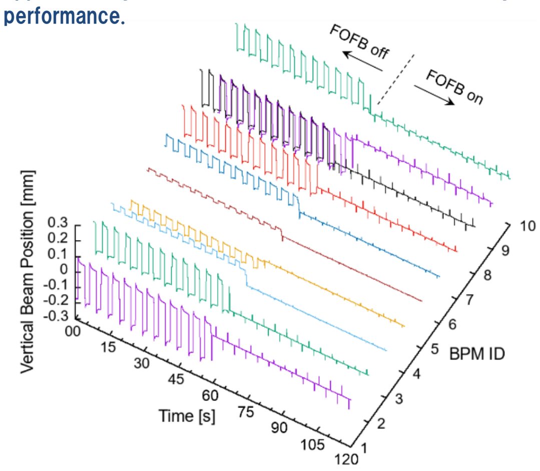
- 40 pairs of these modules sufficient to cover 80 BPMs were prepared and installed.
- The shelves were placed at each of the six BPM stations for distributed module placement.
- The 10-kHz FA data from SFP ports of each AMC is transmitted to a central "feedback control (FBC) unit" through an optical data link.
- The FBC unit performs the matrix calculation for orbit correction and transmits the results to fast-steering magnet power supplies through high-speed DACs (36 channels, 16-bit, 500 MSPS max.).



(a) Layout of the new BPM stations (BPM ST#1–#6) and FBC unit.
(b) The new FOFB system diagram for the PF-ring.

➢ Beam Test Results

- The orbit feedback test was conducted by connecting only 10 BPMs and 8 fast-steering magnets to the new setup.
- A fast-steering magnet outside the feedback loop was excited with a 40% duty cycle pulse wave.
- Tentative feedback bandwidth was measured at approximately 20 Hz, about 70 times the current system performance.



4. Summary and Future Plans

- Since FY2020, the KEK PF-ring has been upgrading its FOFB system.
- The new system features a MicroTCA-based digital signal processor for each BPM, interconnected via optical fibers.
- Extensive beam tests on individual BPM electronics and the entire system demonstrated excellent performance, as expected.
- We are working on stabilizing the temperature of the electronics installation environment and implementing a calibration function using tone signals.
- We plan to introduce the new system for user operations as early as FY2024.
- Future steps include replacing magnet power supplies with digitally controllable units and expanding FOFB to the horizontal direction.
- This upgrade also serves as R&D for the next generation of PF light sources.