Replacement of the Single-Pass BPM System with MicroTCA.4-based Versatile Electronics at SPring-8

MOP022

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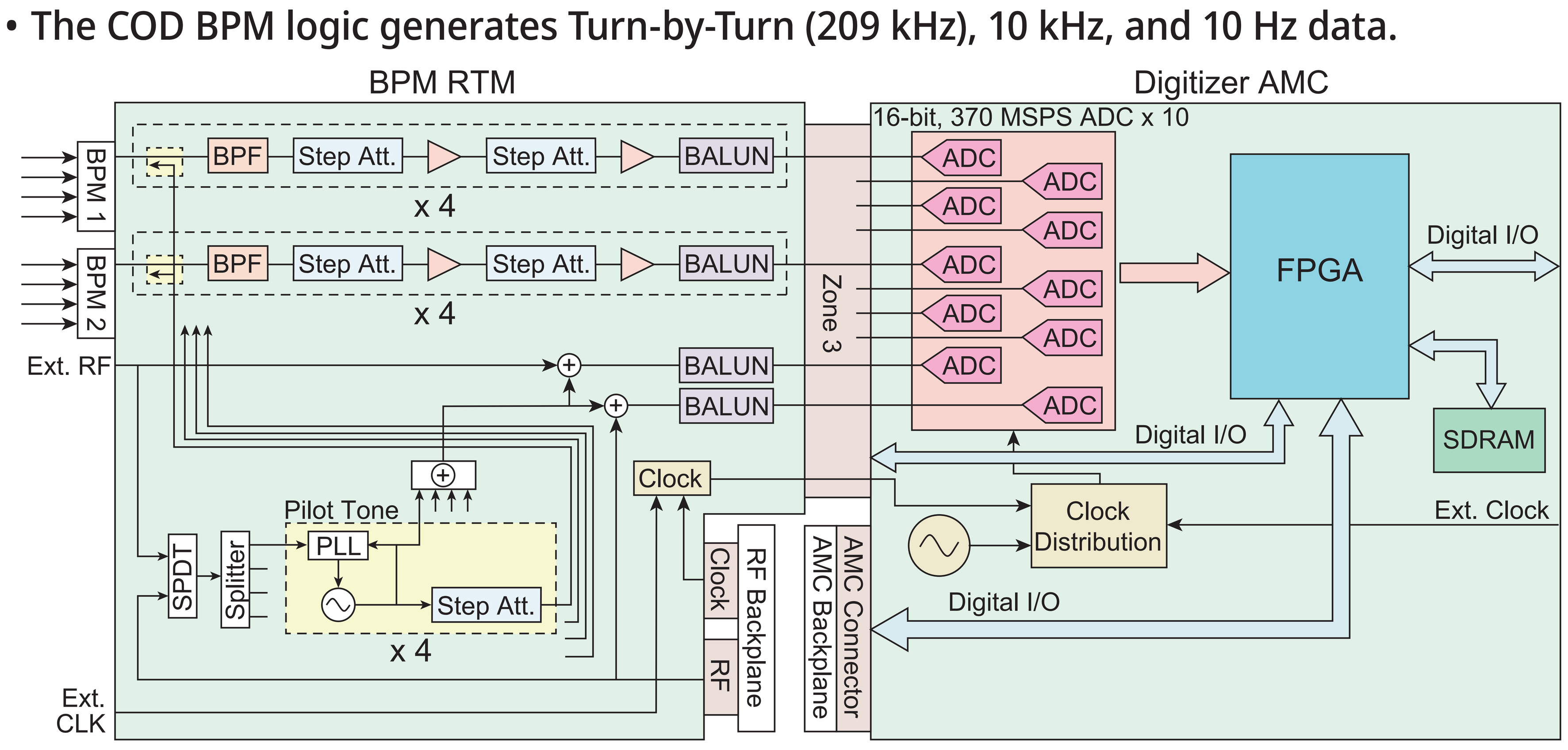
Introduction

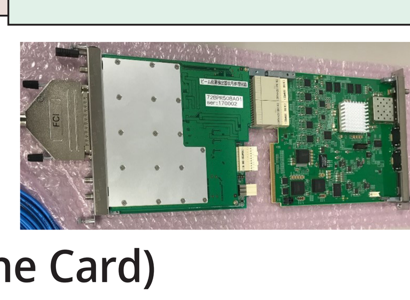
- Low-emittance upgrade of the SPring-8 storage ring, SPring-8-II [1].
  - Natural emittance: 2.4 nm rad → 100 pm rad
  - Beam energy: 8 GeV → 6GeV
  - Lattice: Double-bend Achromat (DBA) → 5-bend achromat (5BA).
- Requirements for the BPM system.
  - Single-pass (SP) BPM resolution: **100 μm std.** (for a 0.1nC injected bunch)
  - Electrical center error: **±100 μm** (before the beam-based calibration)
  - Stability: **5 μm peak-to-peak** for 1 month
- Developed BPM components
  - Button BPM electrode made of molybdenum [2].
  - Investigation of radiation tolerant coaxial cables.
  - Readout electronics based on MicroTCA.4 (MTCA.4) [3]
- Old SP BPM electronics have been replaced with the new MTCA.4-based electronics.
  - 24 BPM readout units in total (1 unit per 2 cells and, in total 48 cells in the SPring-8 storage ring)
  - One BPM in every 2 cells is used for SP BPM.
  - Three MTCA.4 units were first installed for the adaptive feed-forward correction of the error kick from the fast helicity switching beamline [4] in 2019.
  - Ten units of the SP BPMs were upgraded to the new electronics in 2021.
  - Remaining eleven units are now being installed in this summer shutdown period.

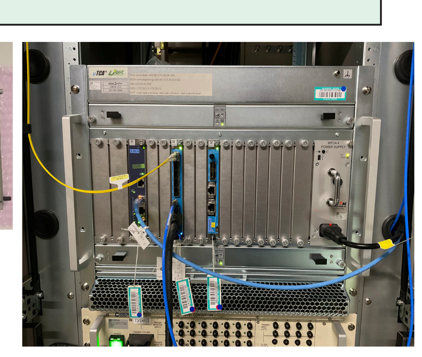
MTCA.4-based Electronics [3]

- Both SP BPM and COD BPM are processed at the same time.
- The COD BPM logic generates Turn-by-Turn (209 kHz), 10 kHz, and 10 Hz data.



- BPM Frontend RTM (Rear Transition Module)
  - Band-pass filter (BPF) at 508.58 MHz (acceleration RF).
  - Level adjustment by step attenuators and amplifiers.
  - Four pilot tone generators for gain correction.

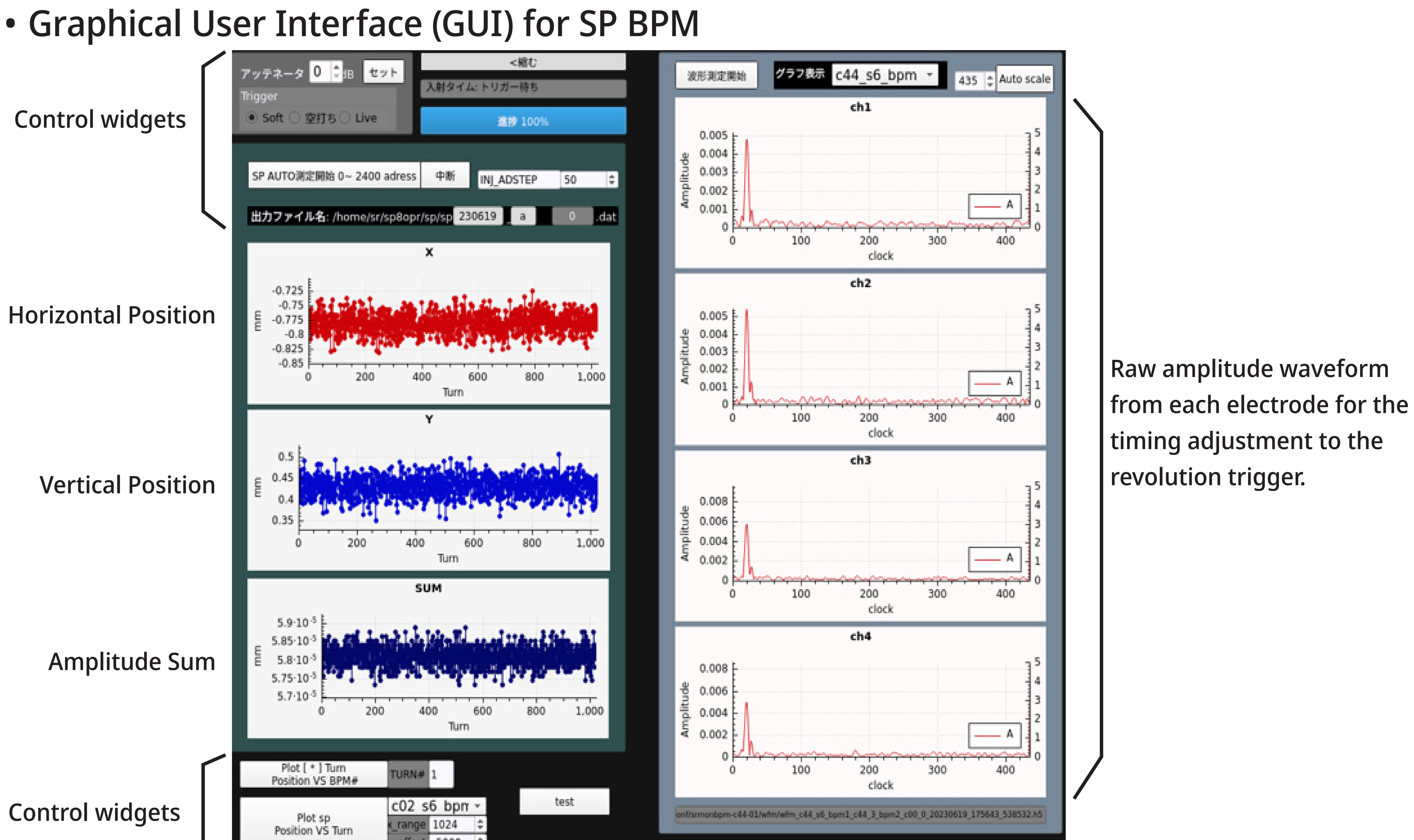




- High-speed Digitizer AMC (Advanced Mezzanine Card)
  - ADC: 10-channel, 16-bit, 370 MSPS max.
  - Under-sampling scheme.
  - Digital down conversion and beam position calculation in FPGA.
- Beam injection trigger etc. are distributed by MTCA.4 trigger modules [5, 6].

Software

- BPM system is controlled by an MQTT messaging system and MDAQ framework [7].
  - All the 10 Hz COD BPM data are stored to the event-synchronized database.
  - The other COD BPM data (TbT and 10 kHz) and SP BPM data are dumped to data files on request.
- Graphical User Interface (GUI) for SP BPM

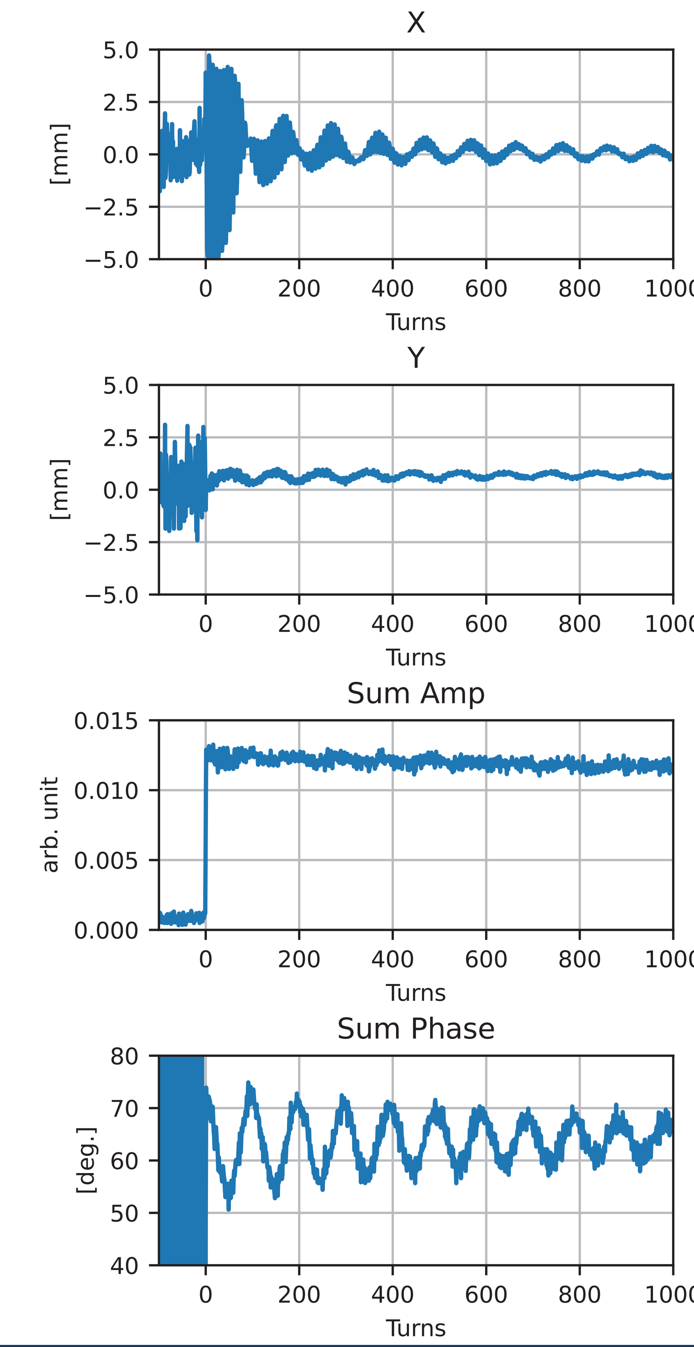


References

[1] SPring-8-II Conceptual Design Report, Nov. 2014. http://rsc.riken.jp/pdf/SPring-8-II.pdf
[2] M. Masaki *et al.*, "Design Optimization of Button-type BPM Electrode for the SPring-8 Upgrade", in Proc. IBIC'16, TUPG18.
[3] H. Maesaka *et al.*, "Development of MTCA.4-based BPM Electronics for SPring-8 Upgrade", in Proc. IBIC'19, WEBO03.
[4] M. Masaki *et al.*, J. Synchrotron Rad., vol. 28, pp. 1758–1768, 2021.
[5] H. Maesaka *et al.*, "Development of a Trigger Distribution System Based on MicroTCA.4", in Proc. IPAC'22, TUPOPT067.
[6] H. Maesaka *et al.*, "Full Energy On-Demand Beam Injection from SACLA to SPring-8 Storage Ring", in Proc. IPAC'21, FRXA01.
[7] T. Sugimoto *et al.*, "Status of the control system for fully integrated SACLA/SPring-8 accelerator complex and new 3 GeV light source being constructed at Tohoku, Japan", in Proc. ICALEPCS'19, WECPL01.
[8] T. Ohshima *et al.*, "Suppression of Stored Beam Oscillation Excited by Beam Injection", in Proc. EPAC'04, MOPKF047.

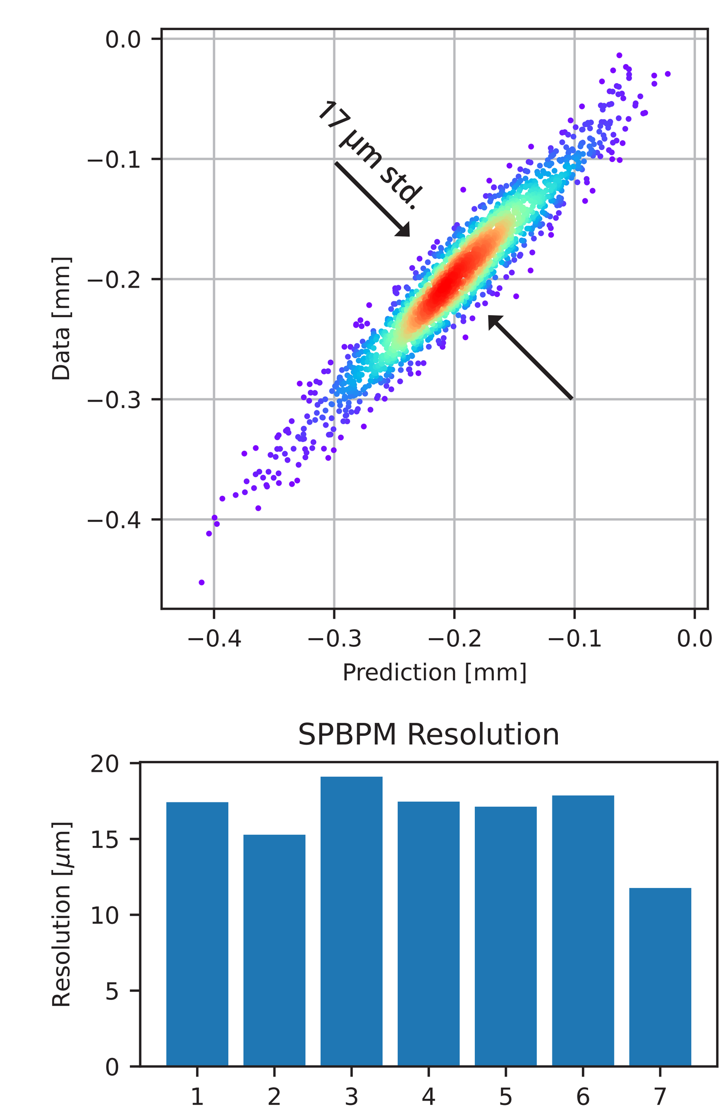
SP Data for Injected Beam

- A single bunch of approximately 0.2 nC was injected.
- Sum amplitude is suddenly increased at the first turn and almost constant after injection.
- Horizontal position shows large betatron oscillation in first a few 100 turns.
  - The injected beam is horizontally offset from the beam orbit.
- Horizontal position also shows synchrotron oscillation (period: ~100 turns)
  - Due to finite horizontal dispersion at the BPM.
  - Errors on energy and timing of the injected bunch.
- Vertical position data has small but finite betatron and synchrotron oscillations.
  - Vertical offset of the beam orbit of the injected bunch.
  - Dispersion leakage to vertical direction.
- Sum phase also shows synchrotron oscillation.
  - Since the sum signal is calculated by the vector sum of complex amplitudes of the four electrodes, the beam arrival phase with respect to the reference RF signal can be obtained.
  - Synchrotron oscillation phase of the sum signal is π/2 shifted from that of position data.
  - This behaviour is consistent with the time evolution of electrons in the longitudinal phase space.



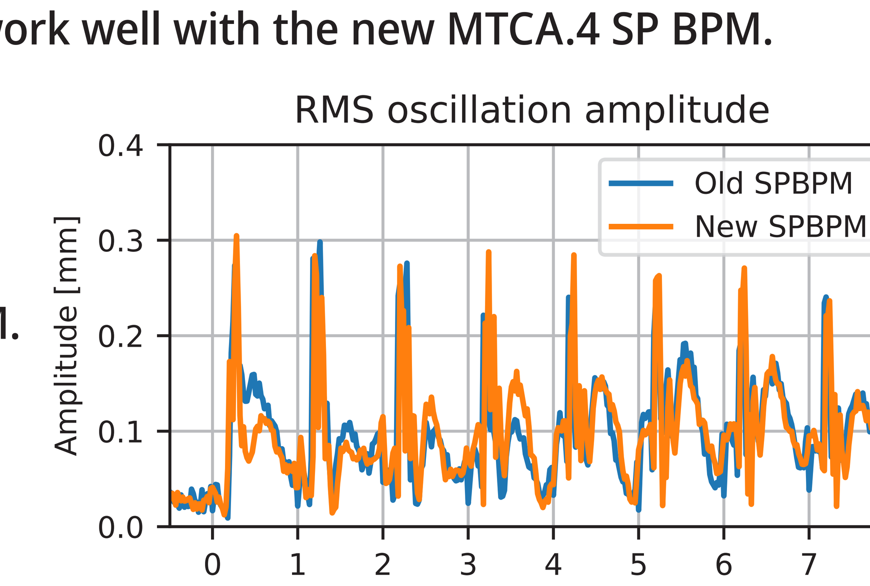
SP Resolution

- SP resolution was evaluated by kicking a stored beam with dipole kickers to make an orbit bump for beam injection.
  - Stored current: 0.1 mA (bunch charge: 0.5 nC)
  - Orbit oscillation amplitude: ~0.4 mm
- SP data from 7 BPMs were taken.
- The beam position of one BPM was compared with the prediction from the the other 6 BPMs.
- Horizontal position resolution: **~17 μm**
  - For an electron bunch with 0.5nC.
  - It corresponds to 85 μm for a 0.1 nC bunch.
- SP BPM resolution satisfies the requirement for SPring-8-II.
  - Since the size of the SPring-8-II vacuum chamber will be smaller than that of the current SPring-8 storage ring, the SP BPM resolution is expected to be better than this measurement.



Injection Orbit Bump Adjustment by SP BPM

- A pulsed orbit bump is generated by four dipole kickers for beam injection at SPring-8.
  - The four kicker magnets need to be matched to avoid the disturbance on the stored beam by closing the orbit bump.
  - Tuning of the kicker magnets is necessary at the beginning of each operation cycle [8].
- Injection orbit bump adjustment.
  - SP BPM data are taken by shifting the kicker pulse timing every 50 RF buckets (98ns).
  - Orbit oscillation amplitude outside the orbit bump due to the unmatched kickers for each bunch address is evaluated.
  - Amplitude and timing of each dipole kicker power supply are adjusted to minimize the error kick.
- Matching of the kickers used to be adjusted by using the old SP BPM system
- The same adjustment procedure should work well with the new MTCA.4 SP BPM.
- We checked the performance of the residual kick measurement of the dipole kickers.
- The obtained orbit oscillation amplitude was consistent with that of the old SP BPM.
  - The difference between the old and new SP BPM was sufficiently small (less than 0.1 mm).
- Consequently, the new MTCA.4 SP BPM system is ready for the tuning of the current SPring-8 storage ring.



Summary

- We developed a MTCA.4-based versatile BPM readout electronics for SPring-8-II.
- A half of the old SP BPM electronics were already replaced with new ones, and the remaining half are now being upgraded in this summer maintenance period.
- The trajectory of an injected electron beam was appropriately observed.
- The SP BPM resolution was obtained to be 17 μm for a 0.5 nC single-bunch.
  - Sufficient for SPring-8-II.
- The residual kick of the dipole kickers for injection orbit bump were compared between the old and new electronics, and confirmed to be consistent each other.
- Thus, the MTCA.4-based BPM electronics is ready for SPring-8-II.