Development Status of the BPM System for the SPring-8-II Storage Ring

TUP16

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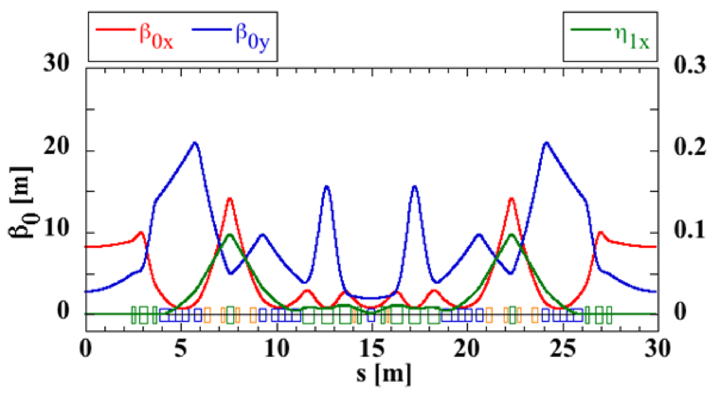
Introduction

SPring-8-II [1–3]

- Beam energy: 8 GeV → **6 GeV**
- Lattice: **5-bend Achromat**
- Natural emittance: 2.4 nm rad → **< 100 pm rad**
- Brilliance at 10 keV will be 100 times higher.



Requirements for BPM System

- Stability: **< 5 µm** (for 1 month)
- COD resolution: **< 1 µm std**
- Single-Pass resolution: **< 100 µm std** (0.1 nC)
- Electorical center error: **< 200 µm**
- COD data rates: 3 types in parallel Turn-by-Turn (209 kHz), 10 kHz, and 10 Hz

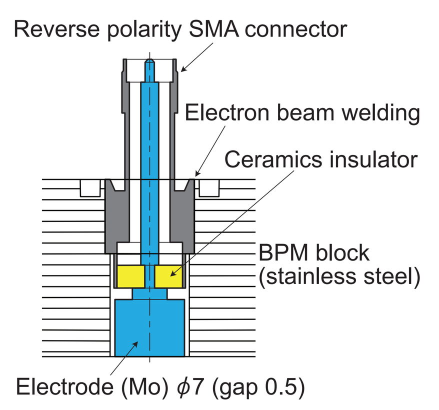
BPM Development Status

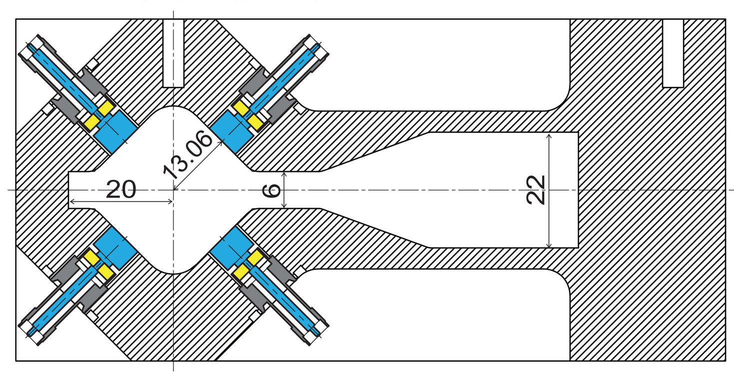
- Employed by NanoTerasu [4-8].
- A part of the readout electronics in SPring-8 was upgraded to the new MicroTCA.4-based one [9].
  - Adaptive feedforward correction of fast helicity-switching beamlines [10].
  - Renewal of the single-pass BPM [11].

BPM System

BPM Head

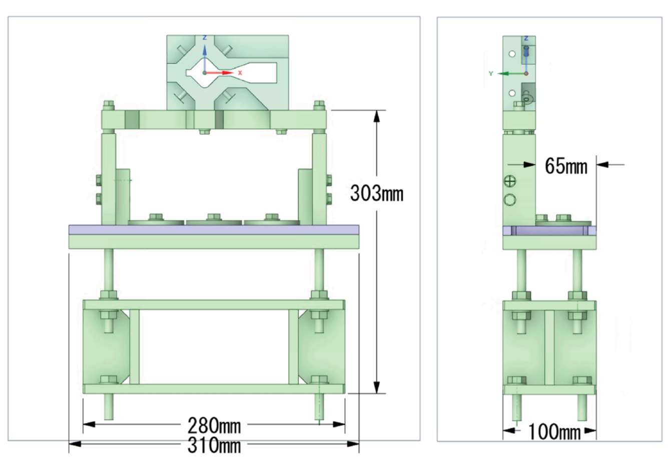
- The cross-sectional shape of the beam pipe was changed from squeezed octagonal [1, 12, 13] to rhombus-like [3, 15] .
  - NanoTerasu is squeezed octagonal [4, 14].
- The button electrode is the same as before [16].
- Electrode material: **Molybdenum**
  - Since molybdenum is better electrical conductivity than stainless steel, trapped-mode heating etc. are dissipated on the stainless steel side.
- A water cooling channel is equipped either upstream or downstream of the electrodes.
- Connector: Reverse-polarity SMA receptacle
  - Any spring materials are attached to the cable side.





BPM Support

- Three BPMs 3, 5, 6 in the 5-bend cell are supported by an X-ray absorber chamber.
- The support for BPMs 1, 2, 4, 7 were designed.
- The position and angle of the BPM can be adjusted.
- Enough strength to be a fixed point.
  - Assuming the stress of 100 N (horizontal) and 350 N (vertical), the displacement was estimated to be less than 30 µm.

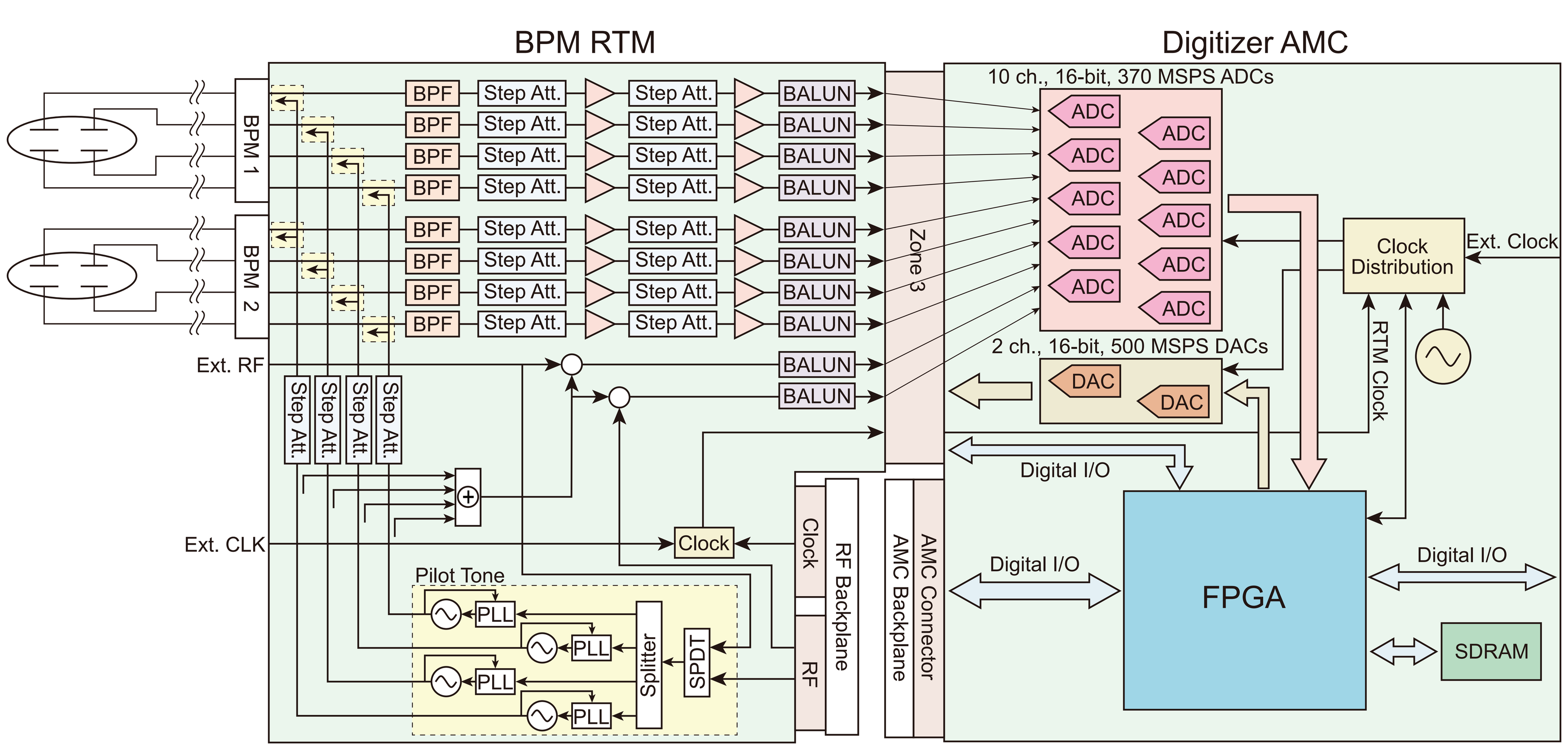


Signal Cables

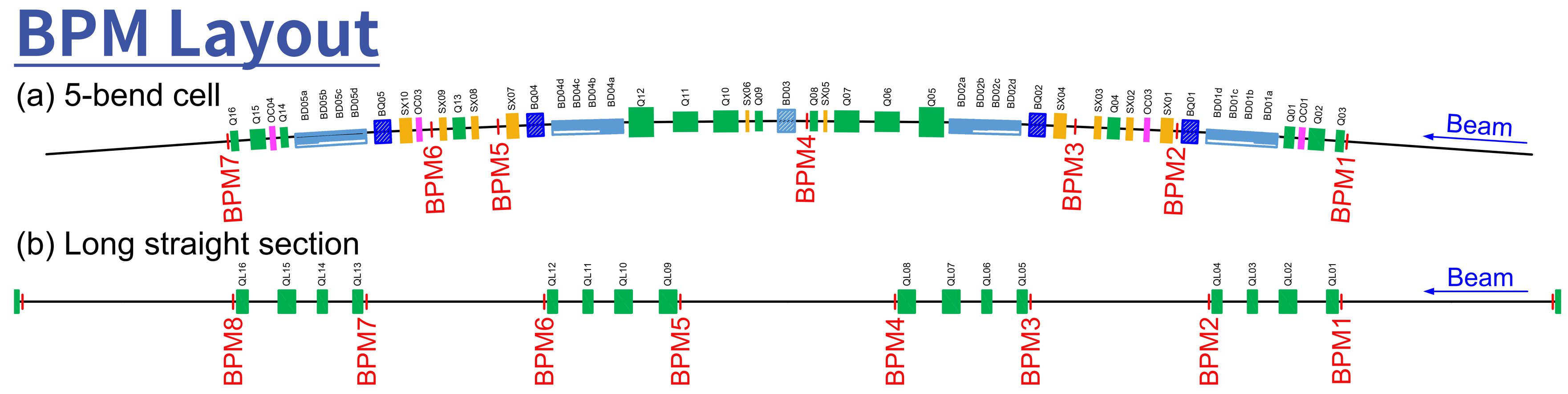
- Three types (A, B, C) of coaxial cables are used.
  - The same as NanoTerasu [5].
- A-cable: **PEEK-insulated semirigid cable**
  - Radiation-damaged cables in SPring-8 became sensitive to humidity and BPM drift occurred [17].
  - Some candidate cables were tested at a radiation environment in SPring-8 [18].
  - PEEK-inslated coaxial semirigid cablses were highly radiation-resistive and has a reasonable price.
- B-cable: **10D corrugated coaxial cable** (polyethylene)
  - Since the radiation dose is not so high around the side of the girder, we selected a corrugated coaxial cable having relatively high radiation-resistance and low-loss characteristics.
- C-cable: **Standard flexible coaxial cable**
  - To relay from corrugated coaxial cables to readout electronics in a 19-inch cabinet.

Readout Electronics

- MicroTCA.4-based electronics were developed [9].
  - An RF frontend RTM and a high-speed digitizer AMC.
  - 16 BPMs (2 cells) can be processed in one unit.
- RF detection: Under-sampling scheme
  - The ADC sampling rate is 363.40 MHz, which is 5/7 of the acceleration RF frequency of 508.76 MHz.
  - The acquired data are digitally down-converted to IQ-baseband data in the FPGA on the digitizer.
- The four types of data stream, Single-pass (208.85 kHz), Turn-by-Turn (208.85 kHz), Fast data (10 kHz), and Slow data (10 Hz) can be generated in parallel.
- The temperature is stabilized by a water-cooled 19-inch cabinet within ± 0.1 °C.
- Pilot tone signals can be injected to signal inputs to monitor gain drifts.



BPM Layout



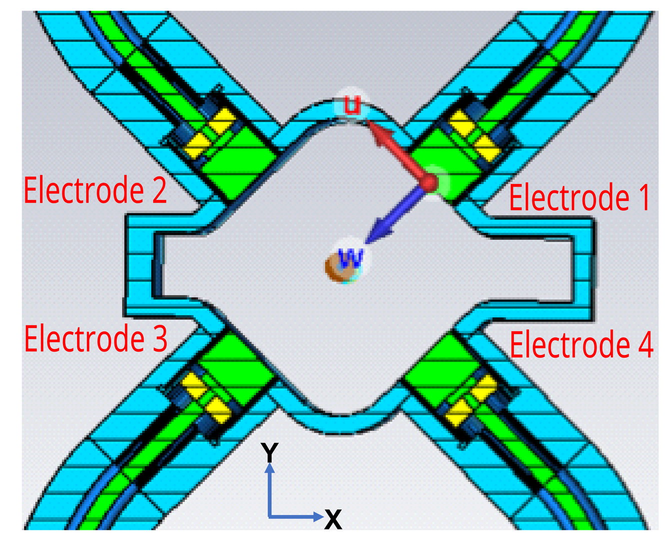
- 5-bend Cell: 7 BPMs/cell x 44, Long Straight Cell: 8 BPMs/cell x 4 → **340 BPMs** in total

Performance Evaluation

3D RF Simulation

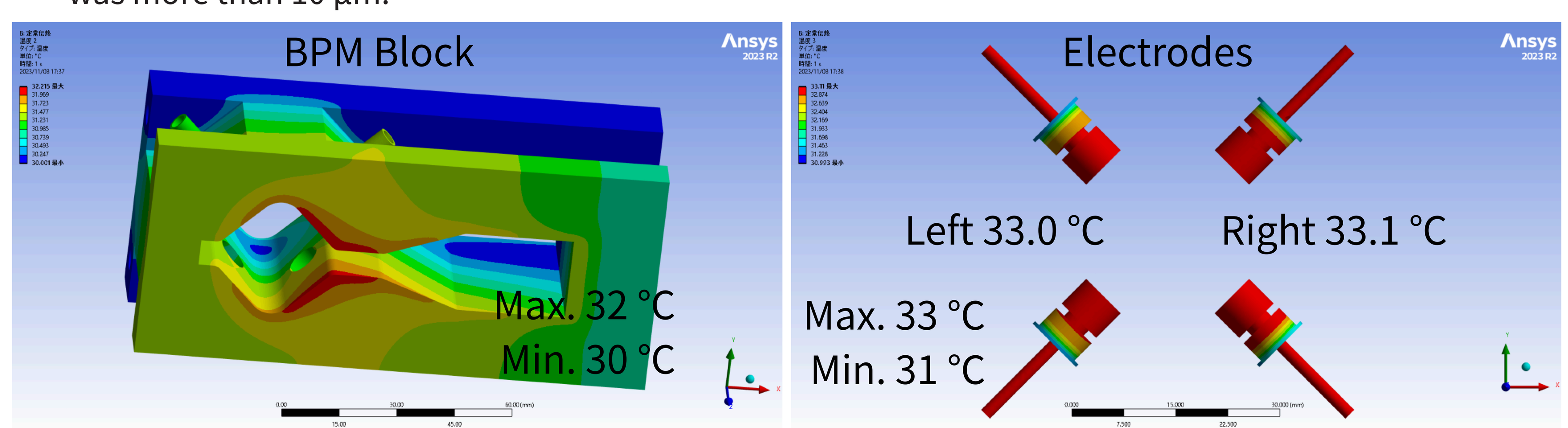
- Position sensitivity: **X: 10.15 mm, Y: 10.24 mm**
  - Definition: The first order coefficient to Δ/Σ.
  - About 30 % lower sensivity than before [16].
  - However, the required resolution can be satisfied.
  - Sensitivity to the machining error is relaxed by the same ratio.
- Heat input from the beam: **1.7 W/BPM**
  - Bunch fill pattern: 406 x 0.5 mA (200 mA)
  - Relatively higher heat input among the possible fill patterns.
  - Bunch length: 14 ps std.
- Contribution to the beam impedance is about 2 % for both transverse and longitudinal directions.
  - No additional treatment to reduce the impedance is needed for the BPM head.

CST Studio



Thermal Structure Analysis [19]

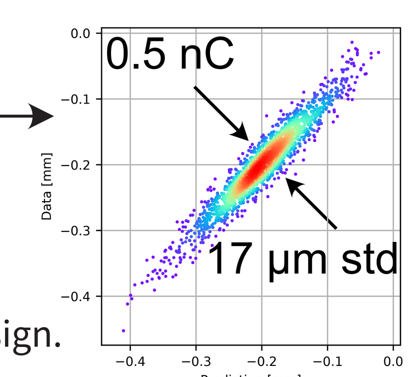
- Cooling water: 30 °C, 4 L/min (either upstream or downstream of the electrodes)
- Heat releases to the air of 27 °C and water-cooled beam pipes are also included.
- Maximum temperature: **33 °C**
- Maximum displacement: **4 µm**
  - If the BPM is not water-cooled, the maximum temperature was 44 °C and the maximum displacement was more than 10 µm.



- Although this BPM head was not tested with an actual electron beam, this analysis was reliable according to the results from another prototype installed into the present SPring-8 storage ring [18].

Position Resolution

- Single-Pass Resolution: **85 µm std.** (0.1 nC) [11]
  - MicroTCA.4-based electronics with the BPM head of the present SPring-8 ring.
  - The SPring-8-II BPM has better resolution since the sensitivity is higher.
- COD Resolution: **0.4 µm std.** (30 mA, 10 kHz fast data) [9].
  - MicroTCA.4-based electronics with the prototype BPM head of the previous design.
  - COD resolution is better than 1 µm for a wide range of stored current.



Long-term Stability

- The BPM stability was within 5 µm for several weeks [9].
  - Top-up operation with a constant bunch fill pattern.
  - The temperature of the electronics was stabilized within ±0.1 °C.
  - Even if the bunch fill pattern was changed, the stability was within 10 µm for 2 months.
- The stability of the water-cooled 19-inch cabinet was evaluated to be within ±0.1 °C.

Electrical Center Error

- The prototype in SPring-8 has 4 BPM in one block and the difference of the BPM readings was within **100 µm**.
- The beam-based alignment result from NanoTerasu showed that the displacement between the BPM electrical center and the quadrupole magnetic center was less than **150 µm std.** [7, 8].
- If BPMs are carefully fabricated, installed, and tested, the required electrical center accuracy for First Turn Steering is expected to be satisfied.

Summary and Prospects

- We have developed a button-type BPM system for SPring-8-II.
- Almost the same BPM system was installed into NanoTerasu and working well.
- Since the cross-sectional shape of the beam pipe was changed, the BPM head was redesigned and the performance was evaluated by simulation etc.
  - The requirements for SPring-8-II is expected to be satisfied.
- Radiation-resistant cables and MicroTCA.4-based electronics are not changed.
- Beam test results in SPring-8 and NanoTerasu were sufficient for SPring-8-II.
- The present SPring-8 storage ring will be shut down and dismantled in 2027 and the SPring-8-II components will then be installed.
- The commissioning of SPring-8-II is scheduled in late 2028.

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