TURN-BY-TURN BPM SYSTEM USING COAXIAL SWITCHES AND ARM MICROCONTROLLER AT UVSOR

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Abstract

A major upgrade of the electron storage ring at UVSOR facility (Institute for Molecular Science, Japan) started from April 2012. To assist the commissioning procedure, we have developed a turn-by-turn Beam Position Monitor (BPM) system which consists of a signal switching circuit, a digital oscilloscope and software. Using this system, we have been able to determine not only the orbit but also the betatron tune. The system was very powerful to achieve the beam storage at the commissioning.

OUTLINE OF UVSOR

A 750 MeV synchrotron light source, UVSOR (Fig. 1), has been operational since 1983. In 2003, the ring had a major upgrade to reduce the emittance and increase the straight sections available for insertion devices. Since then, the ring has been called UVSOR-II. Since 2010, the storage ring had been operated for users fully in the top-up injection mode, in which the beam current is kept constant at 300 mA.

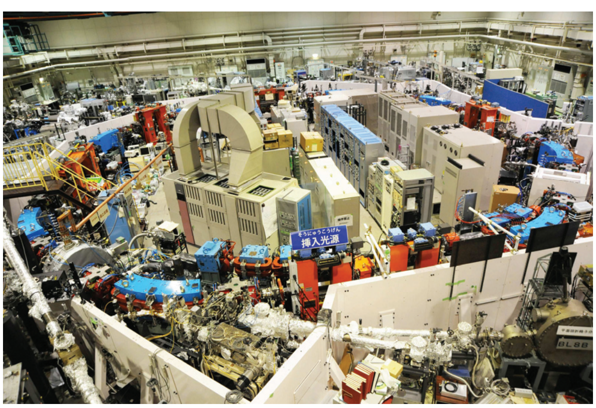

Figure 1: UVSOR-III electron storage ring.

In 2012, a new upgrade program is in progress. The bending magnets were replaced with combined-function ones to reduce the emittance by about a factor of two. A new in-vacuum undulator was installed in the last straight section reserved for insertion devices. A pulse sextupole magnet for injection without a bump orbit was constructed and is ready for commissioning. After this upgrade, the ring is called UVSOR-III. Parameters of UVSOR-III are shown in Table 1.

Table 1: Main Parameters of UVSOR-III

Electron Beam energy	750MeV
Circumference	53.2m
Straight Sections	4m x 4, 1.5m x 4
Emittance	17nm-rad
Energy Spread	5.4m x 10^{-4}
Betatron Tunes	(3.70, 3.20)
Momentum Compaction Factor	0.033
XY Coupling(presumed)	3%
RF Accelerating Voltage	100kV
RF Frequency	90.1MHz

BPM AT UVSOR

UVSOR-III storage ring has 24 BPMs (Fig. 2), each of which consists of 4 button electrodes (Fig. 3 and 4). We use a commercial signal processing system (Bergoz Co. [1]) for regular operation.

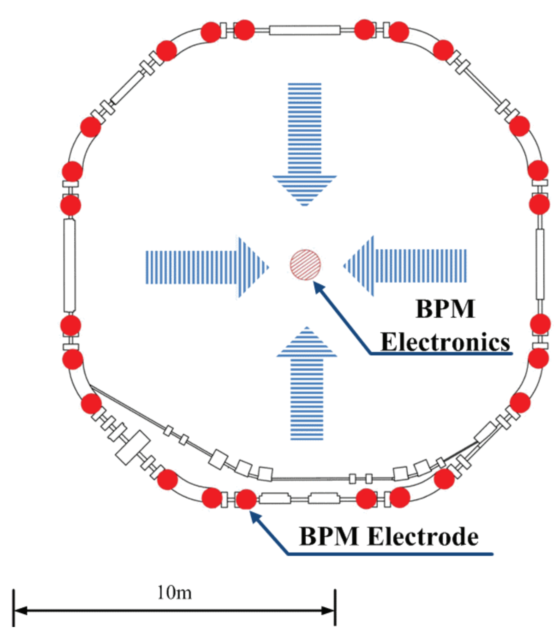

Figure 2: Layout of the BPM heads along the ring.

Position of the electron beam is calculated using the equations:

$$X = K_X \frac{V_A - V_B - V_C + V_D}{V_A + V_B + V_C + V_D} \qquad (1)$$

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$$Y = K_Y \frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D} \quad (2)$$

Here Kx,y is the sensitivity parameter, $V_{A,B,C,D}$ is the electric voltage induced by the electron beam at each electrode. The Kx, Ky, are listed in Table 2.

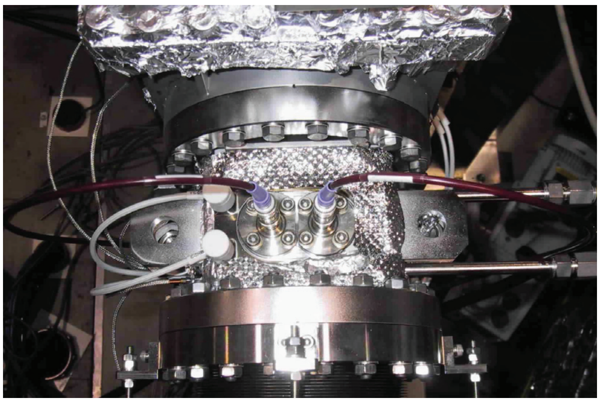

Figure 3: Electrodes of BPM.

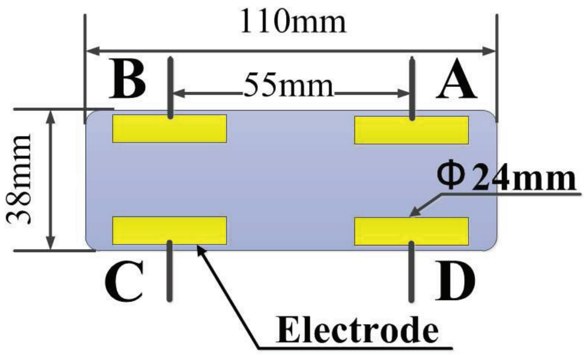

Figure 4: Layout of electrodes.

Table 2: Position Sensitivity (Kx, Ky) of Electrodes

	Bending section	Straight section
Kx (mm)	12.89	13.61
Ky (mm)	41.84	26.6

The characteristics of the cable (FHPX-5D (1/4"), Hitachi Cable) used between the electrode and the electronics are shown in Table 3, 4. This cable is manufactured with deep helical corrugations in the outer conductor for flexibility, and has a foam-polyethylene dielectric that offers good electrical performance. This coaxial cable is used in normal BPM system.

Table 3: Characteristics of Coaxial Cable [2]

Frequency	Attenuation (dB/100m)
100MHz	6.04
1000MHz	19.8

DESIGN AND CONSTRUCTION OF TURN-BY-TURN BPM SYSTEM

At the commissioning, especially before success of beam storage, we have to find out how many turns the beam has circulated, where the beam has lost. It is also important to measure the orbit parameters before the storage, such as closed orbit or betatron tunes. Most of these can be realized by a turn-by-turn BPM system. On the other hand, such a system is not necessary in the daily operation. Considering these, we have decided to construct a turn-by-turn BPM system as follows.

- We construct it as low-cost and simple as possible.
- We use an existing digital oscilloscope for waveform observation and recording.
- We use existing RF cables that are normally used for connecting the BPM heads and Bergoz signal processing system.
- We set the oscilloscope in the ring and we control it through LAN.
- We develop a signal switching box that can be controlled through LAN.

The block diagram of the system is shown in Fig. 5.

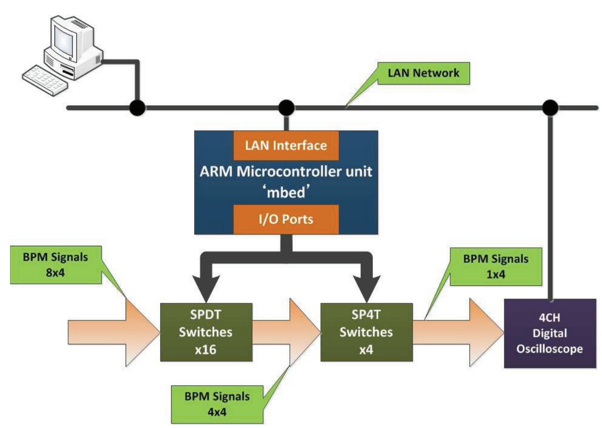

Figure 5: Block diagram of BPM system.

OVERVIEW OF SIGNAL SWITCHING BOX

The signal switch box is shown in Fig. 6 and 7. The total number of the BPM electrodes in UVSOR is 96, but, as the first step, we have constructed a system in which only signals from 8 BPM heads can be treated.

Since the BPM signal is a weak (tens of mV to sub-mV) high-speed pulse (hundred ps bunch length corresponds to several GHz in frequency region) by electron beam circulating about 90 MHz, we have used coaxial switches (CCR-33-506 and CCR-38, TELEDYNE COAX SWITCHES) to switch signals at low attenuation.

We had also considered using semiconductor switches. However, as shown in Table 5, since generally losses of coaxial switches were less and wider frequency bands than those of semiconductor switches, we decided to use coaxial switches.

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Figure 6: Signal switching box (front view).

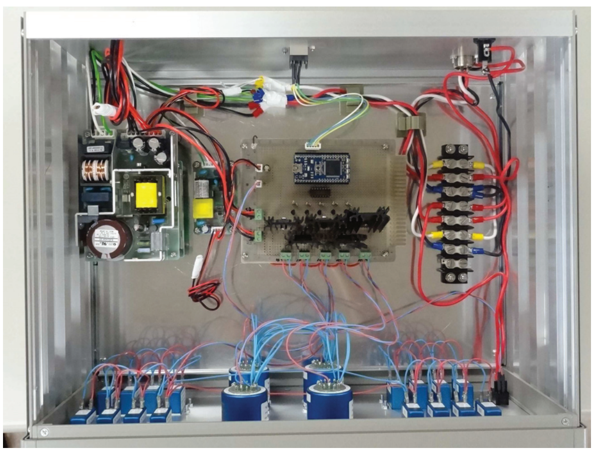

Figure 7: Signal switching box (inside).

Table 4: RF Parameters of Coaxial Switches [3] and Certain Semiconductor Switch

Products	Frequency	Insertion Loss (max)
CCR-33-506	DC-6GHz	0.2dB
CCR-38	DC-6GHz	0.2dB
Semiconductor	DC-2.5GHz	3.8dB

First, we select 4 X 4 = 16 from 8 X 4 = 32 BPM signals by SPDT (Single-Pole Double-Throw) type coaxial switch. Next, we select 1 X 4 = 4 by SP4T (Single-Pole 4-Throw) type coaxial switch. We record 4 signals from one BPM head by 4-channel digital oscilloscope (5GHz sampling frequency, 1GHz / 2GHz analog signal band) while selecting the BPM heads one by one. The data was analysed off-line.

REMOTE CONTROL OF SWITCHING BOX

We decided to control the coaxial switches by a microcontroller, which can be controlled remotely through LAN.

There are a variety of microcontroller products, with some differences in CPU, clock frequency, the number and type of peripherals, and the number of pins. This time, we have adopted 'mbed'.

The 'mbed' is the ARM microcontroller development kit by NXP semiconductors. ARM microcontroller is a generic term of a microcontroller core design information (IP: Intellectual Property) of the ARM company in UK. Semiconductor companies sign licensing agreements with ARM company, product and sell ARM microcontrollers by adding original peripherals [4]. The 'mbed' has a variety of functions shown in Table 5 with Cortex-M3 core, which is one of the 32 bit ARM microcontroller. We connect the 'mbed' to a PC with USB, transfer the program that we have developed.

We program the 'mbed' with C language. The Integrated Development Environment (IDE) of the 'mbed' is on the Web server and run on a Web browser. In this environment which is generally called to 'Cloud Computing', we can develop regardless of Operating System of PC if we have an internet connection [5].

Table 5: Key Features of the 'mbed' [6]

CPU	ARM Cortex-M3
Processing speed	100MHz, 120MIPS(max)
Memory	512kB Flash ROM, 64kB SRAM
Ethernet	10/100BASE-T
USB	USB2.0 OTG
A/D converter	12bit X 8
D/A converter	10bit

The 'mbed' can be connected to LAN by simply connecting to the LAN connector. The device control through LAN often requires expertise, such as TCP/IP, but the control application for the BPM system was constructed in HTML (and CSS) which implements JavaScript library that can handle multiple I/O ports. In other words, we can construct it like a general web page.

First, we store necessary files for the 'mbed'. When we access the 'mbed' from the web browser, the 'mbed' responds as HTTP server, a control application is displayed in web browser. By using the application, we can control the coaxial switches by controlling I/O ports of the 'mbed' via JavaScript library.

PERFORMANCES

An example of the observed BPM signal waveform is shown in Fig. 8. An example of injection beam trajectory is shown in Fig. 9. The data are simply processed by Eqs.

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(1) and (2), using the peak voltage obtained from the waveform as shown in Fig. 8, and no compensation for the non-linear responses is applied.

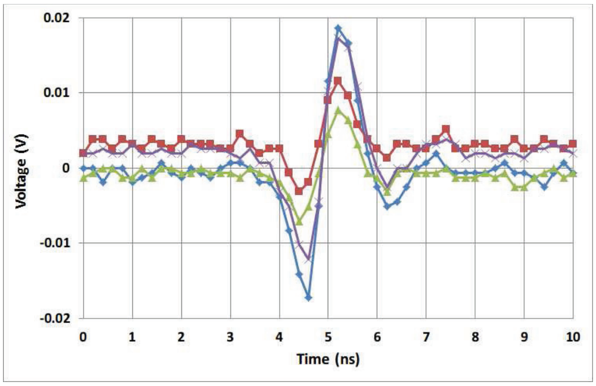

Figure 8: An example of BPM signal waveforms from a BPM head.

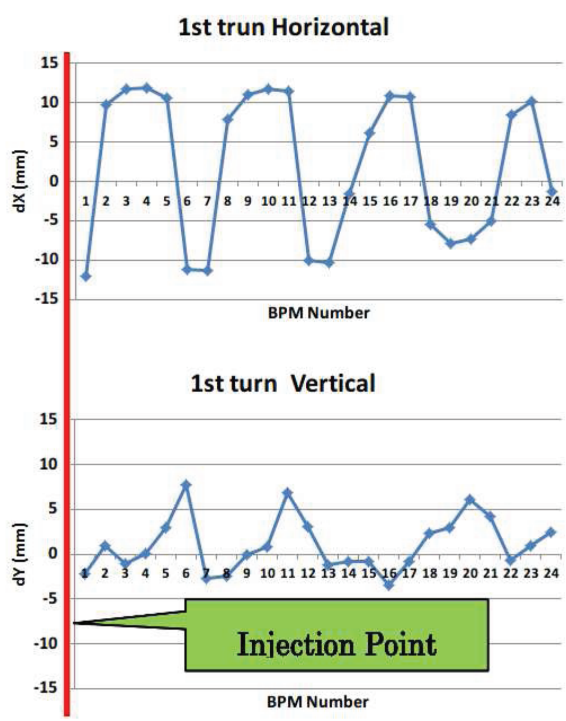

Figure 9: An example of measured injection beam trajectory.

The betatron tune could be also determined by observing multi-turn orbit. At present, ν_x is 3.7 and ν_y is 3.2 (Fig. 10). This was very useful during the commissioning.

An example of accuracy check is shown in Fig. 11 using a stored beam. The fluctuation is typically around sub-millimeter, whereas periodic fluctuation is clearly seen. The period is 5 turns, and this is simply due to the fact that beam revolution period is not integer multiple of the sampling period of oscilloscope. Divergence in the position data also should depend on the mismatch of the lengths of each cable for 4 electrodes.

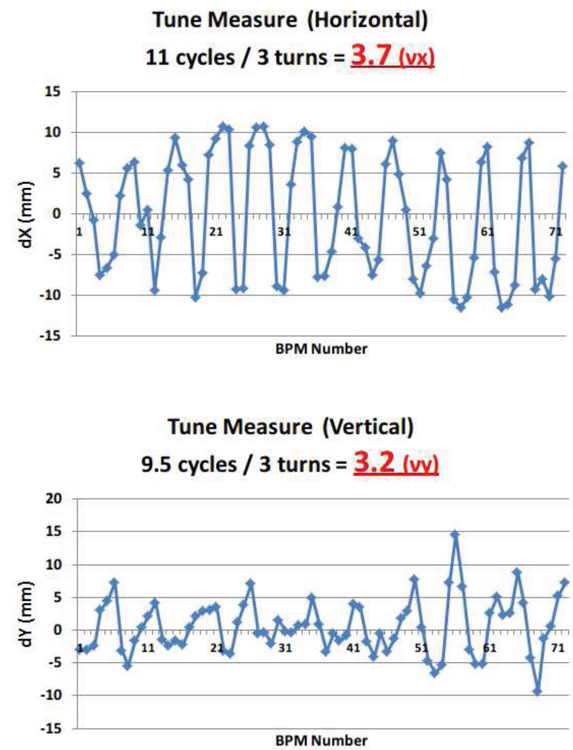

Figure 10: Measured beam position for first three turns after injection.

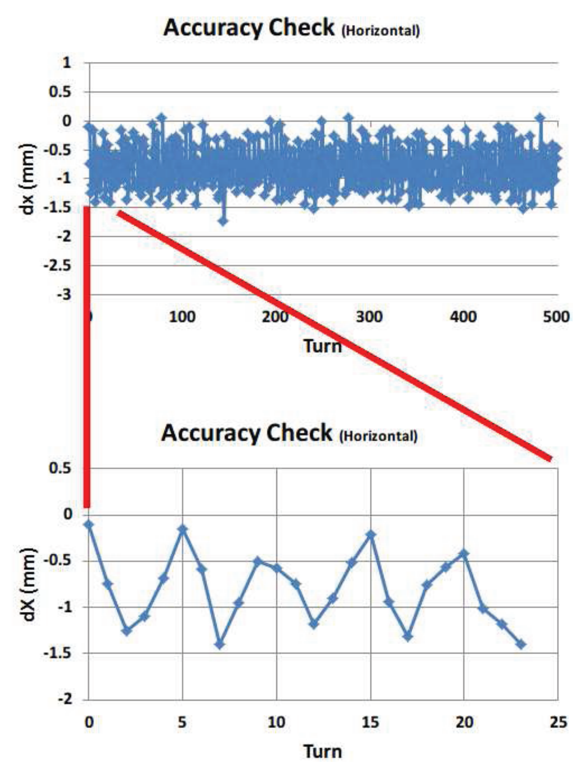

Figure 11: Turn-by-turn BPM data of the stored beam.

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CONCLUSION AND FUTURE PLAN

We have developed a turn-by-turn BPM system as switching the BPM signals through LAN with coaxial switches and the 'mbed'. It was demonstrated that the system was very powerful to achieve the beam storage at the commissioning.

We have some following future plans to improve the BPM system.

First: Improvement of accuracy by adopting advanced data processing to extract more exact peak of waveform and improve the accuracy of beam position.

Second: Expansion of the switching system to deal with 24 BPMs. Another switching system to switch signals to ordinary BPM or turn-by-turn BPM.

Third: Full automatic and fast data acquisition and fully automated data processing.

REFERENCES

[1] http://www.bergoz.com.

[2] "HITACHI HIGHLY FOAMED POLYETHYLENE DIELECTRIC HIGH FREQUENCY COAXIAL CABLE", p.5, 7, Hitachi Cable; http://www.hitachi-cable.co.jp/catalog/T302.pdf.

[3] CCR-33 Series and CCR-38 Datasheets, TELEDYNE COAX SWITCHES; http://www.teledynecoax.com.

[4] Shuu Nagahara, "Why 32bit?", Transistor Gijutsu Vol.48 No.558, p.73, CQ Publishing (2011) (in Japanese).

[5] Yoshikazu Okada, "Fundamentals and application productions of 'mbed' programming", "Thorough research of latest ARM / Cortex microcontrollers", p.5, CQ Publishing (in Japanese).

[6] "Appendix A High-performance microcontroller! specification of 'mbed'", "Introduction of ultra-handy microcontroller 'mbed'", p.116, CQ Publishing (in Japanese).

ISBN 978-3-95450-119-9