PHASE SPACE MONITOR SYSTEM AT THE PHOTON FACTORY STORAGE RING

Y. KOBAYASHI, T. MITSUHASHI, A. UEDA, AND T. KASUGA

Photon Factory, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba, Ibaraki 305, Japan

ABSTRACT

A beam-monitor system which can detect a transverse betatron oscillation of a single-bunch beam turn by turn, has been developed at the Photon Factory Storage Ring (PF-Ring). By measuring the beam positions at two differently-located beam-position-monitor electrodes, beam tracks were experimentally obtained on the transverse phase space. This system, along with the fast kicker magnets, allowed us precise and attractive studies on the nonlinear beam dynamics similar to the particle tracking simulations on computers.

1 INTRODUCTION

The observation techniques for the nonlinear beam dynamics experiment have been developed in several circular accelerators [1]. In both of proton and electron machines, a phase space monitor system which is a combination of turn-by-turn beam position monitors and a fast kicker magnet seems to be adopted as a standard tool.

The PF-Ring has been stably operated as a dedicated synchrotron light source for more than ten years. In this ring, many nonlinear magnets exist; twenty-two sextupoles for chromaticity corrections, eight octupoles to suppress the transverse instabilities, and so on. At present, an emittance upgrade program of this ring is in progress [2]. The beam emittance will be reduced one-fifth smaller than the present one by doubling the number of the quadrupoles and sextupoles in the normal cell sections. However, these magnets need to excite more strongly; especially the sextupoles will be ten times stronger to achieve minimum emittance. Therefore it is more important to understand the nonlinear effects on beam by these magnets. Under the circumstances we have designed and constructed a phase space monitor system for the nonlinear beam dynamics since four 1991. A set of horizontal and vertical fast kicker magnet have been installed four years ago [3]. Recently, a pair of turn-by-turn beam position circuits have added.

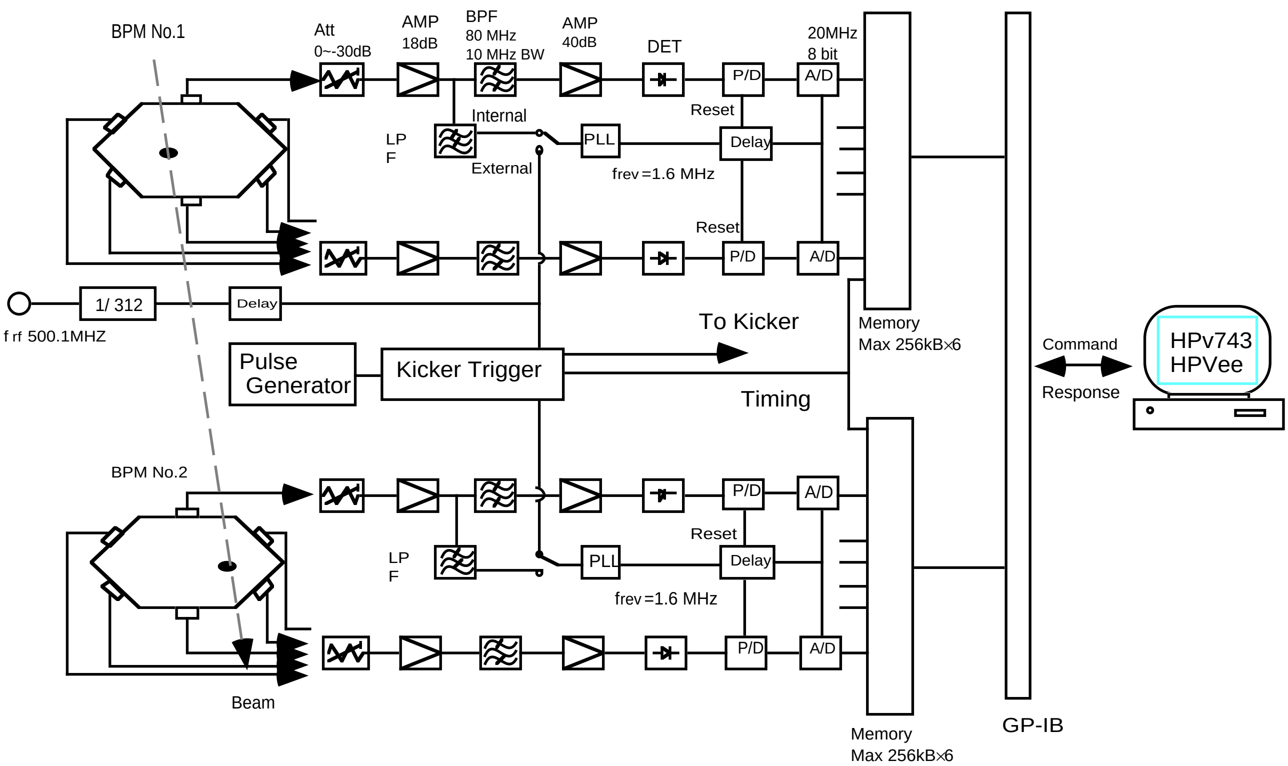

Figure: 1 A block diagram of the phase space monitor system

2 HARDWARE DESCRIPTION

2.1 Fast kicker magnets

The horizontal and the vertical kicker magnets were installed in the ring to deflect a stored single-bunch beam in transverse directions instantaneously. The magnets were designed as a window frame ferrite core type with a double turn coil. They were connected to the independent pulsing power supply (pulser) with a narrower pulse width than a revolution paired. A charging and discharging timing are controlled by external trigger circuits. The field strength of the magnets is proportional to the charging high voltage because the ferrite core is not saturated up to maximum voltage. Then the strength is enough to kick out the beam from the ring.

2.2 Position detection circuit

A block diagram of the system is shown in Fig.1. The system comprises two position detection circuits, which have six independent channels, and a timing circuit used to synchronize the detection with a trigger signal of the fast kicker. Each channel consists of a variable attenator, a bandpass filter, RF amplifiers, a peak detector with sample hold, a 8-bit flash ADC, and a 256-kbyte memory. Since an input signal width is less than 1 nsec, the pulse width is stretched through the bandpass filter to make a peak detection easier. Each gain of six channels is adjusted in ±2% with a variable attenator. The digitized signals by the ADCs are sent to the memories within the revolution period (624 nsec). After the data are filled in the memories, they are sent to an on-line computer (HP v743) through the GP-IB interface.

2.3 Selection of the Beam-Position-Monitor

As the BPM electrodes, we selected PM02 and PM03 at a long straight section of 5 m long [4] by considering the following requirements: 1) no nonlinear magnets exist between the BPMs; 2) phase advance of the betatron oscillation is hopefully more than 45 degrees for both horizontal (x) and vertical (y) directions, and 3) beta functions (β_X, β_Y) at the BPMs are desired to be suitably large (5 ~ 10 m) and the same. These bring us a good resolution and a small systematic error of the beam angle.

3 PERFORMANCE OF THE SYSTEM

3.1 Deduction of beam position and angle

Beam positions are deduced with the similar manner as the COD measurements, but non-linearity of the BPM are more precisely corrected by off-line, using the following equations,

$$X = \sum_{i=0}^{6} \sum_{j=0}^{6} kx\,(i,j) \cdot U^i \cdot V^j \ ,$$

$$Y = \sum_{i=0}^{6} \sum_{j=0}^{6} ky\,(i,j) \cdot U^i \cdot V^j \ . \qquad (1)$$

Here, U and V are the measured data, and kx and ky are the two dimensional polynomial coefficients, which are calculated using a mapping data of the BPM. On the other hand, the beam angle (x', y') are simply obtained from the two positions since there are no magnets between the BPM's.

3.2 Position resolution

The position resolution was investigated with a stored single-bunch beam of 5 mA. A horizontal beam position without any kick is shown in Fig.2(a), which was measured with PM02 during 16384 turns. As seen from its histogram of Fig.2(b), the standard deviation of the horizontal position was less than 0.1 mm, which corresponds to the resolution of the position monitor. On the other hand, the vertical resolution was slightly over 0.1 mm. These values were the same in the PM03. The resolutions are achieved at present when the stored beam current is more than 1.0 mA.

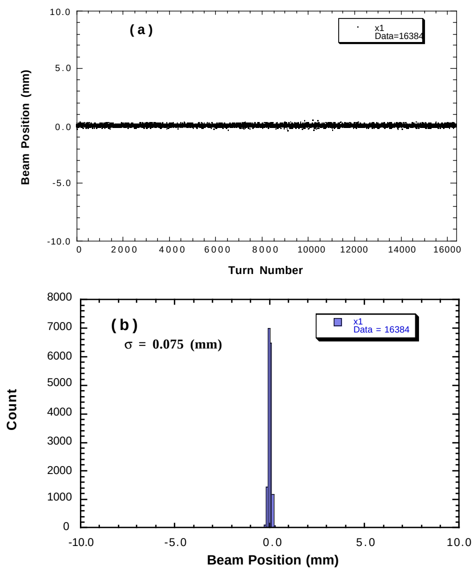

Figure 2: (a) A horizontal beam position in one BPM measured without any kick. (b) A histogram of the beam position.

3.3 Dynamic range and linearity

Figure 3 shows the investigations of the dynamic range and the linearity of the system. The horizontal axis is a charging high voltage supplied to the kicker magnet which is proportional to the kick angle. The vertical axis is an initial amplitude of the large betatron oscillation. The dynamic ranges were in 14 mm (horizontal direction) and 9 mm (vertical direction), respectively, which covers the physical aperture of the ring. Moreover, the linearity of the system was confirmed in 5% up to this limitation.

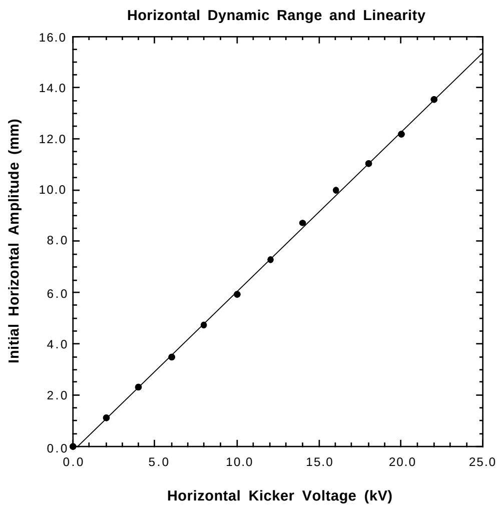

Figure 3: The estimations of the horizontal dynamic range and the linearity of the system

4 EXPERIMENT

With this system, interesting experiments on nonlinear beam dynamics are under way. As an example, Fig.4(a) displays a horizontal phase space plot measured near a 3rd order resonance (ν_x = 8.33). The phase space tracks denoted by points form a triangle due to 3rd-order resonance effect. As another example, a vertical phase space plot measured near 4th-order resonance (ν_y = 3.25) is shown in fig.4(b). This shows a phenomenon that the beam was trapped on the 4th-order resonance island.

5 SUMMARY

The phase space monitor system has begun to operate for the study on the nonlinear beam dynamics at PF-Ring. The position resolutions were less than 0.1 mm in the horizontal direction and slightly over 0.1 mm in the vertical direction. The dynamic range were in 14 mm, which was limited by a physical aperture.

6 ACKNOWLEDGMENTS

The authors wish to thank Prof. Kobayakawa, the director of the Light Source Division of the Photon Factory, and other staff for their supports. They also thank Prof. Kamiya of ISSP for his suggestion, and Mr. Matsushita of Asahi Engineering & Trade Co., Ltd. for the design and production of the position detection circuits.

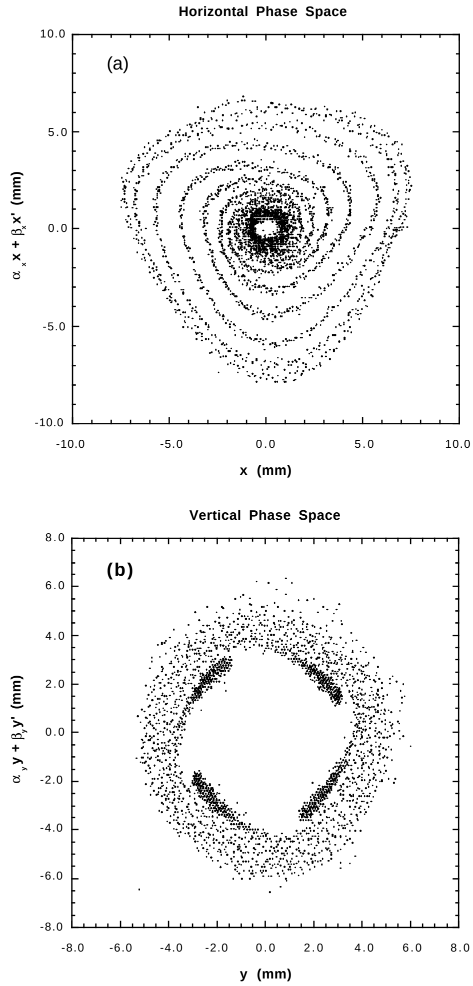

Figure 4: (a) The horizontal phase space plot measured near 3rd order resonance (ν_x = 8.33). (b) The vertical phase space plot measured near 4th order resonance (ν_y = 3.25) .

7 REFERENCES

[1] S. Kamada, “Experimental Techniques and Observations of Nonlinear Dynamics in Particle Accelerators”, AIP Conference Proceedings 344, p.1, 1994

[2] M. Katoh et al., “ Status of the Emittance Upgrade Program at the Photon Factory Storage Ring”, proceedings of the 10th Symposium on Accelerator Science and Technology, p.401, 1995

[3] Y. Kobayashi et al.,” Experimental Measurement of Dynamic Aperture at the Photon Factory Storage ring”, Proceedings of the 1993 Particle Accelerator Conference, p.215, 1993

[4] Photon Factory Activity Report #1, IV.2.5.2 Beam Monitors, P. IV-25, 1982/83