RENEWAL OF BPM ELECTRONICS OF SPRING-8 STORAGE RING

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Abstract

The signal processing electronics of the SPring-8 Storage Ring beam position monitors (BPM) were replaced during the summer shutdown period of the year 2006. Since then, the new electronics have been put into operation for user experiment runs. The purpose of the renewal was to upgrade the performance of the position measurement system, i.e. the position resolution, the speed of the measurement, etc. The position resolution of them in the real operation condition was estimated by using the stored beam, in the following way. The closed orbit distortions (COD) were repeatedly measured with the interval of four seconds in order to obtain the square mean (SM) and their square root, i.e. root mean square (RMS) of differences between two consecutive measurements. The obtained SM values included the intrinsic resolution of the position measurement system and the effect of the beam motion. The effect of the beam motion was separated from the obtained SM data in order to estimate the intrinsic resolution. For the separation, the influence of the beam motion was assumed to be proportional to the betatron function values at the BPM locations. As a result, the intrinsic resolution was estimated to be better than 0.1 μm.

INTRODUCTION

The signal processing electronics circuits for the beam position monitors (BPM) of the SPring-8 storage ring were renewed during the summer shutdown period of the year 2006. All 24 sets of the circuits covering the whole ring were replaced on this occasion. From September 2006, they were put into operation and included in the periodic orbit correction loop. The purpose of the replacement was to improve the performance of the beam position measurements: faster measurements, better position resolution.

The SPring-8 storage ring works as a third generation synchrotron radiation light source with the horizontal emittance of 3×10^{-9} m rad. To extract the highest performance as a light source with such a small emittance, the orbit stabilization is one of the most important issues to be achieved. The BPM are one of the key components to stabilize the beam. The BPM are necessary to monitor the stability of the beam orbit, even if they were not included in the feedback loop to stabilize the beam [1].

The electronics that were used until before the summer of 2006 achieved the resolution in the sub-micron range, however, the measurement speed was rather slow; over 20 seconds were necessary to obtain the COD data of the whole ring. A faster system with better position resolution had been desired.

The performance goal of the new electronics was set to sub-micron position resolution with 1-kHz bandwidth for the 100-mA stored current. The basic performance was confirmed by bench tests using the prototype circuits and the signal generator (SG) for the signal source [2].

For the next step, we evaluated the position resolution of the BPM system with the production version of the electronics using the actual beams. We report on the position resolution evaluated by using the beam in the actual operation condition of the storage ring.

ELECTRONICS CONFIGURATION

The electronics employed a multiplexing method to reduce the effect of characteristics difference of the circuits. The detection frequency was chosen as the same frequency of the radio frequency (RF) acceleration frequency of the storage ring: 508.58 MHz. The signals pass through the band pass filters that select the detection frequency after the selection by the multiplexer. They are fed into the RF amplifiers and mixed down to 250-kHz intermediate frequency (IF) signals.

The IF signals are sampled by 16-bit 2-MSPS ADC with the record length of 2048 for each electrode, which corresponds 1.024 ms duration of the sampling. Because of this time duration for sampling, the basic effective bandwidth is 1 kHz.

The sampled data are sent to DSP board made as a VME module in which the signal amplitudes are calculated from the sampled data. The calculated amplitudes are converted to the beam position data in the DSP and sent to the work stations in the central control system through the network.

One set of the electronics circuits has four signal passes and every pass covers three BPM. Since one BPM is composed of four electrodes, one signal pass switches 12 times to complete one measurement cycle.

Switching twelve times completes the measurement of the COD of the whole ring, because all the 24 sets of the circuits and all four passes in each set of electronics process the signals in parallel,

Typically, it takes 15 ms to complete one measurement cycle inside the DSP; 12 times 1-ms sampling plus some overhead.

Longer time is necessary to make measurements by the workstation in the control system, typically more than 1 s, because of the data transfer through the network, the access time to the database through database management system to store the data, and the processing time of the workstation including the disk I/O and GUI on the display.

EVALUATION OF THE POSITION RESOLUTION

The basic characteristics of the circuits were measured and evaluated by using the prototypes [2]. This time, as the first and the most important step, we performed the estimation of the position resolution with the actual operation condition of the storage ring.

Method of Estimating the Position Resolution

In actual condition we adopt the averaging the position data in the DSP by 100 times, which took 3-s measurement time composed of 1.5 s in the DSP averaging and the process overhead of about 1.5 s through the network and database access. This averaging makes the effective bandwidth 10 Hz.

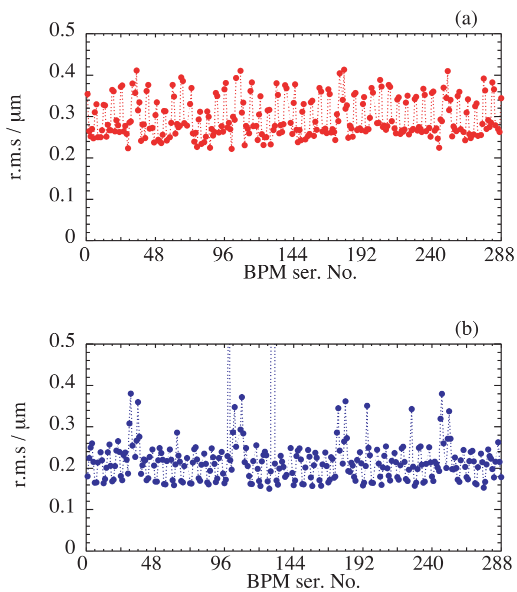

Figure 1: RMS values vs. BPM serial numbers. Lines just connect the points. (a):Horizontal, (b):Vertical direction. In the vertical direction, 2 points are out of the scale; they are 0.8 µm at serial No. 99 and 1.9 µm at serial No. 130.

To estimate the position resolution, the closed orbit distortion (COD) data were measured repeatedly every four seconds.

The differences between two successive measurements were calculated for every BPM, and the square mean(SM) values and their square root, i.e. root mean square (RMS) values of the differences were obtained to estimate the reproducibility of the measurements.

These obtained values included both the resolution of the measurement system and the effect of the beam motion during the two consecutive measurement interval.

In Fig. 1 the obtained RMS values are plotted against the BPM serial number. A distinctive pattern is observed in Fig. 1.

Since the storage ring has four-fold symmetry in its lattice structure, the data were parallel translated by multiples of quadrant of the ring and over plotted. The results are shown in Fig. 2. The points well coincide barring some exception points.

The pattern resembles the betatron function patterns; the square root of the betatron function values are also plotted in Fig. 2.

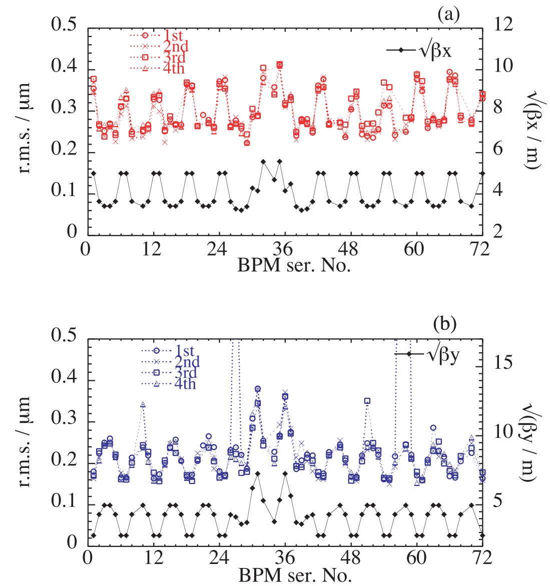

Figure 2: RMS values vs. BPM serial numbers for the left vertical axis. Square root of the betatron function values at the BPM locations are also plotted in black marks and lines for the right vertical axis. The points are translated by multiple of quadrant of the storage ring. (a): Horizontal, (b):Vertical direction. Open circle: first quadrant, cross: second quadrant, square: third quadrant, and triangle: fourth quadrant.

Separation of the Effect of Beam Motion

We considered that the effect of the beam motion in SM values was proportional to the betatron function values at BPM locations. Therefore, a following model can be postulated. In the model, the SM values are composed of the intrinsic resolution of the measurement system and the effect of the beam motion which is proportional to the betatron function; i.e.

$$SM_i = v_0 + A\beta_i \; , \qquad (1)$$

where SM_i is the SM value of the i-th BPM, β_i is the betatron function value at the i-th BPM location, v_0 is the variance of the measurement repeatability of the system, and A is the proportional constant.

We plotted SM as a function of betatron function values in Fig. 3. According to the model, a regression analysis was done with the fitting parameters of A and v_0 for the data in Fig. 3. For the fitting, the data those show exceptionally large SM values were excluded.

The obtained fitting parameters are shown in Table 1.

Taking the square root of the obtained parameter v_0, the intrinsic resolution was evaluated to be 0.13 µm for the horizontal and 0.10 µm for the vertical directions.

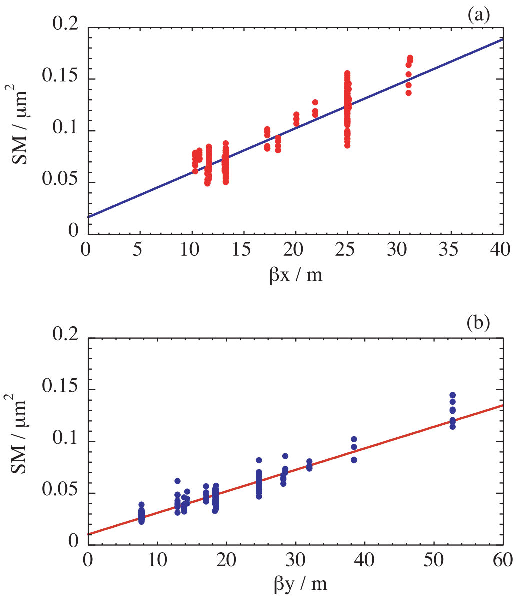

Figure 3: SM values vs. betatron function values at the corresponding BPM locations. The betatron function values are calculated ones with the lattice parameters of the optics for the operation condition. (a):Horizontal, (b):Vertical directions. The lines are the fitted ones with the equation (1). The parameters obtained by the fit are listed in Table 1.

Table 1: The Parameters Obtained by the Fit.

	$v_0\,(\mu m^2)$	$A(\mu m^2/m)$
horizontal	0.0166 ± 0.0023	0.00430 ± 0.00012
vertical	0.0101 ± 0.0008	0.00208 ± 0.00004

Discussion

The obtained resolution values are worse by three to seven times as the values obtained by the prototype and the SG, which were 0.02 µm for horizontal and 0.03 µm for vertical directions.

The reason for this discrepancy is unclear.

A possible explanation is that the influence of the beam motion was not fully eliminated from the data by this kind of procedure. The resolution values obtained with the actual operation condition of the storage ring beams show that the horizontal resolution is worse than the vertical one by 1.3 times. On the contrary, the data obtained with SG as a signal source show that the vertical resolution is worse than the horizontal one by about 1.5 times. This ratio of 1.5 corresponds to the ratio of the sensitivity coefficients which are determined by the geometrical configuration of the electrodes in the cross sectional shape of the vacuum chamber.

If the resolution is determined by the signal to noise ratio (S/N) of the circuits and the sensitivity coefficients, the ratio of the resolution obtained with the beam should be much closer to the ratio of the sensitivity.

This suggests that the obtained resolution values using the actual beams still include the effect of the beam motion, and the intrinsic resolution determined by the circuit performance itself would be much better than the values estimated by the procedure taken this time.

Further investigation, including the study of the influence of the multiplexing [3], etc., should be done for clarifying the reason of the discrepancy between the bench test data and the actual beam data.

SUMMARY

The electronics for SPring-8 storage ring BPM were renewed during the 2006 summer shutdown and put into operation.

The position resolution of the BPM system was estimated using actual beam, and found to be better than 0.1 µm with the effective bandwidth of 10 Hz.

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