BEAM POSITION MONITOR AND KICKER FOR THE SPRING-8 TRANSVERSE BUNCH-BY-BUNCH FEEDBACK

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Abstract

A high-resolution beam position monitor and a wideband kicker for the SPring-8 transverse bunch-by-bunch feedback system are developed. To avoid the increase of effective emittance by unwanted kicks by a feedback driven by noise, the monitor is designed to have high position resolution of the order of micro meters for single pass of 0.25nC bunch by adopting shorted stripline structure. Also a kicker for the feedback and the experience of those are described.

INTRODUCTION

A transverse bunch-by-bunch feedback is in operation to suppress the instabilities in the SPring-8 storage ring. The parameters of the ring are shown in a Table 1. The vertical emittance is small and the beam size at the feedback is 9μm(rms). The allowable amplitude (rms) of the motion driven by the feedback should be less than 10% of that and is ~1 μm.

Table 1. Parameters of the SPring-8 Storage Ring

Energy	E	8 GeV
Average Current	I	100 mA
RF Frequency	f_{RF}	508.58 MHz
Harmonics	h	2436
Bunch current at multi-bunch operation (2000 bunches)	I_b	0.24 nC
Revolution Period	T_0	4.8 μs
Emittance / Coupling	ε / κ	6.6 nm / 0.2 %
Beta function †	β_H / β_V	25 m / 6 m
Beam size †	σ_H / σ_V	400 μm/ 9 μm
Beam Pipe Radius (elliptic shape)	r_H / r_V	45 mm / 20 mm
Transverse Radiation Damping Time	τ_β	8.3 ms
Feedback Damping Time	τ_{FB}	~ 1ms

† : Values at BPMs and kickers for feedback

REQUIREMENT FOR BPM

Effective Emittance Degradation by Noise

The analysis of the effect of the random error/noise in measured beam position signal on the beam quality is performed. This shows that the random error drives a feedback and kicks a beam and increases the effective emittance with the relation as

$$\sigma_x = \sqrt{\varepsilon\beta} = \frac{\sqrt{T_0\tau}}{\tau_{FB}}\sigma \qquad (1)$$

where, T_0 is a revolution period and τ and τ_{FB} are a total damping time with feedback and other effects and a damping time only with feedback, and σ is the rms position resolution of a BPM. This relation shows that the increase of the effective emittance is larger for larger ring and faster feedback damping. And the bunch charge of the ring at multi-bunch operation is smaller than the other rings and the vertical size of beam pipe also larger, the requirement on the resolution of BPM is more severe.

Position Resolution

The relation in Eq.1 is $\sigma_x = 0.07\ \sigma$ for the SPring-8 feedback of which damping time is 1ms. The vertical beam size (rms) is 9μm, hence, the requirement for the vertical position resolution of the BPM is 13 μm for one pass of 0.24 nC bunch if the allowable degradation of the beam size is less than 10%.

From the result of the button type BPMs for C.O.D. measurement[2], shows that the resolution of the button type BPM is one order smaller than requirement.

Carrier Frequency

For the ease of the handling, the RF acceleration frequency, 508.58MHz, is chosen as the carrier frequency. A 933MHz Bessel type low pass filter is inserted to the signal from the monitor to reject unnecessary higher frequency signals.

POSITION MONITOR

To fulfill the requirement, we developed a new monitor for the feedback. The design of the monitor is performed with MAFIA.

Shape

A shorted stripline type monitor is adopted to obtain higher voltage signal to fulfill the requirements described in previous section. The shape of the BPM is shown in Fig. 1, 2 and 3.

Its advantages over button type BPMs are

(1) compact : It is difficult to make large button type BPM because of its complicated structure.

(2) easy to fit to elliptical shape of the beam pipe of the ring.

Disadvantage over stripline type is that its impedance seen from ports is zero by shorted structure, while the impedance of stripline is matched to cables. This makes a unwanted signal to feedback.

Independent in Horizontal and Vertical

To make RF signal processing stage simple, a pair of stripline electrodes are placed horizontally and vertically to detect the position of those direction independently. This is realized by the advantages of shorted stripline structure.

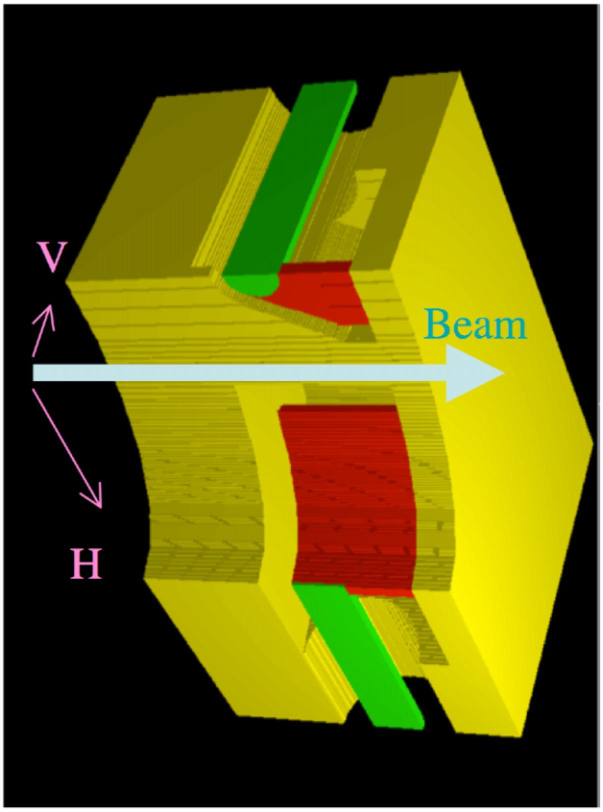

Figure 1: The structure of the position monitor. One quarter is shown and arrows show a beam axis and vertical and horizontal directions.

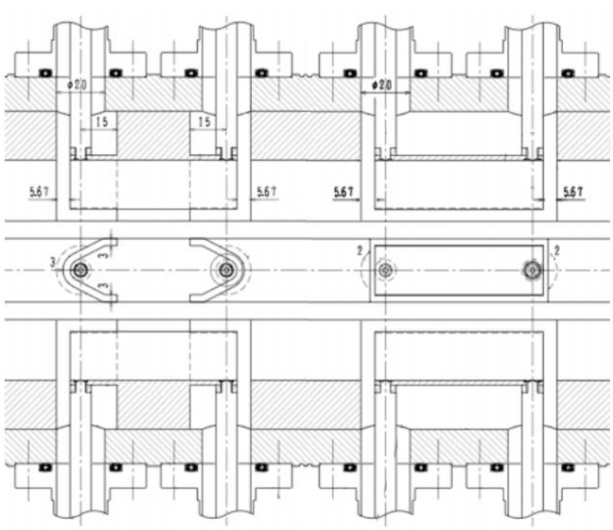

Figure 2: View of upper part of the chamber from the beam (top-bottom: horizontal, depth : vertical, left-right : beam axis). Left two sets of shorted striplines are the BPMs and right striplines are 7cm kickers. The beam pipe is a ellipse of diameter 90mm(H) × 40mm(V)

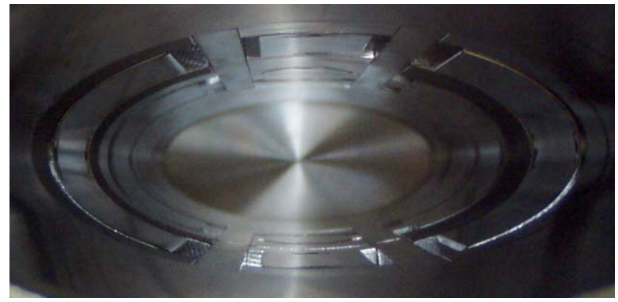

Figure 3: View from a beam port. 7cm striplines for kickers(near side) and shorted stripline type monitors (far side) are seen.

Signal Level

A gap of monitors scrapes a field of a beam and produces a signal of voltage s(t). At a stripline, a half of the scraped field propagates to an output port and the other half along with stripline. The field along with stripline is reflected by shorted wall and reverses the sign of its voltage, then propagates back to gap and then to the output port. A button type structure scrapes the field at upstream part and downstream part of a round shape gap. Both case, the produced signal is s(t)–s(t+d/c) where d is the scale of the twice of radius of button or the twice of the length of shorted stripline. The strength of the signal produced by the scraped field is proportional to the longitudinal width of gap(g) and transverse width of gap(w). At frequency of which wavelength is much longer than d/c, the voltage level of the signal s(t)–s(t+d/c) is proportional to d. Table 2 is the comparison of the dimensions and the signal level with the button type monitor. Table 2 shows the dimension of the monitors and measured signal level.

Table 2. Comparison with Button Type

	Shorted stripline	Button
Longitudinal gap width (g)	3 mm	0.5 mm
Transverse gap width or Diameter (w)	20 mm	10 mm
Length or Radius (d)	20 mm	5 mm
Horizontal offset from the beam axis	0 mm	14 mm
Horizontal monitor signal level † (normalized to button)	18	1
Vertical monitor signal level † (normalized to button)	8	1

† : after 933MHz Bessel type low pass filter

Resonances

Low Q resonance at ~1.5GHz can be seen in the monitors. However, the damping time of the horizontal monitor is 1ns and is faster than the bunch spacing, 2ns, and the build up of the signal is negligible. In vertical, the taper structure is attached at the end of the stripline as seen in Fig. 1 and 2 and this enhances the damping and the damping time is two times faster than that of horizontal.

Sensitivity

The sensitivity of the monitor is obtained from the calculation with MAFIA and is

$$x/\mathrm{mm} = \frac{1}{0.08}\frac{V_1 - V_2}{V_1 + V_2} \quad \left(= \frac{1}{0.07}\frac{(V_1+V_4)-(V_2+V_3)}{V_1+V_2+V_3+V_4} \right)$$

$$y/\mathrm{mm} = \frac{1}{0.07}\frac{V_3 - V_4}{V_3 + V_4} \quad \left(= \frac{1}{0.05}\frac{(V_1+V_2)-(V_3+V_4)}{V_1+V_2+V_3+V_4} \right)$$

where $V_{1,2,3,4}$ are the voltage from a pair striplines or a set of button monitors. Those values are almost the same as the button type BPM for C.O.D. shown in bracket[2].

Reduction of Reflection

A signal produced at the stripline of the monitor is lead to the feedback system with cables using connectors. Mismatches at connectors reflect a signal at some amount and send back to the monitor. The impedance of the shorted stripline type monitor is intrinsically zero and the monitor reflects back signals with 100% reflectivity to the feedback system. At the feedback, signals from pair of the striplines are subtracted each other to produce the difference signals of them (Fig. 4) and the voltage of this signal is proportional to the beam position. The reflected signals that come to the feedback have some delay and some amplitude usually uncontrollable amount and the subtraction is not performed and produces comparable or larger signals that has no position information. This causes the offset in the position signal and its reduction is necessary. To reduce this, two 6dB attenuators are used. One is placed at the monitor and one is placed before the feedback as shown in Fig. 4.

Position Resolution

At the input to ADC of the feedback system, which is placed after RF amplifier, down converter and base band amplifier, the position resolution is 5µm and is fulfill the requirements, 9 µm. No observation of the degradation of the emittance caused by the feedback is reported by users of synchrotron light.

KICKER

New 7cm stripline type horizontal and vertical kickers are also installed in the same chamber as BPMs. The same cross sectional shape as the monitor is used as shown in Fig. 2. The feedback also uses three 45cm long stripline kickers that are also used to shake a beam for tune measurement and its transit time factor at 250MHz is 0.3. The feedback have to suppress an instability driven by higher order mode of acceleration cavities at ~200 MHz. If long stripline is used, the unnecessary gain at low frequency arises and may produces increase of the effective emittance. To avoid this, the shorter stripline kicker is also installed.

The length of the kicker is 7cm and the transit time factor has flat frequency response to $f_{RF}/2$.

COUPLING CANCELER

To save the length, the monitors and the 7cm kicker are placed side-by-side in a single vacuum vessel (Fig. 2). This produces the coupling between the vertical monitors and vertical kicker through the beam pipe. This coupling is less than -90dB between the kicker and the monitor at far side. The monitor signal is down converted to be base band signal at front-end RF circuits of the feedback, and this eliminates the coupling in principle. However the gain of the feedback is so high and the even stray coupling in the feedback system drives positive feedback loop.

To reduce this coupling to suppress this positive feedback, a circuit to suppress the coupling is attached as shown in Fig. 4. The coupling between the kicker and the monitor at near side is higher than the monitor at far side and the subtraction of signal of the near side monitor with proper attenuation from the signal from the far side monitor to cancel the signal by coupling. The feedback gain can be rise +20dB with the coupling canceller.

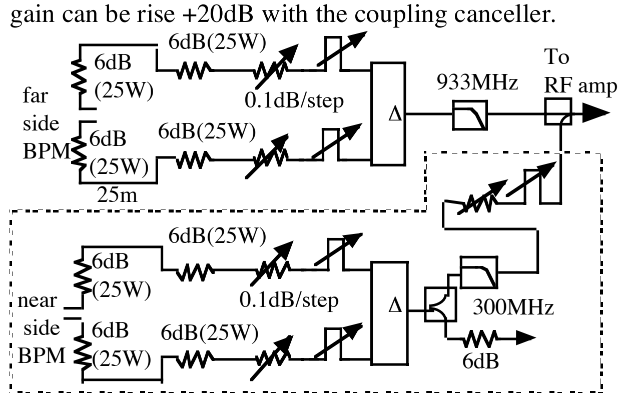

Figure 4: Front-end circuits for BPM with coupling canceller(inside of dotted line). The output of the circuits is send to an RF amplifier.

SUMMARY

The beam position monitor of micro meter resolution for a single passage of 0.24 nC bunch is developed to suppress the increase of the effective emittance driven by noise to the feedback. Also stripline kickers and the coupling canceller are developed. No increase of the emittance of the beam is reported by users of synchrotron light.

ACKNOWLEGEMENT

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REFERENCES

[1] T. Nakamura, S. Date, K. Kobayashi, T. Ohshima, "Transverse Bunch-by-bunch Feedback System for the SPring-8 Storage Ring", EPAC'04, Lucerne, June 2005, p. 2649.

[2] by S. Sasaki (SPring-8)