Beam Position Monitor of the Synchrotron at Hyogo Hadron Therapy Center

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Abstract

Beam position monitors of the synchrotron are required to get accuracy of $\pm 1mm$, at Hyogo hadron therapy center. And we achieved it within $\pm 40mm$ in horizontal monitors and accuracy of $\pm 0.1mm$ around the center in vertical ones on the RF frequency between 0.95MHz and 6.75MHz. Auto-gain-control technique is applied to the head amplifier. So, operators do not need to be care of setting gain of the electric circuit.

1 Introduction

Super periodicity is six at the synchrotron of Hyogo hadron therapy center [1] [2]. It is effective for COD correction that four pairs of a beam position monitor and a steering magnet (two for horizontal, other for vertical) are set in each super period. Horizontal beam position monitors are installed at the position of horizontal steering magnets near focusing quadrupole magnets. Vertical beam position monitors are installed at the position of vertical steering magnets near defocusing quadrupole magnets. Accuracy of beam position monitors is required to be within $\pm 1mm$ at beam extraction. S/N ratio must be over 40dB at 10^7ppp(C^{6+}) of beam intensity.

2 Pick-up electrode

The horizontal beam position monitor consists of four copper plates which are diagonally cut (two plate for right signal and other for left signal). There is no plates on the side of pick-up plates of horizontal beam position monitors, because of reduction of noise due to beam hitting [3]. On the other hand, side pick-up plates are mounted on vertical beam position monitors, for obtaining high output voltage as same as that of horizontal ones. Difference of capacitance between two pick-up plates of a monitor is trimmed within $\pm 2pF$ by changing gaps between pick-up plates and a vacuum chamber. This trimming is useful to obtain good accuracy of beam position measurement. The size of pick-up electrodes for horizontal beam position monitors is 214mm wide,

28mm high and 235mm long. That for vertical beam monitors is 106mm wide, 52mm high and 235mm long. Output voltage is estimated with next equation,

$$V_{p-p} = \frac{0.5eNl_e}{BCl_c}$$

where, e is electric charge, N is number of particles $\times$ charge number, l_e is length of electrode, B is bunching factor, and C is capacitance of electrode. Table 1 shows output voltage of pick-up electrodes.

Table 1
Output voltage of pick-up electrodes

Ion	Dose Rate (Gray/min)	Number of particles (ppp)	Output of Hor. BPM (Vp-p)	Output of Vert. BPM (Vp-p)
H^+	5	1.2×10^{11}	0.42	0.54
H^+	2	5.0×10^{10}	0.18	0.22
C^{6+}	5	2.2×10^9	0.047	0.059
C^{6+}	2	8.2×10^8	0.017	0.022

3 Electronics

Figure 1 shows total block diagrams of electronics. Head amplifiers are mounted near each pick-up electrodes. A switcher, a heterodyne & detector, a ΔR processor, a local oscillator, a isolation amplifier and a digital multi meter are mounted on a rack at the room for synchrotron power supply. ΔR is displacement of the beam position. ΔR is calculated by next equation,

$$\Delta R = \frac{R-L}{R+L}$$

where, R is the amplitude of the signal from the right pick-up electrode, L is the amplitude of the signal from the left one.

Figure 2 shows block diagrams of a head amplifier. Input impedance is $100k\Omega$ which is converted by a FET transistor to low impedance enough to ignore input current noise of a operational amplifier. Signal of sum of R output and L output is detected and fed back to voltage control gain amplifiers. On this system, voltage gain is controlled from 1.25 to 1.25×10^4 automatically. So, gain setting to adjust to beam intensity is not required of operators of the synchrotron.
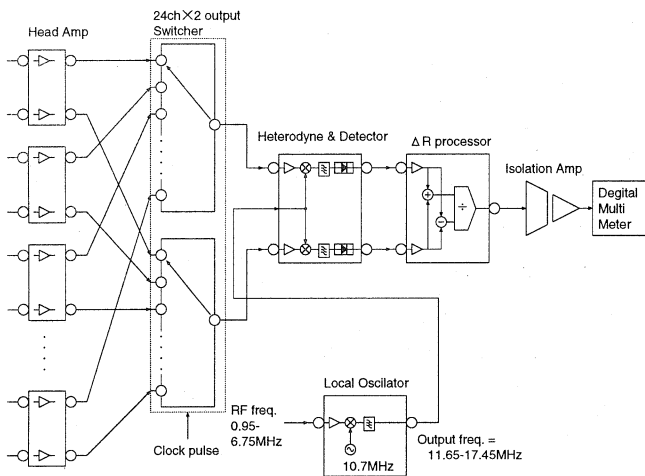
The switcher has forty eight input ports and two

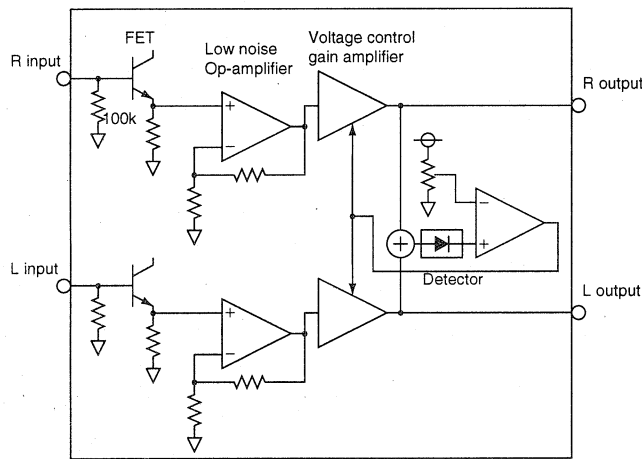Fig. 1   Electronics of beam position monitor
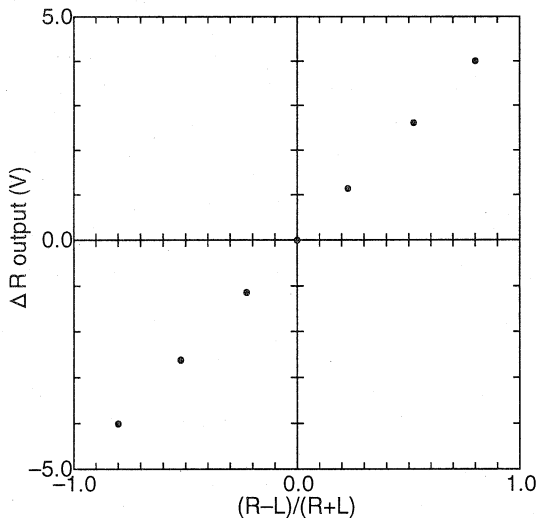

Fig. 2   Head amplifier

output ports (twenty four input ports and a output ports for R signal other for L signal). These ports are switched forward from the smaller number channel to the larger number channel when a clock pulse is arrived at the switcher. Delay for switching is under $10\mu sec$.

Intermediate frequency of the heterodyne & detector is 10.7MHz. Operational amplifiers are used but any RF amplifiers are not used, because the operational amplifier is more stable than the RF amplifier against varying input frequency and temperature. Bandwidth of the filter down the mixer was determined to 15kHz, because of easiness of manufacturing and diminution of noise. Good linearity of the set of the heterodyne & detector and the ΔR processor covers wide range over 20dB(figure 3).

For obtaining constant output level with different RF frequencies, auto-gain-control technique is also applied to the local oscillator.

4 Measurements with RF signal

Measurements of input equivalent noise level of head amplifiers were done with condensers, 150pF, which were installed to input connectors, and with which the pickup electrode was simulated. The noise level is achieved to $3.8nV/\sqrt{Hz}$.

Measurements of the position of an antenna which was inserted between pick-up electrodes and loaded with RF signal were done with the electronics for the purpose of correcting gradient of the linear function. Figure 4 and Figure 5 show output voltage of a beam monitor. We obtained 24.34(mm/V) for horizontal and 5.947(mm/V) for vertical as parameters of conversion. Figure 6 and 7 show distortion from the linear function. Accuracy of vertical beam position which is important for storing large beam current is $\pm0.1mm$ around center. Accuracy of horizontal beam position which is important for extracting beam efficiently is $\pm1mm$ within $\pm40mm$.

Fig. 3   Linearity of the set of heterodyne & detector and ΔR processor
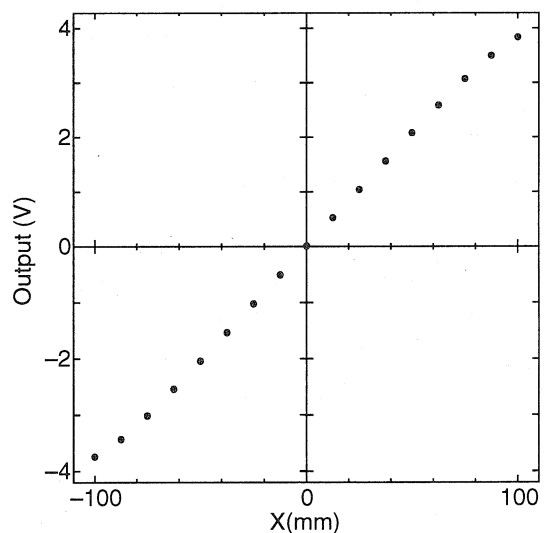

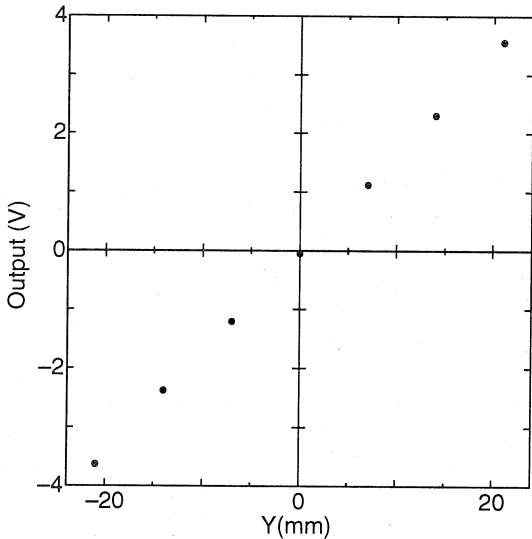Fig. 4   Output voltage of horizontal beam monitor

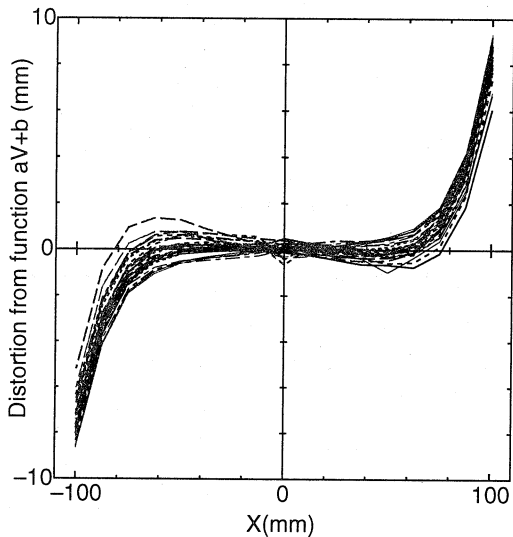Fig. 5   Output voltage of vertical beam monitor

Fig. 6   Distortion of all horizontal beam monitors from linear function. Input frequencies are 0.95, 3, 6.75MHz. Offset of center is fixed at the same monitor.
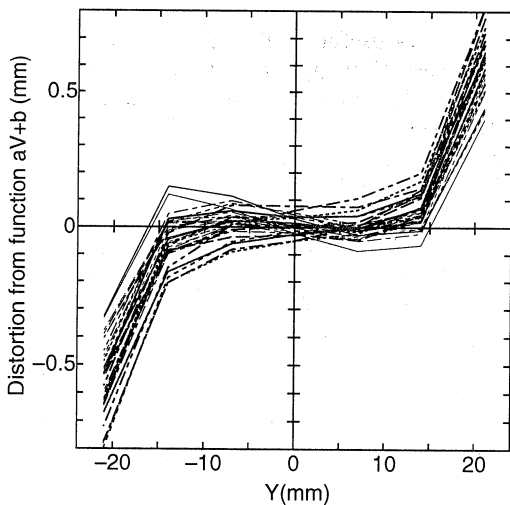

Fig. 7   Distortion of all vertical beam monitors from linear function. Input frequencies are 0.95, 3, 6.75MHz. Offset of center is fixed at the same monitor.

5 Conclusion

Input equivalent noise level of head amplifiers is $3.8nV/\sqrt{Hz}$, and bandwidth of the output is about 15kHz. On the other hand, the output of electrode is expected to be about $73\mu Vrms$ at 10^7ppp (C^{+6}), which is much smaller than the beam intensity at the time of first commissioning. So, S/N ratio is over 40dB. We get good resolution enough to commissioning.

With these beam position monitors and electronics, it is possible to measure beam position accurate enough to our purpose.

Acknowledgement

References

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[3] M. Kanazawa et al., "BEAM MONITORS FOR RF CONTROL IN THE SYNCHROTRON TARN-II",7th Symposium on Accelerator Sciences and Technology, RCNP, 1989, p210