BEAM MONITORS FOR RF CONTROL IN THE SYNCHROTRON TARN-II

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Abstract

Beam position and phase monitors have been developed to control a RF acceleration system of the heavy ion synchrotron TARN-II at INS (Institute for Nuclear Study, University of Tokyo) in collaboration with INS and NIRS (National Institute of Radiological Sciences). Performance test has been done to check white noise level, and accuracies of position and phase. Now these monitors are being used in TARN-II. This paper describes pick-up electrodes, electronics and its performance with test pulse, and results of beam experiments.

Introduction

Heavy ion accelerators are required to accelerate many kinds of ions. However, these intensities are limited to low values because of its limited capability of an ion source. The beam monitor in the heavy ion synchrotron must work with intensity of wide range. On the other side an injection energy of heavy ion is low and its velocity is then increased largely with RF acceleration in the synchrotron. The beam monitor must treat the signal of wide range frequency, and this fact make it difficult to obtain $\Delta\phi$ (phase difference between the beam and the RF cavity voltage), and ΔR (displacement of the beam position in the horizontal plane) with low intensity beam.

We have developed electrostatic pick-up monitors (position monitor and phase monitor) being used for RF control. We have also a plan to use the same type of monitor for the purpose of COD (Closed Orbit Distortion) detection, tune measurement, relative beam intensity monitor (for adjustment of beam injection and measurement of beam life time), and bunched beam shape monitor.

So the requirements for this monitor are summarized as follows.

- To make white noise and RF noise as low as possible.
- To monitor bunched beam shape correctly.
- To obtain $\Delta\phi$ and ΔR correctly during the acceleration period when the RF frequency will be swept from 0.5 MHz to 8 MHz.

Pick-up electrode

Fig. 1 shows a unit of pick-up electrodes for the ΔR and the $\Delta\phi$ monitor which are mounted in the same vacuum chamber. The ΔR monitor consists of four diagonally cut copper plates (two plates for right signal and other two for left signal) and the $\Delta\phi$ monitor consists of two rectangular copper plates. The electrodes are insulated by ceramic block each other and also from ground plates. There is no side pick-up plates to diminish the noise due to beam hitting. Inner cross section of pick-up electrode is 150 mm wide, and 50 mm high. The lengthes of the ΔR and the $\Delta\phi$ monitors are 194 mm and 50 mm long, respectively. To guard the pick-up electrodes and the ceramic (against low energy ion) there are thick stainless steel window frames at the both end of the vacuum chamber. The window dimensions are 148 mm wide and 46 mm high. The gap between pick-up electrode and ground plate determine its capacitance. We have adjusted the gap so that the capacitances of each electrode have become 130 pF for the ΔR monitor and 107 pF for the $\Delta\phi$ monitor including a capacitance of feedthrough (14 pF) while the designed value is 100 pF each. Two units of monitor are symmetrically installed upstream and downstream of the RF cavity, and the coresponding signals from the both units are then combined to produce each beam signal. This summation is expected to reduce the RF noise and to improve a signal to RF noise ratio, because the RF noises on them are considered to have opposit phase.

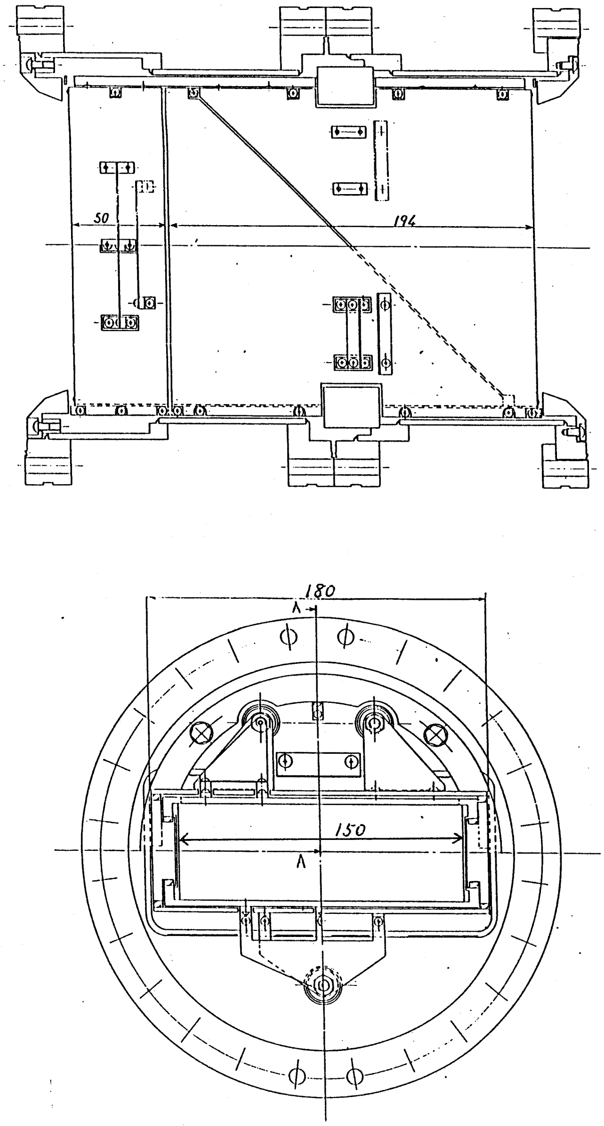

Fig. 1 Electrostatic pick-up electrode

Electronics

Fig.2 shows block diagrams of electronics. The first amplifier directly connected to each electrode is of an FET impedance conversion type from an input impedance of 100 kΩ to an output impedance of 50 Ω in a frequency region below 100 MHz, and has selectable gains of -10dB or 20 dB. A second amplifier has selectable gain of 0 dB or 40 dB.

The beam signal is further amplified by a double heterodyne module (Fig.2-1) whose gain is selectable between 10 dB and 60 dB by 10 dB step. In this module the input signal is mixed firstly with a signal of $(50+f_{RF})$ MHz in a DBM (Double balanced mixer). A fixed frequency (50 MHz) signal which contains informations of amplitude and phase of the input fundamental signal is only passed with a bandpass filter of 10 kHz bandwidth. To reduce the wave form distortion of output, we have chosen a frequency of 50 MHz. As a signal for a processor module, a 455 kHz signal has been made from the above 50 MHz signal and a 49.545 MHz signal of a synthesizer with the DBM and a low pass filter of 5 kHz.

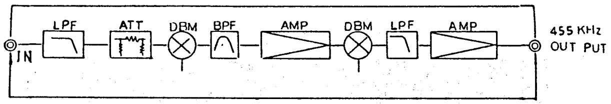

Fig.2-1 Double heterodyne module

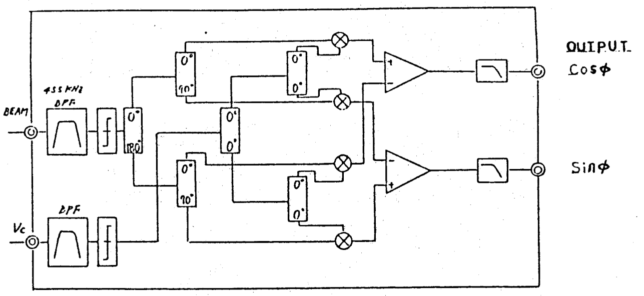

Fig.2-2 Δφ processor

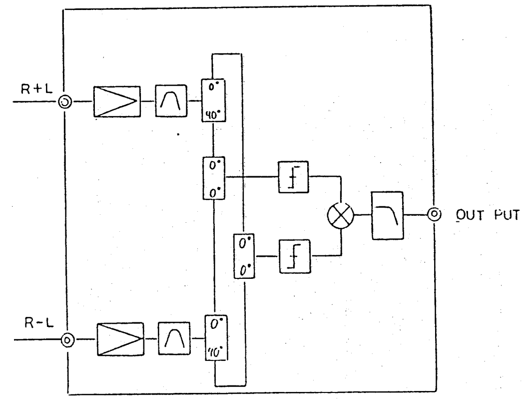

Fig.2-3 ΔR processor

Four kinds of 455 kHz signals which contain the informations of amplitude and phase of the input signals are prepared. For the beam phase monitor there are the beam bunch signal and the RF voltage signal of the cavity. For the position monitor there are the left position signal (L) and the right position signal (R).

To monitor the signal level there are buffer modules. In the buffer module for the ΔR monitor, 455 kHz signals of (L-R) and (L+R) have been made from the 455 kHz signals of L and R.

To produce the Δφ and the ΔR output signals, these 455 kHz signals are processed with a synchronous detection technique (see Fig.2-2 and Fig.2-3).

For the Δφ detection, a following signal has been produced with 90° quadrature hybrids and the DBM from the beam and the cavity signals.

$$\sin(2\pi ft+\phi_b+90^\circ)\sin(2\pi ft+\phi_c)$$
$$=1/2\sin(\phi_c-\phi_b)+1/2\sin(4\pi ft+\phi_b+\phi_c),$$

here f is 455 MHz, ϕ_b is a beam phase, and ϕ_c is a phase of the RF cavity voltage. Using a difference amplifier to compensate temperature dependence and filtering below a frequency of 5 kHz, a following output level is obtained (Fig. 3-1).

$$5\sin(\phi_b-\phi_c)\quad (V)$$

For ΔR detection, following two signals have been produced from the input signals of $(R+L)\sin(2\pi ft+\phi)$ and $(R-L)\sin(2\pi ft+\phi)$.

$$(R+L)\sin(2\pi ft+\phi+90^\circ)+(R-L)\sin(2\pi ft+\phi)$$
$$=\{(R+L)/\cos\alpha\}\ \{\cos(2\pi ft+\phi-\alpha)\}$$

$$(R+L)\sin(2\pi ft\phi)+(R-L)\sin(2\pi ft+\phi+90^\circ)$$
$$=\{(R+L)/\cos\alpha\}\ \{\sin(2\pi ft+\phi+\alpha)\}$$

Here $\tan\alpha=(R-L)/(R+L)$. Limitting the amplitudes of above two signals, and mixing with the DBM, we obtain a following signal;

$$\cos(2\pi ft+\phi-\alpha)\sin(2\pi ft+\phi+\alpha)$$
$$=1/2\sin 2\alpha+1/2\sin(4\pi ft+2\phi).$$

Filtering below a frequency of 5 kHz, following output of ΔR processor is obtained (Fig.3-2).

$$2.5\sin\ [2\arctan\{(R-L)/(R+L)\}]\quad (V).$$

A random noise level has been checked on following electronics at the input frequency of 5MHz.

1) the first amplifier plus the second amplifier with capacitance of 100 pF at the head.
2) the heterodyne module
3) 1) plus 2)

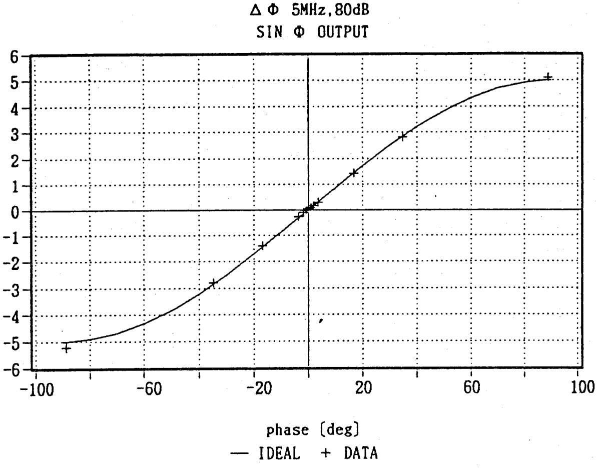

Fig.3-1 Δφ processor output

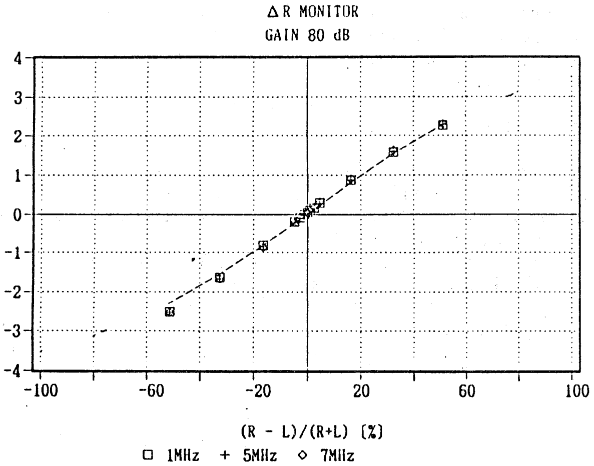

Fig.3-2 R processor output

From these measurements input equivalent noise levels are 1.7 nV/√Hz in the both cases of 1) and 3). This indicates that the noise level of the amplifieres determine the noise level of the entire monitor system. Thermal noise from a parallel connection of a capacitance of pick-up electrode and a resistance which determine the input impedance of the first amplifier can be written as follows;

$$\overline{v^2_n} = 4kT\Delta fRe(Z)$$

here k=1.38 x 10^{-23} (J/K), T is temperature (K), Δf is width of observing frequency, and Z is impedance. In the case of the selected high gain (20dB) of the first amplifier

$$R_e(Z)= R/\{1+(2\pi fCR)^2\}$$

here f is frequency of noise, R is resistance, and C is capacitance. With the values of T=290(K), C=110pF, R=100kΩ, and f=5MHz, we obtain 0.1nV/√Hz as a thermal noise. Considering smallness of this value, the FET white noise of the first amplifier is considered to be dominant in the white noise level of the total system.

Considering the white noise level in the beam moniter electronics, accuracies of ±2° for the Δφ detection and ±1mm for the ΔR detection of the total system will be obtained with beam signal voltage of 10 μVrms on each electrode.

Beam test

The influence of the RF noise from an entire system (i.e. the pick-up electrodes, the beam monitor electronics, and cablings) has been investigated by the use of a real beam and a real rf accelerating system at the heavy ion synchrotron TARN-Ⅱ. Fig.4-1 shows output signal of the second amplifier of the ΔR monitor just after the RF capture of proton beam with the frequency of 1.5 MHz, which shows that we can monitor the beam shape correctly.

As a relative intensity monitor to adjust injection parameters and to measure the beam life time, we have used the output signal of 455 kHz just processed by the double heterodyne module.

Preliminary results on the Δφ and the ΔR detections are shown in Fig.4-2 and 4-3 with RF frequency of 8 MHz, respectively. We have the statistical accuracy of ±2.5° for the Δφ detection and ±1 mm for the ΔR detection. In this case a circulating beam intensity in the ring is about 10^8 particles.

Discussion

As the Δφ and the ΔR monitors for the RF feedback system, sufficient accuracies have been obtained with the beam intensity of about 10^8 particle/ring. The white noise level is about -120 dBm equivalently at the input of the first amplifiers. At 1 MHz the RF noise level is very low at the accelerating voltage of 2 kV. In the case of 8 MHz, the RF noise level was increased to -105 dBm, which has made systematic bias on the Δφ and the ΔR detections with the low intensity beam.

This beam monitor electronics has been also developed for a synchrotron of HIMAC$^{1)}$(Hevy Ion Medical Accelerator in Chiba) at NIRS. In this synchrotron the beam intensity from 10^7 to 10^{11} particle/ring is required. For this requirement the white noise level of 1.7 nV/√Hz is low enough. Because of a higher rf voltage of 12 kV in the HIMAC synchrotron, further investigations to suppress the rf noise are necessarily made.

Acknowledgement

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References

1. A.Itano et al., HIMAC Synchrotron. These proceedings.

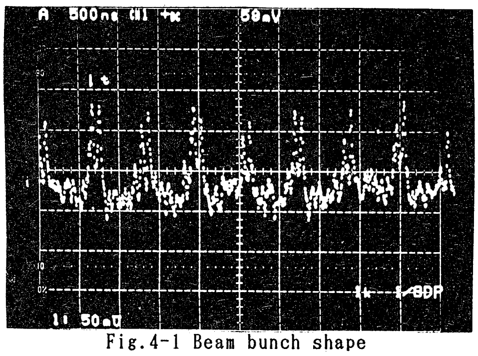

Fig.4-1 Beam bunch shape

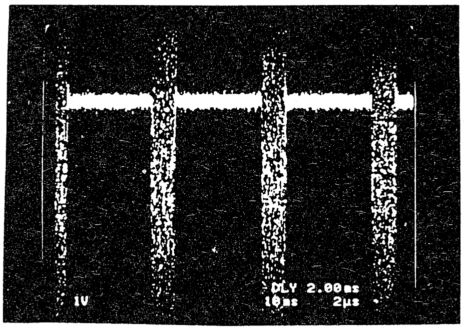

Fig.4-2 Δφ processor output(The beam injection and RF capture have been repeated with a period of 30 ms.).

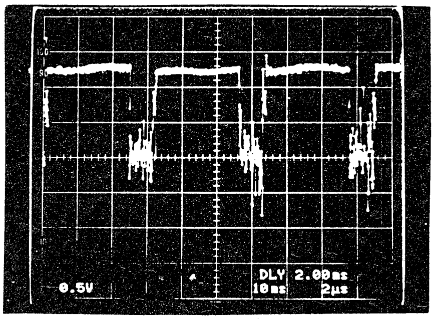

Fig.4-3 ΔR processor output(The beam injection and RF capture have been repeated with a period of 30 ms.).