A Single-Passage Beam-Position Monitor in the TRISTAN AR-to-MR Transport Lines

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Abstract

A beam-position monitor (BPM) has been installed in the transport lines between the Accumulation Ring (AR) and the Main Ring (MR) of TRISTAN. This monitor comprises stripline and button electrodes, detectors and charge-sensitive ADCs. The detector is a homodyne type synchronous-receiver at 70 MHz with four channels corresponding to four electrodes. Operation software automatically displays the detected beam position and its charge on a TV screen after each passage of the beam. The system is stable and is used to monitor the drift of the beam position. This is a brief report on the monitor. Details are seen in ref.[1].

1. INTRODUCTION

The TRISTAN Main Ring (MR), an electron/positron collider, catches a bunch extracted from the Accumulation Ring (AR). This bunch is transported through a long line with a length of 170 m for injection into the MR. Before, we could not easily watch a bunch during the transfer. If some trouble occurred in the line, we had no useful tool to diagnose it. Thus, the efficiency of the transfer, defined as the injected beam charge in the MR divided by a circulating charge in the AR, was poor. In order to improve the efficiency and to clarify the transportation status, a nondestructive beam position monitor is required.

The transport lines [2] guide electron and positron beams of 8 GeV from an AR extraction point to an MR injection point. The AR accumulates an electron or positron beam of 2.5 GeV up to the required beam-current level. The magnetic field of the AR increases for a ramping beam energy of up to 8 GeV. The beam is then extracted from the AR. The magnetic field decreases after the extraction until the next beam. This AR cycle takes about 60 seconds, not constant, since the period depends on the required accumulated beam-current and other injection conditions. Thus the extraction is irregular. There are two symmetrical lines: one for an electron beam and the other for a positron beam. Each line is about 170 m long and comprises eighteen dipole magnets, twenty-four quadrupole magnets and some correction magnets.

2. DESIGN

An extracted beam from the AR is a single bunch with a charge of 1 - 25 nC. This charge depends on the beam current of the AR. The rms bunch length of a bunch is expected to be about 20 mm, or 67 ps. The beam position should be detected in one passage of a bunch, since the period of the extraction is very long and irregular. The required specifications for a position measurement are:

accuracy : 0.5 mm
resolution : 0.1 mm
dynamic range : 30 dB
number of monitor station : 4 for each line.

In order to avoid external noise and to obtain a good S/N ratio, a simple homodyne receiver using a synchronous detector has been adopted, which directly rectifies an RF ringing signal without any frequency conversion. Since the noise spectrum of the kicker exists up to 30 MHz, the detected frequency should be greater than 30 MHz. When the frequency is greater than 100 MHz, however, it is technically difficult to rectify. The loss in a cable increases as the frequency increases. On the other hand, the transfer impedance of a pick-up electrode, such a stripline or a button, is proportionally increased as the frequency increases in the region below 100 MHz. Therefore, the detected frequency was chosen to be 70 MHz.

An expected peak voltage of the ringing using the narrow-band method is proportional to the bandwidth of a BPF, and is given as

$$V_p \cong 2 \cdot eN \cdot |Z_t| \cdot \Delta f \qquad (1)$$

Here, $|Z_t|$ is the transfer impedance of a pick-up electrode and Δf is the full bandwidth of a BPF. Assuming $eN=1$ nC and $\Delta f=10$MHz, the peak voltage picked up by the stripline is $V_p=40$ mV, when $|Z_t|=2\Omega$ at 70 MHz. In the case of the button, the peak voltage is one-order less than that of the stripline and is expected to be 2 to 4 mV. It is not difficult to detect the RF signal with the amplitude of several mV.

Two methods are considered to obtain the beam position. One is called an analog method, which generates the Δ/Σ function before the RF detection. This method requires hybrid junctions and a divider in an analog circuit. One may note some errors in the analog circuit and the coupling among the beam signals from the electrodes. The other is a digital method, where the digitization using a ADC is performed before the Δ/Σ function. The resolution of the ADC limits the dynamic range of the system. This is covered by a programmable attenuator. In order to avoid errors due to the coupling among channels, the one-to-one method has been adopted, where each beam signal picked up by each electrode is detected and digitized.

3. SYSTEM

Fig. 1 shows approximate locations of the monitor stations in the transport lines. The total number of the monitors is ten. Five monitors are installed for each line. The monitors are installed near quadrupole magnets, and are called E/P03, E/P04, E/P23 and E/P24. Letters E and P mean electron and positron line, and the following numbers called after quadrupole magnets also mean locations. The monitors at E21 and P21 are used to generate a timing pulse for detection. The monitors at E/P03 and E/P04 are mounted at the upper-stream side, and mainly watch the extracted beam from the AR. On the other hand, the monitors at E/P23 and E/P24 watch the injection condition to the MR.

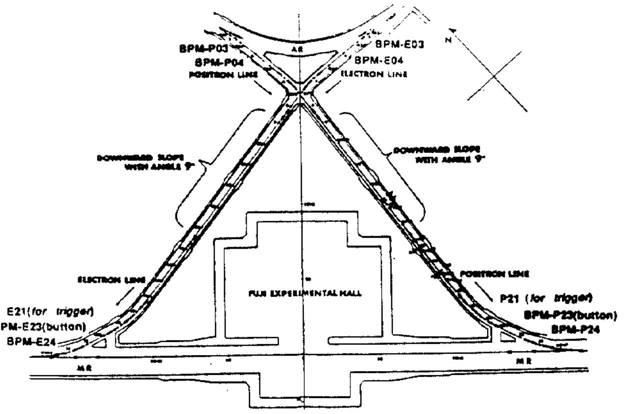

Fig. 1 Locations of the monitor chambers in the transport lines.

Fig.2 shows an outline of the system. The system comprises pick-up electrodes, cables, detectors and ADCs. The beam pulse picked up by each electrode is directly sent to the West-Room of the AR through a cable, where detectors and ADCs are mounted in a rack. The room temperature is kept constant. Before a beam pulse is fed to a detector, the pulse passes through a coaxial SPDT switch (single port double transport, Teledyne (CS-33S10)) and a programmable attenuator (Weinschel 3201). The switch is used to select either an electron or positron beam. The switches have 32 channels of inputs corresponding to each signal from the electrodes. The programmable attenuator can control the signal level in steps of 4 dB. The detector rectifies a 70 MHz component of a beam pulse. The ADC holds the charge of a beam pulse gated by a timing pulse. A beam signal picked up by E/P21 is bipolar, and is converted to a pulse with constant level of NIM and a width of 300 nsec by a zero-cross discriminator. This NIM-pulse is delayed by 1 to 2 μs in order to overlap it on a crest of a detected pulse; it is fed to the gate input of the ADC. This closed system has advantages of being jitter-free and easy to maintain. The detector and the ADC are common for electron and positron beams for easy maintenance. Stored digital data are read by a computer network of TRISTAN.

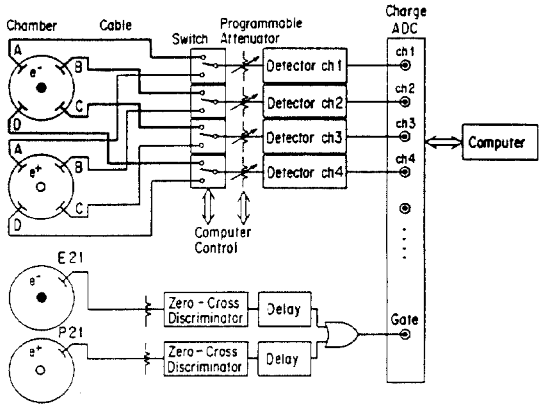

Fig. 2 Outline of the beam position monitor.

Fig. 3 shows a block diagram of one channel of a BPM detector. A beam pulse is stretched by a LPF (low-pass filter), the cut-off frequency of which is 100 MHz, and passes through a BPF. The center frequency of the BPF is 70 MHz, and the bandwidth is 10 MHz. The BPF converts a pulse to a ringing waveform with a frequency of 70 MHz. The duration of the ringing is 140 ns, and depends on the bandwidth, (10 MHz). In order to avoid any distortion in the ringing waveform, a SAW (surface acoustic wave, Murata SAF70MH00N) filter is used. The ringing waveform is amplified with a low-noise amplifier (NEC, 2SC3358, NF=1.1 dB) and is then sent to a synchronous detector. The bandwidth of the detector is determined by the cut-off frequency of the LPF, (500 kHz).

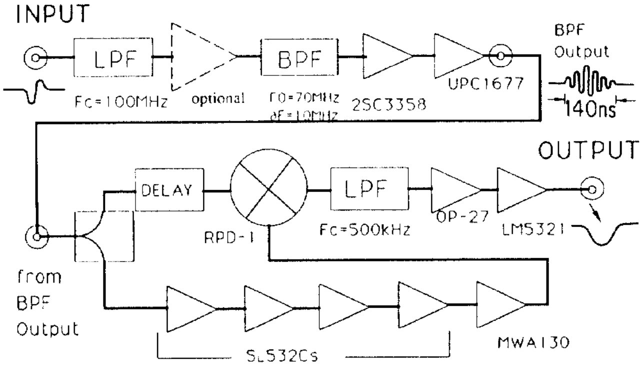

Fig. 3 Block diagram of the detector electronics.

4. PERFORMANCE

The resolution of the detection system was measured by repeatedly reading the position data about 100 times. Fig. 4 shows the standard deviation of the position data change as a function of the input charge. A standard deviation of 10μm was obtained at full scale. The standard deviation is roughly proportional to the input level. This means that the resolution of the detector is mainly determined by that of the ADC, where the ADC has 11 bits. However, it was found that the pedestal of the ADC fluctuated with 3 - 4 counts.

Therefore, the expected best resolution is about 8 µm, which agrees with the measured value.

The long-time stability was tested. A pulse with an amplitude of 70% of the maximum level was applied to the detector through a four-way divider. Position data were recorded every one hour. Both variations in the horizontal and vertical directions settled within ±50 µm. No drift was observed.

The nonlinearity of the detector produces a position shift which depends on the input level. In order to reduce the nonlinearity, the gain of the detector is changed from a fixed value to be a function of the input level. A correction curve, which is the difference between a linear line and the measured values, is obtained using a second-order polynomial. The correction is common among the four channels and the four detectors for simplicity. A position shift was also measured with an artificial imbalance of the input level. Attenuators of 6 dB were inserted at two channels, (the A &D channels of the detector). This imbalance produces a position offset of 6 mm. Fig. 5 shows the position deviation from the reference with and without a correction. The position shift is reduced to be less than 0.2 mm from 0.8 mm in the range of 20 dB.

Early during a beam test the system suffered from external noise. First, a noise was observed in a detected beam-pulse. It was found that this noise invaded through a power line of AC 100 V for a scope. A shielded transformer was inserted there in order to eliminate the noise. Next, the gate pulse generated by a beam-pulse was doubly triggered by reflections in the signal line. An attenuator made the reflections negligibly small.

The long-time stability was recorded during routine TRISTAN operation. The stored position data are useful for investigating the stability of the extraction components of the AR.

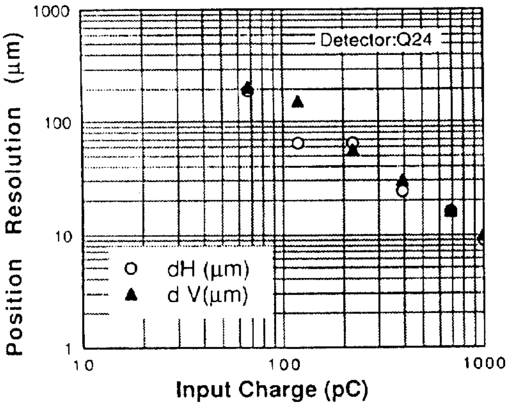

Fig. 4 Position resolution as a function of the input charge.

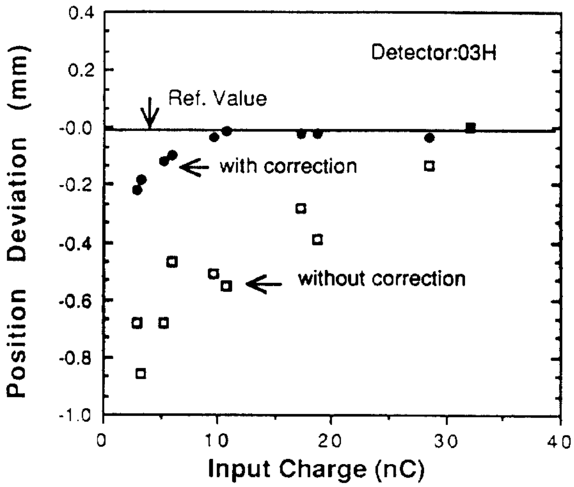

Fig. 5 Position deviation vs. input charge with a horizontal position offset of 6 mm.

5. SUMMARY

A BPM system has been installed in the transport lines. A homodyne receiver is used at 70 MHz in order to avoid any external noise. The system contributes to the diagnosis on the transfer process. The performance of the BPM system is summarized as follows:

1) The resolution of position is 10 µm rms value at the full scale.
2) The position accuracy is about 0.3 mm over a dynamic range of 16 dB.
3) The minimum detectable beam-charge is 1.0 nC. The dynamic range is more than 30 dB using a programmable attenuator.
4) The absolute value of beam-charge is unclear. A systematic error may exist.
5) Storing beam-position data is useful for monitoring its drift.

REFERENCES

[1] T.Ieiri and M.Arinaga, A Single-Passage Beam-Position Monitor System for the TRISTAN AR-to-MR Transport Lines, KEK Report 93-02 (1993).

[2] M. Kikuchi et al., Extraction system of TRISTAN accumulation ring and transport line to main ring, The 5-th Symp. on Accelerator Science and Technology, KEK, Japan (1984) p. 306.