IEEE Transactions on Nuclear Science, Vol.NS-24, No.3, June 1977

BEAM PROFILE MEASUREMENTS FOR KEK 12 GEV PROTON SYNCHROTRON

H. Ishimaru, Z. Igarashi, K. Muto and S. Shibata

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 300-32, Japan

Introduction

Various beam profile monitor systems provide a invaluable tool for studying beam behavior throughout the acceleration cycle on main ring and booster. Non-destructive slow profile monitors are used for injection, magnet, r.f., internal target and fast extraction studies. The time resolution of the slow profile monitor is 30 μsec. Multiwire secondary emission profile monitor which is sensitive enough to work with single bunch is used for injection tuning. Single wire secondary emission scanners are used for circulating beam. These profile monitors are cross-checked in precision. As the application of non-destructive profile monitor, position monitor is installed in main ring and booster.

Non-Destructive Profile Monitor

Design principle of non-destructive profile monitor for circulating beam is simple mechanism and stable operation. Electrostatic parallel plates and multi-channel ion collector scheme are applied[1-3] The ions liberated by the proton beam are accelerated to the grounded grid, which is electrostatic noise shielding, and collected on the electrodes. The sum of ion current collected by each segment of the electrode is proportional to the beam current. The electrode for horizontal profile is 320 mm wide, 300 mm length and 120 mm high, and for vertical profile is 200 mm wide, 300 mm length and 120 mm high. The ion collector electrodes are 3 mm wide, 100 mm length and 1 mm spacing. A schematic diagram of the non-destructive profile monitor is shown in Fig.1. For horizontal and vertical profile

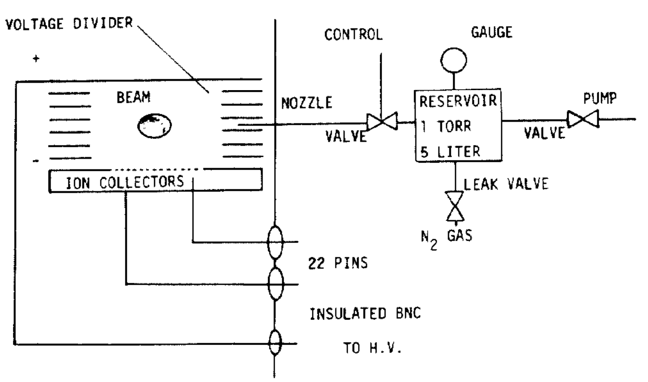


Fig.1 Schematic diagram of the non-destructive profile monitor.

monitors 32 and 16 collector electrodes are mounted respectively. Applied voltage is 10 kV which is correspond to electric field of about 1.4 kV/cm. To improve the uniformity of the electric field, dividing electrodes and resistors are installed. The thick stainless steel window frame whose size of inner square is smaller than the aperture of the electrodes was placed at upstream of the electrode to suppress secondary charged particles. The ion collectors are surrounded by a thin stainless steel sheet electrostatically. The ground of the electrodes are insulated from vacuum chamber to reduce the induced noise[4,5] In a case of vertical monitor, ion collector electrodes are

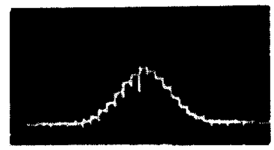


Fig.3 Horizontal profile for main ring. 100 μsec after injection. 4 mm/bin.

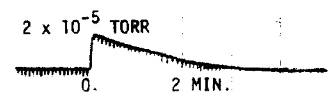


Fig.2 Pressure variation for gas injection.

mounted outside of the beam radially. If ion collector electrodes are set inside of the beam radially, lost beam impinges on the ion collectors directly.

To improve the sensitivity of the monitor the gas injector is installed in monitor vacuum chamber. The nitrogen gas injector is controlled remotely. The pressure variation vs. time is shown in Fig.2. This pressure bump such as 1×10^{-5} torr has no relation to beam life.

The signal processing and display are performed without computer. The signals from ion collectors are fed to amplifiers, sample-hold circuits, an analog multiplexer and a cable driver. These electronics are near the detector. The sampling time is chosen to 30 μsec. The amplifier consists of FET input operational amplifier RCA 3130 with gain of 1200 for main ring and 500 for booster. Zero level drift of the output signal from analog multiplexer is within 5 mV. Typical output signal is about 1 volt. The display of the beam profile is selected to single sampling as shown in Fig.3 or mountain view display as shown in Fig.6. In a case of mountain view display a large storage scope Tektronix 611 is used. A schematic diagram for moutain view display is shown in Fig.4. The time chart is shown in Fig.5. An example of the moutain view profile is shown

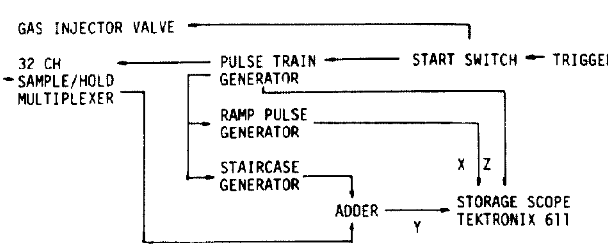


Fig.4 Block diagram of electronics for mountain view display.

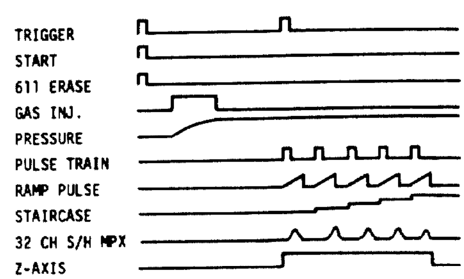


Fig.5 Time chart of the mountain view display.

in Fig.6 for main ring and Fig.7 for booster. In the booster display fast sampling 200 μsec/step is chosen. The space resolution is checked by a single wire scanner at injection. For main ring non-destructive profile agrees with the profile from the single wire scanner at present intensity 50 mA for the first turn at 500 MeV. But for booster non-destructive profile does not agree with the profile from the single wire at intensity of 500 mA at 20 MeV. These problems are due to the coulomb force interaction with the ionized thermal ions and space charge potential of the proton beam. It was observed that the width of the detected beam profile varied with the electric field strength and beam intensity. It was also observed that in a case of electron collection, beam width was narrower than the ion collection as shown in Fig.8. There is a real profile between the ion collection and the electron collection profile.

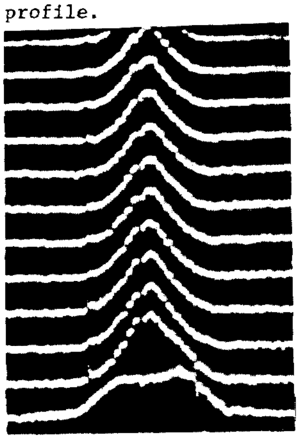
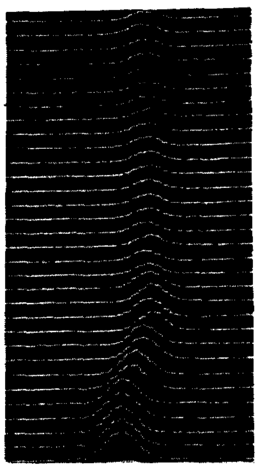


Fig.7



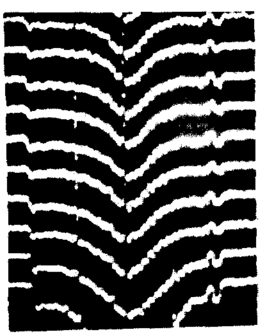


Fig.8

Fig.6 Horizontal mountain view display for main ring, 5 msec/step, 4 mm/bin.

Fig.7 Horizontal mountain view display for booster, 200 μsec/step, 4 mm/bin.

Fig.8 Electron collection profile for booster, 200 μsec/step, 4 mm/bin.

Multiwire Secondary Emission Monitor

To provide accurate information on the shape and the position of the beam at injection of main ring and booster, the detectors are used of the secondary emission type. The grid detector consists of 16 horizontal and 8 vertical tungsten foils, 0.025 mm thick and 0.75 mm wide on glass epoxy frame. Each strip is kept under tension by a coil spring. The space between strips is 2.5 mm. The positively 300 volts biased electrode which is an aluminum foil of thickness of 0.025 mm is placed between horizontal and vertical strips.

Positive voltage of 300 volts is applied to the wire frame to sweep the secondary electron produced by proton beam impinging on the wires and ionizing the residual gases. The strong dependence on bias voltage of beam profile is observed. If bias voltage is zero, base line of the profile is going to negative.

The electronics for secondary emission monitor are same for one of the non-destructive monitor. The gain of an amplifier is 20 for 500 MeV and 1 for 20 MeV. An example of the injected beam profile for main ring is shown

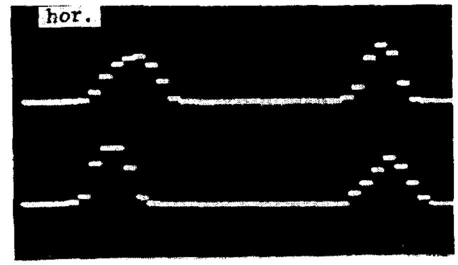


Fig.9 Horizontal and vertical profile for main ring injection by multi-wire monitor.

in Fig.9.

At present time, display of these profile does not use a computer. In the near future computer controlled profile and position will be displayed on the graphic terminal Tektronix 4010.

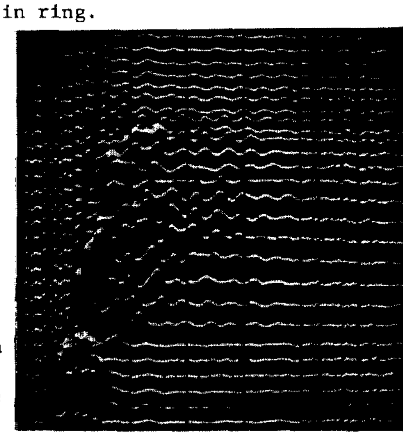
Single Wire Secondary Emission Scanner

Single wire secondary emission scanners are installed in main ring and booster. This wire scanner has fast time response for beam bunch. The wire is 0.001 mm thick, 0.25 mm wide tungsten foil. Booster wire is burnt out sometimes. The radiation from surface is dominant in cooling of wire. Then thin tungsten foil is preferable. The scanning mechanism consists of dynamic bellows, ball screw, ball bush and servo motor. The position is monitored by linear potentiometer with accuracy of ±0.1 mm. The wire scanner being used here is located just downstream from the injection septum in the booster, so the wire scans both the injected and circulating beams. The secondary emission current from the wire is shown in Fig.10. From this signals beam profile vs. time is obtained by electronic circuit as shown in Fig.11. It is possible to visualize the multiturn injection process and to see the apparent septum thickness and the betatron oscillation as shown in Fig.10 and Fig.12.

The non-destructive profile to single wire profile as shown in Fig.13 agree within ±5 % at the intensity of 5×10^{11} ppp in main ring.

Fig.10 Secondary emission current from single wire located just downstream of booster injection septum.

10 μsec/div.



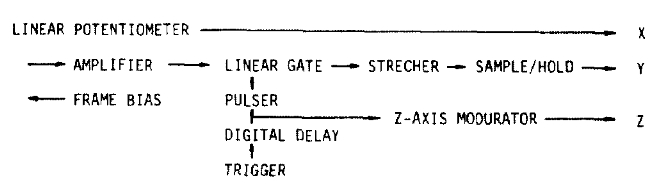
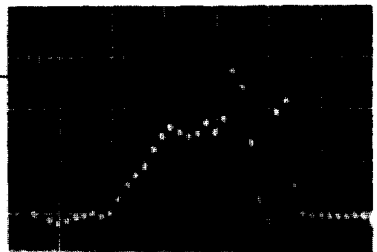


Fig.11 Block diagram of electronic circuits of the single wire profile monitor.

Fig.12 Booster horizontal profile by single wire scanner located just downstream from the injection septum.

1 μsec sampling



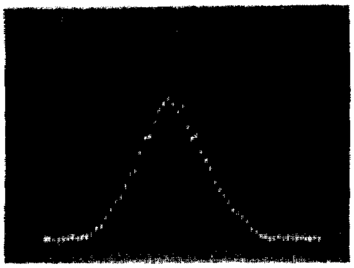


Fig.13 Main ring vertical profile by single wire scanner, 10 μsec after injection and 2 μsec sampling, 13.5 mm/div.

Gas Ionization Position and Intensity Monitor

Beam position and slow intensity monitor are measured by the application of the non-destructive profile monitor. The ions are propelled along the electric lines of force transverse to the beam axis to triangular collection electrodes. The beam position is given by

$$R = K \frac{R^+ - R^-}{R^+ + R^-}$$

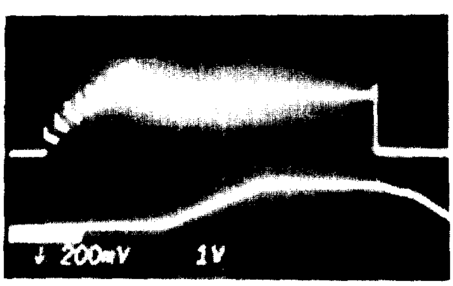
where K is constant due to the geometry of collection electrodes. The diagonally cut rectangular collector is 170 mm wide and 120 mm long. K factor is 85. Assuming the ion collection efficiency and vacuum pressure are constant, output signal is,

$$I_p \propto \sigma(E)(R^+ + R^-)$$

where $\sigma(E)$ is ionization probability. Time resolution of this monitor is approximately 10 μsec.

Constant pressure is preferable. Then automatic pressure controller Granville-Phillips is installed in monitor vacuum chamber. The pressure is set to 4×10^{-6} torr for main ring. Leak gas is nitrogen. Pressure variation for long time is within ±3 %. Amplifiers with gain of 50 are set for main ring and booster. A typical intensity signal for main ring at 9 pulses acceleration is shown in Fig.14. The sum signal and

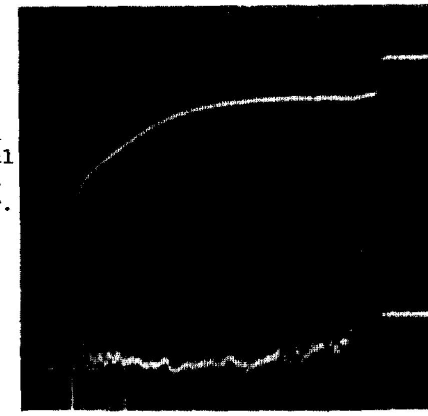
Fig.14 A typical gas ionization intensity signal for main ring. 0.2 sec/div. final intensity is 5×10^{11} ppp.



position signal for booster are shown in Fig.15. It is under testing to use the gas ionization monitor for the signal source of ΔR feedback for RF cavity. Signals from input amplifiers are fed to two transient recorders Biomation 8100, which are interfaced to anda mini-computer Melcom 70.[6] Beam position, current and particle number are displayed on the graphic terminal Tektronix 4010 with correction of ionization probability and beam velocity by computer as shown in Fig.16. This gas ionization monitors are insensitive to bunching or debunching of beam.

Fig.15 Sum signal and position signal for booster by gas ionization monitor.

5 msec/div.



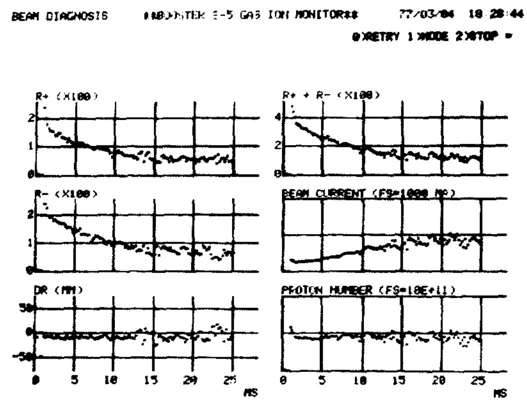


Fig.16 Computer controlled position, intensity and particle number display for booster.

Conclusion

This monitor system have been proved to be useful for tuning and study of main ring and booster. Main problem of non-destructive profile monitor is the expansion of profile by space charge effect of high intensity beam and slow response to bunch. Further investigation is in progress. We have no problem for multi- and single-wire monitors.

Acknowledgements

We would like to thank Prof. T. Nishikawa for his encouragement. This work is due to the efforts of a great number of people. We would like to thank Control, Vacuum, Beam Transport, RF, Booster and Main Ring group for their cooperations.

References

1. F. Hornstra, et al., 6-th International Conference of High Energy Accelerator 1967. 374
2. W.H. Deluca, Nuclear Science, 16 1969. 813
3. C.D. Johnson, et al., Nuclear Science, 16 1969. 909
4. H. Ishimaru, Vacuum 26 1976. 243
5. H. Ishimaru, Vacuum 1977, to be submitted.
6. T. Katoh, et al., Control Computer System for KEK Proton Synchrotron, this Conference, 1977.