THE TEV I BEAM POSITION MONITOR SYSTEM

S.D. Holmes, J.D. McCarthy, S.A. Sommers, R.C. Webbes, and J.R. Zagel
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, IL 60510

Abstract

The TeV I Beam Position Monitor System is described. This system is designed to provide accurate orbit information during both the commissioning and operational phases of the Fermilab Antiproton Source’. The system is required to provide position information with submillimeter resolution for both single turn orbit measurements with beam intensities in the range 1 x 10^7 to 1 x 10^11, and multiple turn (closed orbit) measurements with beam intensities in the range 1 x 10^7 to 5 x 10^11. The system has already been used during commissioning of the Debuncher to measure the first turn through the ring, the horizontal and vertical betatron tunes, the closed orbit, the dispersion, aperture, and chromosticity. During normal antiproton operation the system will be used to monitor beam position throughout the accumulation process.

System Overview

A block diagram of the BPM system is given in Figure 1. Parallel systems are used for the signal processing of single turn and multiple turn measurements. Single turn-by-turn measurements are processed by a wide bandwidth (5 MHz) system which relies on 53MHz signals produced by the bunched beam. This system is very similar to the present Fermilab Tevatron system. Multiple turn (closed orbit) measurements are processed through a lower frequency (2.4 MHz in the Debuncher and 6.3 MHz in the Accumulator), narrow bandwidth (75-1000Hz) system which relies on gaps in the circulating beam, Schottky noise, and/or modulation produced by low frequency RF for signal generation. The narrow bandwidth produces an analog average which typically extends over several hundred turns and is necessary to reduce the contribution to position resolution from noise in the system. In addition to analog averaging we are prepared to average digitally up to 256 measurements at any particular pickup to obtain submillimeter resolution even at very low signal.
levels. Six systems of the type shown in Figure 1 exist in each ring. Signals from the pickups are multiplexed so that each system services between 15 and 20 pickups.

Pickups

There are 120 beam pickups in the Debuncher and 90 in the Accumulator. In general there is one pickup at each quadrupole. This results in more than five position measurements per plane per betatron wavelength in each ring, and provides more than sufficient information for precision alignment of closed, injection, and extraction orbits. The pickups themselves have either diagonally cut cylinders or rectangles, depending on location, with signals capacitively coupled from the beam. The diagonally cut geometry is used in both cases because it produces a signal which is linear in the beam position. To maximize signal levels the pickups cover the full arcuate and every effort has gone into minimizing their capacitance to ground. The pickups are bidirectional to accommodate beams circulating in either direction and in the Accumulator also function as clearing electrodes.

Three varieties of pickups are used. The Debuncher pickups and the low dispersion Accumulator pickups are both cut cylinders with a length of 10 cm. The apertures are 70 mm and 50 mm respectively. Both pickups have a total capacitance to ground of 75 pf. The plates themselves have a measured coupling capacitance of 11 pf. The pickups in the high dispersion regions of the Accumulator are rectangular with an aperture of 270 mm by 49 mm with a length of 10 cm. The total capacitance of the pickups to ground is again 75 pf and the coupling capacitance is 15 pf.

Tunnel Preamps and Switchable Gain Amplifiers

The desire to measure low intensity beams results in the need to be sensitive to small signal levels. Under some conditions the signals are less than 1 microvolt into a high impedance load. To preserve signal integrity against external noise and possible attenuation due to unwanted capacitance preamplifiers are connected directly to the vacuum feedthroughs on the pickups. The preamp is a combination sum and difference amplifier with FET inputs. Taking the sum and difference of the two electrode signals at the front end minimizes any apparent center position offset that could otherwise be introduced by unbalanced gain in downstream amplifiers. The input impedance of the preamp is 35 pf in parallel with 100 KOhms and the measured equivalent input noise approximately 2.5 nV/Hz. The common mode rejection ratio varies from 55 db below 10 MHz to 48 db at 53 MHz.

To compete further with noise picked up on signal cables between the tunnel and service building electronics additional amplification in the tunnel is necessary. The design goal is to maintain a minimum sum signal of one millivolt rms on the cables to the service buildings. A pair of matched switchable gain amplifiers located in the tunnel near each preamp provide the additional gain needed to see the low intensity signals generated by circulating antiprotons. The gains of the two channels are required to track to 1% and the phases to 5° over the range 2.4 MHz to 53 MHz. The dynamic range of the signal levels expected requires that the gain of these amplifiers be remotely selectable over the range 0 to 60 db in 20 db increments.

Beam Position Analog Processors

The function of the beam position analog modules is to convert amplitude information into band limited DC levels appropriate for digitization. Two DC levels are supplied—one proportional to the beam intensity and the other proportional to the normalized beam position. Two separate beam position modules are used. The rf module processes wideband 2.4 MHz signals and the low frequency module processes narrowband, low level, 2.2 (or 6.3) MHz signals.

The rf beam position module is a modified version of the Fermilab Tevatron module. It is used during commissioning and diagnostic periods when protons are circulating in the two rings, and during antiproton operation when a large number of antiprotons have been accumulated. The amplitude to phase conversion technique is used to produce a normalized position output over a wide (40 db) dynamic range. The original Tevatron module is modified by replacing two in-phase power combiners with quadrature combiners to accommodate difference and sum rather than left and right inputs.

The low frequency module is designed to handle the narrowband, low level signals produced by antiprotons in closed orbits in both the rings. It operates on a single harmonic of the revolution frequency relying on signals produced either by a gapped beam, beam Schottky noise, or rf modulation. The Debuncher module is designed to operate at the fourth harmonic of the revolution frequency (2.36 MHz) and the Accumulator module at the tenth harmonic (6.28 MHz). Since the signal to noise ratio at the input to the low frequency module is low a heterodyne scheme is chosen so that the system bandwidth can be made as narrow as possible consistent with the information bandwidth of interest. After passing through a pre-selection filter which rejects any unwanted harmonics, the incoming beam signals are down converted to an intermediate frequency of 10 KHz. The I.F. signals are then sent through 1 KHz wide filters and into an amplitude to phase conversion unit. The filters are amplitude and phase matched to 0.5 db and 2° respectively within the passband.

A beam position module can service up to 10 different beam pickups via the input multiplexer as shown in Figure 1. The multiplexer is a modified version of the module which was used in the old Fermilab Main Ring BPM system.

A Position Gain and Offset Module performs additional signal conditioning. The module provides programmable magnification and offsets as well as signal averaging via a low pass filter. Filter values of 75, 200, 500, and 1000 Hz are available. The filter is bypassed entirely if the system is being used in turn-by-turn mode.

Digital Signal Processing and Controls

The digital signal processing and interfacing to the Fermilab Accelerator Control Network (ACNET) is done in a manner similar to the Tevatron beam Position System. The digital position and intensity signals are digitized on BPM daughter cards and read out under the control of a Multibus-based microprocessor system. Each Multibus crate is controlled by two 256 microprocessors, one of which handles communications to the host system through CAMAC, the other controlling set up of hardware and
data collection. The primary changes relative to the Tevatron system arise from the much shorter revolution period of the Debuncher and Accumulator rings than the Tevatron (1.6 microseconds vs. 22 microseconds).

The position and intensity signals generated from the position modules enter the Analog Box via the position gain and offset module. The slow signals are digitized on a standard Tevatron BPM daughter card. The fast signals generated by the turn-by-turn system require one new Multibus board (Fast Access Board—FAB), a modified Multibus turn-by-turn (TBT) board, a new analog box master daughter card (MAD), and four highly modified daughter cards.

The FAB card provides timing and control of the fast turn-by-turn system. No data is stored on the FAB card; this function is performed by the TBT board. Selection is provided to allow delay of up to 65535 turns of beam prior to collecting up to 1024 turns of position and intensity data. A continuous run mode allows data taking to proceed on the TBT card until beam is extracted providing a circular buffer of the last 1024 turns. Individual enables are provided to allow data taking to be triggered by either one of two external pulses or by a software trigger.

The MAD card provides the fast daughter cards timing pulses for the capture of data, initiates and supplies a 20 MHz clock for the A/D conversion, and coordinates readback of data. The fast daughter cards contain the 8 bit ADC's which digitize the position and intensity information. The TBT board is identical to the Tevatron TBT board except for minor control signal modifications. This board receives data from the fast daughter cards under the control of the FAB board and stores the information in a 1024 x 4 channel memory.

Operational Experience

The BPM system has three modes of operation: 1) single turn orbit; 2) turn-by-turn at a fixed detector; and 3) closed orbit. The first two use the fast (turn-by-turn) system and can only be operated with beams containing >1 x 10^10 particles per 53 MHz bunch (10^13 particles total). The third uses the slow (narrowband) system and can measure down to 10^9 circulating particles with the appropriate beam structure. Because the signal processing electronics is multiplexed the observation of a complete orbit on a single turn actually requires the injection of 10 (in the Debuncher, 8 in the Accumulator) separate beam pulses.

At this time the entire BPM system shown in Figure 1 is in place and operational in the Debuncher with the exception of the switchable gain amplifiers. These amplifiers are not needed for commissioning with protons. Figure 2 shows the first turn orbit in the Debuncher as measured with the BPM system on April 25, 1985. This orbit was measured using ten consecutive beam pulses of 8 GeV protons delivered from the booster via the main ring. Each pulse contained approximately 10^10 protons in ten 53 MHz bunches. The reproducibility of the measurements indicates that the resolution is better than a millimeter. The turn-by-turn system has also been used to measure the tune of the Debuncher by observing the first 512 turns measured on a particular detector in the ring.

Figure 2. First turn orbit in the Debuncher.

Figure 3 shows the Debuncher closed orbit measured by the BPM system. Because of the multiplexing scheme employed, a closed orbit measurement can extend over a time period from a few tens of milliseconds up to a few seconds depending on the amount of analog and digital averaging desired. This orbit was measured with about 10^11 circulating protons.

Figure 3. Debuncher off momentum closed orbit.

Acknowledgments

We wish to acknowledge the contributions of the following people to both the construction and commissioning of the TeV I BPM system: J. Arthur, T. Bagwell, J. Budlong, R. Gerig, D. Howard, D. Martin, R. Marquardt, W. Merz, T. Savord, W. Sax, and J. Smolucha.

References

2. G. Dugan, invited talk at this conference.