A BEAM POSITION MONITORING SYSTEM FOR THE FERMILAB BOOSTER

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Abstract

The recently installed beam position monitoring system designed for the Fermilab Booster is described. Signals from stripline pick-ups are processed by heterodyned AM-to-PM position circuitry which features wide dynamic range and normalized position outputs with wide bandwidth. Measurements are made to an accuracy of better than 1mm over a 70mm aperture with beam intensities ranging from less than 5E10 to more than 5E12 protons. An independent beam-synchronous timing system can track a fractional turn of beam through the cycle as the particle velocity nearly doubles. A Multibus/CAMAC data acquisition system interfaces 96 channels of closed orbit and single turn position information, and 4 channels of turn-by-turn position information, to the main control system.

Introduction

The Fermilab Booster is a 75 meter radius rapid cycling synchrotron which accelerates protons from 200Mev to 8Gev with a 15Hz maximum repetition rate. The machine lattice is divided into 24 identical periods; each with four combined function magnets, a 6m straight section, and a 1.2m straight section. The accelerating system, operating at h=84, sweeps from 30.3Mhz to 52.8Mhz during the 33ms acceleration cycle as the particle velocity increases from beta of .57 to .99. The betatron tune of 6.7 sets a lower limit on the number of BPM locations required to obtain good closed orbit measurements. A design with both radial and vertical pick-ups in each long and short straight section was chosen.

The Booster BPM system is modeled after that of the Fermilab Energy Doubler.[1] Signals from the pick-ups are processed in RF position modules to produce intensity (sum signal) and normalized position outputs. Position signals are sampled and digitized in the 12 channel analog box controlled by a Multibus system in communication with the CAMAC links of the main control system. Use of individual electronics for each pick-up avoids the complications and inconveniences associated with signal multiplexing. Built-in DC and RF test features are available for monitoring cable connections and general system integrity. Electronics is housed in eight racks distributed around the equipment galleries of the Booster. Figure 1 is a block diagram of the system hardware.

Pick-ups

Beam size and mechanical constraints in the short straight sections dictated a pick-up design with a clear aperture of 118mm, a length of 180mm, and both radial and vertical electrodes at the same longitudinal position within one housing. The new pick-ups replace ferrite window-frame devices which were never well understood, calibrated, or maintained; lacked suitable frequency response; and contributed significantly to the longitudinal impedance of the machine structure. A four-electrode impedance matched stripline geometry as depicted in Figure 1 was chosen. For simplicity, one style of detector was fabricated

*Operated by the Universities Research Association under contract with the U.S. Department of Energy.

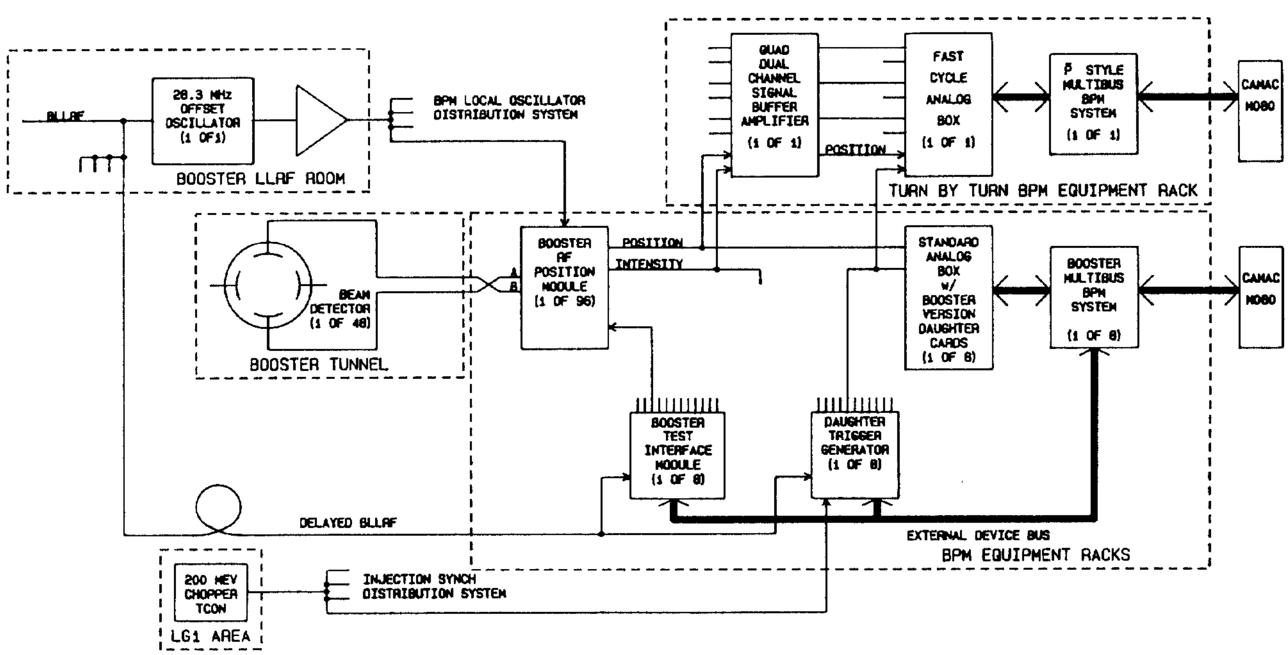

Figure 1. Booster BPM block diagram.

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PAC 1987

and used in both the long and short straight locations. Each electrode subtends an azimuthal angle of 60 degrees and forms a 50 ohm transmission line with the detector housing. Signals from the upstream end of each line are brought out through vacuum feedthroughs and the downstream end of each line is terminated within the vacuum housing.

Using stretched wire techniques, the electrical center, position sensitivity, and longitudinal impedance of the pick-up geometry were measured and found to be suitable.[2] The electrical center was found to be independent of frequency to 200Mhz. A position sensitivity of 0.52db/mm is well approximated at all frequencies of interest with a small correction for off-axis position in the orthogonal plane. In addition to the extensive generic measurements made on a small sampling of the pick-ups, the electrical center of each individual pick-up was measured relative to mechanical survey references on the housing and recorded, to be used as a correction to beam measurements. The rms center position offset for 54 pick-ups was found to be 0.5mm. Some of this error is known to be systematic and related to mechanical asymmetries in some of the pick-up housings.

Analog Signal Processing

Signals from the pick-ups at the fundamental RF frequency are processed by the RF modules. The amplitude modulation to phase modulation (AM-PM) processing technique widely used at Fermilab[3] was also selected for the Booster because of its ability to produce fast and accurate normalized position signals over the required signal level range. However, unlike other Fermilab systems which deal with essentially fixed frequency inputs, the Booster system must contend with the nearly octave frequency variation during the cycle. Direct implementation of the AM-PM technique over octave bandwidths is possible; however, components to perform the necessary RF functions in the 30-50Mhz range are expensive and not readily available with the required performance tolerances. The Booster RF modules are implemented with a heterodyned frequency conversion front-end. 28Mhz IF signals are processed in AM-PM/phase detector electronics which is essentially the same as that used in the Fermilab Main Ring/Saver RF modules. This method requires a mixer local oscillator drive signal which is obtained from a phase-locked frequency translation loop tracking the Booster accelerating frequency. The typical RF module is accurate to ±0.5mm over a 50db input signal level range and has a frequency sensitivity equivalent to ± 0.25mm of beam position. The output bandwidth of the normalized position signal is about 2Mhz, fast enough to produce an accurate signal for a single pass of 20 beam bunches (about one fourth of the Booster circumference).

Signal Acquisition

Closed Orbits

Closed orbit measurements may be made throughout the Booster acceleration cycle. Data collection and processing is controlled by the standard Fermilab Multibus and analog box BPM system,[4] operating with parameters downloaded through the accelerator control system. A user selected number of position samples from each of the 96 position channels are averaged to obtain the closed orbit information. The throughput rate of the standard analog box and Multibus equipment is not sufficient for turn-by-turn measurements, so sampling is limited to a maximum rate of once every four turns.

The position signals are digitized on daughter cards in the analog boxes. In other installations at Fermilab, the RF module intensity signals, as input to the daughter cards, provide the necessary timing information to start the sequence of sampling and digitization. However, multiturn H^- injection into the Booster results in a circulating beam with no structure at times comparable to the revolution period. An external beam synchronous timing system was developed which generates the necessary triggers and applies them, as pulses, to the unmodified intensity input of each daughter card. Intensity measurements via the control system from BPMs are sacrificed, though the information is available in analog form at the RF modules.

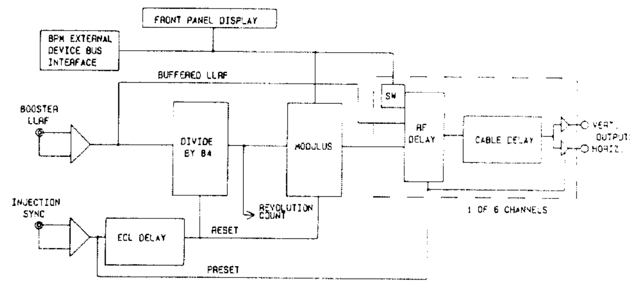


Figure 2. Daughter Trigger Generator block diagram.

The heart of the synchronization system is the Daughter Trigger Generator Module (TRG), shown in block diagram form in Figure 2. TRG utilizes a counter which receives a properly delayed Booster low level RF signal and beam injection sync pulse to generate a reference revolution frequency clock. The beam revolution period in Booster is faster than the 5us minimum data collection period of the standard BPM analog box and Multibus system. The clock is therefore further divided by a modulus, in the range of 4 to 15, to generate the basic daughter card cycle timing. The modulus is operator programmable, downloaded via the external device bus of the BPM system. Independent delay channels then generate the unique triggers for each daughter card. Each channel provides a delay of an integral number of RF cycles to compensate for beam transit delays which vary during the acceleration cycle and a fixed time delay to compensate for cable lengths. The RF delay is switch selectable from 0 to 15 cycles and the cable delay is jumper selectable from 0 to 200ns in increments of 20ns. The resultant output triggers are synchronous, to within one RF period throughout the acceleration cycle, with the arrival of signals from a reference particle passing each pick-up.

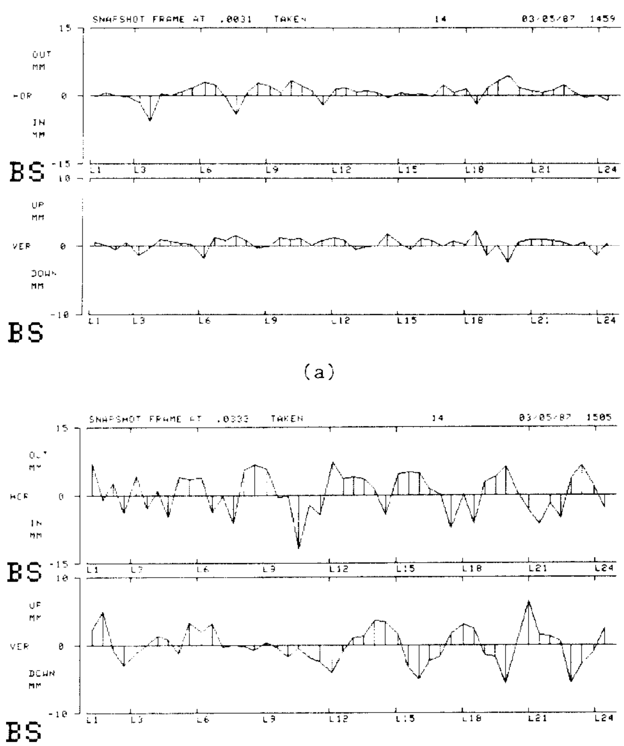
Turn-by Turn Position

A separate analog box and Multibus system as modified for the Fermilab antiproton rings[5] provides four channels of turn-by-turn measurement capability. The normal data acquisition period is reduced below the required 1.6us by doubling the analog to digital convertor clock frequency and cutting the maximum number of channels in the analog box to four. Sharing the outputs of four RF modules used by the closed orbit system, position samples for 1024 consecutive turns any time in the Booster cycle can be processed. Daughter card triggers are generated by a TRG modified for a modulus of one.

Operational Experience

The turn-by-turn portion of the Booster BPM system became operational in the spring of 1986 following the installation of the first prototype detector. While the turn-by-turn system has been used for tuning injection, its primary value has been in providing tune measurements at any time during the acceleration cycle. Because of this system, we have, for the first time, good measurements of the variation of tune with momentum during the entire Booster acceleration cycle.

The BPM closed orbit system started producing reliable orbit measurements in mid-January of 1987. Our experience has been that the precision, i.e. pulse-to-pulse reproducibility, of the system is 0.1-0.2 mm. This corresponds to the system design specification. To date the BPM's have been used to study the variation of the closed orbit throughout the Booster acceleration cycle and to study the behavior of the recently commissioned transition jump system.[6] Figure 3 shows the measured Booster closed orbit at low energy (a) and at high energy (b).



(a)

(b)

Figure 3. (a) Low field and (b) high field Booster orbits.

The Booster contains DC correction elements used to smooth the orbit at low energies. Since these elements have almost no effect at high energies, the orbit shown in Figure 3b reflects the misalignment of magnetic elements in the ring. This data will ultimately be used to realign magnets in the Booster in order to improve the aperture. Figure 4 shows a measurement of the Booster dispersion function with the transition jump system on. The measurement is done by taking the difference between two orbits which have the beam purposely run at different radial positions. Figure 4 corresponds to orbits differing in momentum by about 0.15%.

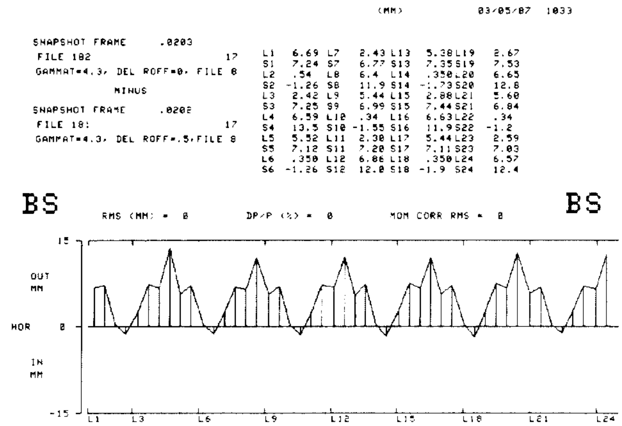


Figure 4. Booster dispersion function measurement with transition jump system operational.

Acknowledgments

The authors wish to recognize the contributions of D. Douglas and B. Ogert for mechanical support; J. Arthur, R. Marquardt, J. Sabo, J. Smolucha, W. South, and E. Stitts for electronics support; Q. Kerns and D. Martin for design support; and F. Sample for applications software. Their efforts were essential to the realization of this BPM system.

References

1. R. E. Shafer et al., "The Tevatron Beam Position and Beam Loss Monitoring Systems," Proceedings of the 12th International Conference on High Energy Accelerators, 1983, pp. 609-615.

2. R. C. Webber, "Calibration of the Booster BPM System," BPM Design Note #25, 1987, unpublished, Fermilab Accelerator Division files.

3. S. P. Jachim et al., "An RF Beam Position Module for the Fermilab Energy Doubler," IEEE Trans. Nucl. Sci., vol. NS-28, No. 3, June 1981, pp. 2323-2325.

4. A. E. Baumbaugh et al., "Beam Position Monitor System for the Fermilab Tevatron," IEEE Trans. Nucl. Sci., vol. NS-32, No. 5, October 1985, pp. 1868-1870.

5. S. D. Holmes et al., "The TEV 1 Beam Position Monitor System," IEEE Trans. Nucl. Sci., vol. NS-32, No. 5, October 1985, pp. 1927-1929.

6. W. Merz et al., "Transition Jump System for the Fermilab Booster," to be published in the Proceedings of this conference.