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A BEAM POSITION MONITOR SYSTEM FOR THE PROTON STORAGE RING AT LAMPF*

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Summary

A high-current Proton Storage Ring (PSR) is being constructed at Los Alamos to accumulate intense pulses of 800-MeV protons from LAMPF for delivery to neutron production targets.[1] The beam's transverse location in the injection channel, ring, and extraction channel will be determined by a beam position monitor (BPM) system. The beam will be detected by stripline sensors that generate 4-quadrant position signals from the spectral components of the beam. Sixty sensors are planned for the installation, with their outputs selected by broadband RF multiplexers. The sensor outputs are processed by a differential phase correlator detector to produce an analog signal proportional to the position of the beam centroid. Digital conversion and processing will give overall resolution of the horizontal and vertical position of the beam at each sensor location to ±2 mm. The monitor will operate over the intensity range of 3×10^8 protons/bunch to 5×10^{13} protons/bunch. The beam-position system contains CAMAC-based instrumentation for display in three formats, including an azimuth histogram, a time plot, and a numerical readout. The monitor system also includes a microprocessor-based check and exerciser unit to serve as a design aid and maintenance tool.

General

Two modes of charge accumulation are planned for the Proton Storage Ring.

(1) Short bunch. In a time period equal to 300 turns of the ring, six short bunches will be accumulated to a level of 1×10^{11} protons/bunch. Bunches have a nominal length of 1 ns. Following the storage cycle, the bunches will be extracted at approximately 1-ms intervals. This storage and extraction cycle will repeat at a 120-Hz rate.

(2) Long bunch. In a time period equal to 2100 turns of the ring, a single 270-ns-long bunch will be accumulated, with a charge of 5×10^{13} protons. The bunch will be extracted in one turn, and the cycle will repeat at a 12-Hz rate.

During the initial orbit alignment of the machine, single microbunches, with about 3×10^8 protons/bunch, will be injected at 0.1 to 1-s intervals. The BPM intensity and position signals will provide information to enable the operator to follow the beam along its path through each segment of the injection, ring, and extraction channels.

Position data will be used to establish an initial closed orbit during this first phase of commissioning. At a later stage the system will be the principal tool used for establishing a precise equilibrium orbit. In routine operation, the monitor system will become an orbit "watchdog," aiding in the overall control of the machine.

Beam Sensor

A typical beam sensor consists of four traveling-wave stripline electrodes arranged in quadrature.[2] Each 30-cm-long, 5-cm-wide electrode is mounted approximately 1 cm from the beamline wall, to give a characteristic impedance of 50 Ω. The electrode structures are housed within the vacuum pumping spools to conserve beamline space, as shown in Fig. 1.

Signals induced on the striplines by LAMPF proton microbunches are narrow pulses having a half-width of about 700 ps, with rise-and-fall times of about 300 ps. Frequency components of the bunch signals exceed 1 GHz. As a bunch passes the sensor, a pulse doublet is produced as shown in Fig. 2. The time between positive and negative pulses is approximately 2.5 ns. The peak amplitude ranges from 160 mV, for a single microbunch, to greater than 10 V for a fully accumulated ring bunch.

The physical layout of the PSR requires that the sensor outputs be transmitted to the processing equipment through cables about 70 m long. To alleviate the gigahertz bandwidth requirement, a pulse-broadening filter is inserted in each line between the sensor and the cable, to reduce possible beam-pulse distortion and lower the bandwidth requirement to approximately 200 MHz. The amplitude symmetry of the doublet is preserved and cable requirements are lessened, so that low-cost RG-213 cable can be used for transmitting beam signals. The broadening filter is a 6th order Gaussian low-pass design[3] having a cutoff frequency of 191 MHz.

Beam Position Processor

The block diagram of the beam-position processing circuits is shown in Figs. 3 and 4. One of the sensors is shown schematically in Fig. 3, with its vertical elements connected through the time-broadening filters to two RF multiplexers. An identical set of equipment is used for the horizontal sensors.

The multiplexers are digitally driven, 500-MHz-bandwidth, RF switches that couple the filtered beam signals from the selected sensor to the processor. The basic multiplexer is a single-pole,12-throw, solid-state, bipolar switch, having a maximum channel-switching time of 2 μs. Appropriate grouping of the basic switch permits 1 beam sensor out of 60 to be selected. A specific area for observation, such as the injection channel, the ring, or the extraction channel may be selected also for examination.

In the short-bunch ring mode, the narrow signals from the multiplexers are passed through 8-section transversal filters that provide an additional time expansion of beam information. As shown in Fig. 2, the narrow single-pulse format produced by the beam sensor is converted to a 200-MHz RF burst lasting for 8 complete cycles, or 40 ns. This information is then easily processed by the position electronics.

The long-bunch ring mode accumulates sequences of microbunches at 5-ns intervals from LAMPF. In this mode the transversal filters are bypassed and the beam signals are transferred directly through the RF multiplexers. Longitudinal dispersion of the protons by space-charge force and momentum spread produces a very complex beam-sensor signal as the accumulation process advances. For this reason an autocorrelation position processor has been chosen as the major building block for the system. This choice permits the simple signal spectrum of the short-bunch mode, as well as the more complex spectrum of the long bunch signal, to be processed by the same system.

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Figure 4 indicates the filtered signals from a typical sensor as $2A\angle\theta$ and $2B\angle\phi$. Because amplitude balance and symmetry is retained throughout the processing circuits, formation of the ratio, B/A, gives the measure of beam displacement from the electrical center of the sensor electrodes.[4] The ratio is developed, without dependence on beam intensity, by converting the amplitude ratio into a differential phase quantity that is processed with limiters and a phase-correlator detector. This method permits the development of a signal proportional to the ratio B/A, for a variety of input spectra. The circuits shown in Fig. 4 accomplish this operation via time delay, multiplication, and integration processes. Signal A is split into two signal components by an RF hybrid power splitter to give equal amplitude outputs at 0° relative phase. Correspondingly, signal B is split into two equal-amplitude components at a relative phase of 0° and 180°. These four signals are combined by two RF hybrid quadrature junctions to produce composite output signals, whose phase difference, ψ_d, can be expressed as

$$\psi_d = \tan^{-1}\left[\frac{\frac{A}{B}\sin\theta + \cos\phi}{\frac{A}{B}\cos\theta - \sin\phi}\right] - \tan^{-1}\left[\frac{\frac{A}{B}\sin\theta - \cos\phi}{\frac{A}{B}\cos\theta + \sin\phi}\right]$$

Equating the phase angles θ and ϕ to zero gives $\psi_d = 2\tan^{-1}(B/A)$. Thus, the measure of the B/A ratio and the off-axis beam displacement is ψ_d. A plot of this function is shown in Fig. 5.

The phase detector output is filtered and amplified to produce an analog position voltage. When $A = B$, $\psi_d = 90°$ and the position voltage is zero because the detector is a double-balanced mixer operating with a $\cos\psi_d$ law. Deviation from $\psi_d = 90°$ gives a positive or negative analog-voltage output proportional to the beam displacement from center. The phase sensitivity at the center of the beam is 6.4°/dB of difference between electrode voltages. A signal indicating presence of beam is also obtained, as shown in Fig. 4.

Digital Processor

A block diagram of the digital processing circuits is shown in Fig. 6. The analog-position signal is applied to a track-and-hold gate that is an integral part of an 8-bit analog-to-digital converter. Timing information derived from the beam-injection triggers and the beam-present signals enables these circuits to sample the position voltages and convert them to 8-bit, 2's complement digital values. Nonlinearities in the analog processor are compensated by a digital amplitude linearizer with fixed nonlinearity. Provisions are made to use the raw data or the linearized information.

The monitor system includes a digital interface that is switchable between a local 8085 µP-based System Exerciser and the PSR instrumentation and control computer that interfaces with the BPM processing electronics through a CAMAC module (LSI/11-23). The CAMAC-based system is used for normal ring operation, whereas the exerciser provides off-line local development capability.

Management of the data-conversion equipment is accomplished by 8085 microprocessor-based hardware. Control and timing is accomplished by TTL circuits, and digital storage is provided by RAM capable of 3-MHz writing rates. System information, channel selection, and data-processing instructions are supplied through the control interface, whereas position values are transmitted via the data interface. Serial digital data transmission is performed by CAMAC and USART hardware.

For off-line development, position data is organized by the display processor and transmitted via the IEEE-488 bus to a Hewlett-Packard Model 1350A Graphics Translator. A local X-Y CRT display provides the visual data presentation.

Display Formats

Three types of displays, which are generated by the Graphics Translator and the X-Y CRT display, have been developed for the system. The translator is a vector generator that stores up to 2048 vectors or characters. Its memory is organized into as many as 32 files. A program residing in the exerciser or system controller develops appropriate data grids on the CRT, controls position data, and manages the alphanumeric displays. Figure 7 shows a simulated azimuth histogram for the 20 ring sensors. Similar displays are available for the injection and extraction channels. The vertical vectors, shown in groups of five along the azimuth lines, represent beam displacement. The most current measurement, and four previous measurements, are displayed for each station. Three scale factors are available (2 cm, 1 cm, and 0.5 cm, full scale). Beam-presence information, together with station location codes, is shown by the lower trace. An alphanumeric display of beam-position values is shown in Fig. 8. The third type of display is a time plot illustrated by Fig. 9. Here, 1000 sequential position values for a particular sensor give a time history of the beam position. This display is useful for observing orbit trends, turn-to-turn coherent effects, etc.

System Development

To date, all of the electronic devices for the BPM system have been designed, and component prototypes are being tested. Tests of model beam sensors, filters, multiplexers, and beam triggers have been made with LAMPF proton beams. System studies are currently underway using prototype devices.

Acknowledgments

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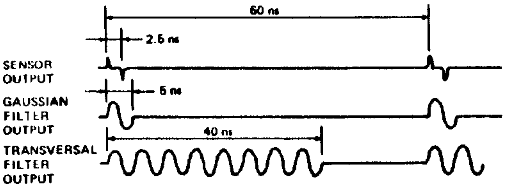
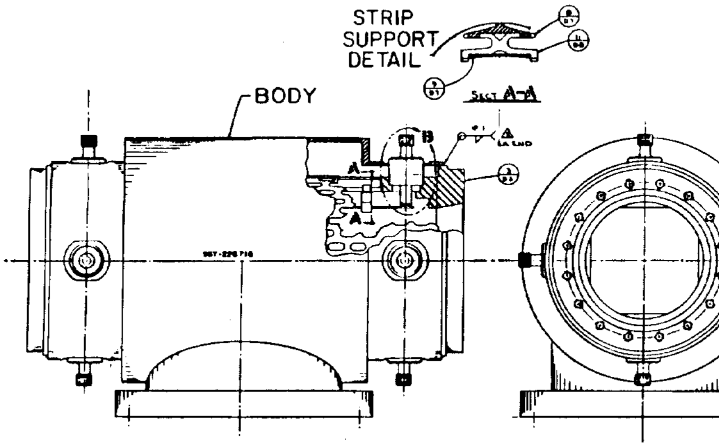


Fig. 2. Timing diagram, short-bunch mode.



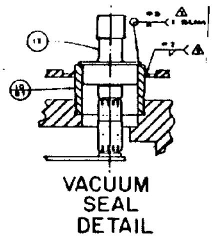


Fig. 1. Beam-position sensor details.

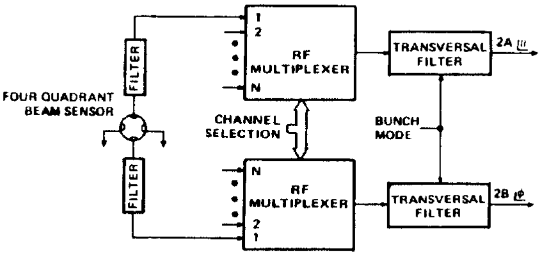


Fig. 3. Block diagram - multiplexer and transversal filter.

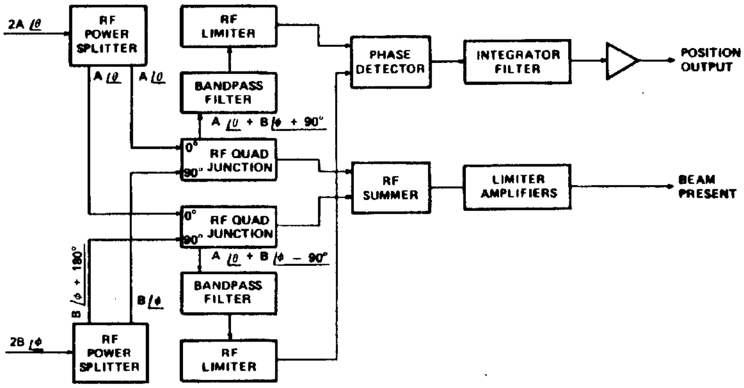


Fig. 4. Block diagram - beam-position processor circuit.

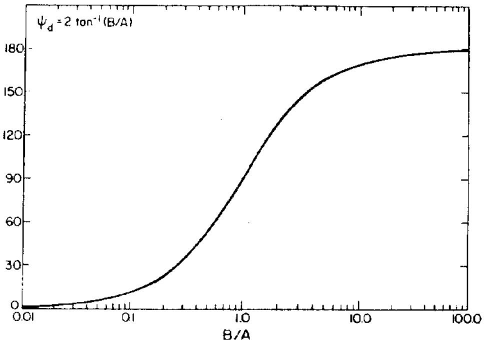


Fig. 5. Plot of phase-processor characteristic.

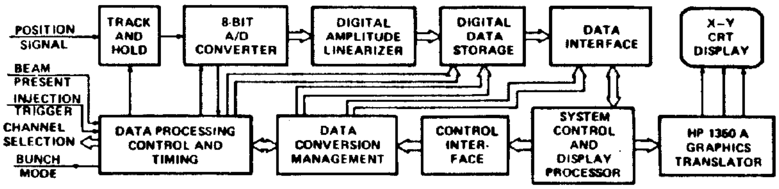


Fig. 6. Block diagram - digital processor.

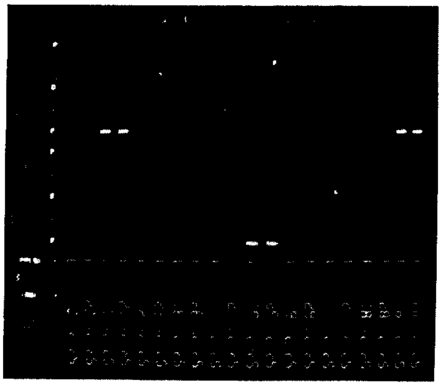


Fig. 7. (Azimuth)

Fig. 8. (Alphanumeric)

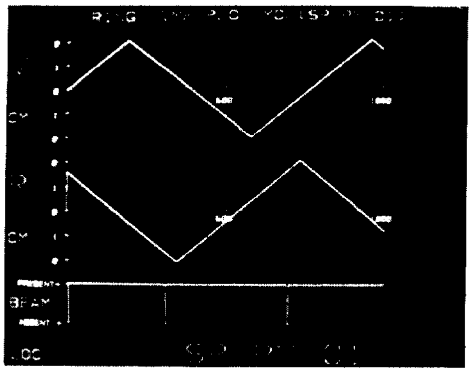


Fig. 9. (Time)

Processor Displays.