THE ENERGY SAVER BEAM POSITION MONITORING SYSTEM

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The Energy Saver requires the simultaneous operation of many control systems in order to run. The systems include Vacuum, Refrigeration, Power Supply, Quench Protection, and Correction Element Systems, as well as the Beam Position Monitor (BPM) and Beam Loss Monitor (BLM) systems. Unlike the other systems, the BPM and BLM systems could not be tested until the Energy Doubler injection studies on April 22.

The BPM detector is a pair of 20 cm long directional couplers mounted inside the main Saver quadrupole at 4°K. There are 216 detectors in all, half vertical and half horizontal. RF signals induced in these striplines are carried to the adjacent Service Building where special NIM modules, using amplitude-to-phase (AM/PM) conversion, generate both analog position and intensity signals with rise times less than 100 nsec.

This combination of directional couplers and the AM/PM module was tested in the Main Ring and found to give position measurements with a precision of ±30 microns at 3×10^{10} ppb (protons per bunch) and ±500 microns at 1×10^{8} ppb, when the accelerator is operating in batch mode (for fixed target physics). In order to make the same circuit operate in collider mode (bunches separated by several microseconds rather than the normal 19 nsec in batch mode) tuned circuits resonant at 53 MHz were included in the AM/PM circuit. The threshold for reliable operation in collider mode is about 1×10^{9} ppb. The natural directivity of the BPM detector allows it to detect antiprotons in the presence of protons and vice versa (the rejection of signals from wrong-way bunches is about 24 db).

Fast comparators (whose threshold is set by the host computer) on the intensity signal trigger fast self-synchronizing sample-and-hold circuits on every position and intensity signal. The self-synchronization is necessary since the detectors coupled to a single processor are spread over about 250 m, and the signals are skewed in time over about 1 microsecond. The intensity signal is amplitude compressed in a logarithmic amplifier (a forward-biased p-n junction is used) and digitized in about 5 microseconds.

Digital processing proceeds in either of two ways. Normally, up to 64 consecutive position digitizations (at the rate of 1 to 4 times per revolution) are averaged to obtain a closed orbit measurement with minimal errors due to coherent betatron oscillations. These measurements are stored in a 5k byte random access memory at specific times to aid in orbit correction calculations, and are also used to initiate a beam abort if the beam strays beyond a position limit. These measurements are also

loaded into a 10k byte circular buffer which is stopped whenever any system fires the abort kicker. These measurements can then be used to reconstruct the orbit prior to the abort.

The second digital processing stores the digitized value of both the position and intensity for a single passage of beam. This requires about 300 nsec of 2×10^8 ppb (i.e. about 3×10^9 protons) which is normally not expected to quench the magnets. Such a beam is very useful in beam tuning. This mode of operation utilizes computer-downloaded gate delays and gate widths which are triggered by encoded timing signals on the 10 MHz Saver clock. Coincidence resolution times between the clock signal and the beam are obtainable with 200 nsec resolution, allowing the following of a single bunch of particles around the ring in collider mode. This processing method is also useful for injection and first turn studies.

The BLM detector is a 110 cc argon-filled sealed-glass ion chamber operated at about 2000 volts. There are about 220 such detectors around the ring. They are coupled to 4-decade logarithmic amplifiers with a 50 msec decay time constant (chosen to match beam induced quench properties of Saver magnets). About 1 nanoamp of dc current is "leaked" into the amplifier to assure a digitizable output even when there are no beam losses. This signal is digitized and stored at 8 msec intervals. Excessive beam losses can also initiate a beam abort.

All of the digital processing is carried out in Multibus. Each system (there are 24) includes three Z80 microprocessors to manage the hardware, the memories, and the link to the Control System. Computer initiated hardware tests are permitted between accelerator cycles and carried out under microprocessor control. These tests include measuring all dc power supply voltages, injecting a dc current into the BPM cables to check cable and detector continuity (the BPM detectors are back terminated), injecting RF into the AM/PM circuits, and ramping the BLM high voltage down and up to induce charge in the current amplifier (the BLM detector interelectrode capacitance is about 2 picofarads). This test thus checks continuity of all cabling and status of the BLM electronics. In addition, all downloaded parameters can be read back for verification. In case of a BPM or BLM failure, their beam abort capability can be defeated by computer control.

In the Control Room, color displays create linear bar graphs of both horizontal and vertical beam position, as well as logarithmic bar graphs of beam intensities and losses around the entire ring. In addition, any or all of the data stored in the random access memories (a total of 250k bytes) can be read into the host computer data base for beam orbit calcutations. On April 22, orbit correction algorithms applied to the single pass position measurements corrected the orbit to about ±1 mm in about 3 injection cycles. (See the cover illustration on this issue.) Based on the success of these tests, obtaining a closed orbit in the near future appears to be assured.

Many groups at the Lab participated in implementing the BPM and BLM systems. The Magnet Factory provided the BPM detectors, the Accelerator RF Group provided the AM/PM circuits, Controls Group provided the BPM analog processing hardware, Research Services provided the Multibus hardware, Radiation Physics provided the BLM detector and electronics, and Accelerator Operations provided the software applications programs and color graphics displays. So all the Lab can share the credit for the successful operation of the BPM and BLM systems.