DESIGN AND COMMISSIONING OF BEAM POSITION MONITORS IN THE IUCF COOLER INJECTOR SYNCHROTRON

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Abstract

IUCF is completing construction of the cooler injector synchrotron (CIS). A secondary emission profile monitor system (harp) is used for beam profile and emittance measurement. The harp design was patterned after a design used for many years at Fermilab [1]. Two, non-interceptive, beam position monitor (BPM) systems have been built to facilitate and enable commissioning and operation. In the 7 MeV injection beamline, high input impedance front-end amps are used to detect the signal from 4-quadrant, electrostatic pickups. The beam in this area will average 200 μA peak, with a pulse width of 100 - 200 μs and repetition rate of up to 5 Hz . In the CIS ring, 4-quadrant, elliptically shaped electrostatic pickups are used for impedance matching to the beamline. An electric field modeling program was used to determine the parameters of the plates in the pickup. Logarithmic amplifiers are used to detect the beam in the CIS ring, providing a linear output and an extended range. A time of flight system is also discussed.

1 BEAM PROFILE MONITOR

1.1 Electronics

The harp uses a 5 printed circuit board stack, with 24 wires on each of the horizontal and vertical detector boards, spaced 1 mm apart. The first, third, and fifth board have 6 wires, spaced 4 mm apart, and are biased with a small voltage to collect scattered electrons. A large range of bias voltages were tried, finding 90 volts to be optimum. The signal is carried from the vacuum chamber on a ribbon cable and through a vacuum connector designed and built in house. A 100 ft. folded and shielded ribbon cable is then used to send the currents to the electronics board which is housed in a NIM crate. The circuit board front-end electronics have 5 MΩ resistors to ground in parallel with 0.01 μF capacitors providing a time constant of 50 ms. The signals are then sequentially multiplexed and integrated. The integrator uses a low bias current op-amp with a shorting switch in parallel with the feedback resistor, which is activated after each channel is read from the multiplexer, zeroing the amp before the next multiplexed channel is read. After a buffer amp, the signal goes to a fast ADC with FIFO memory. This type of ADC allows the user to acquire data at a fast rate and display it whenever it is desired. The timing for the harp electronics is incorporated on the circuit board, using a programmable array logic chip (PAL). A trigger from the master timing clock initiates the PAL, which sends out the appropriate pulses to the devices on the board and provides the ADC clock. The data acquisition parameters can changed by reprogramming the PAL. During commissioning, a stand-alone display system is used, incorporating a PC and graphical programming package, HP VEE, from Hewlett-Packard [2]. In the operational system the signals will be displayed at the operations console through the controls computer.

1.2 Operation

The harp has been the primary diagnostic during commissioning of the CIS ring. Two harps have been placed in the ring injection beamline and one in the ring. The first harp is mounted in front of a stop, allowing one to monitor intensity while adjusting the profile. The harps are moved in and out of the beam path using air actuated insertion devices. The flexibility of this setup, allows an operator to observe a harp display of first turn beam in the CIS ring along with multi-turns (Fig. 1) and also accumulate maximum intensity with the harp out of the beam path.

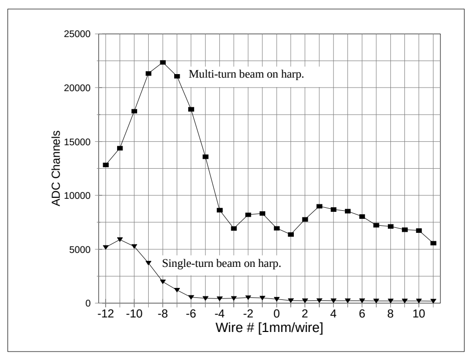

Figure 1: Horizontal harp display. The lower trace is first turn beam in the CIS ring. The upper trace is multiple turns.

2 BEAM POSITION MONITORS

2.1 Injection Beamline

The 7 MeV injection beamline and the CIS ring have a non-interceptive BPM systems designed into them. The injection BPMs have not been useful because of electron stripping from the H- beam. When electrons are stripped from the beam their flight angle can change so that they strike the electrostatic pickup, saturating the electronics. A biased guard electrode has been tried but has had little beneficial effect. The system should be useful when proton beams are accelerated.

2.2 Accelerator Ring Pickups

When a beam pipe with circular cross-section is divided into four segments as electrodes to measure beam position (upper and lower segments for vertical position and right and left segments for horizontal position), it is obvious by symmetry that all four segments should be cut with the same arc length to get equal responses (equal induced currents) to a beam pulse traveling along the centerline of the pipe. An elliptical cross-section will behave very differently, since some points on the pipe are significantly farther from the centerline than others. If the long axis of the ellipse is horizontal, then the upper and lower segments will have to be much smaller than the right and left segments to get the same response. It is necessary, then, to be able to calculate where to cut the pipe to get segments of the appropriate size.

Past experience indicated that to a good approximation the charge induced on the beam position segments could be computed electrostatically, i.e. electrodynamic (radio frequency) corrections were apparently small. Therefore the relative responses of a set of segments of any given size were calculated as a two-dimensional electrostatic problem with the segments held at ground and with a point charge (actually a line charge in three dimensions) at the desired beam position. The system was enclosed in a rectangular boundary also held at ground. The relative responses of the segments should then be proportional to the total charge induced on the surface of each segment. By Gauss' Law, the surface charge density on a conductor is proportional to the magnitude of the electric field strength just outside the surface.

Calculations were done with the electro/magnetostatic program MagNet by Infolytica Corp. This program includes the capability of defining a curve as a succession of line segments by manually selecting end point locations with a cursor. The program can then generate a graph of electric field strength magnitude vs. position along the curve. Graphs of this type were produced for each segment and then integrated by finding the area under the graph line to get a number for each segment which should be proportional to the total charge. Calculations of this type were done both to determine the segment sizes which should be cut and to predict the relative responses of the four electrodes to various beam positions.

2.3 BPM Electronics

The CIS ring uses elliptically shaped 4 quadrant electrostatic pickups. They are positioned at the entrance and exit of each of 4 bending magnets. Each pickup has a dedicated set of electronics attached to it. The detectors used are Analog Device, AD640 logarithmic amplifiers [3]. The log amp detector design [4] was selected for it's wide dynamic range, 65 dB, and ease of use, requiring no local oscillators or mixers. The log amps are followed by low noise op-amps with 30 kHz active filters. The difference of the log amps, L-R, and U-D, gives the normalized position in the horizontal and vertical planes. The sum of the two horizontal signals provide the intensity. The signals go to dedicated high speed ADC modules with on board memory. This type of signal buffering allows the operator to view the position and intensity history of the beam during injection, and ramping in great detail.

2.4 BPM Operation

The log amp detector has been very useful during commissioning. The intensity output from the amp can be displayed on an oscilloscope (Fig. 2) showing the lifetime of the injected beam in log scale. Intensity was detected even when the rf buncher was turned off, because of the beam self bunching in the high "Q" cavity. The high bandwidth of the detector gave a very accurate position measurement during the short time the beam was in the ring between injections. One can imagine tracking the position, in a 100 microsecond scale if need be, during the ramping, acceleration process, correcting ramp parameters.

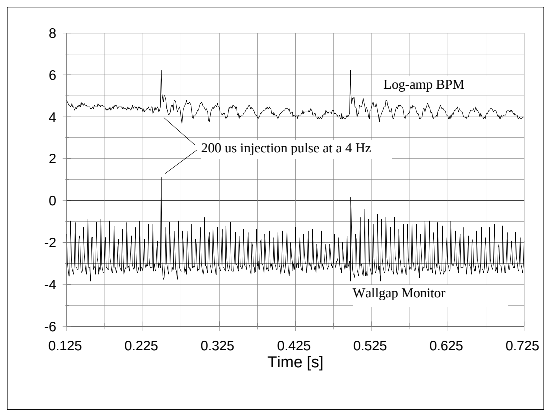

Figure 2: Injected and stored beam in the CIS ring. The top trace is the DC output of the log-amp BPM intensity. The lower trace is the WGM RF output.

Two, more conventional BPMs, are used in the ring for beam feed-forward. The system uses diagonally cut pickups, a 10.7 MHz intermediate frequency (IF), and AM to PM convertors to measure the position of the beam in the horizontal plane. The system has yet to be tested with beam.

3 TIME OF FLIGHT

A time of flight system (ToF) is being used in the 7 MeV injection beamline to detect changes in the beam energy from the RFQ/DTL. The system is similar to the one used at TRIUMF [5], where as, a change in energy is measured as a change in phase between two pickups of a fixed, known distance apart.

3.1 Electronics

The 200 us, pulsed, beam is accelerated through the RFQ/DTL, using a 425 MHz RF amp. The non-interceptive, resonant, beam pickups are immediately down stream of the accelerator, 2.5 meters apart. A beam signal is detected, buffered and sent to the ToF electronics. An Analog Device AD607 [6] is used as an RF to IF, 10.7 MHz, convertor.

The AD607 is normally used in wireless communications as a down-convertor amplifier. It has a mixer and log amp with AGC, as well as, an I & Q demodulator, all in a 20 pin surface mount chip. It has been tested in the lab as an AGC beam position detector with a 75 dB range.

The output of the AD607 is a constant 300 mV signal, which is fed into limiting amps and then a type II phase detector. The output is filtered to a DC level and amplified, sample/held, and buffered. The signal then goes to an ADC, to be displayed on a controls computer electronic strip chart, a constant monitor of the 7 MeV energy.

3.2 Operation

The theoretical resolution of the ToF was calculated as 1.5 keV/degree. In preliminary testing with beam, the resolution was 3.8 keV/ degree when calibrated against a down stream bending magnet, this disparity has yet to be solved.

4 ACKNOWLEDGMENTS

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