BEAM DIAGNOSTIC SYSTEMS AND THEIR USE IN THE NEW IUCF BEAM LINE [*]

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Abstract

Diagnostic tools developed for and being used in a new 30 m beam line (BL1C) connecting the IUCF high intensity polarized ion source (HIPIOS) with the injector cyclotron are described and the results obtained with them are detailed. These devices include non-intercepting beam position monitors, wire scanners, and beam sweeper systems. Studies of rf beam bunching have been performed using a high bandwidth current readout. Programs have been developed for automatic emittance measurements and beam centering in the beam line.

I. BUNCHER EFFICIENCY TESTS

The combined efficiency of the HIPIOS terminal f/3 buncher, the BL1C f buncher, and the 2f/3 buncher [1] was measured at the end of the beam line, 2 meters upstream of the injector cyclotron inflector magnet. To perform the tests, a water cooled, wide bandwidth stop was installed in the beamline. A dc coupled, FET amplifier was used at the pickup to measure the unbunched, as well as the bunched, beam. The FET amplifier does not discriminate the beam signal, allowing for easier measurements.

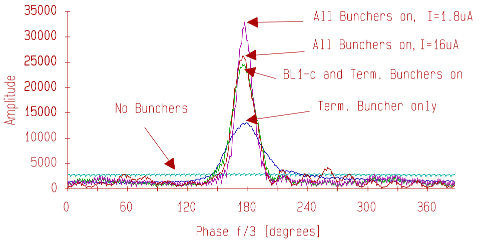

Figure 1. Bunched beam signals compared on a beam stop.

The display in Figure 1 shows the effect of different buncher configurations on the beam. One can see that the terminal buncher is actually more of a prebuncher, and was not designed to bunch the beam into a small phase space. The figure also shows that the tightest bunches occur when using all of the available bunchers and smaller beam currents. When the beam current is increased, the bunching is not quite as sharp and the phase spread increases; space charge effects are suspected. Plans have been made to move the BL1C buncher from its present location to a section further down stream, closer to the injector cyclotron. While this will require more voltage to bunch the beam, it is hoped that the space charge effect can be minimized.

Figure 2 shows the percentage of the total dc beam that is bunched using the different buncher schemes available. The phase acceptance of the injector cyclotron has been measured to be 12 degrees. It can be seen that the best bunching obtained was approximately 60 percent. These measurements are consistent with measurements taken under a variety of running conditions.

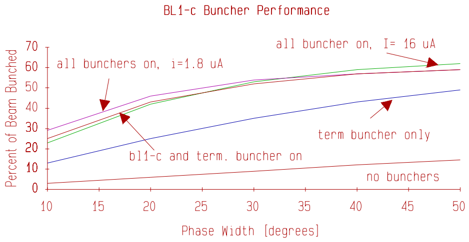

Figure 2. BL1 Buncher Efficiencies

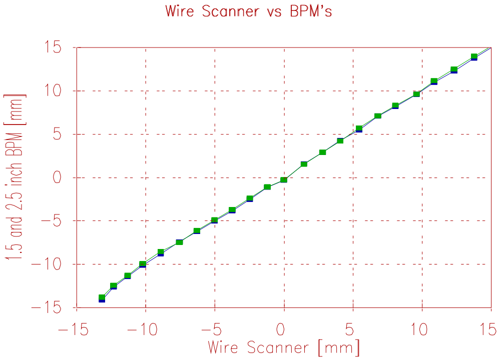

Figure 3. BPM linearity compared to a wire scanner over a 30 mm range.

II. BEAM POSITION MONITOR (BPM) PERFORMANCE

BPM position [2] linearity has been cross-calibrated against a mechanical, spinning wire type beam profile monitor (wire scanner) [3]. A beamline section consisting of a 1.5 inch radius BPM, a wire scanner, and a 2.5 inch radius BPM was incorporated into the initial design for this purpose. In Figure 3, as the beam is moved 30 mm, the wire scanner position output is plotted vs that of the two BPM's. In Figure 4, the difference between the wire scanner and BPM's can be observed. The wire scanner measurement has an accuracy of $\pm$ 0.13 mm, with the BPM's having a computer readout resolution of $\approx$ 0.05 mm. The above data was taken under normal operation conditions with a proton beam current of 20 μA. The theoretical position resolution at this current is $\approx$ 0.03 mm. The BPM performance may be limited by the 60 Hz line noise on the interconnecting cables prior the ADC. This interference can be minimized by analog filters or averaging after digitization, both of which cut system band-

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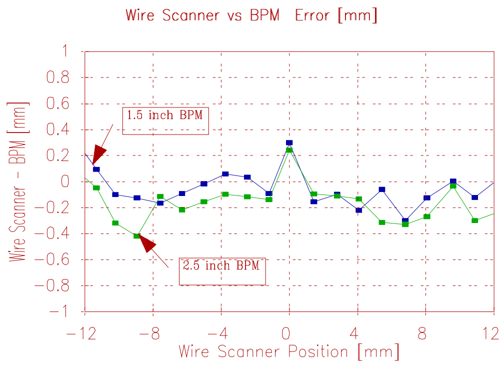

Figure 4. Difference between BPM and wire scanner readings.

width. A better solution would be the use of differential inputs on the ADC.

III. BEAM EMITTANCE MEASUREMENTS

The emittance of the beam at the beginning of the line has been measured using a technique similar to that described by Ross et al. [4]. The output of a wire scanner located 1m downstream of a quadrupole magnet was digitized and recorded as a function of quadrupole magnet current. Programs were written which set the quadrupole polarity, step the quadrupole current through a predetermined range, digitize the wire scanner output, fit the beam width and calculate the emittance. This information is then available as input to beamline modelling software and for the beam sweepers described in section V of this paper. The system measures both horizontal and vertical emittance. A measurement typical of the horizontal results is shown in Figure 5 (where the crosses are the measured data points and the solid line is the result of the fitting algorithm). The horizontal emittances measured are in good agreement with the design values whereas the vertical emittance is approximately 50 % larger than the design goal. Non-linearities in the 15 keV terminal beam line are the suspected source of the problem and studies of the optics of that line are under way to attempt to find a solution.

IV. BEAM CENTERING AND AUTOSTEERING

The beam line has been designed [5] so that steerers and BPMs are located approximately every 90 degrees in betatron phase advance. A program has been written which adjusts the steerers to position the beam to preset values (normally zero) along the length of the beamline. This program is used both to center the beam in the line when first turning systems on and to maintain its position while quadrupole magnets are being adjusted to change focussing conditions. This latter use has proven quite helpful in normal beamline setup. The system routinely maintains the beam's position to ± 1mm. Figure 6 shows the BPM display for the first two legs of the beam line after the steering program has been run. (At the time these measurements were being made the beam was not being transported all the way to the cyclotron.) The horizontal measurement at BPM 12 was not one that was included in the procedure. (In order to maintain a one to one correspondence between steerer and BPMs one had to be omitted in that section.) BPM 9 is not used because of its proximity to the rf buncher and the resulting noise on its signals.

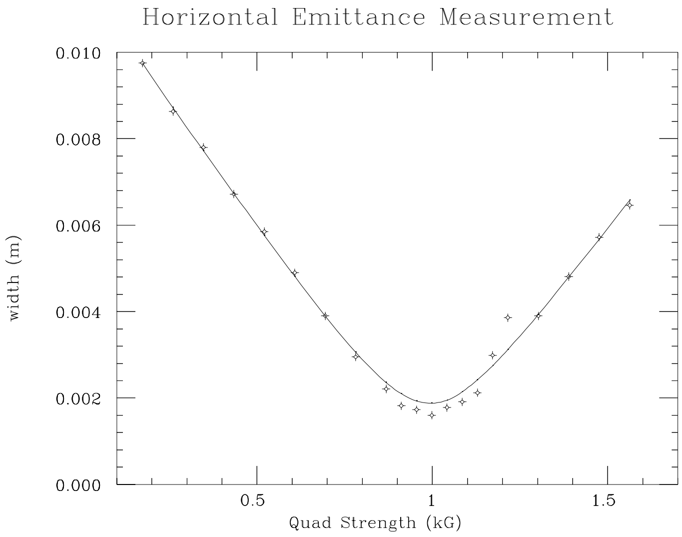

Figure 5. Horizontal Emittance Measurement and fit to data (solid curve).

V. BEAM SWEEPING SYSTEM AND FOCUSSING

The information (σ_{11},σ_{22}, r_{12}, σ_{33}, σ_{44}, r_{34}) obtained in the emittance measurements can be used to generate the phases and amplitudes for the beam sweeping system's control module. Four 10 Hz modulators can be used to vary the current in four steerers to move the beam centroid around a beam ellipse. This ellipse is scaled down by a factor of 2 or 3 from the phase space ellipse obtained by transforming the measured ellipse through the drift space between the emittance measuring quad and the sweeper system. The BPM system output voltage proportional to peak centroid position provides a measurement of the beam envelope. Using this system it is possible to obtain a display of the beam envelope along the full length of the beam line. The quadrupole magnets can then be adjusted to provide the desired focussing conditions. There are displays showing the location and sharpness of waists in each straight section. Rather than tuning the quadrupoles independently, four linear combinations of quadrupole currents have been defined to provide independent control of the location and sharpness of focus in each plane. With these ”combos” and displays of focussing properties, it will be much easier to both adjust the focussing manually and to define algorithms for automatic control.

In the limited development time used to date for this system, it has shown promise as a beam development tool. Further work needs to be done to optimize ”combo” coefficients and to calibrate the 10 Hz modulators. Similar ”combos” involving the last four quadrupoles in beam line appear to make optimizing injection of the beam into the cyclotron easier than independent tuning of the four quadrupoles. This is also an ongoing development project.

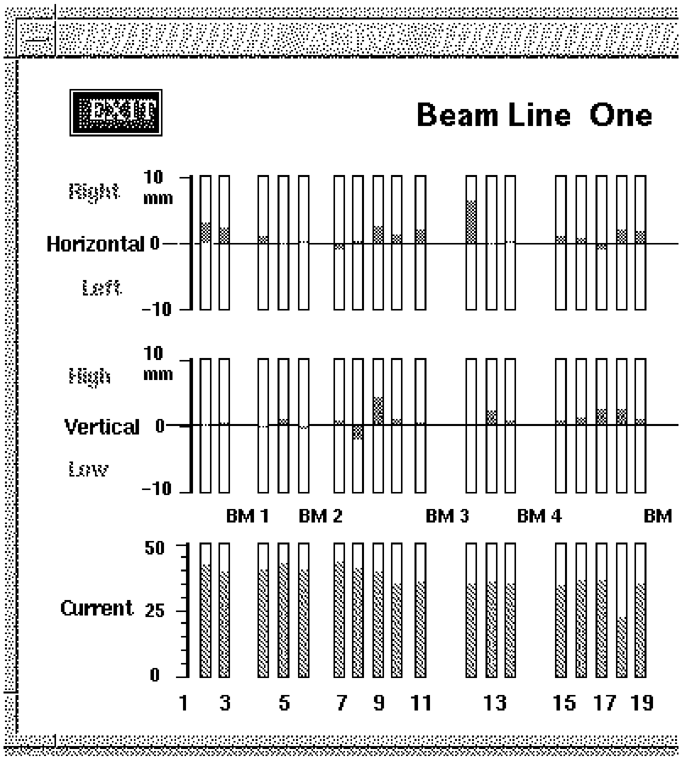

Figure 6. Beam Positions after Automatic Centering.

References

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[5] W.P. Jones et al. Beam Line 1C and Beam Line 1: Design and Tuning Procedures, IUCF Internal Report, 1992.