BEAM TRANSPORT SYSTEM FOR THE IUCF HIGH INTENSITY POLARIZED ION SOURCE

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ABSTRACT

The new High Intensity Polarized Ion Source[1] (HIPIOS) being built at IUCF is designed to increase the intensity of polarized beams by approximately an order of magnitude. The 30 m long beam transport system which connects the 600 kV ion source terminal to the cyclotrons, has been designed with the goal of increasing the transmission of beam from the source to extraction from the main stage cyclotron by another factor of five. In this paper we will discuss the new beamline design and improvements to the beam bunching and injection systems which should provide this increase in transmission efficiency. The beam diagnostic system and procedures planned for tuning the beamline are discussed.

1. GENERAL DESCRIPTION OF SYSTEM

The beamline (BL1) consists of three 90 degree sections with a dispersion free double waist at the end of each. The third section is followed by two quadrupole doublets coupling the line to the injector cyclotron. Each 90 degree section consists of 5 quadrupoles and two dipoles. The first two are quite similar, with the magnets in the sequence QQDQDQQ. The quadrupole between the dipoles will be used to zero dispersion and its derivative; the other four will be used to adjust the location and size of the double waist in the straight section. The third section was designed to splice into an existing beamline and its optics are somewhat different. Its magnets are in a QDQQDQQ configuration. Rf bunching will take place in the straight section at the end of the first 90 degree section, and polarization measurements will be made in the second. The second straight section will also contain slit systems to produce a pencil beam and steerers to use this pencil beam to map out the acceptance of the cyclotron. The quadrupoles and dipoles have been designed to have apertures of twice the expected beam envelope. Because of the low rigidity of the beams in the line this has not had a significant impact on magnet costs.

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2. BEAM DIAGNOSTIC SYSTEMS

2.1. Introduction

The beam diagnostic systems include a nonintercepting beam position monitoring (BPM) system, phase pickups and longitudinal profile monitors; these latter two systems will be discussed in the section on beam bunching. Since the beam intensity will be so high (in the range from 1 to 100 μA), all these systems will be able to process information with high bandwidths (100 kHz) while still providing excellent (60 dB) signal to noise. Consequently, they will be used in high speed hardware feedback loops to keep the ion optical parameters optimized.

2.2. The BPM System

The BPM system, although based upon our previous designs for the Cooler and present cyclotron beamlines, has been completely redesigned. The systems will process information at rates up to 100 kHz, have a nominal accuracy of 0.1 mm, and precision of 0.02 mm. The entire system (pre-amplification and vector sum and differences of the rf signals, rf-IF conversion, and signal processing) is all contained on a single 4 layer board. Although the board will accept signal with frequencies as high as 60 MHz and will operate with an IF as high as 1 MHz, there are no standard "rf" components with exception of mixers. Instead, high speed operational amplifiers are used in both in the rf and IF sections. Such a design would not have been possible, or would have been prohibitively expensive, 5 years ago. The board has 6 analog inputs and 4 analog outputs. The input signals consist of: 4 information signals from the 0.05 m length electrodes (vertical top and bottom, and horizontal left and right); the local oscillator; and a calibration signal which can be switched on the board to any of the four signal inputs. The board also outputs 4 information signals (corresponding to the 4 input information signals):

the horizontal and vertical beam positions, beam intensity, and quadrupole moment.

3. EMITTANCE MEASUREMENT

At the entrance to BL1, a quadrupole and wire scanner are being used to measure emittance of the beam entering the line by measuring beam size as a function of quadrupole strength. This information will then be input to a TRANSPORT calculation to determine the settings of the quadrupoles needed to bring the beam around the first corner with the desired properties.

3.1. Measuring Beam Envelopes

After the emittance has been measured, we will be in a position to use the BPM system to measure beam envelopes even though the BPM's are only measuring the centroid of the beam. The procedure planned is to use two x-y steerers located in the drift space before the first quad to sweep the beam along the surface of an ellipse that has the same shape and has one fourth the area of the beam. By making synchronous measurements of the beam centroids and steerer settings the shape and size of the beam ellipse at each BPM will be obtained.

4. BEAM STEERING AND CENTERING

BL1 has been designed so that, starting at the beginning of the line, pairs of steerers and BPM's are located approximately every 90 degrees in betatron phase advance (in both traverse planes) along the beamline. Redundancy is provided by the fact that each BPM measures both horizontally and vertically and there are some BPM locations that are used for vertical information with the horizontal information being a secondary consideration.

It is planned to steer the beam by stepping down the beamline using each steerer in turn to zero the beam's position at the BPM 90 degrees downstream of the steerer. Although this procedure can be easily performed in a "manual" mode, the entire operation will be automated.

5. QUADRUPOLE TUNING PROCEDURES

5.1. Dispersion Control

BL1 is designed to have zero dispersion in the straight sections. For the first two corners which have a quadrupole magnet centered between the dipoles, there is a unique setting of that quadrupole which will zero the dispersion everywhere in the subsequent straight section. The BPM at the entrance to the quadrupole following the second dipole in the corner will be used to measure the change in horizontal position while the control computer is varying the two dipole fields. The sensitivity of this method is such that a 1% error in quadrupole strength will give a 0.8 mm position shift at the BPM when the dipoles are being varied by +/- 1%. This position amplitude is about 50 times the BPM system resolution, and thus it should be possible to set these quadrupoles with a precision of about 0.01%.

Setting the quadrupoles in the third corner is somewhat more complicated because there are two quadrupoles between the corner dipoles. However the effect on dispersion of one of the quadrupoles is four times than that of the other. Thus by using the sensitive quad in an analogous way to those in the first two corners, it will be possible to zero the dispersion in the last straight section in a straightforward manner.

5.2. Focussing Adjustments

In order to provide control of the position and sharpness of the waists in the straight sections, software controls for combinations of quadrupoles will be created. It is possible to generate four combos (linear combinations) which independently adjust the position of the x or y waist and the sharpness of the x or y waist. Combo's of the readouts from the beam sweeping system will provide a measurement of each of these parameters. Consequently there will be a unique readout for every control, leading to simple "manual" or automatic setting of quadrupoles.

6. BEAM BUNCHING AND PHASE CONTROL

6.1. Overview

There is a two-stage bunching system. In the ion source terminal there is a gridded single-gap buncher with a ramp waveform. This buncher will operate at the cyclotron frequency, or the 2nd or 3rd subharmonic for beam pulse-selection. This system pre-bunches up to 90% of the beam into a 60 degree width bunch for further bunching by a resonant klystron buncher in the beamline. This second buncher has an adjustable length to maximize the transit time factor for any beam species and any cyclotron rf frequency. The location of this buncher determines the ratio of the beam energy spread to phase spread at the injector cyclotron. It is located 21 m upstream of the cyclotron to provide beams with an energy spread of +/- 1.5 keV and +/- 4 degrees.

6.2. Buncher System Beam Diagnostics

Both bunchers will be phase-locked to the beam, consequently automatically compensating for the myriad of mechanisms which can cause a change in the beam phase with respect to the bunchers. The voltage of the high energy buncher needs to be scaled as a constant plus an amount proportional to the square root of the beam current due to space charge effects; this will be done in hardware using a beam intensity monitor and fast signal processor to send a beam current dependent reference signal to the automatic level controller (ALC).

At the entrance to the cyclotron, the beam bunches will be about 0.005 m in length. To measure their length we are using a Longitudinal Profilometer (LPM) which consists of 3 parallel chemically-etched grids, separated by 0.002 m, mounted with their surfaces normal to the beam direction. The outer two grids will be grounded to prevent the center grid from sensing the electric field from the beam before its arrival. The signal will be taken from the center grid. We do not have instrumentation capable of resolving such high frequency signals; instead, a Bunching Factor Diagnostic (BFD) will calculate the bunching factor by comparing the amount of power detected at multiple harmonics of the fundamental frequency.

We may, in addition, have automatic tuning of the buncher amplitude and phase. The buncher amplitude would be controlled by modulating the amplitude and synchronously detecting the output of the BFD to generate an error signal. A similar system would modulate the buncher phase and synchronously detect the beam current at the output of the cyclotron.

7. MATCHING TO INJECTOR CYCLOTRON

The injection system for the Injector Cyclotron consists of two electrostatic cylindrical inflectors. The first element is used to compensate for the fringe fields of the cyclotron magnets and bends the beam in the opposite direction as the second element. The gap in this element has been increased by 25% to minimize its restrictions on the beam and provide greater flexibility in steering. The second element has been one of the primary restrictions for the present beamlines and because of voltage holding capabilities in a confined space it is not possible to increase its gap. In the current system, the distance between the inflection elements and the rf buncher is much less than in the new system and as a result the energy spread in a beam of a given pulse length is much larger than in the new system (+/- 5.0% rather than +/- 0.3%). This places a significant limit on the transmission from existing beamlines to the cyclotron.

Four tuning combos will be generated using the last four quadrupoles to adjust the positions of the two waists and their sizes inside the cyclotron.

8. BEAM INTENSITY MODULATION SYSTEM (BIMPS)

An electrostatic quadrupole which is located after the junction of the new beam line with two existing injection lines will be used to modulate the beam intensity when beam is being shared by users with significantly different intensity requirements. This quadrupole, which will be off for the high intensity operation, will be pulsed on to blow up the beam when the switching magnet is set to bring beam to the secondary user who requires a less intense beam. This system has already been tested and found to be very effective in the present beamline, providing modulation of the beam current by a factor of 1000 on a 1 μs time scale.[2)]

9. SUMMARY

The beamline has been designed to incorporate diagnostics which can, in essence, provide an error signal for each variable in the line. This will lead to a significant reduction in the time needed for manual setup of the beamline and will make it possible to fully automate systems as they are commissioned.

10. REFERENCES

1) Derenchuk, V. et al., these procedings.
2) M. S. Ball, B. Hamilton, private communication.