OPTIMISING INJECTION INTO CELSIUS WITH A STEERING FEEDBACK AND BETA-MATCHING SYSTEM

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Abstract

In order to provide reproducible conditions, a steering feedback system consisting of two beam position monitors and two steering magnets is installed in the beam line immediately upstream of the injection point into CELSIUS. Moreover, a 1 mm Aluminium wire placed vertically on the horizontally moving stripping foil mechanism measures the beam profile and the emittance. This allows adjusting upstream quadruples to optimise injection conditions. Preliminary operational result is presented.

1 INTRODUCTION

CELSIUS[1] is a cooler-storage ring accelerator for ions from the Gustaf Werner Cyclotron. It is primarily intended for nuclear and particle physics experiments with stored, cooled and accelerated ion beams interacting with extremely thin internal targets. The ring consists of four 90 degrees arcs and four straight sections. One straight section is used for injection into the ring.

There are two modes of injection into CELSIUS[2]. These are called multi-turn injection and stripping injection. The injection takes place when the bumper magnets displace the position of the closed orbit on the injection straight section during injection.

A very important task, on which beam development effort are taking place, is to make it possible to combine proton therapy and operation of CELSIUS at the same time. Thus to combine WASA (Wide Angle Shower Apparatus) and proton therapy, we need to use the electron cooler to accumulate 180 MeV protons, which are injected by multi-turn injection without stripping. We have stored 10^9 180 MeV protons by this kind of injection, to be compared with more than 10^{11} with the usual method of stripping injection. Thus we need to improve the efficiency of the multi-turn injection without stripping, which has to be used for polarised protons, 180 MeV protons, and heavy ions.

Slow drifts in the cyclotron and the beam line magnets make it necessary to adjust the CELSIUS injection parameters from time to time during experiments in CELSIUS. Here we demonstrate how the two beam position monitors, that are installed in the CELSIUS injection line and will be used to automatically adjust steering magnets, to keep the incoming beam path centered. This will also make it possible to adjust the focusing of the beam without at the same time getting unwanted changes in its position and angle at the injection point. A 1 mm aluminium wire has also been attached vertically to the stripping foil mechanism system. This system is equipped with a movable arm to measure the horizontal emittance and profile of the incoming beam. The beam parameters will be deduced by scanning upstream quadruples.

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2 HARDWARE

2.1 Stripper Foil and Telescope

A new stripper foil mechanism equipped with a vertical 1 mm aluminum pin had been designed, constructed and installed at the CELSIUS entrance. This new mechanism has space for three different stripper foils of different thicknesses in order that suitable foil thicknesses can be used for different ions that can be stripping injected. The foils have an open vertical edge. The two thin foils are of carbon, the thick one is of aluminium. The position of the foils is adjusted remotely through the control system.

The stripper telescope consists of a pair of detectors 15 cm apart. They are installed near and outside the beam line close to the CELSIUS entrance. Each detector is consisted of a 0.5 cm thick, 4 by 5 cm plastic scintillator and a light-guide mounted onto a photomultiplier(PM). The two detectors are in coincidence to reduce the background count rates generated by them. The faces of the scintillators are perpendicular to the direction of the particles in the beam line. The scintillators emit light as the secondary particles pass through them. The emitted light is collected by the PMs and the PMs signals are transmitted through a discriminator to a counter. A counter registers the number of counts per second and resets itself just before the new pulse arrives from the cyclotron.

2.2 Beam Position Monitors

The two dual axis beam position monitors installed in the beam line immediately upstream of the injection point into CELSIUS have a pair of hollow electrodes each on which the signals are induced. Each hollow tube is diagonally cut (about $45°$) and insulated to make two electrodes. The two BPMs are installed 3.5 meters apart in a drift space to have sufficient lever arm to measure the angles and positions. The induced signals which are linearly related to the beam positions are first pre-amplified, then fed to an amplitude detector and via a multiplexer to an analog to digital convertor(ADC). Finally, the signals from the ADC are sent to the work station through the Digital Signal Processor interface (Fig.-1). The detection electronics has 8 channels and produces charge independet horizontal and vertical positions in each BPM [3].

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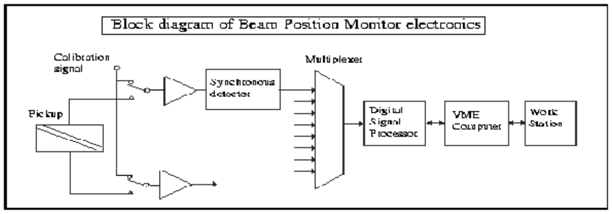

Figure 1: *Block Diagram of BPM Electronics*

3 PROFILE AND EMITTANCE MEASUREMENT

In order to convert the beam flux density as a function of position into a measurable signal, we scanned the incoming beam with a 1 mm aluminum pin at the CELSIUS entrance[4]. A scintillator and a photomultiplier installed near and outside the beam line, detect the secondary particles emitted as the step motor driven pin scans across the beam 0.8 mm every 3 seconds and produces a signal proportional to the number of particles intercepting the pin. It is assumed that the transverse particle density is a near-Gaussian distribution. The spatial r.m.s. beam width at the scanning point, $\sqrt{\sigma_{11}(1)}$, can be determined, (Fig.-2).

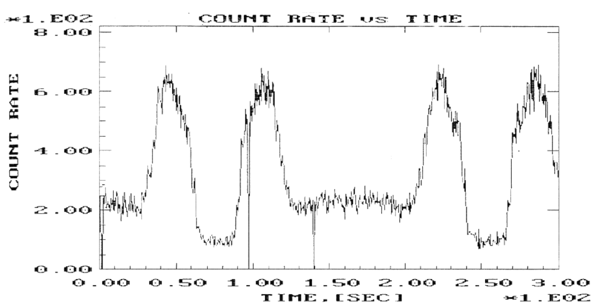

Figure 2: *Beam profiles and emittance measurements at the CELSIUS injection. The stripper pin was scanned across the beam by two in-and-out cycles.*

If a beam has matrix $\sigma(0)$ at some point, z_0, and matrix $\sigma(1)$ at some other point, z_1, downstream, the transformation of the beam between z_0 and z_1 is given by a transfer matrix R:

$$R = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \quad (1)$$

such that

$$\sigma(1) = R\sigma(0)R^T \quad (2)$$

where R^T is the transpose of R. Since it is only $\sigma_{11}(1)$ that we can measure at the scanning point, we write out the expression for this element as a function of the incoming beam $\sigma(0)$ as

$$\sigma_{11}(1) = R_{11}^2\sigma_{11}(0) + 2R_{11}R_{12}\sigma_{12}(0) + R_{12}^2\sigma_{22}(0) \quad (3)$$

The elements of $\sigma(0)$ can be deduced from a set of three measurements of $\sigma_{11}(1)$ obtained from beam conditions described by three different transfer matrices[5]. To vary the transfer matrices, we change the parameters of the magnetic beam line elements by varying the gradients of the upstream quadruples Q_F30 and Q_F31. By doing so, the size of the beam spot at the pin position varies as described by eq. (3) along with the transfer matrix just defined. The elements of the matrix were extracted from a set of profile measurements taken at several quadrupole settings[4]. In fact we took eight independent width measurements rather than just three to obtain the matrix element of $\sigma(0)$, namely $\sigma_{11}(0), \sigma_{12}(0), \sigma_{22}(0)$, and the data were subjected to least-squares analysis.

In a test run the r.m.s. value of the horizontally measured beam profile at the CELSIUS entrance have been evaluated to be $\sqrt{\sigma_{11}} = 1.5\,\mathrm{mm}$.

The beam emittance, often defined as

$$\varepsilon = \sqrt{\det \sigma} = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2} \quad (4)$$

can deduced from the beam's matrix parametrized by the Twiss parameters in the following way

$$\sigma = \varepsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix} \quad (5)$$

with $\alpha = -\sigma_{12}/\varepsilon, \beta = \sigma_{11}/\varepsilon$, and γ_{22}/ε, where $\beta\gamma - \alpha^2 = 1$. Using the beam matrix elements the emittance is calculated to be $\varepsilon = 5.3\,10^{-6}\,\pi$m-rad which is roughly consistent with emittance measurements close to the cyclotron.

4 AUTOMATIC ALIGNMENT

An automatic position measurement and correction system has been developed. First the response of the BPMs to steering magnets STM_F10 and STM_F11 upstream, are determined by changing their excitations and observing the changes of the BPMs signals. This yields the response matrix.

Inverting this matrix and multiplying it with the beam position deviation vector yields the correctors excitations needed to correct the position to its desired value. This system was tested by changing the current in an upstream bending magnet and letting the feedback system correct. Figure-3 shows the beam positions in the first two rows, and the actual corrector excitations in the third and fourth. We clearly see that an externally induced perturbations deviate the beam from its desired position, but then the correction system automatically brings the beam back to the desired position.

Tests of this system show that it is possible to correct the beam positions within a few pulses arriving from the cyclotron with an error of about 220 μm[4]. The beam reproducibility measured by the BPMs have an r.m.s. of about 150 μm as shown figure-4.

5 ACKNOWLEDGEMENTS

The Author wishes to express his gratitude to the International Atomic Energy Agency (IAEA) for their sponsor-

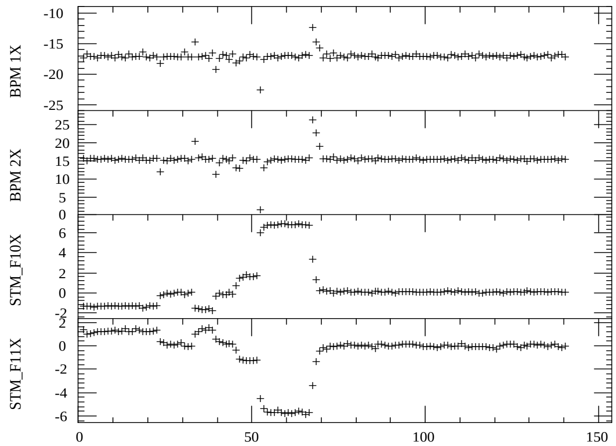

Figure 3: *The top two rows show the beam positions, and the bottom two rows represent the deviation and steering feedback correction in both BPMs.*

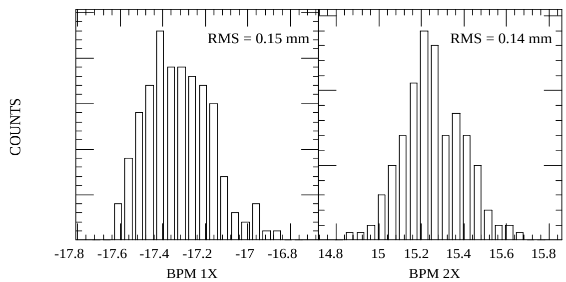

Figure 4: *The center of mass distribution of the pulses as measured by the BPMs*

ship. Special thanks to the director of the Svedberg Laboratory, L. Nilsson, and the technical director, D. Reistad for their hosting and supporting. I am grateful to my home institute AEOI especially my supervisors, M. Haji-Saied and H. Afarideh for creating such an opportunity for me. The step by step supervision and support of V. Ziemann through out this project is deeply appreciated. Thanks to T. Bergmark, and M. Bengtsson for making the BPMs work. The information about diagnostics reported here profitted greatly by discussions with J. Zlomanczuk.

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