FERMILAB RECYCLER DIAGNOSTICS

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Abstract

The Fermilab Recycler Ring is a permanent magnet storage ring for the storage and cooling of antiprotons. The following note describes the diagnostic tools currently available for commissioning, as well as the improvements and upgrades planned for the near future.

1 INTRODUCTION

The Fermilab Recycler is an integral part of the Fermi III luminosity upgrade. For the Recycler to fulfill its design purposes it must be able to inject and circulate all the antiprotons without loss, store up to 2E12 antiprotons in the ring for sufficient amount of time without loss, and be able to cool the antiproton beam.

2 COMPONENTS

The following is a list of the diagnostic tools currently available and a brief description of their capabilities and limitations.

1. Beam Position Monitoring (BPM) system: the detectors are the split tube type, with its capacitance forming a resonant circuit with the pre-amplifier module mounted in the tunnel on the beam pipe. The resonance frequency was chosen to be 7.5 MHz, which would be the final beam frequency in the Run IIb scenario. It has been understood that the detector plates capacitively couple, mixing the difference signals, resulting in the loss of sensitivity. Vertical signal loss is greater than horizontal due to different geometry. Furthermore, the Recycler currently injects 2.5 MHz beam coalesced in the Main Injector, which contain only some 7.5 MHz component. Hence trigger timing and beam RF structure are critical for stable BPM performance. Work has been performed in the tunnel and service buildings to measure and calibrate timing, offset and gain of all BPM channels [1].
2. Transverse Schottky detectors: these are 1 meter long by 7 centimeter diameter split tube capacitive pickups located in the MI-30 sector. The detectors are transformer coupled to 50-ohm output via heliax cable running upstairs to the MI-30 service building to the electronics. The detectors are resonated at the harmonic number n = 238.5 (21.421 MHz); the resonant frequency of the detector is adjusted with a movable iron slug in and out of the primary inductor coil. Measurements were performed to determine that the detectors have enough sensitivity for real Schottky signals; the low measured S/N ratio agreed well with estimate [2]. Signals from the Schottky detectors are routed to a signal analyzer in MCR for tune reading, as well as a vector signal analyzer (also in MCR) for continuous monitoring of betatron band power (emittance). The signals are somewhat noisy but adequate for proton studies carried out currently. However, an upgrade is necessary for emittance monitoring of cooled antiproton beam in the future.
3. Ion Profile Monitors (IPM's): the working principle of the IPM and its application can be found in [3]. Briefly, the IPM's use microchannel plates to collect and amplify ions produced by beam passing through the residual gas in the detector. The Recycler IPM's are located in the 40 sector, and it proved beneficial to intentionally shut off the ion pumps in the proximity for good IPM measurement. Beam size and centroid position information can be extracted from the measurement on a turn by turn basis, providing valuable information of injection position and lattice mismatches.
4. Beam Loss Monitors (BLM's): the Recycler does not have a dedicated BLM system at this point, but shares the Main Injector BLM system in the tunnel. Due to its proximity to the Main Injector it is technically challenging to differentiate beam loss except with timing information. Nevertheless the BLM system has provided reliable information in the aperture scans and orbit studies.
5. Wide Band Stripline Pickups: these are 1.4 meter long (1/4 wavelength of 53 MHz) striplines with a 1 GHz bandwidth and 9.3 nsec doublet separation for measurements of high frequency structure within the beam (proton or antiproton) bunch. A noise source is currently coupled to the beam through the downstream pickups.
6. Direct Current Transformer (DCCT): the DCCT measures the DC beam current in the ring. It has a resolution to 5μA, accuracy of $\pm$1% and linearity of $\pm$0.01%.
7. Toroids: these are AC-coupled to the beam for transient measurements such as beam current at injection, extraction or a specific turn during circulation.

3 MEASUREMENTS

All studies have been with reverse protons injected through the RR-32 line with the exception of a successful attempt of injecting antiprotons into the Recycler. Currently about 100% of the beam travels from the Main Injector through RR-32 and is injected into the Recycler at Lambertson 328. Toroids 330 and 213 show near 100% first turn efficiency, but a fast beam loss occurs within the first 10 turns. The lifetime of the circulating beam is over 20 hours during quiet time with a scraped beam until the beam grows in size and begins to fill the aperture.

1. BPM orbit measurement for first turn injected beam and closed orbit. The Recycler beam orbit is critical to beam dynamics due to feedown effects in the numerous gradient magnets around the ring. The BPM system performed with good stability once the timing, offset and gain calibration were completed and a consistent beam RF structure is maintained. For absolute position verification we depend on a combination of model predicted three-bump or single kick magnitude and calibration data.
2. A detailed account of the BPM Turn-By-Turn (TBT) analysis method can be found in [4]. The Recycler BPM system combined with a TBT analysis program has the ability to make tune measurement, lattice function measurement and other analyses (Fig. 1).
3. Tune and chromaticity measurements with transverse Schottkies: Without coherent driving sources the Recycler tunes can still be observed marginally above noise. Chromaticity measurements are made by changing the orbiting frequency of the beam (related to momentum change by the slip factor) and measuring the corresponding tune shifts.
4. Emittance monitoring: The output signal from the Schottky detectors are monitored continuously for beam emittance tracking (Fig. 2).
5. Aperture studies: with the combination of BLM's DCCT and local three-bumps apertures can be scanned fairly precisely at the apex of the three bump (Fig. 3).
6. IPM measurements have been made for the turn-by-turn behavior of the injected beam (Fig. 4). The IPM system provides valuable turn-by-turn information especially pertinent to the Recycler performance. Studies are under way to quantify the effects of beam intensity, high voltage setting and vacuum on the data.

4 UPGRADES

The following upgrades have been planned in the near future to improve the diagnostic capabilities. Tunnel hardware upgrades will be made in the coming shutdown (September 2001).

- Transverse Schottky detector upgrade: the sensitivity of a Schottky detector is

$$S = \frac{l}{dc}\sqrt{\frac{R\omega_0 Q}{C}}\left[\frac{\Omega}{m}\right] \qquad (1)$$

where l is its length, d diameter, c is the speed of light in vacuum, R is the impedance, ω_0 its resonant frequency, Q the unloaded quality factor and C the capacitance. The output voltage from the detector is

$$V = X_0 e f_0 \sqrt{N} S \qquad (2)$$

where X_0 is the rms beam size, e is the unit charge, f_0 is the revolution frequency, and N is the number of particles.

For improved signal to noise it appears a longer detector is the answer; however, longer plates also means larger capacitance. Since a smaller diameter is usually not acceptable, the factor remaining to be tweeked is Q, the quality factor of the resonant circuit. Analysis showed that for the Schottky circuit such as ours, any series resistance to the inductor has a detrimental effect on the quality factor. Wall resistance in the detector and resistances in the feedthrough connection are two such examples. While a high Q factor is crucial for strong signals, the impedance matching is also important for the final performance. These issues are being considered in order to upgrade the Recycler transverse Schottkies with no compromises. Besides increased sensitivity to small cooled antiproton beam, improved transverse Schottky response could also yield information on chromaticity, which is the difference of the transverse sidebands.

- Longitudinal Schottky detector: A new detector will be made to monitor the longitudinal frequency, its width and the momentum spread. In addition, the area of the longitudinal signal is proportional to the number of particles, so the detected power can be calibrated to give a precise measurement of very small amount of beam that may not be detectable by other means.
- All Schottky signals will be delivered via receivers for continuous emittance monitoring in the style of the Antiproton Source [5].
- Precision mechanical scrapers with stepping motors will be installed, along with scintillation counters immediately downstream, for the calibration of transverse emittances. Currently the calibration is made using a magnetic three-bump scrape, DCCT readout and BLM. This is not very precise due to the limited sensitivity to very small beam current of the DCCT and the model dependent value of the three-bump displacement. A combination of mechanical scrapers,

longitudinal Schottky deetector and scintillation counters will greatly improve the accuracy of the calibration.

- The BPM TBT is an extremely powerful tool for the measurement of non-linearities [6]. Software upgrade will include such programs to measure resonance driving terms derived from frequency analysis of TBT data of betatron oscillation.

5 CONCLUSION

The Recycler performance has improved considerably in the past year, and upgrades to the diagnostic tools outlined above are critical for the continuing improvement of the Recycler performance to meet its Run II goals. The upgrades will not only improve the needed precision of the individual measurement, but will also increase our confidence in the measurements by providing ways of cross calibrating the diagnostic tools.

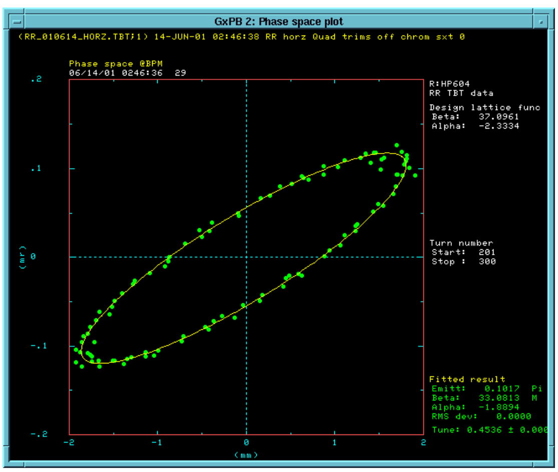

Figure 1: Turn-by-turn beta function measurement

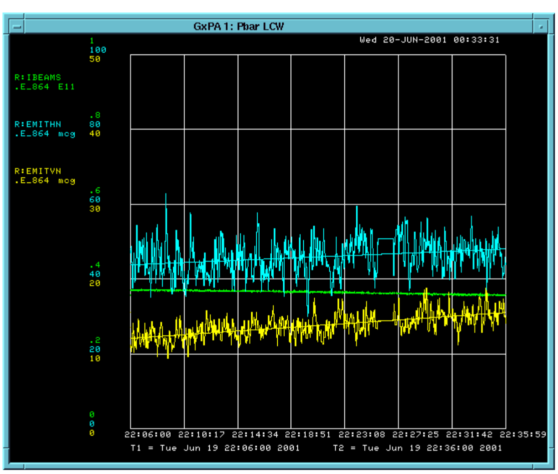

Figure 2: Emittances and beam current monitoring

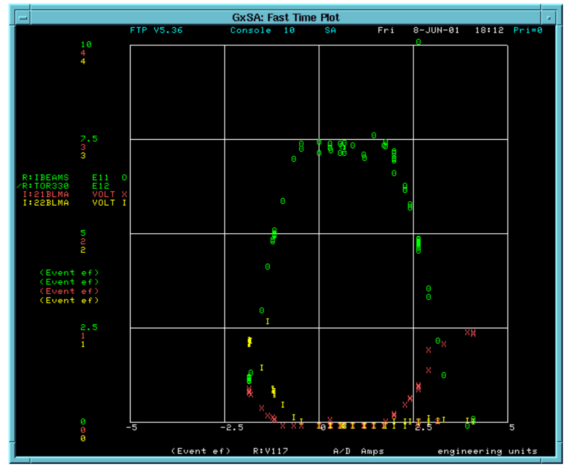

Figure 3: Aperture scan using three-bump, DCCT and BLM’s

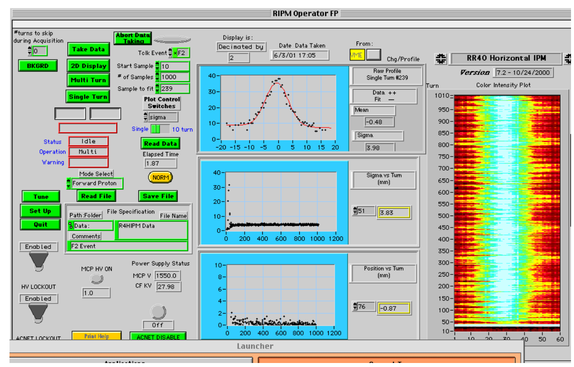

Figure 4: Turn-by-turn data from Ion profile Monitor

6 REFERENCES

[1] P. Prieto, “MI-60 Recycler and Lab BPM Measurements”, private communication

[2] J. Crisp, “Instrumentation”, private communication

[3] A.A. Hahn and J.R. Zagel, “Observation of Bethe-Bloch Ionization Using the Booster Ion Profile Monitor”, FERMILAN-FN-670, June 1998

[4] M. Yang, “Lattice Function Measurement with TBT BPM Data”, Conference Preceedings, PAC, 1995

[5] D.W. Peterson, “Schottky Signal Monitoring at Fermilab”, AIP Conference preceedings, 1991

[6] F. Schmidt, R. Tomas, A. Faus-Golfe, “Measurement of Resonance Driving Terms at the Cern SPS Using Turn-By-Turn Data from Beam Position Monitors”, PAC preceedings, 2001