RECYCLER

REQUIREMENTS FOR THE RECYCLER RING & ASSOCIATED TRANSFER LINES BPMs

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OUTLINE OF THE TALK

- Introduction
- Definitions and measurements
  - Closed orbit
  - Single turn flash
  - Continuous Mode (Background flash)
  - Turn-by-turn
  - Intensity
  - Calibration
- Beam structures
- Specifications
  - Time structure
  - Dynamic range and precision
  - Number Of BPMs
- Summary

RECYCLER BPM SYSTEM

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Features of the present recycler BPM system

- 30 cm long elliptical split-pipe detectors, with axis dimensions of 9.6 cm X 4.4 cm
- In the straight sections, round split-pipe BPMs with 10 cm aperture
- The signals are pre-amplified in the tunnel
- Signal processing is done in the service buildings
- It incorporates the ion clearing system

RECYCLER BPMs

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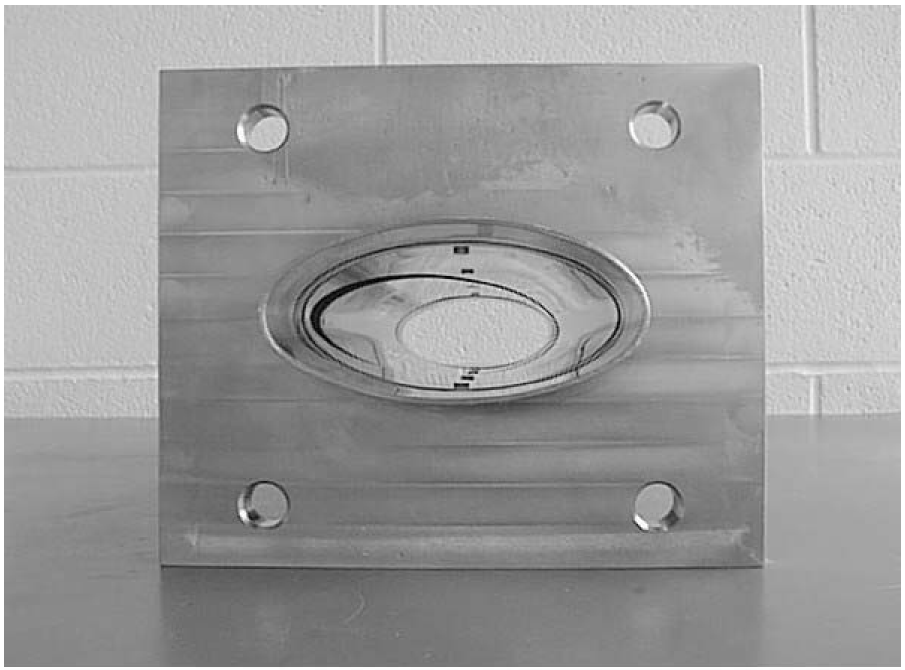

End View

Top View

Split tube BPM Design

Pictures - Courtesy Jim Crisp

11.25.2002

DEFINITIONS

- Flash Mode – Single turn position of the beam around the ring at a specified time/turn.
  - Injection Orbit – First turn position of the beam around the ring.
  - Last Turn Orbit – Last turn position of the beam around the ring before the kicker kicks out the beam.
- Continuous Mode – Position data taken at 720Hz continuously.
- Closed Orbit Mode – Average of ~100 background flashes.
- Turn by Turn Mode for bunched beam - Flash data (**at every BPM simultaneously**) for up to 1024 consecutive turns .

WHAT DO WE NEED TO MEASURE ?

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Closed Orbit:

- To understand where the beam is
- To maximize the aperture, and
- To understand and reduce the feed down effects from the combined function magnets

We need a time resolution of ~ 10ms (cf 1sec. MI ramp, 50ms Recycler counter wave). Allows to observe orbit in RR several times during the MI ramp and its effect on the RR beam.

WHAT DO WE NEED TO MEASURE ? – Cont.

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Flash Orbit –

Deviations of the beam from the Closed orbit because of

- Injection (First Turn) Orbit / Counter wave bumps
- Extraction (Last Turn) Orbit
- Injection Lattice match
- Fast perturbations of beam for any particular turn

We need a trigger time resolution of 132ns (see the time structure slide).

WHAT DO WE NEED TO MEASURE ? – Cont.

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Beam position at any point as a function of time (Continuous Mode)

- To have a continuous monitor of beam position @720 Hz for events such as bumps and sudden beam losses

This is the basic data of the BPM system

- It is used to measure three bumps and aperture scan
- It is the input to the fast time plot
- And provides loggable data

WHAT DO WE NEED TO MEASURE? – Cont.

TURN-BY-TURN MEASUREMENT **SIMULTANEOUSLY** AT EVERY BPM

- To measure the lattice functions of the machine by observing the betatron oscillation caused by a ping.
- To measure non-linear properties of the lattice.
- To observe evolution of unpredictable events such as sudden beam loss or oscillations.
- Study beam dynamics
- Measure Injection Oscillations.

LATTICE MEASUREMENT

Lattice functions can be measured using TBT or Closed orbit.

Turn-by-Turn

- Measure β & α lattice function per BPM.
- Get **phase advance** measurement directly from TBT data per BPM (errors are uncorrelated and systematic free)
- Insensitive to the accuracy of kick magnitude.
- Few kick sources

Closed Orbit

- Measure **phase advance** and β lattice function per BPM
- Potentially better position resolution (due to averaging)
- Need minimum of two kick sources, beta at the kickers and phase advance between them.
- Systematic errors also include kick strengths & BPM calibration.

WHAT DO WE NEED TO MEASURE? - Cont.

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BEAM Intensity (±5%*) at all BPMs for single turn measurement

- To diagnose position of beam loss (RR does not have an independent BLM system).
- Intensity measurement is also a useful cross check on the validity of the measurements
- Can also be used to diagnose non-functioning BPMs

*** - Possibly after calibration**

CALIBRATION

A calibration system must be provided to allow the required position and intensity precision to be maintained over several years.

- BPM Calibration system is needed for checking and calibrating
  - Hardware from the amplifier to the Front end electronics in the service building, and the
  - Software
- BPM calibration software is needed to perform these function and store calibration data in user friendly manner

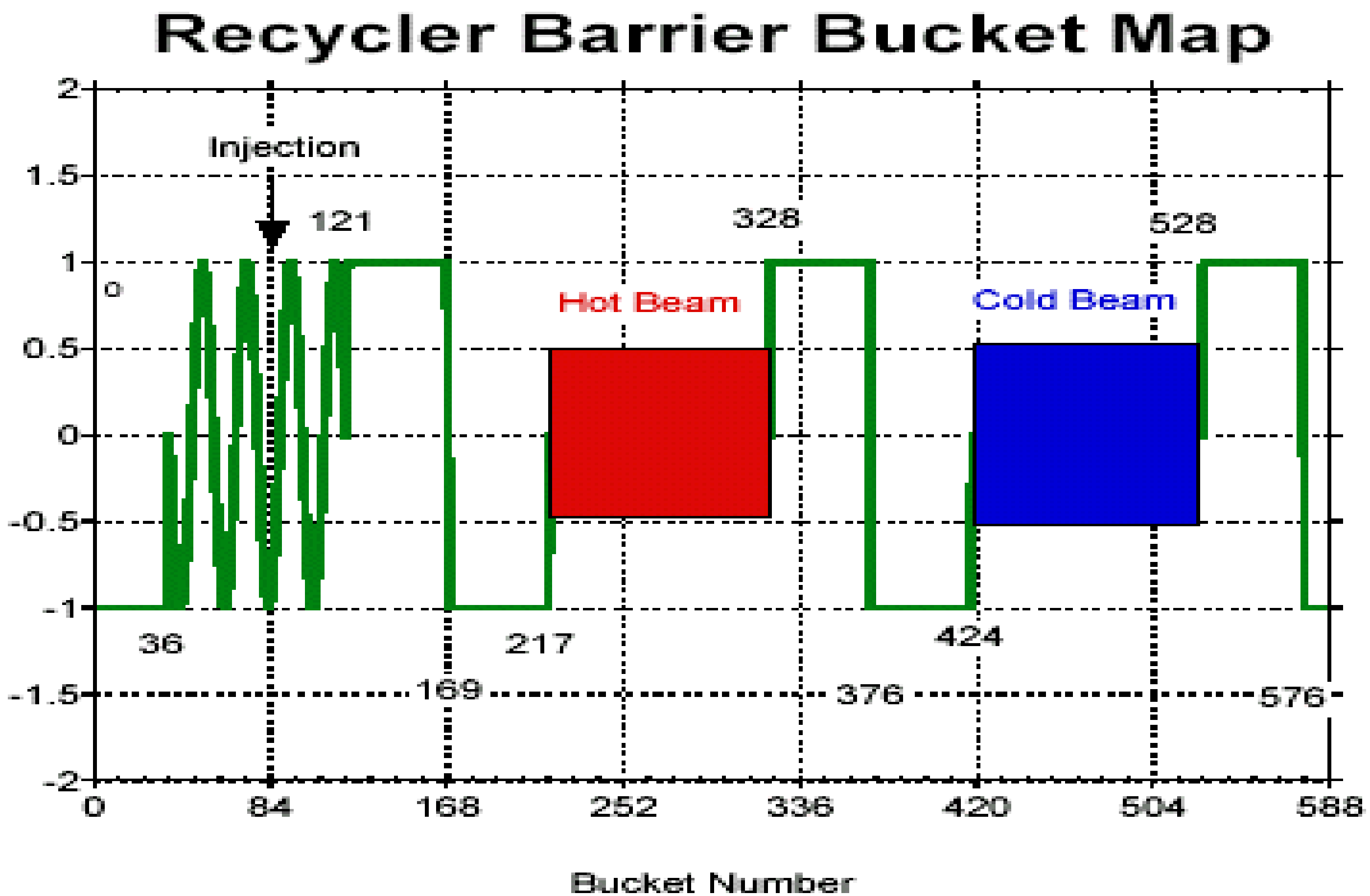
BEAMS IN THE RECYCLER

RECYCLER OPERATIONAL MODES:

- Protons will be used for setup and tests (except cooling).
- Anti-protons will be used for normal operations.
- Reverse proton injection with 2.5MHz or 7.5MHz time structure for tune-up during normal anti-proton operations (both protons and anti-protons in the machine at the same time).

We do not require simultaneous measurement of the bunched and the barrier bucketed beam.

RECYCLER BARRIER BUCKET MAP



TIME STRUCTURE

2.5 MHz – In this mode of operation the RR completes a bucket to bucket transfer of 4, 2.5MHz bunches spaced 396ns apart. The RR can either receive or transmit beam in this configuration. This configuration is used for

- Proton tune-up of the Recycler
- Reverse protons from RR to MI to Accumulator
- Pbar transfers from Accumulator to MI to RR, and RR to MI
- Recycling of Pbars from the Tevatron.

TIME STRUCTURE – Cont.

7.5MHz – This scenario is expected if the Tevatron goes to 132ns bunch spacing mode. In this case the essential purpose remain identical as in 2.5MHz mode.

TIME STRUCTURE – Cont.

"Debunched" beam inside barrier buckets or Stored Pbars

- Barrier pulses in the Recycler are currently 48 RF buckets (906 ns).
- The number and positions of the barriers may vary.
- During injection and extraction 2.5 MHz beam is also present.

The Fourier spectrum of the beam current varies depending on the positions of the barriers.

TIME STRUCTURE – Cont.

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53 MHz Bunch Structure:

The BPM system is NOT required to measure 53 MHz beam in the Recycler.

If available it might be used for diagnostic purposes (for example, if MI can't see 2.5 MHz structure, then 53 MHz will be used for transfer line orbit studies, and we will be able to see the beam as it passes through the RR).

For 53 MHz structure the pre-amps should be able to withstand 40 bunches with current up to 2.5E10/bunch.

DYNAMIC RANGE

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We need to be able to measure:

- From 0.5E10/bunch (2.0E10 total) to 7.5E10/bunch (30E10 total) particles for 2.5MHz transfers.
- From 0.2E10/bunch (2.4E10 total) to 4.0E10/bunch (48E10 total) particles for 7.5MHz transfers.
- From 20E10 to 400E10 particles for debunched stored beam.

When the stored beam exceeds 400E10 particles we expect to attenuate the signals. The dynamic range of 20 will be adequate.

INTENSITY CALCULUS

- 2E10 – requires 3E10 pbars, a reasonable number to use for tuning and pilot shots, given the expected stacking rate.
- 30E10 – maximum pbar extracted from Accumulator without degrading emittances.
- 20E10 is the lower limit for the stored/debunched beam in barrier buckets.

MEASUREMENT PRECISION OVER THE FULL DYNAMIC RANGE

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This is 3σ, or ~99% of the measurement should be within these limits.

Absolute - True position relative to the center of the BPM. **(Covers long term stability, intensity dependence & spectral dependence.)**	±1.00 mm ± 5% of the actual position.
Relative - Difference between two measurements on subsequent turns with stable beam. **(Covers short term stability and resolution).**	±0.40 mm

PRECISION CALCULUS

Recycler beam pipe radius is 22mm. 1mm beam position error loses ~10 % of the acceptance.

We use orbit differences to study the lattice. The orbit differences are limited to ~ 3mm to avoid beam losses, and non-linear effects. We need 5% resolution to achieve 10% in β.

NUMBER of BPMs

- We are proposing to modify a BPM at each half cell. (This is the same algorithm as the Tevatron and the MI.) The modified horizontal BPMs will be at the focusing and the vertical at the de-focusing locations. The RR has 104 half cells/plane with ~ 90^0 phase advance.

- We need 211 BPMs (104 Horizontal & 107 Vertical) in RR, 26 BPMs in the transfer lines, a total of 237 BPMs.

- The RR at present has 422 BPMs. The associated transfer lines have 26 BPMs.

NUMBER OF BPMs – Cont.

Why every half cell:

- To observe maximum orbit excursions.
- To determine all possible orbit motions unambiguously (to see the sine and cosine terms).
- To verify the operation of the correctors. There is one corrector every half cell in RR.

NEW SOFTWARE

We are trying to minimize the software effort required by adopting the present software as much as possible. The major changes that we need are:

- The capability to read out every BPM on TBT
- A simple to use test of the integrity of the system (a combination exercise of the calibration and a list of non-functioning BPM's)

SCHEDULE

- January 2003 shutdown – Take out and modify off-plane pre-amplifiers.
- February to May 2003 – Reinstall modified pre-amplifiers on on-plane channels in the tunnel, as tunnel access schedule permits, and commission the new BPM electronics.
- May 2003 – Use the new system for beam studies at least one month before summer shutdown.

An improved working BPM system is needed by 5/2003.

SUMMARY

RECYCLER

Dynamic Range	20:1
Intensity Accuracy	5%
Absolute Position Accuracy	1.0mm±5% (3σ)
Relative Position Accuracy	0.4mm (3σ)
Flash Trigger Time Resolution	132ns
Closed Orbit Time Resolution	10ms
Analog Bandwidth	2.5 MHz min$^{m.}$
Bunch Structure	2.5MHz/7.5MHz/BB, 450-900ns BB edge
Number of BPMs	211 + Transfer Lines (26)
Display Mechanism	R39, FTP/SNP, SDA

Current clearing electrode functionality need to be maintained and HV(±500V) protection must be included.
Commission the new system by May 2003.

CLOSED ORBIT MEASUREMENT OF CIRCULATING PBAR @ ~ 200 BPMs

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1. PURPOSE : During operations the Recycler will be in this state most of the time -- circulating, cooled antiprotons, with an RF barrier bucket. Continual monitoring and tracking of beam positions will be an essential diagnostic for tracking, understanding, and correcting orbit changes over time scales of MI ramp times to years.
2. BEAM CONDITIONS : Intensity range= 20e10-400e10 and longitudinal emittance range = 2 eV-sec – 108 eV-sec. RF gap width range = 450-900 nsec. Barrier bucket size = 1824-11172 nsec. 54 eV-Sec of cold beam and 108 eV-Sec of hot beam could be present at the same time in the Recycler.
3. ACCURACY : <0.15 mm rms measurement to measurement rms deviation
4. LONG TERM STABILITY : <0.2mm long term drift
5. TIME RESOLUTION : <10msec
6. NONLINEARITY : <5% and over the full intensity range
7. ELECTRICAL OFFSET: <0.5 mm uncertainty
8. DATA COLLECTION: Triggered on multiple TCLK/RRBS events; triggered manually; continuous @ up to 720 Hz
9. DATA STORAGE/DISPLAY : FTP/SNP @ 720 Hz, SDA, Data logger, R39 PA

FLASH ORBIT MEASUREMENT OF INJECTED BEAM @ ~ 200 BPMs

RECYCLER

1. PURPOSE : During the Recycler operation we will inject 2.5 MHz (4 bunches) pbar/proton beam for tune up and storage. Monitoring of single turn beam position is required for reliable injection and extraction of the beam.
2. BEAM CONDITIONS : Intensity range= 0.5e10/bunch (2e10 total) – 7.5e10/bunch (30e10 total) and longitudinal emittance range = 0.5 eV-sec/bunch – 3 eV-sec/bunch, in the presence of beam in the barrier bucket. This beam is bunched in 2.5 MHz.
3. ACCURACY : <0.15 mm rms measurement to measurement rms deviation
4. LONG TERM STABILITY : <0.2mm long term drift
5. TIME RESOLUTION : <132 nsec
6. NONLINEARITY : <5% and over the full intensity range
7. ELECTRICAL OFFSET: <0.5 mm uncertainty
8. DATA COLLECTION: Triggered on multiple TCLK/RRBS events; triggered manually
9. DATA STORAGE/DISPLAY : SDA, Data logger, R39 PA

FLASH ORBIT MEASUREMENT OF INJECTED BEAM @ ~ 200 BPMs

RECYCLER

1. **PURPOSE : During the Recycler operation we will inject/extract 7.5 MHz (12 bunches) pbar/proton beam for tune up and storage. Pbar beam will be the recycled beam from Tevatron after collider operation. Monitoring of single turn beam position is required for reliable injection and extraction of the beam.**
2. **BEAM CONDITIONS : Intensity range = 0.2e10/bunch(2.4e10 total) - 4e10/bunch (48e10 total) and longitudinal emittance range = 0.5 eV-sec/bunch – 0.65 eV-sec/bunch, in the presence of beam in the barrier bucket. This beam is bunched in 7.5 MHz.**
3. **ACCURACY : <0.15 mm rms measurement to measurement rms deviation**
4. **LONG TERM STABILITY : <0.2mm long term drift**
5. **TIME RESOLUTION : <132 nsec**
6. **NONLINEARITY : <5% and over the full intensity range**
7. **ELECTRICAL OFFSET: <0.5 mm uncertainty**
8. **DATA COLLECTION: Triggered on multiple TCLK/RRBS events; triggered manually**
9. **DATA STORAGE/DISPLAY : SDA, Data logger, R39 PA**

TURN-BY-TURN ORBIT MEASUREMENT OF INJECTED BEAM @ ~ 200 BPMs

RECYCLER

1. **PURPOSE : During the Recycler operation we will inject 2.5/7.5 MHz (4/12 bunches) pbar/proton beam for tune up and storage. Monitoring of Turn-by-turn beam position is required for lattice and beam dynamics studies.**
2. **BEAM CONDITIONS : Similar to flash condition**
3. **ACCURACY : <0.15 mm rms measurement to measurement rms deviation**
4. **LONG TERM STABILITY : <0.2mm long term drift**
5. **TIME RESOLUTION : <132 nsec**
6. **NONLINEARITY : <5% and over the full intensity range**
7. **ELECTRICAL OFFSET: <0.5 mm uncertainty**
8. **DATA COLLECTION: Triggered on multiple TCLK/RRBS events; triggered manually**
9. **DATA STORAGE/DISPLAY : SDA, Data logger, R39 PA**