TURN-BY-TURN TRANSVERSE PHASE SPACE MEASUREMENTS IN REAL TIME*

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Abstract

The South Hall Ring at the MIT-Bates Linear Accelerator is a 190 m circumference 1 GeV electron ring for use by nuclear physics experiments. Real-time turn-by-turn measurements of the beam transverse phase space in the ring are made using an EPICS based BPM data acquisition system, interfaced with a C/Motif application for data analysis and operator interface. Data acquisition is performed such that multiple BPMs acquire data synchronously. By acquiring data at a rate many times the ring revolution frequency, it is possible to make reliable turn-by-turn beam position measurements, even in the case of varying beam conditions. The application program uses an efficient algorithm for data reduction, and provides various modes for presenting data to the user. Details of the system design, including data acquisition, analysis, and the graphical user interface, are presented.

1 INTRODUCTION

Proper injection into a storage ring requires matching the trajectory of the incoming beam to the desired transverse phase space coordinates in the ring. In particular, operation of the South Hall Ring (SHR) at the MIT-Bates Linear Accelerator Center in pulse-stretcher mode requires that the beam be injected such that it lies just inside the separatrix dividing the horizontal phase space into an inner stable region and an outer unstable region. This separatrix is defined by the tune of the ring, and the strengths of the octupoles used for extraction [1]. To help in establishing the proper phase space match, we have developed instrumentation and application software to measure the transverse phase space of the centroid of the beam, on a turn-by-turn (TBT) basis in the SHR. Similar measurements have been made in the past [2]; the aim here is to acquire, analyze, and present the data on a time scale suitable for interactive use in tuning the ring and injection line.

2 DATA ACQUISITION AND ANALYSIS

To measure the transverse phase space of the centroid of the beam at a specific location in the ring, two Beam Position Monitors (BPMs) near the location of interest, and separated by roughly 90º phase advance from each other, are used. The transfer matrices between the BPMs and the desired location are determined by knowing the ring layout, and the strengths of the relevant quadrupoles, taken from the accelerator controls system (EPICS).

The minimum rate of data acquisition from the BPMs is determined by the ring revolution frequency, in this case 1.576 MHz. However, we have found it advantageous to acquire data at a faster rate. By triggering the 8 bit flash ADCs at 40 MHz, we acquire 25 samples per turn. These data are then used in a fit to determine the beam position at the BPMs on each turn. The fixed parameters of the fit are that there are exactly 25 data samples per turn (which is set by a trigger phase locked to the TBT clock), and that the beam position (betatron oscillation amplitude) is constant over any given turn. The free parameters are the betatron oscillation amplitude on each turn, and the phase of the TBT fit relative to the data. One of the advantages of acquiring data at a rate greater than the revolution frequency and then doing a fit is that it is not necessary to precisely time the triggers to the BPM ADCs in order to guarantee that they are looking at the same part of a turn. Also, there is no danger of setting a trigger close to the transition from one turn to the next, which could introduce noise into the measurement. Finally, there is greater immunity from noise which can result from the beam position not being constant over one turn.

The ADCs are triggered within a few microseconds (before or after) of injection into the ring. The data for each BPM is acquired in a buffer with a capacity of 4096 bytes. This gives room for 163 turns, which is sufficient for the phase space measurement. This is also short compared to the SHR damping times, and the times for filamentation to take place. These effects therefore do not complicate the interpretation of the data.

The Bates BPM data acquisition system includes a mode which guarantees that data from different BPMs are acquired simultaneously. This allows us to use the TBT data from the two BPMs knowing that the turns are synchronized. The BPM resolution is ±40 µm.

3 USER INTERFACE

The operator interface is a Unix based program written in C, using X-windows and Motif. On start-up, it prompts the user for the ring location where the phase space is to be measured, sets the appropriate BPMs into the 40 MHz synchronous data acquisition mode, and determines the strengths of the quadrupoles needed for the transfer matrices which will be used. Data acquisition then begins automatically.

The display shows the results of the phase space measurements (angle vs. position) simultaneously in both the horizontal and vertical planes. The program provides

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the operator with various information and options, including:

- Continuously displaying data, displaying all data acquired after each injection and then pausing until instructed to continue, or displaying data one turn at a time and then pausing;
- Specifying the time to wait between plotting data points, or between data sets acquired after each injection, when not waiting for user instruction to continue;
- Specifying how many turns after the initial trigger to skip before displaying data (to avoid injection transients) and how many turns to plot in total;
- Whether to use absolute or relative zeroes for the BPMs, in either the horizontal or vertical planes;
- Options for archiving the raw BPM data to disk, for later replay using the same program;
- The age of the most recently displayed data; and
- The capability to make a hard-copy of the display.

A sample of the user interface is shown in Fig. 1.

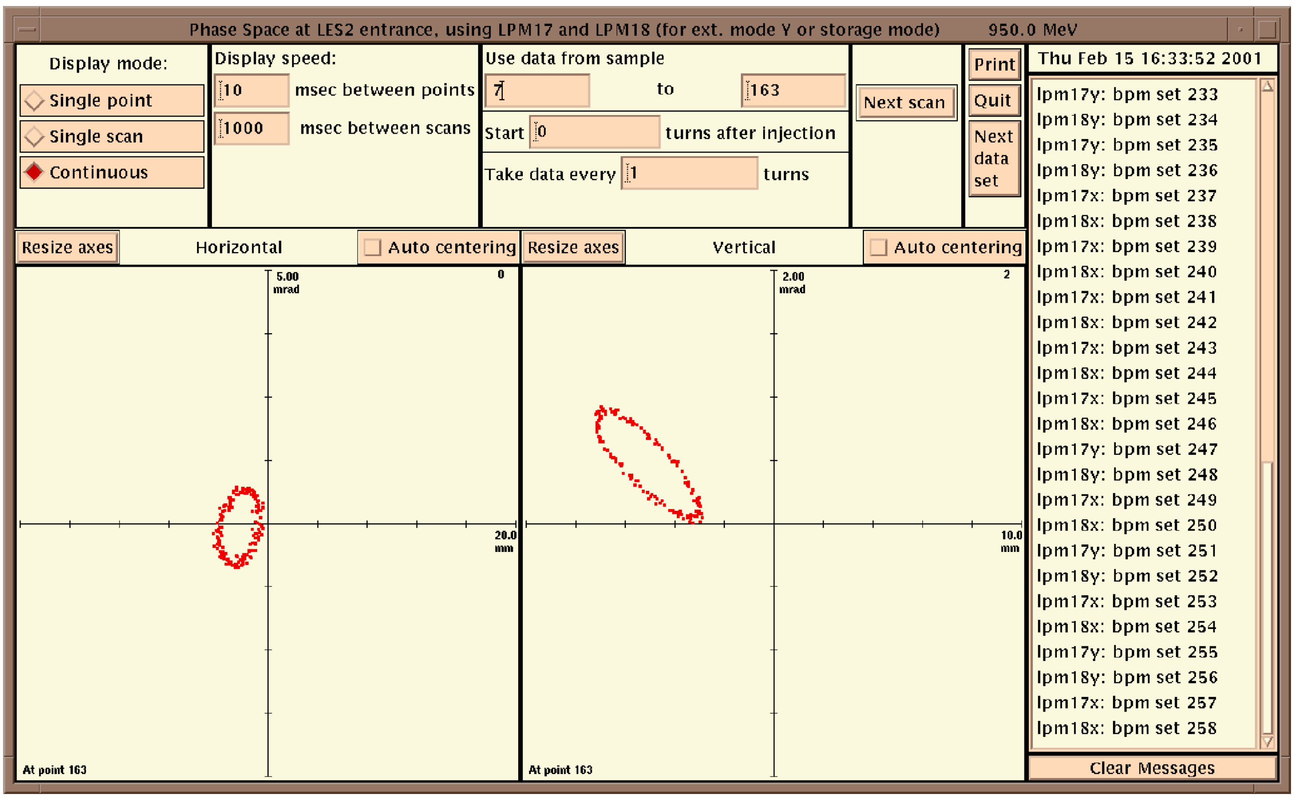

Figure 1: Sample of the ring transverse phase space measuring program user interface, showing real data. The ellipse on the left shows horizontal data (angle vs. position), and that on the right vertical data. Each dot in an ellipse represents the *x-x'* (or *y-y'*) data from one turn.

4 SUMMARY

We have implemented a system for making turn-by-turn transverse phase space measurements of the centroid of the beam in the SHR. It uses two BPMs which make multiple beam position measurements during each revolution period. A graphical user interface performs an efficient analysis of these data, and displays the results to the operator. The interface also gives the operator various options for displaying and manipulating the data.

5 REFERENCES

[1] Jacobs, K. D., et al., “Operational Experience with Resonantly Extracted Beams”, these proceedings.

[2] Morton, P. L., et al., “A Diagnostic for Dynamic Aperture”, in *Proc. of the 1985 Particle Accelerator Conf.*, pp. 2291–2293.