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BEAM QUALITY MEASUREMENTS IN FERMILAB MAIN RING

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Introduction

Each Main Ring cycle the Fermilab Booster injects 13 batches, each containing 84 rf bunches into the Main Ring. We have measured bunch distributions in longitudinal width, in phase angle with respect to the Main Ring rf, and in transverse position. A system has been developed which utilizes data from all the bunches and derives numbers indicative of these distributions. The system is used to help determine the source of operational problems. It is also used in a slightly different mode to observe the behavior of any number of bunches throughout Main Ring acceleration. This paper describes the analysis and display of the data, and how the system has aided Main Ring and Booster diagnostics.

Motivation for the Beam Quality Monitor

The Beam Quality Monitor is the culmination of an effort to know as much as possible about each bunch in the Fermilab Main Ring. In particular, there is an interest in knowing the quality of the bunches sent from the Booster into the Main Ring. "Mountain Range" photographs have long been the primary means of measuring bunch widths and longitudinal phase errors, and observing the oscillations of these quantities on subsequent revolutions.

The Beam Quality Monitor consists of three basic components:

1.) A set of pickups and electronics packages[1] that produces for each bunch a voltage proportional to

   a.) bunch width
   b.) longitudinal phase error
   c.) horizontal position
   d.) vertical position

2.) A snapshot digitizer system[2] which converts these voltages to digital information according to any timing scheme desired.

3.) A software package which controls the snapshot digitizer system, and analyzes the data.

Analysis of Data

The software used to control and analyze the Beam Quality Monitor data resides on the Fermilab Xerox 530 controls computer. The program receives up to 1536 bytes of data from each of two inputs. One input is always the Time (Phase Error) Discriminator while the other input can be switched to the Width Discriminator, to the horizontal position, or to the vertical position. While the data has been transferred to Fermilab's Cyber 175 computers for further analysis, most of our experience has come from work done with the Xerox 530.

The Monitor operates in two basic modes. One of these is designed to monitor Booster beam as injected into Main Ring. In this mode the system is set to digitize the data from each bunch on its first pass around Main Ring. This demands that the monitor know precisely when each batch from Booster will arrive, and into which buckets the beam is being injected. This is referred to as the Beam Quality Mode.

The second mode is called the Diagnostic Mode. This mode allows data from any bunch, or adjacent bunches to be gathered on subsequent revolutions until all 1536 bytes of snapshot memory are filled.

Data Display in Beam Quality Mode

Figure 1 shows a display generated in the Beam Quality Modes. The display grid is divided into the thirteen batches, each of which contains up to 84 bunches from the Booster. The upper display indicates the longitudinal widths of all 1092 bunches in units of nanoseconds (one nanosecond equals about 19° of the rf wave). The bottom grid shows the centroid of each bunch with respect to the low-level rf wave. A display of this type can be used to estimate Booster longitudinal emittance, as well as point out the variation between Booster batches. It is the best diagnostic aid in tuning the injection phase offset in Main Ring, and may also be used while tuning the Booster low-level rf system.

If desired, this data can also be presented in numerical form. The average and standard deviation of all 1092 bunches are calculated as well as the average value and standard deviation for each batch. Finally, the standard deviation of the batch averages and standard deviations are derived. An example is shown in Figure 2.

Data Display in Diagnostic Mode

Figure 3 is an example of data taken with the system in the Diagnostic mode. In this case the data was taken for four bunches beginning with bunch ten. Data taking began when beam entered the Main Ring, and continued every 400th revolution until the snapshot memory filled up at 3.645 seconds (about 300 GeV). The width input on the upper grid clearly shows the tight bunching which occurs at transition, and the spreading of the bunches about 400 msec later due to the action of a device designed specifically to do this, the Main Ring Bunch Spreader.[3] Figure 4 more clearly shows the oscillations in the time Discriminator at the synchrotron frequency. As expected, the width of this bunch oscillates at twice the synchrotron frequency.

Application of Beam Quality Monitor

The monitor has been used in a variety of ways during the six months of operation since it was installed. One immediate application was to study the effects of the Booster longitudinal harmonic dampers.[4] These dampers were first used in 1976 to suppress coupled bunch motion. Evidence for the usefulness of

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these dampers was beam loss in Main Ring as well as the familiar "mountain range" photographs shown in the reference. More recently, after many improvements to the Booster, efficiencies in Main Ring seemed to indicate that the dampers were unnecessary. Regular use of the Beam Quality Monitor during different operational modes supported the fact that the widths of the bunches and their phase errors were well within acceptable limits without the dampers. The dampers are no longer used.

Another application of the monitor has been the timing of the Booster extraction and Main Ring injection kickers, all of which kick vertically. The monitor has been used in the Beam Quality Mode to take vertical position data of the injected beams' first pass. Figures 5 and 6 show one batch. Figure 5 is before proper timing and Figure 6 is after.

The monitor makes measurements of the longitudinal bunch width as a function of intensity very easy. This facility of the monitor was used in the study of intensity dependent time shifts.[5,6]

Plans for Beam Quality Monitor

The electronics for at least one additional input are being developed. This will be a bunch-by-bunch intensity monitor providing the capability of correlating beam loss with other observed bunch motion.

Software improvements will include a fast Fourier Transform routine which will aid in derivation of numbers such as synchrotron frequency. See Figure 7.

Finally, plans call for the development of a dedicated 68000 microprocessor system which will calculate summary data and drive the displays. This will free the console for tuning, and make the display available continuously anywhere in the control room.

References

1. Longitudinal Beam Signal Processing for the Fermilab Beam Quality Monitor; E. Higgins, C. Moore; paper E-36, this conference.
2. Snapshot Digitizer System for the Fermilab Main Accelerator; R. Pasquinelli; paper E-12, this conference.
3. The Bunch Spreader is a device in the Main Ring low level rf system which spreads the bunches longitudinally by shaking the phase of the rf at twice the synchrotron frequency. The purpose of this is to minimize extraction losses by reducing space charge effects.
4. Longitudinal Motion of the Beam in the Fermilab Booster; C.M. Ankenbrandt, J.E. Griffin, R.P. Johnson, J. Lackey, and K. Meisner; IEEE Trans. Nucl. Sci. NS-24, p. 1449 (1977)
5. Measurement and Compensation of Coherent Laslett Tune Shifts in the Fermilab Main Ring; R. Gerig, C. Moore, S. Pruss; paper F-33, this conference.
6. Measurement of Incoherent Laslett Tune Shifts in the Fermilab Main Ring; R. Gerig, C. Moore, S. Pruss; paper F-34, this conference.

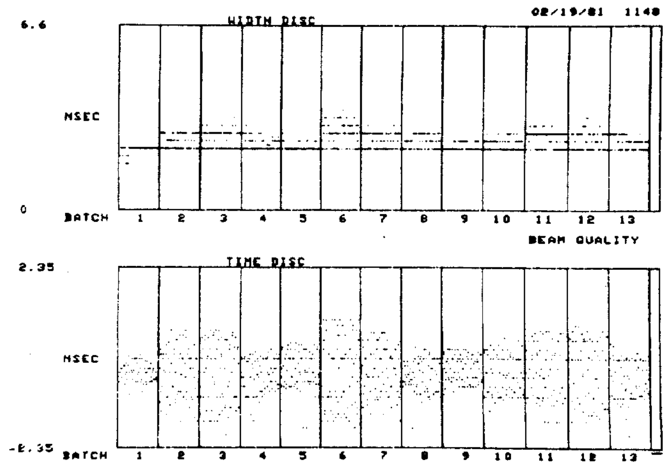

Figure 1. Beam Quality Mode

BOOSTER ATROCITY DATA 03/02/81 1247

	TIME DISC NSEC AVG	TIME DISC NSEC STDDEV	WIDTH DISC NSEC AVG	WIDTH DISC NSEC STDDEV
BATCH 1	-.115	.618	5.466	.856
BATCH 2	.072	.58	5.611	.825
BATCH 3	-.025	.81	5.716	.708
BATCH 4	-.044	.574	5.305	.559
BATCH 5	.232	.991	5.647	.731
BATCH 6	.264	.637	5.895	.464
BATCH 7	-.012	.58	5.831	.828
BATCH 8	.102	.658	5.785	.495
BATCH 9	-.115	.815	5.362	.813
BATCH 10	.236	.647	5.791	.672
BATCH 11	.206	.829	5.826	.473
BATCH 12	-.077	.457	5.28	.954
BATCH 13	-.144	.646	5.733	1.7
STD OF ALL BUNCHES		.682		.854
AVERAGE OF AVERAGES		.045		5.634
STDDEV OF AVERAGES		.149		.213
STDDEV OF STDDEV		.141		.321

Figure 2. Beam Quality Mode Summary Data

The title reflects the authors' bias.

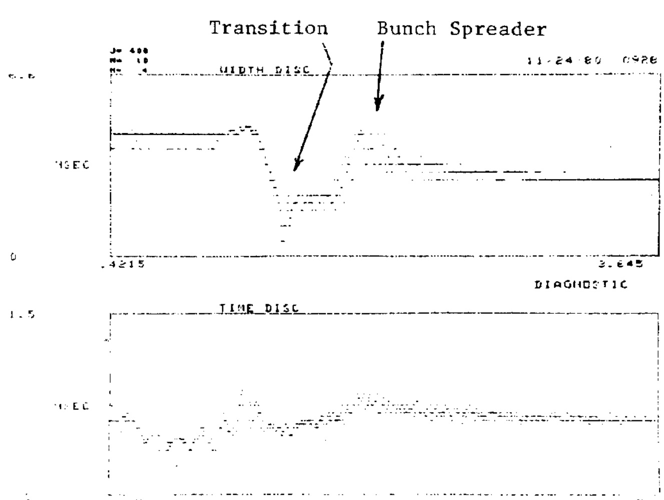

Figure 3. Diagnostic Mode

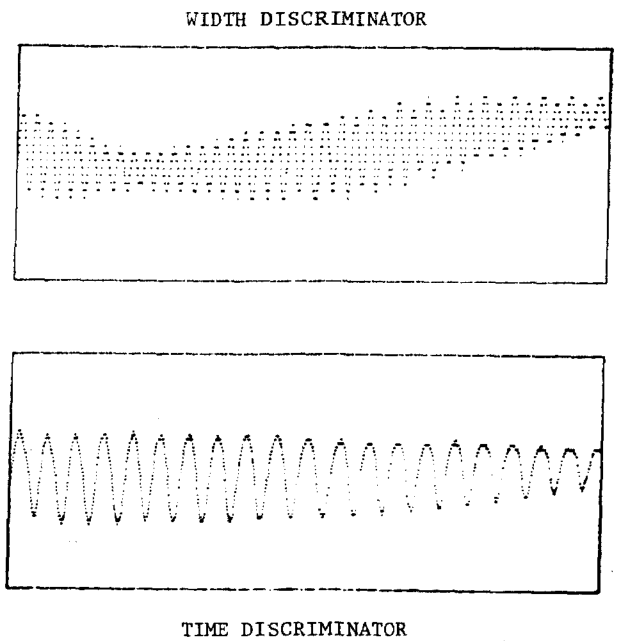

Figure 4. Relationship between phase oscillations and width oscillations.

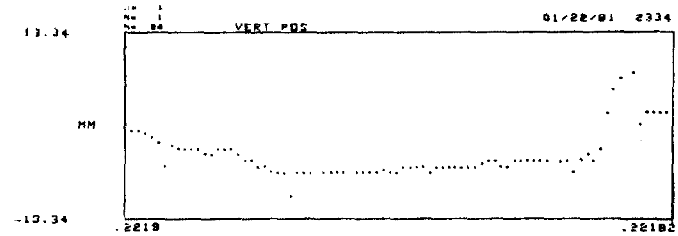

Figure 5. Before kicker timing.

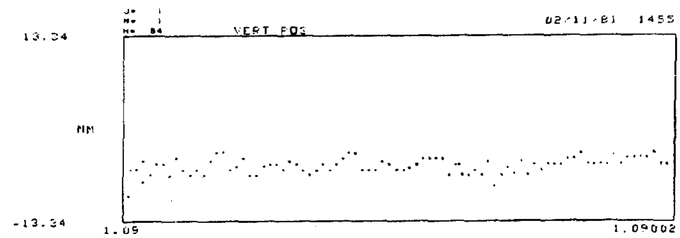

Figure 6. After kicker timing.

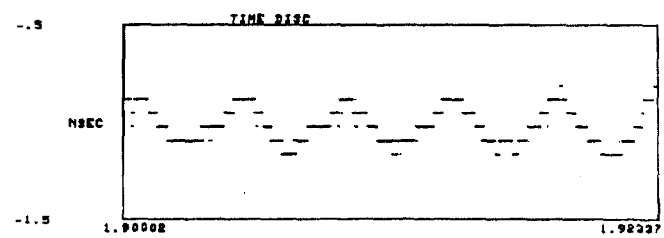

Figure 7. Synchrotron frequency.
215 Hz during Bunch Spreader