Proposed Data Acquisition System for the Fermilab Booster

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ABSTRACT

At present, studies involving the FNAL Booster (or in fact most accelerators) depend on knowing exactly what detector one has to look at and at what time. Because of this, most studies are done "on-line" and involve looking for repetitive effects using a limited number of detectors. In this paper we propose to design a Booster Data Acquisition System (BDAQ) for the FNAL Booster. In essence this system consists of a large number of digitizers with circular memory buffers. After a machine cycle of interest, these buffers are frozen and then read out into a mass storage device. This paper discusses the hardware and software capabilities needed to make such a data data acquisition system a powerful tool for doing accelerator physics studies and improving machine performance.

I. INTRODUCTION

In many ways the Fermilab Booster is an interesting machine to consider when looking at aspects of accelerator data acquisition systems. Because of its rapid cycling nature, it is very difficult to study using traditional methods. The machine is also relatively small and compact and hence a good candidate for demonstrating the feasibility of accelerator data acquisition systems. Table 1 list some of the relevant parameters of the Fermilab Booster [1].

Table 1. Fermilab Booster Parameters

H^-	multiturn injection (< 10 turns)
E_{inj}	200 MeV kinetic
E_{ext}	8.0 GeV kinetic
circumference	474.2 meters
harmonic #	84
Q_x , Q_y	6.8
gammat	5.4
f_{RF}	30.3 - 52.8 MHz
V_{RF}	950 kV , 17 RF cavities
transverse aperture	20 pi mm-mrad (normalized)
longitudinal dp/p	~ +/- 0.6 %
cycle rate	15 Hz
max accelerated intensity	$3.0 * 10^{12}$

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Accelerator control and data acquisition are two separate problems. Because they are designed for completely different functions we do not want the design parameters of one system to adversely affect the other. There obviously has to be a data link between the control system and the data acquisition system, but this can be relatively slow and simple.

II. DIGITIZERS AND RATES

The list of digitizers and rates needed for the Booster is shown in Table 2. f_0 is the revolution frequency (which varies from 360 kHz at injection to 628 kHz at extraction). The memory depth per channel that is needed to record one Booster acceleration cycle is also given. In addition to these channels we will also need to integrate test equipment (eg. spectrum analyzers) into the system.

TABLE 2: Booster Digitizers

RATE	MEMORY DEPTH	#CHANNELS	ACCELERATOR DEVICES
30kHz	1K	250	magnet currents
f_0	16K	400	BPMs, BLMs RF fanbacks, profile monitors beam current
$84*f_0$	1400K	10	beam dampers RF parameters
> 4 GHz	120,000K	2	bunch structure

At the higher digitization rates we would not normally store information for the entire acceleration cycle. One would think of only taking partial information at 4 GHz and at the RF frequency. But even so we will easily generate a total of 20 Mbytes of data per machine cycle. Only a few digitizing rates are used in order keep the hardware configuration simple. On an event of interest a trigger pulse will freeze all the circular buffers and the data acquisition will read out all the data. The above table gives the buffer memory needed for one acceleration cycle. Twelve Booster cycles are needed to fill the Main Ring at Fermilab. Although we believe that Booster acceleration cycles behave independently, enough memory depth for 2 Booster acceleration cycles should be considered in order to study cycle-to-cycle correlations.

Options exist for all the above digitizers. Commercial companies such as Lecroy and Analtek offer digitizing systems with appropriate data rates and memory depths. A design also exists for a VME based "Quickdigitizer" at Fermilab that has 4 channels, 1 MHz per channel digitizing rate and a memory buffer of 64K samples per channel. We propose to use this "Quickdigitizer" for all frequencies up to the revolution frequency, and the Lecroy 6841 for the RF frequency. The >4 GHz digitizers are commercial oscilloscopes and will have allowable memory depth limitations.

The exact hardware used will of course depend on detailed analysis of cost, performance and ease of software support.

III. COMPUTER HARDWARE

The digitizers for the acquisition system will sit at approximately 6 to 8 locations around the Booster. At each location we assume that there will one or more VME crates. The digitizer memories are mapped into VME memory space. Each crate has a controlling microprocessor card (such as a card based SPARC workstation) and all of the crates are connected by a vertical bus to a central processing node. This node can be a real computer or a crate full of VME based processors. How much local (crate-level) processing of information should there be before it is sent to the central node? If the vertical bus has enough bandwidth and the central node has sufficient resources to process incoming data, then the simplicity implicit in the local processor software outweighs any advantages one might reap from having local processing power. The needed bandwidth depends on how fast one need to read all the data for one acceleration cycle. This is obviously a rather flexible number. The fastest desired response is to collect and process the data in 33 milliseconds, ie. one Booster machine cycle. A less capable system that takes a few seconds will still have a "real-time" feel. Given present computer and network hardware trends, the latter is not an unreasonable design goal.

Initially we are considering using VME based SPARC workstations connected by ETHERNET to a central SPARC workstation for a prototype system.

IV. ACCELERATOR PHYSICS NEEDS

The list of foreseeable accelerator physics investigations that would be made possible (or made much more efficient) by a fully fledged BDAQ is long. Although the list is presented here as a piecemeal set of objectives, ordered by increasing data acquisition requirements and complexity, it can be conceptually broken into "phase I" and "phase II" tasks. The former are tasks that are either easy to perform, or are of high enough priority that they deserve concentrated attention as soon as possible. They may be performed with a relatively modest subset of of the final system. "Phase II" tasks are those that, although of less immediacy, are nonethless important if the full performance of the Booster is to be achieved. These aspects require the complete implementation of BDAQ hardware and software.

Although it cannot be listed, a third phase of physics investigations exists. After the system has been commissioned, and initial issues resolved, evolving topics will be recognized as important and interesting. This is in the nature of the physics program that a successful Booster Data Acquisition System will make possible.

Turn-By-Turn data from a few Beam Position Monitors, some status information

A minimal arrangement in which Physics can be performed requires

a) a few channels of Turn-By-Turn (TBT) digitization of Beam Position Monitors (BPM's),

b) a few 30 kHz channels for status logging of various parameters

c) the 25 kHz "pinger" now under construction.

This would enable the measurement of tune and chromaticity though the ramp, in essentially the same way that it is being done using the UDAS [2] setup in the Main Ring. Some investment in additional analysis software is necessary, and the system software is already in place.

The same configuration would allow for the measurement of smear, and the observation of resonances, much as these measurements have been successfully performed in the Tevatron. With the use of a somewhat larger number of TBT signals from BPM's, so that a reasonable average can be calculated, it will also be possible to track the RF offset versus time.

Complete Acquisition of BPM's, Loss Monitors, and Status Information

The next configuration assumes that TBT signals are available from all BPMs, and from all Beam Loss Monitors (BLMs). It also assumes that the full complement of 30 kHz status channels, such as from magnet power supplies, is available.

This enables an initial investigation of beam current losses throughout the Booster cycle. The commonly observed loss of 20% to 30% of intensity at injection into the Booster is a particularly important effect. Full coverage of the BPM's allows an analysis of the evolution of the closed orbit with time. This, correlated with the pattern of losses recorded by the BLMs (in time and space), should give strong indications of the underlying Physics of the losses. However, a complete picture of the role, for example, of space charge interactions, needs more detailed information.

Complete BPM acquisition also enables the measurement of transverse transfer functions. The simplest example of this is the measurement of beta functions and phases, as already attempted in the Tevatron. The only attempt so far failed, apparently because of systematic errors in BPM readbacks. Because of the much larger availability of beam time in the Booster, there is a much greater chance of making this promising scheme work there - with benefits to all Fermilab accelerators. Other examples of transverse transfer functions include the measurement of coupling effects, and nonlinear sextupolar effects, both globally and locally.

Ion Profile Monitors

A complete outfitting would have two horizontal Ion Profile Monitors (IPMs) and one vertical IPM. Each would have 32 channels, giving a measurement of the beam profile once per turn (or possibly faster).

One IPM is already built and is in the process of being commissioned. The detailed information from these devices will enable us to look at many effects such as the evolution of the transverse distribution just after injection into the Booster. This study is important to the study of space charge blowup at injection into low energy proton synchrotrons. It should also be possible to use the two horizontal IPM's to reconstruct the distribution of the beam in horizontal phase space.

A corollary of the depth of potential uses promised by the IPMs is the fact that a relatively large amount of analysis software will have to be written, and a lot of experimentation done, before the IPMs will be fully operational and fully utilized. It is in this kind of situation that the pre-packaged data processing tools, such as MATLAB, show their power and versatility for playing with the data, in order to learn how best to manipulate them.

Inter-bunch monitoring, several channels at RF frequencies

Longitudinal Coupled Bunch Instabilities (LCBI's) at present cause the longitudinal emittance in the Booster to blow up during each cycle. Preliminary experimental data suggests that the main culprit is the large impedance due to RF cavities [3]. A tracking digital longitudinal beam damper [4] is being built and installed in the Booster to counteract the LCBI.

A data acquisition system operating at this level would provide much more accurate information about the longitudinal mode that is driving the emittance growth. It would provide the diagnostics required for monitoring the performance of the damper, and for performing experiments on the behavior of the instability. Here, again, the exploratory nature of the investigation is greatly aided by on-line tools such as MATLAB, at least until a standard operational analysis can be defined and coded.

Transition crossing performance, and transition jump analysis

At least one channel of the 4 GHz digitizer is necessary in order to be able to study the detailed behavior of the Booster as it jumps across transition. A mountain range display of the evolution of a longitudinal bunch profile can be generated from this data and used for direct comparison with results produced by the simulation code ESME [5]. In addition to the important desire to experimentally validate ESME, the study of the efficiency of the Boosters transition jump is useful for other reasons, for example, how the various quantities change with time in the vicinity of transition: horizontal and vertical tunes, the closed orbit, RMS(Dp/p), horizontal beam size (and emittance), dispersion, and beam loss distribution. The Ion Profile Monitors have an essential role to play here, as well. None of this information is available at present.

Booster transition crossing studies are important for designing a transition crossing scheme for the Main Injector [6]. While some transition crossing studies aimed at the Main Injector - such as investigation of higher harmonic cavities - can be done in the Main Ring, the availability of the Booster and its gamma-t jump make transition studies there very desirable.

If it is feasible, it is desirable to not only measure the alpha-1 parameter in the Booster, but also to design a scheme to show that its control is possible and understandable.

Intra-bunch monitoring, a couple of channels at about 5 GHz

Intra-bunch monitoring is extremely valuable for other studies. The efficiency of the process of beam bunching at injection into the Booster is not well diagnosed or understood. This process might well be important, in addition to space charge effects, in causing the large intensity losses at injection. The Linac Upgrade will accentuate the importance of this effect, by making space charge effects less important.

A combination of IPM data and intra-bunch data makes possible a presentation of the evolution of the horizontal, vertical, and longitudinal emittances through the cycle. Although the acquisition system required is quite demanding, the analysis to get this information is not, and the result is a shorthand summary which would present clear signatures for various ailments of the Booster.

CONCLUSION

Eventually, with the whole of the proposed system in place - or a configuration not too far beyond it - it will be possible to study the evolution of the internal distribution of the charge in a bunch, on a Turn-By-Turn basis. In fact, the individual elements of such a scheme of "whole bunch tomography" are fairly straitforward. Two things remain to be done. The first is to integrate all the various pieces required for a Booster Data Acquisition system together. The second is to face up to the learning task that will be necessary to perform the experiments, and understand the results

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