A HIGH SPEED, MULTI-SAMPLING DATA ACQUISITION FOR BEAM DIAGNOSTICS

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Abstract

A program is developed to collect accelerator data using a high speed digitizer and to display data for beam diagnostics. The digitizer has speed up to 2 Gs/s and is multiply retriggerable up to 1024 traces. The signal can be from either wall current monitor for longitudinal dynamics or the strip-line detector for transverse dynamics. The FFT spectral analysis of individual data trace gives the frequency composition of the signal from a train of beam bunches. The FFT analysis of transposed data gives the spectral composition down to sub-synchrotron frequencies. The data is displayed as a plot of single trace, mountain ranges, or 2-dimensional contours to give different perspectives. The physics examples are given.

1 INTRODUCTION

This write-up is about an effort at Fermilab to have a computer program that will serve as a user interface to a TEKTRONIX RTD720 fast digitizing oscilloscope for the purpose of control, readback, and display data. This fast digitizing scope is currently used at Fermilab for beam diagnostics in Tevatron and in Main Ring. The signal comes either from a strip-line beam position detector for observing the head-tail instability or from the wall-current monitor for studying the longitudinal beam dynamics. In either case the digitizer is sufficiently fast for the signal that carries a fundamental frequency of 53 MHz RF.

Most of the reasons for having such a computer program are obvious, not counting the fact that a scope usually sits in a noisy place with cables running everywhere. A computer has large amount data storage space, can make data available to anybody any time and almost any where. It provides much better graphical capability than a simple scope. It allows user to manipulation data numerically rather than mentally, things like re-calibrating, corrections with special algorithm, fitting, or applying analysis tools such as FFT. A program also has the ability to present data in a way that gives evolutionary perspective of signal being observed, not just individual traces. This program is written to be part of the Fermilab Accelerator Control software and can be used readily for studies.

2 DIGITIZER DATA

Data acquisition

The RTD720 is a 2 Gs/s, multiply retriggerable digitizing scope. It has a memory of 0.5 Mbyte and can be partitioned in may ways for the combination of record length and number of records up to 1024. Once armed, it will respond to the external triggers as many times as was requested. Trigger signals are synchronized with the beam revolution such that the digitization starts always at the same place along the beam bunch train. Successive triggers are usually an integral number of beam revolutions apart, depending on the objective of study.

The digitizer is linked to the Fermilab Accelerator Control NETwork (ACNET) via GPIB interface. All the control knobs pertaining to the operation of an oscilloscope can be done through this link, as well as the return of error messages. It takes about 15 seconds to read off half MByte of data which can be saved to file to be retrieved later.

Data display

With the amount of data available the only way to view and understand it at a reasonable amount of time is through graphical display. A 3-dimensional display requires porting data over to other graphical programs and is not covered here. Three basic types of display are implemented and described here.

i. Trace by trace

A trace display is basically reproducing what one normally sees on a scope with the added advantage that many traces are available. This is where one looks for basic characteristics of the signal, such as bunch spacing and signal magnitude. Figure 1 shows a single trace of Tevatron wall current monitor signal.

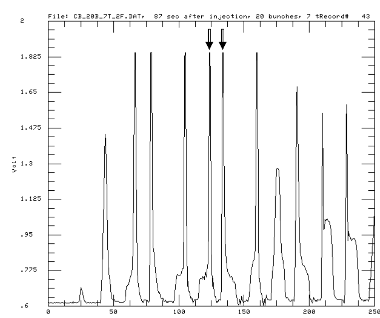

Figure 1: Fermilab Tevatron wall-current monitor signal as digitized in one single trace.

ii. Mountain range

This is a display that has kind of 3-D look, could be kind of messy, and may not always give accurate perspective. A traditional Mountain Range display was implemented through the use of scope and TV camera and is available only as images from TV display. With RTD720 the mountain range display can be replayed forward, backward, and with as many traces as

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reasonable on the computer screen. Figure-2 is a good example of a mountain range display showing the process of beam bunch coalescing within the Main Ring operation.

iii. Contours

Short of doing 3-D graphics contour plot is the next best thing for viewing two dimensional array of data. Figure-3 is an example with data on two individual bunches plotted in the time/trace space. There are 30 sets of the same kind of data as that of Figure 1 but taken successively in time. The horizontal array index is the digitizer sample number at an interval of 0.5 ns, and the vertical array index is the trace number, at an interval of 1.36 ms. Depending on the data being plotted the interpretation of the array index will be different. From the contour the relative magnitude of data within the array can be visualized.

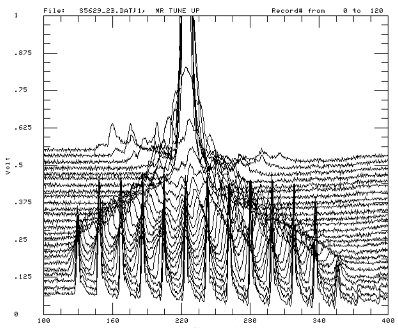

Figure 2: Mountain range plot of Fermilab Main Ring wall-current monitor signal. Data was captured during a collider run setup, at the time 13 proton bunches were being coalesced.

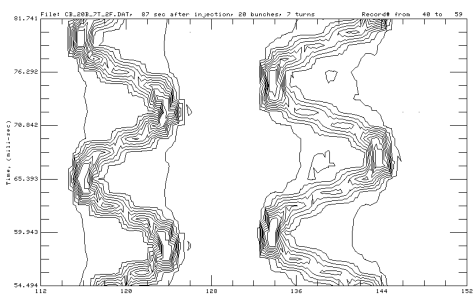

Figure 3: Contour plot of a Tevatron wall-current monitor signal. Only two of the bunches are shown in this plot for a duration of about 27 ms.

Data manipulation

The advantage of having the digitized data is that it can be retrieved, re-scaled, added to other data from other signal, arithmetically. It can also be ported over to specialized program for specific type of analysis. Listed below are functionalities already implemented.

i. FFT

This is probably the most common thing to be done to the digitizer data to obtain frequency composition of the signal, making the digitizer work like a spectrum analyzer. To use this feature effectively one has to plan ahead and partition data such that a longer stretch of data can be used for analysis.

ii. Transposed data

The digitizer data is organized in a trace by trace sequence for each trigger given. It is sometimes useful to see the data from all the consecutive traces but of same location within a trace. Such transposed data therefore allows a view of the signal evolution.

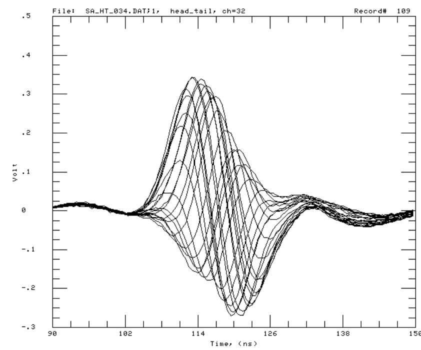

Figure 4: Difference signal of a strip-line BPM detector as was digitized. The effect of reflection can be seen to have distorted the actual signal.

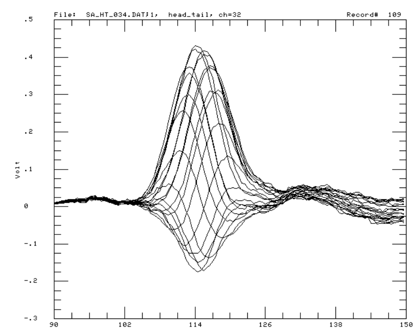

Figure 5: The same strip-line BPM detector signal as in last figure except that the effect of reflection is removed.

iii. Reflection correction

For signals from strip line BPM detector the reflection is inevitable. A common practice would be to used a longer, Quarter-Wave type, detector such that the reflected signal does not overlap the actual beam signal. In real life the beam bunch length could be quite a bit longer or such detector may not be available. The effect of reflection, in principle, can be unfolded to show the actual signal, limited only by the noise level and the resolution of digitizer.

3 APPLICATION EXAMPLES

Clearly, program like this could be useful to other types of beam studies. It could be used for the longitudinal injection matching study. With possibly even higher sampling rate in the future the transition crossing could also be a good application. Given below are the background information relevant to the examples already given so that reader may feel free to draw their conclusion.

Head-tail instability

The head-tail instability has been observed both in Fermilab Tevatron [1] and Main Ring [2]. Figure 4 shows the signal as was digitized with distortion caused by reflection and Figure 5 shows the edited signal with the effect of reflection removed. Removing reflection requires that the reflection coefficient and reflection delay time be matched. Some thing that could also be of interest. While procedure clearly is not perfect the signature of head-tail mode Ø can readily be identified [3].

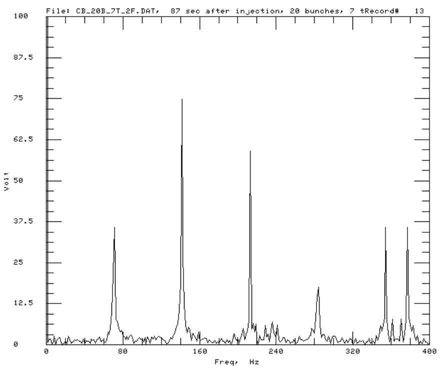

Figure 6: The FFT spectrum of the transposed data for trace position at 118.5 nano-seconds.

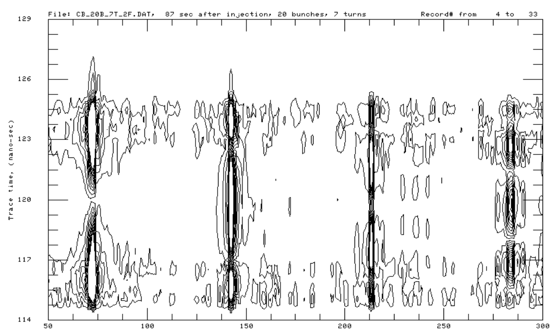

Figure 7: Contour plot of FFT spectrum of transposed data at trace locations from 114 to 129 nano-seconds.

Coupled bunch instability

Figure 1, 3, 6, and 7 are all from the same set of data which contains 1024 traces [4]. The uneven spacing between bunches seen in Figure 1 is indicative of instability effect. The two bunches marked by the arrow heads are also contour plotted in Figure 3, which shows the synchrotron motion of the beam bunch longitudinally. A FFT spectrum of transposed data, at 118.5 ns of each trace, is shown in Figure 6. The 70 Hz synchrotron frequency and its higher harmonics are visible. The spectrum is symmetric around the cut-off frequency of 367 Hz, due to the fact that traces were taken at 1.36 ms apart. In Figure 7 is the contour plot of a collection of spectrum as shown in Figure 6, except that each is at different trace time. It covers the entire left beam bunch shown in Figure 3, and indicated by the vertical axis. It is apparent that the spectral sensitivity depends greatly on the trace time.

Beam coalescing

During the Fermilab collider mode operation up to 13 proton bunches are coalesced to increase single bunch intensity. This coalescing process was done at the Main Ring before transferring the beam to Tevatron. Shown in Figure 1 is the mountain range plot of data taken at the setup time of collider run 5629, July 1995. Only every five traces, or approximately 5 ms apart, are displayed. For comparison, the same data is displayed in Figure 8 as contour plot, with 125 traces of data at 1 ms apart. In both figure the process start at the bottom of plot with 13 proton bunches clearly visible. The bunches diffused and finally came together and were captured as a single bunch at the top of plot. A small portion of the beam was not recapture by the RF bucket and started to wonder away.

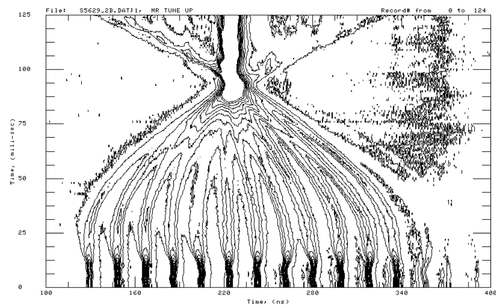

Figure 8: Contour plot of Main Ring wall-current monitor signal during proton beam bunch coalescing. A total of 125 traces of data at about 1 ms apart are included in this plot.

4 CONCLUSION

It is hoped that the effort presented here will result in more than just pretty pictures, that it will promote faster understanding in diagnosing and identifying problems, and that the advantage of this remarkable digitizer be fully utilized. Most of the functionalities implemented are quite basic. It is assumed that more elaborated analysis of the beam data, such as looking for the position, intensity, and the length of each individual bunches, will be done by porting data over to specialized programs.

5 ACKNOWLEDGMENT

I would like to thank Dr. S. Assadi for his generous offer of his study data as examples and many conversations on this subject.

[1] S. Assadi, private communication.

[2] J. Chou and G. Jackson, "Experimental Studies of Transverse Beam Instabilities at Injection in the Fermilab Main Ring", Proceedings of 1995 IEEE Particle Accelerator Conference, Vol. 5, p.3091.

[3] Garett, "Beam Observation and the Nature of Instabilities", CERN SPS/87-18 (AMS)

[4] Assadi, private communication.