TUNE MEASUREMENT METHODS IN THE FERMILAB MAIN RING

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Abstract

The Fermilab Main Ring has three different systems for measuring the betatron tune. The three systems are designed around a resonant beam pickup which interfaces to independent data collecting hardware. The data collecting hardware systems consist of a Hewlett Packard 35665A Dynamic Signal Analyzer, a Tektronix 3052 DSP and a Generic Finite State Data Acquisition (GFSDA) microprocessor system. This paper will describe the systems and the methods for measuring the betatron tune and chromaticity in the Fermilab Main Ring.

1 TUNE MEASURING SYSTEMS

The tune measurement systems for the Fermilab Main Ring provide data for operations that allow the betatron tune and chromaticties to be measured to improve machine efficiencies and troubleshoot machine problems. The three tune measuring systems used provide different analysis of the tune measurement data to provide a quick and clear tune or chromaticity measurement.

1.1 Beam Excitation for Tune Measurements

Most transverse tune measurements require that the beam be excited transversely by a kicker magnet referred to as a "pinger" or random noise that is applied to the low level input of the transverse beam damper system in order to enhance the betatron tune signal. The excitation for both systems can be applied in the horizontal or vertical plane. The pinger is most often used for tune measurements made at a specific time in an acceleration cycle since it can only be fired a few times within the cycle due to its slow charge/recovery time. The excitation from the noise source of the damper can be used to make tune measurements for the complete acceleration cycle. More details of the damper system can be found in [1].

1.2 Tune measurement overview

Data collection for the three tune monitors centers around a resonant capacitive pickup located at A17 in the Main Ring. The signal from the pickup then passes through a receiver that references the pickup frequency to the revolution frequency of the beam. The output of the receiver is sent 500 ft through heliax to the Main Control Room where it interfaces to a unity buffer amplifier and the signal is then distributed to the three different tune monitors. Details on the resonant beam pickup can be found in [2].

Beam sync triggers are used to trigger each monitor independently. Data collection is accomplished through dedicated software applications for each tune monitor system. Figure 1 depicts a block diagram of the three Main Ring tune monitors. A software sequencing application provides control over setting up timing and reference of beam sync triggers and also control over the use of the pinger or noise source to excited the beam. Gathering tune data using the sequencer application allows for the beam excitation with the pinger or noise source to be accomplished in a single Main Ring acceleration cycle. A detailed description of the sequencer software can be found in [3]. Use of the pinger and noise source are destructive to the beam when used to help measure the tunes and are minimized during high energy physics operations.

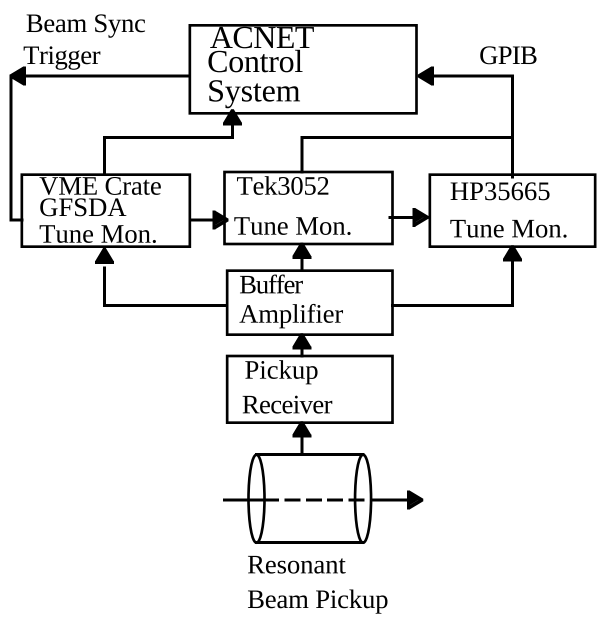

Figure 1: The block diagram of the betatron tune measuring system used in the Main Ring.

1.3 *Operational machine modes for tune measurements*

The machine conditions for operational tune measurements follow two fundamental cycles. Cycles used for Tevatron injection are 3.3 seconds long and for colliding beams 10 seconds long. These cycles accelerate protons from 8 to 150 Gev with a revolution frequency of 47417 and 47746 Hz respectively. The tune is typically horizontally 19.44 and vertically 19.42. Fixed target intensities for multibatched beam are typically 1 E12 to 2.81 E13 protons/pulse where collider intensities are 2.5 E12 protons/bunch. Antiproton production cycles

* Operated by Universities Research Association Inc., under contract with the U.S. Departement of Energy.

accelerate protons from 8 to 120 Gev and have a minimum cycle time of 2.4 seconds.. These are single batch cycles with typical intensities of 2-3 E12 protons/pulse.

2 METHOD USING THE TEK3052

The Tektronix 3052 Digital Signal Processing instrument is used to capture the resonant pickup signal of the beam to gather the betatron tune. This instrument is a VME based microcomputer that uses a UNIX operating system controller. It can acquire data with updates rates up to 200 µsec per frame with four slower frame modes to optimize viewing and processing functions. It has a 25.6 M sample/sec D/A converter in a bandwidth of 0-10MHz. This instrument provides a color spectrogram (frequency vs. time with amplitude color coded) that allows the tune over the entire Main Ring acceleration cycle to be captured and viewed. Tune data is acquired by initiating a tune measurement sequence from the sequencer application mentioned earlier and waiting for the completion of the acceleration cycle. The tune data is then transferred from the TEK3052 to the ACNET control system over a General Purpose Instrumentation Bus (GPIB) by a separate application program. The application then is used to analyze the betatron tune as a function of time of the Main Ring acceleration cycle. The application also provides a graphical interface that allows easy and detailed analysis of each tune spectrum as a function of time. Figure 2 is a plot a tune vs. time of a 120 Gev Main Ring antiproton production cycle acquired by using the TEK3052 tune monitor.

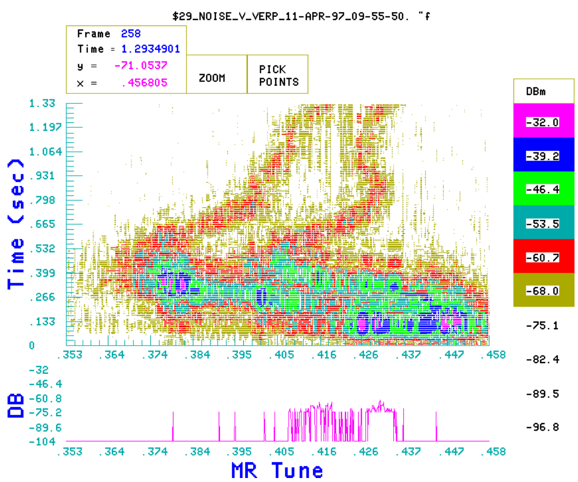

Figure 2: Tune data for a Main Ring acceleration cycle using the TEK3052.

3 METHOD USING THE HP35665A

This tune monitor uses the Hewlett Packard 35665A Digital Signal processor to process the betatron tune data of the resonant beam pickup. A specific software application is used to control tune measurement setups and acquisition. This does not use the general sequencer application for setting up tune measurements like the TEK3052. The time of tune measurements in the acceleration cycle are input as a table into the application. There can be multiple requests for different times in the cycle but it requires a complete acceleration cycle to acquire a single requested time. Once the data for a cycle is obtained from the HP35665A is then transferred by GPIB to the ACNET control system where each cycles time request is saved in a file. The application uses a fitting algorithm to calculate the horizontal and vertical betatron tune from the fast fourier data of the HP35665A. The application also provides a calculation of the coupling. Figure 3 shows the betatron tune results taken with the HP35665A tune monitor.

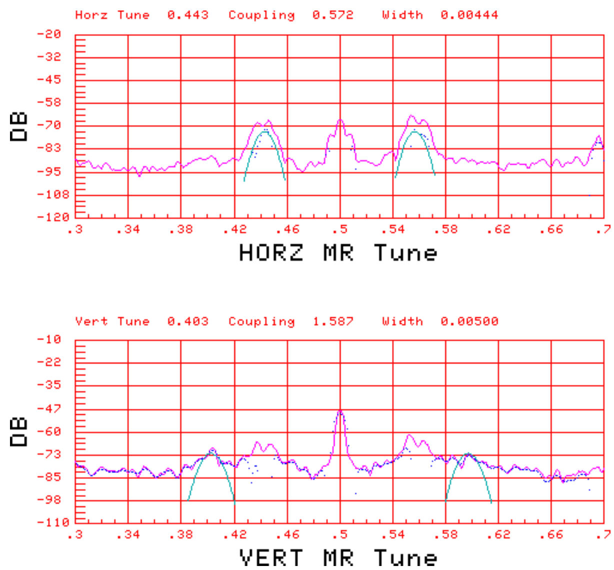

Figure 3: Tune measurement made with the HP35665A tune monitor showing the horizontal and vertical tunes.

4 METHOD USING THE GFSDA

The GFSDA tune monitor hardware consists of a VME crate with a 68060 processor. The crate contains an 8 channel, 16 bit ADC with on-board memory for 5000,000 digitizations per channel and houses extra memory for data storage. The crate also contains necessary cards for network communications and timing for other accelerator data. The GFSDA digitizes horizontal and vertical Main Ring resonant beam pickup signals and completes a fast fourier analysis on board the VME microprocessor for faster and more efficient data retrieval. There are two software applications associated with the GFSDA. One application is dedicated to controlling the GFSDA microprocessor and digitizer as a finite state machine. As a finite state machine flexability is gained in allocating times for consecutive sets of tune data. The maximum rate at which consecutive tune data can be taken is 15 Hz. The second software applications associated with the GFSDA allows tune data to be retrieved from the VME processor and analyzed at the ACNET controls console. Operationally, tune measurements are made with the sequencer software similar to the TEK3052 monitor to coordinate beam excitations with the pinger or damper noise source. It also coordinates timing as to the acceleration cycle to take data. Once the sequence is completed, tune data is retrieved from the software application where it can be analyzed. The analysis software provides a colorspectrogram for viewing the tune as a function of time and also provides a data correlation analysis between the horizontal and vertical beam pickup signals to enhance the tune measurement. Figure 4 is a plot of tune versus time using the GFSDA tune monitor to acquire the betatron tune for 120 Gev antiproton production cycle. More details on the GFSDA can be found in [4].

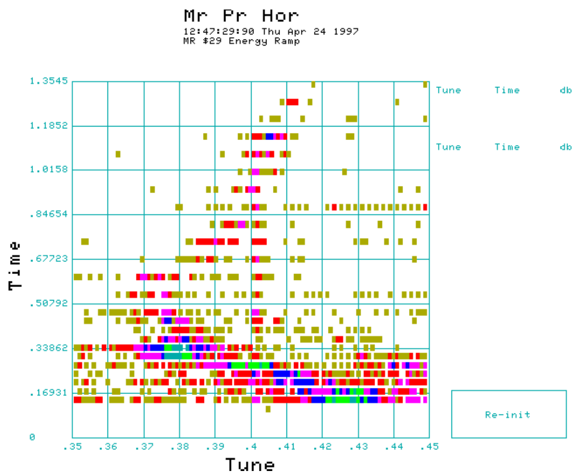

Figure 4: Horizontal tune measurement of the Main Ring antiproton production cycle using the GFSDA tune monitor.

5 CHROMATICITY MEASUREMENTS

Chromaticity measurements are made with the same hardware and software application that is used to measure the tune using the HP35665A. The chromaticity can be determined by:

$$\delta\upsilon = \zeta \, dp/p$$

where $\delta\upsilon$ is the change in tune, ζ is the chromaticity and dp/p is the deviation of ideal momentum. The method of measuring the chromaticity is done by moving the beam radialy to different positions using the low level radio frequency (RF) and the horizontal and vertical tune are measured as a function of position at a specific energy in the acceleration cycle. The data is then fit to a polynomial to calculate the chromaticity. The chromaticity is then plotted as a function of time in the acceleration cycle. Figure 5 is a plot of the chromaticity vs. time of a 120 Gev antiproton production cycle.

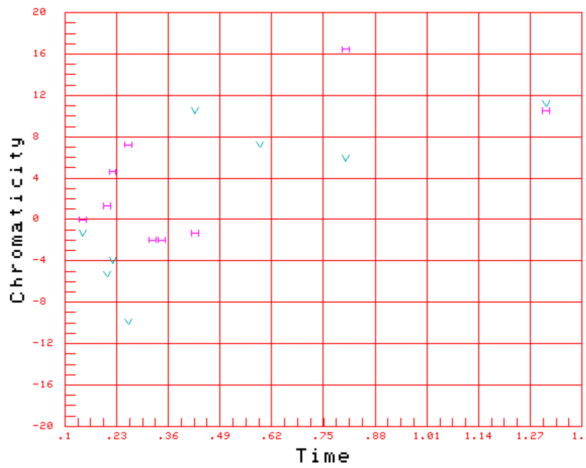

Figure 5: Chromaticity measurement made in the Main Ring using the HP35665A.

6 DISCUSSION

In the past, most tune measurements in the Main Ring were made at a single time in the acceleration cycle. If the tunes were measured over the entire acceleration cycle, it would require many beam cycles and was usually destructive to the high energy physics program and laborious to acquire data. The TEK3052 and GFSDA now can retrieve tune data for the complete acceleration cycle in one cycle. It also has been difficult to measure the tunes from 9 to 20 Gev in the acceleration cycle without exciting the beam transversely. The HP35665A and the GFSDA can passively average tune data for consecutive acceleration cycles to enhance the betatron tune. The GFSDA can also enhance these tune measurements by correlating tune data between the horizontal and vertical beam pickup plates. Current chromaticity measurements in the Main Ring are time intensive which takes many cycles to complete a single energy measurement. When the Main Ring is replaced by the Main Injector, it will be easier to make specifications for the hardware and software for tune and chromaticity measurements. The Main Injector will most likely adopt a version of the GFSDA which will also include software upgrades for making chromaticity measurements.

REFERENCES

[1] J. Crisp, "Main Ring Slow Damper Noise Gates",, Fermilab Operations Bulletin #1204.

[2] P.J. Chou et. al., "A Transverse Tune Monitor for the Fermilab Main Ring", Proc. PAC95, pg. 2479, 1995.

[3] J. Annala and A. Braun, "The New Colliding Beams Sequencer", Fermilab Operations Bulletin #1234.

[4] D. Herrup, "Realtime Tune Measurements in Slow-Cycling Accelerators", Proceedings of this Conference.