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A VXI/LabVIEW-based Beamline Tuner

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Abstract

A general purpose beamline tuner is being developed to reduce betatron oscillations resulting from missteering during beam transfer. The tuner is based on VXI instruments controlled by a LabVIEW program running on a Macintosh computer. VXI digitizers take turn-by-turn data from beam position monitors followed by an analysis of the data in the time- and frequency- domains. The results, the phase and amplitude of the betatron oscillations, are communicated from LabVIEW to the control system over a tokenring network. An application program at a control console calculates the required changes in the correction elements from the phase and amplitude to reduce the oscillations. The beamline tuner is self-contained and easy to adapt to other beamlines. Early results indicate that the tuner outperforms the current system.

I. INTRODUCTION

During a collider run it is important to achieve the highest possible luminosity. Betatron oscillations of the beam result in a growth of the beam emittance which decreases the luminosity during beam-beam collision. The betatron oscillations occur when the beam is not injected onto the closed orbit. The task of a tuner, therefore, is to adjust the correction elements so that the beam is injected onto the closed orbit. An overview of injection tuning methods is given in [1].

The current Tevatron injection tuning system uses a method that measures the beam position signal of 13 consecutive beam position monitors (bpm) at the first turn and then subtracts the beam positions of the closed orbit at those locations. The resulting data represents the betatron oscillation to which a sinusoid is fitted to determine the phase and amplitude. To do a proper fit, the phase advances, the beta values and the dispersion values at each bpm location must be accurately known. Because the method assumes that all beta values are the same and ignores the dispersion, it introduces errors in the calculations. The current system also suffers from the limitation that it can handle only one bunch per ring. The digitizers trigger on beam intensity and multiple bunches in the ring would lead to triggering on a wrong bunch. This means that the tuning of the injection must be separate from the actual loading of the ring for a collision shot. The time from tuning to loading the last bunch is often more than an hour. Meanwhile the drift of various elements can invalidate the calculated corrections resulting in betatron oscillations of up to one millimeter. The injection tuning of the anti-protons is also done in a separate step. To avoid wasting precious anti-protons, protons are reverse injected from the Tevatron into the Main Ring. The correction method is the same as for proton or forward injection. The current system is described in [2].

An advantage of using many, e.g. 1024, turn-by-turn measurements for injection tuning is that the current betatron tune can be determined and unwanted frequencies as noise or synchrotron oscillations due to dispersion, can be filtered out. Also, only a single detector per plane is needed, eliminating the error due to inaccurate betafunctions and phase advances. The turn-by-turn method has already been successfully applied at Fermilab for the accumulator and is described in [3].

II. CONFIGURATION

The hardware centers around two Tektronix VX4240 digitizers, one for each plane. A 7.5 MHz clock for the digitizers is derived by a special CLOCK module from a beamsync signal. A V177 card decodes from the same beamsync signal an event that triggers the digitizers at a rate of 47 kHz, or once per turn. The digitizers sample on the first positive clock edge after a positive trigger edge. Since both the clock and trigger are derived from the beamsync signal, the beam is always sampled at the same point in the beam position waveform. Different bunches are selected by directing the V177 to change the delay of the trigger. To start the sampling on an injection, a V177 module decodes an injection event that arms the digitizers from the Tevatron Clock signal. To be able to look at Tevatron and at Main Ring injections, HP E1366A RF multiplexers switch the V177 cards between the Main Ring and Tevatron bpm signals and between the Main Ring beamsync and Tevatron beamsync signals.

A Macintosh IIci controls the VXI crate through a MXI interface. The Macintosh connects to the accelerator control's Tokenring network, enabling it to exchange information with an application program on a control console. An independent control signal can cycle the power to the Macintosh and VXI crate to perform a remote reboot. The configuration is shown in figure 1.

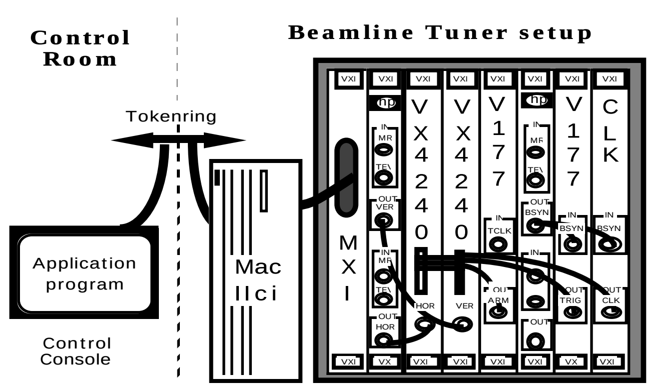

Figure 1. The configuration of the beamline tuner.

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III. OPERATION

The Mac IIci runs the graphical programming language LabVIEW which includes a VXI library. All crate modules are controlled using this library. The Acnet (Accelerators Control Network) Interface library, developed in-house and described in [4], handles the communication from LabVIEW to the control system. At startup, the VXI modules are initialized and the Acnet interface is activated. After the injection and data has been taken, the analysis starts. The first step of the analysis is a Fourier transform of the turn-by-turn measurements. A peak search in a range around the expected betatron tune determines the current tune. If two peaks are found, the betatron oscillation is assumed to be coupled and a warning is given since the analysis assumes an uncoupled motion. The algorithm continues with the largest peak as the current tune. The next step is an inverse Fourier transform of only the frequencies within the range. This removes the dc offset, various noise sources, e.g. 60 Hz, and the synchrotron oscillation due to dispersion. The third step is to analyze the amplitude of the oscillation on damping due to decoherence and on additional oscillation due to coupling. The found damping coefficient is used to even the amplitude of the signal so that an undamped sinusoid can be fitted. A warning is given if coupling is found. The Levenberg-Marquardt algorithm from the LabVIEW analysis library does the fitting. Because the damping in both Tevatron and Main Ring reduces the oscillation to noise levels in less than 80 turns, only up to the first 30 turns are suitable for fitting. Currently, the fit uses only 15 turns in order to handle a small degree of coupling. The Tevatron runs in general with only a minimum of coupling which is not a problem for the analysis. The earlier calculated tune and amplitude are used as initial guesses for the fit. While a damped sinusoid could have been fitted, it would introduce one more parameter to estimate and lead to a slower or possibly wrong convergence. The results of the fit, figure 2, are communicated to an application program running on a control console under operator supervision.

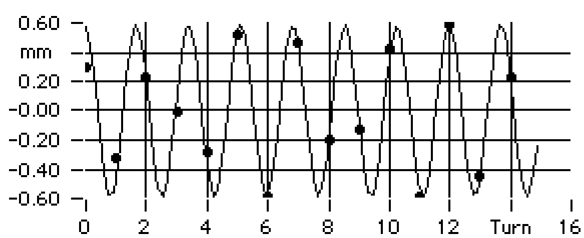

Figure 2. A fit by the beamline tuner.

The console application program then calculates and sends out the adjustments to the corrections elements. The application bases its calculations on the results of studies. These studies relate settings of corrector elements empirically to the estimated phase and amplitude. With this approach, the lattice functions were not needed. The left diagram of figure 3 shows the oscillation vector, the estimated phase and amplitude, move in a line as one of the correctors is changed. This is because only the amplitude is a function of the corrector setting while the phase depends on phase advance from the corrector to the bpm. By using two correctors at different phase advances, the measured amplitude and phase can be decomposed in terms of the correctors' oscillation vectors. The right diagram of figure 3 shows the relation between the amplitude of the oscillation and the value of the setting. This relation, in combination with vector decomposition, yields the adjustments to the correction elements for any phase and amplitude of the betatron oscillation.

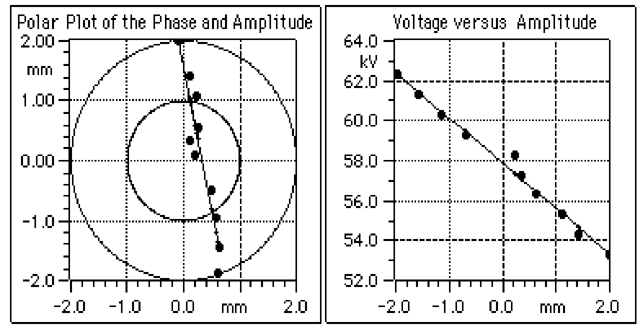

Figure 3. The results of the E17 injection kicker study.

The application program, shown in figure 4, provides the operator with a user-interface to control what bunch from what ring should be sampled and whether the calculated settings are sent out.

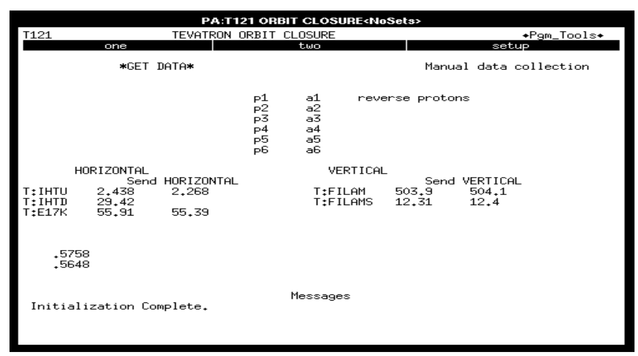

Figure 4. The console application program.

The functionality of man-machine interface could also have been implemented by directly displaying the Macintosh screen with the beamline tuner's menu on a control console using the application XGator or on a Macintosh using Timbuktu. However, providing the operator with a standard interface was more important than using only one programming platform. The remote display is being used though, for diagnostic purposes and expert adjustments to the operation of the beamline tuner, figure 5. The beamline tuner can store the measurements including the results and current algorithmic parameters in a file. This file can be uploaded using Appleshare, Timbuktu, or a FTP application. The data can then be analyzed with various parameter settings using an off-line version of the tuner. The same data transfer applications can download updates of the beamline tuner software made on a development system.

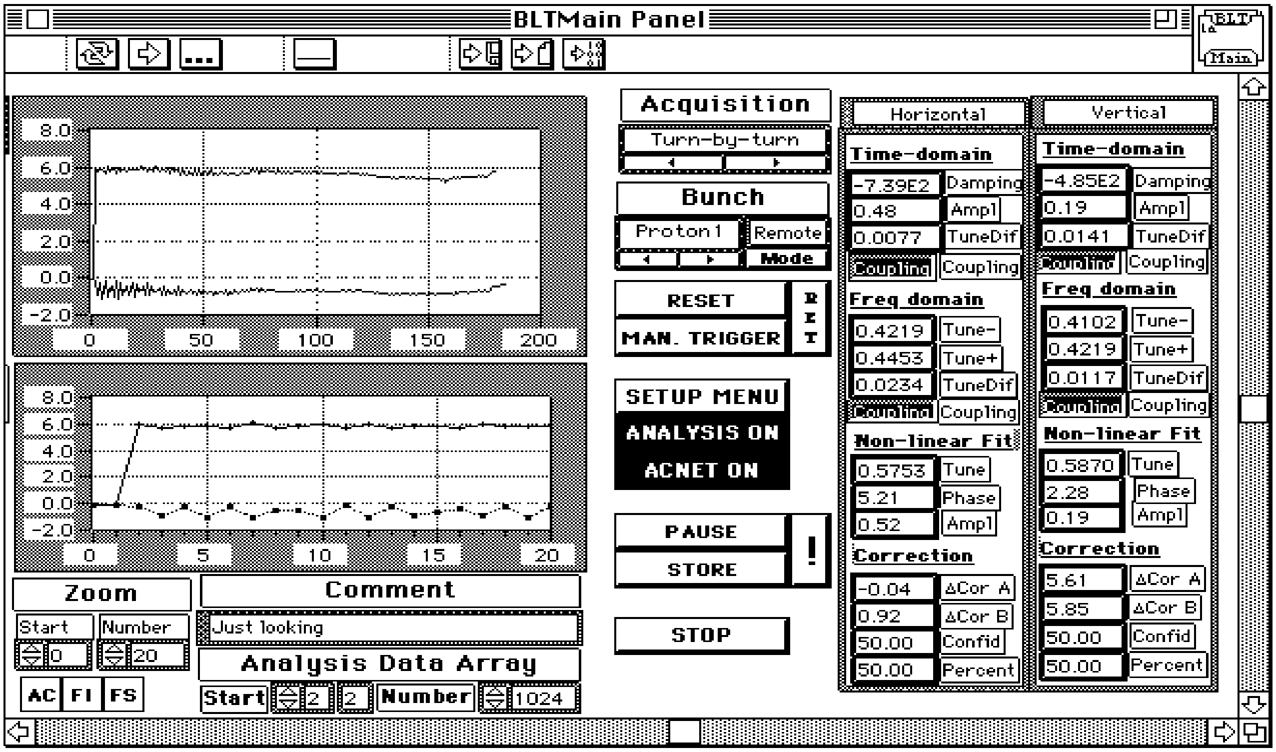

Figure 5. The beamline tuner's display and menu.

IV. CONCLUSIONS

Early experiences indicate that the beamline tuner can accurately correct betatron oscillation of 0.3 mm and larger. The old system often leads to oscillations of up to 1 mm in the horizontal plane for the last proton bunches because of the long wait between tuning and loading. The difference of a 0.3 mm compared to a 1 mm oscillation would reduce the emittance by about 20 percent.

The VXI/LabVIEW system operated in a reliable manner and proved to be easily adapted to enhancements in software and hardware. The off-line version proved very useful in determining the proper settings of the parameters of the algorithms. The additional direct access to the beamline tuner provided the expert with a wide variety of menu options to change the operation of the modules or algorithms or to diagnose the system on-line.

V. ENHANCEMENTS

Future enhancements are planned in order to reduce betatron oscillations to an amplitude of 0.1 mm.. The beam position wave form of a single bucket bunch has only a 150 nsec wide range where its value represents the beam position. For a perfect bpm module this range is flat and it does not matter where it is sampled. In practice, however, the signal shows a slope or a small oscillation. Therefore it is important to always sample within nanoseconds on the same spot. The clock signal derived from the beamsync signal showed a jitter of up to 5 nsec. By applying a phase-locked loop, this jitter should be reduced to sub-nanoseconds. Another problem is that the range is not always 150 nsec, but is smaller at some bpms. With a 7.5 MHz clock the smallest step is 130 nsec. This means that in some cases samples are taken at the edge of the valid region. By using a fast delay generator, the clock signal can be skewed, giving control over the point of sampling in terms of nanoseconds. Another option is to use a faster digitizer, e.g. running at 53 MHz, thus reducing the delay step size. All options are currently implemented to compare the results.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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