Real-Time Feedback Control of the Tevatron Tunes and Chromaticities

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Abstract

We are developing a system to provide real-time feedback for control of the Tevatron tunes and chromaticities during collider operations. In the past the Tevatron has not had the capability for continuous adjustment of these parameters, and various machine operations (injection, the ramp and squeeze to low-β, for example) have led to emittance growth and beam loss. Time-varying persistent currents have also been a serious problem. In future Tevatron collider runs we will have continuous tune and chromaticity measurements available. These will be the inputs to a Multibus II[1] processor which will calculate the corrections to the various quadrupole and sextupole power supplies needed to maintain the tunes and chromaticities at their specified values. These corrections will be transmitted around the Tevatron to the individual supplies. We will describe this system and the ways in which we intend to use it.

Introduction

In future collider runs the Tevatron will store up to 36 p and 36 $\bar{p}$ bunches with intensities of up to 33E10 p's/bunch and 7E10 $\bar{p}$'s/bunch[2]. In order to hold the linear beam-beam tuneshift parameter to 0.016, the bunches will be separated at all but two interactions points both horizontally and vertically in helical orbits. The operating point has been chosen to be (20.59, 20.59). This is between the $1/7^{th}$ and $3/5^{th}$ resonances and allows a total tune space of about 0.03.

The tune space will be consumed by the chromatic tune spread ($\Delta\nu = \xi\delta p/p$) and the tune spreads from both the head-on and long-range beam-beam interactions. There are accelerator operations which can cause the tune to vary in ways that cannot be easily modelled or controlled. These include injection, acceleration, and the squeeze to low-β. The chromaticities also change during these operations. Time-dependent persistent current effects cause ξ to change while the Tevatron is set at 150 GeV for p and $\bar{p}$ injection and in the first few seconds of acceleration[3]. Because the ramp rate of the superconducting magnets is limited, these processes (especially acceleration and squeezing) can take minutes. If the tunes are not controlled during these periods, the tune spread can overlap resonances, leading to emittance growth and/or beam loss. Adjusting the tune and chromaticity circuits point by point (for example, at intervals of a few seconds) is very time consuming. It does not prevent uncontrolled excursions between the set points, and must be re-done whenever the accelerator conditions (ie., the closed orbit) are changed.

With the Tevatron separated orbit upgrade the problem of controlling tunes and chromaticities will become more complicated. Previously there were only 7 circuits: focusing and defocusing quadrupole and sextupole circuits and 3 skew quadrupole circuit. All of these acted identically upon p's and $\bar{p}$'s. With separated orbits we have the ability to control the tunes and couplings of the p's and $\bar{p}$'s independently of each other with sextupole circuits located at positions where the two beams are separated (studies have shown that there is no reason for independent chromaticity control). Approximately 30 new "differential feeddown" sextupole circuits will be used in addition to the previously mentioned circuits[4]. Different circuits will be used depending upon which accelerator operations are occurring and the relationship between the helix and the feeddown circuits. The complexity of this system requires an automated system for controlling these circuits.

The system we have decided to build is a feedback system. The Tevatron has been instrumented with 2 sets of horizontal and vertical Schottky detectors[5]. They are located such that vertical and horizontal p and $\bar{p}$ tunes can be measured independently and simultaneously. These signals will be used as the inputs to a set of phase lock loops (the "tune tracker" circuits) whose outputs will be a single number proportional to the fractional part of the tune[6]. Each tune tracker will have 2 outputs, a fast (up to 100 Hz. bandwidth) and a slow (1 Hz.) output. The bandwidths will be adjustable. The slow channels will be used for tune measurements when the Tevatron is in a static state (the 150 GeV front porch, stores) and we can afford to wait for very precise measurements. The fast channels will be used when the accelerator conditions are rapidly changing, such as during the actual injection process, ramping, and squeezing. There will also be a lock-in bit which indicates that the loop has locked properly. These devices have been built, and will be installed in the Tevatron by the summer of 1990. There are also plans to build a "chromaticity tracker" which will modulate the RF frequency and use the outputs of the tune trackers to calculate ξ_x and ξ_y. These 14 signals (8 tune signals, 2 chromaticity signals, and 4 lock-in bits) will be the inputs to the CBA processor[7]. The CBA processor is to use these input signals to calculate corrections to the necessary quadrupole and sextupole circuits to keep the tunes to within 0.002 of the desired values when the fast tune channels are used, and to within 0.0005 for the slow channels, and the chromaticities within 3 units.

Successful implementation of CBA requires tight control over other Tevatron parameters. The feeddown correction scheme is designed to work differentially on p's and $\bar{p}$'s. This requires that the Tevatron closed orbit with the electrostatic separators turned off pass through the centers of the magnets. If there are deviations from this "zero-orbit", there will be a "common-mode" tune shift of both the p's and $\bar{p}$'s, and CBA may try to correct the wrong circuits (ie., the feeddown circuits rather than the quadrupole circuits). In addition, we must ensure that the tune trackers are accurately measuring the tunes.

HARDWARE

The CBA processor must fit within the established Fermilab accelerator control system, ACNET[8]. This includes computers and links for communications between the operators and local processors and diagnostic equipment, power supplies, their controllers and the links they use. It is relatively easy to install an additional microprocessor enjoying all the advantages of this system. The presence of a group in the Accelerator Division developing Multibus II processors for the new front end computers[9] for this network made it attractive for us to use the same system.

A functional diagram of CBA is shown in Fig. 1. We have only included the tune tracker inputs. The path is the same for the chromaticity tracker. The central element in the system is the Intel 386/116 processor with 8 Mbytes of DRAM memory and a 16 channel Intel iSBX 311 Analog Input Board on the SBX site. The analog outputs and lock-in bits of the tune and chromaticity trackers will be digitized by the ADC. Data "filtering" (primarily checks of the lock-in bits and

*Operated by the Universities Research Association under contract with the U. S. Department of Energy

checks that the values make sense) will be done by the processor. The processor will also run the feedback algorithm to calculate the changes needed for the power supplies. The 8 Mbytes of memory will serve as a local data logger and diagnostic memory, as well as storage for parameters needed for CBA's operation.

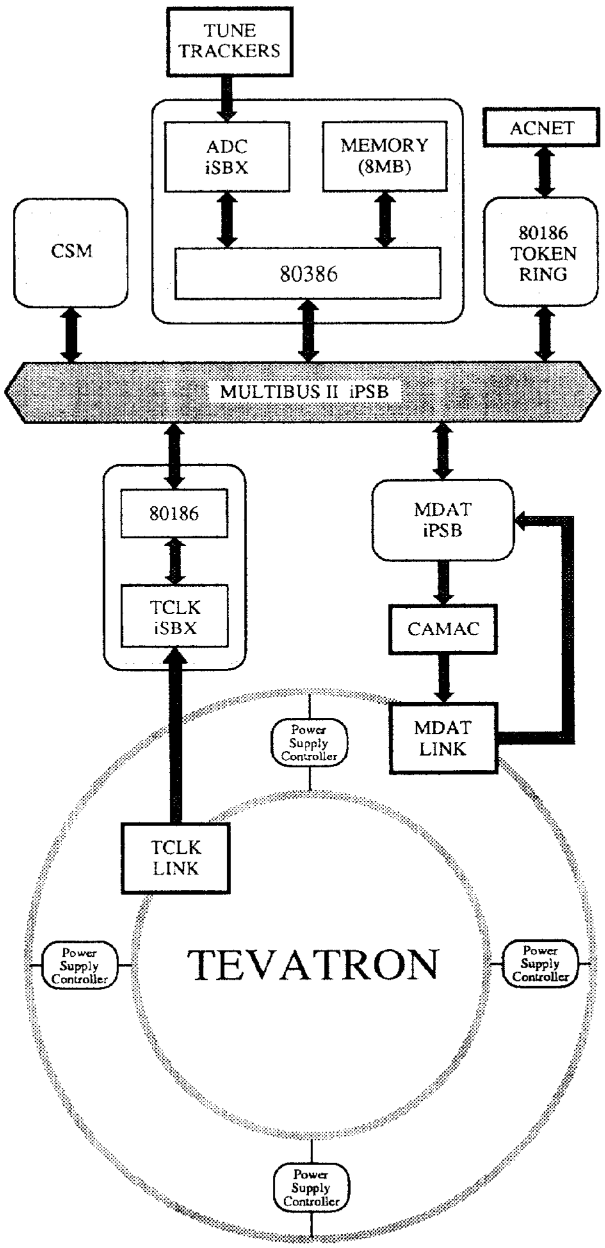

Figure 1: Functional diagram of the CBA system.

Communications between CBA and ACNET occur over the Token Ring link. Within CBA, this is implemented on a Micro Industries 186/110 base board using the Texas Instruments TMS 380C16 chipset. The Token Ring link is being designed to run at 4 MHz., although it will be possible to upgrade it to 16 MHz operation. This link will be used to transfer data from the memory to users on ACNET for display in the Main Control Room or for offline analysis. It will also be used for downloading of constants, and eventually for downloading of microcode. The accomplishment of these tasks will require a significant investment in applications code, and until this code is developed we plan to communicate with CBA through an IBM PC connected directly to the 386/116 card through an RS-232 port.

Both the TCLK and MDAT cards are needed to interface to existing Fermilab accelerator-wide links. TCLK refers to the Tevatron CLocK system[10]. Accelerator timing information is encoded on this link, and is available for whatever device decodes TCLK. The TCLK events of interest to CBA will be events such as injection, start of acceleration, start of squeeze, etc. CBA will take specific actions upon receiving such events. The complexities of distributing clock events within a single crate (many modules may require different events and the requirements may change dynamically) have led us to build the Multibus II TCLK decoder using the SBX site on a Micro Industries 186/110 card.

The MDAT link is another fast link for communicating data describing the current state of the accelerators. The update rate can be as fast as 720 Hz. CBA will read this link to determine the Tevatron bend bus current, and will distribute the corrections to the feeddown power supplies on MDAT. The MDAT receiver/transmitter is essentially a passive card and is based on the Intel MPI chip and supports all Multibus II addressing. Our card does not have the ability to initiate interrupts on the iPSB bus. Other modules in the crate have read/write access simply by requesting from or writing to the card. The data CBA will put on MDAT will be the current changes needed in the tune, chromaticity, and feeddown circuits. The MDAT outputs are processed by a CAMAC parallel-to-serial converter and then placed on the link. Each power supply controller will read MDAT and decode the information relevant to it. The current increment will act as a vernier for the programmed table already in the power supply controller. The controllers are standard Fermilab power supply ramp generators[11].

SOFTWARE

Much of the software we will use for this project has been (or is being) developed as general use microprocessor software in the Accelerator Division. The 80386/116 will run the MTOS[12] operating system and the 80186 cards will run a locally written operating system and Transport code. The high-level code running in the 80386 will be done using a protocal known as Object Oriented Communications (OOC)[13].

The CBA-specific analysis code will be implemented using finite state machines within OOC. State changes will occur on clock events or on a clock event and a delay. The periodic routines will be called at anywhere between a 15 Hz. rate and a 120 Hz. rate, depending upon the bandwidth of the tune trackers. Each state will have a table of "target" values for the tunes and chromaticities and information on which circuits to control. The values may change through a state, depending upon the accelerator conditions. The data logger facilities have been mentioned. We plan to log all of the analog inputs, the current MDAT values for the feeddown sextupoles and the newly calculated values which are to be put on the link, and any intermediate calculations which may be of interest. There will also be a circular buffer in which we will store many hours worth of data (probably using the 1 Hz. values for the tunes). We will also provide programs to analyze CBA data in the Main Control Room.

All code will be written in C. Code development and debugging will occur on the Accelerator Division Vax Cluster. We are now using accelerator data taken during the 1988-1989 collider run to evaluate various feedback algorithms.

We intend to provide full closed loop diagnostics for all elements within the CBA crate. One possibility for doing this is to include a DAC on an SBX connector (either on the 80386 processor card or on the TCLK card) and use its outputs as the inputs to the ADC. We can then write a "Tevatron simulator" to run in the 80386 to generate "simulated" Tevatron tunes and chromaticities. The rest of the data path would be identical to real Tevatron use. The advantage of this system is that it is completely contained within the CBA crate. Another possibility is to set up a separate test stand with a PC and a CAMAC crate with DACs and other diagnostic equipment. The PC would then act as the "Tevatron simulator" and program the DACs which would then be inputs to the CBA ADCs. The advantage of this method is that we would have a system that is totally independent of operational CBA and there would not be extra processes running in the CBA 80386. During operation we also intend to monitor several "dummy" MDAT channels to ensure that data are being put on the link properly. We will also dedicate two channels of the ADC to continuous tests (for instance, ground and +10 v.).

PLANS

The hardware for CBA is now nearly complete (only the final version of the MDAT card has not yet been received). The MTOS operating system has been working on the 386/116 card for many months, and the code for the TCLK card is being written now. The OOC code has not been ported to Multibus II. However, a version (including finite state machines) has been installed and working on the VME systems in the Accelerator Division. We expect to have OOC running on Multibus II in the middle of the summer. Our plan is to develop a simple analysis package working only with the vertical tune (the range of the tune trackers is 0.35-0.45 in the fractional part of the tune. In fixed target running the vertical tune is around 0.38 and the horizontal tune 0.48) and be able to run CBA parasitically during the current fixed target run and during collider studies. During this time we will be developing both microcode and applications code. Our goal is to have a working system at the start of the next collider run in mid-late 1991.

Both the hardware and software for CBA will be flexible enough to allow the system to be expanded.

CBA depends upon using Schottky detectors to detect oscillations in the beam at the betatron frequency. This has not been a problem in the Tevatron, as there are (unknown) sources of noise driving the beam at the betatron frequency, and the tune signals are at least 10 db. above the noise. We would like to eliminate this noise, as it does cause some degradation of the beam and makes diagnostics more difficult. If we do succeed, the true Schottky signals may be only several db. above the noise levels, and it may be difficult for the tune trackers to find the proper tune. In that case we must be able to inject noise into the Tevatron whenever we want to make a measurement. We have made provisions to do this by using beam position monitors or directional kickers connected to a noise source. CBA must be informed of the status of the noise source, and eventually control it. The chromaticity tracker is another example of such a device. CBA must know when the device is enabled and calculate the corrections to the chromaticity sextupole circuits accordingly.

ACKNOWLEDGEMENTS

Many thanks are due to Mike Harrison for suggesting this project, and to Dave Finley and Gerry Jackson for many discussions about physics goals. Peter Lucas and Bob Ducar have encouraged the project from within the Controls Group. Jim Fitzgerald designed the tune trackers and Keith Meisner is designing the chromaticity trackers. Joe Gomilar has also helped assemble many of the components.

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