Control of the Time and Energy Dependent Parameters of the Upgraded Tevatron Collider

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Abstract

The upgraded Tevatron Collider has two new matched low beta insertions and operates with electrostatic separators to have different orbits for the proton and pbar beams. A general-purpose application program has been developed which allows the operator to control approximately 200 function generators and associated timers to commission, tune, and operate the machine. The program and relevant aspects of the Fermilab controls environment are discussed.

Introduction

With the replacement of the low beta insertion at B0, used during the first two Collider runs, and the addition of a second and identical insertion at D0 the number of quad circuits for controlling the lattice optics increased from 4 to 24. The addition of electrostatic separators and feed-down circuits to the already existing circuits used to control the proton tune, chromaticity, and coupling brings the number of circuits to be controlled to 78 excluding dipole circuits.[1] In addition to the increased number of circuits, many steps are required to bring protons and pbars into collision at the interaction regions and remain separated everywhere else.

With the prospect of the new VAXstation work stations as operator consoles[2] and the increased complexity of the Collider, an effort to design and implement the next generation Collider Software was initiated. The PDP-11 era software responsible for the Tevatron operation had been designed under the constraints of the PDP-11 consoles (i.e. Fortran source code and restrictive memory limitations required large programs to be heavily overlaid). Three independent programs coordinated by a fourth - the Colliding Beams Sequencer (CBS) [3] were required for the operation of the Tevatron during the last Collider run , helical orbit studies, and low beta studies. Much code was duplicated in the three programs and any hardware changes or reconfiguration required (sometimes extensive) code modifications. Since the VAXstations are virtual memory machines and C source code is being supported, a new user interface was written such that a single program, the Collider Ramp Generator (CRG), would be responsible for controlling the time and energy dependence of all circuits during all phases of Collider operation and studies. Many calculation algorithms [4] utilized in these programs are being converted to library routines.

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A goal in the design for the operational control of Collider devices is to download all the necessary time and energy parameters (and timing events) in all circuits for the complete filling cycle at the end of the previous store during the "recover" process. Thus allowing clock events to initiate the transitions from injection to low beta with collisions. To facilitate this goal, a Fermilab designed microprocessor based programmable ramp generator (i.e. 465 series of CAMAC modules) [5] with digital and analog outputs is utilized. This module has 16 ramps (or interrupt levels) which are a function of time and/or energy. Each is triggered by the 'OR' of up to 8 clock events. It has a digital input for the Machine DATa link. One of the machine parameters transmitted on this link is the current (or energy) in the main Tevatron bus. This is used by the module to interpolate output values within its energy tables.

Collider Requirements

There are three "states" of the accelerator with respect to its energy: injection, acceleration, and flattop. Acceleration can be considered as a transition between injection and flattop where the energy of the accelerator changes. An energy ramp for the accelerator is defined as a collection of energy steps. Generally, all devices track the energy of the accelerator and have energy tables with values at each step. All of the beam manipulations at a constant energy (either injection or flattop) are carried out by time ramps. The values in the time ramps are considered deltas to the "base value" of the energy ramp at injection or flattop. Time ramps are generally triggered at the desired time by either the CRG or CBS programs. Figure 1 shows the currently defined ramps for the Collider operation along with the "clock events" used to trigger the ramps.

Program Organization

Generally speaking, a machine physicist or operator will want to control some set of devices (called PARAMETERS in the CRG) at a particular time in the cycle (i.e. injection, opening the helix, ramping, during the squeeze, etc.). Using the CRG, a user would specify a time in the cycle (called a RAMP) and a set of parameters (called a GROUP) to display parameters for adjustment.

There can be many GROUPS associated with each ramp. There are two types of ramps for the hardware module which are classified by their independent variable: energy ramps and time ramps. When the energy of the accelerator changes or a

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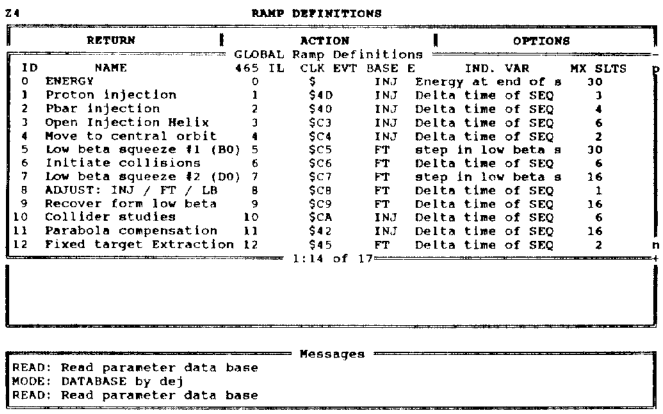

Figure 1: CRG Parameter database page image showing the currently defined ramps for use in Collider operation.

time RAMP is triggered, all devices in each of the GROUPS will synchronously generate their downloaded waveforms. A collection of RAMPS are stored in one of the USER FILES which then contains a complete set of information required to configure the accelerator for a specific operational mode (i.e. Collider operation with one or two insertions, fixed target mode, turn on mode, studies, etc.). To configure the accelerator for the desired operational mode the user would ACTIVATE a USER FILE. This will download all RAMPS defined in the file to the hardware ramp generators. This could take many minutes depending on the number of RAMPS in the file, the number of GROUPS in each ramp, and the number of PARAMETERS in each GROUP, and is only done when the mode of operation is changed.

CRG Parameter Database

One of the main goals of the program design was to accommodate the changing requirements of the accelerator without the need of software modifications. Therefore, a program database consisting of three classes of objects was designed to allow the on-line creation of parameters, groups, and ramp definitions. Interface routines to this database are provided to allow the input, modification, display, copying, and concatenation of each of the three classes.

From these interface routines, the user may specify how accelerator devices are related to each other (which set of PARAMETERS are assigned to a GROUP and which algorithm is used to calculate the output waveforms). The PARAMETERS are considered the low level or base class of objects and contain hardware and program control information. These may represent a desired physics quantity (such as tune, chromaticity) or a specific hardware device to be controlled or both. Currently there are two members to the parameter class: ramp cards and timers. All GROUPS have "input" PARAMETERS which are used to tag the input variables modified by the user and "output" PARAMETERS which are the current or table values to be loaded into the hardware ramp generators.

Program Calculations

The user is provided with the tools to input parameters in machine physics terms which requires a set of algorithms to relate input parameters to the required current waveforms destined for the hardware ramp generators. Many of the algorithms utilized are derived from mathematical models of the machine system while others are simple linear relationships. A library of all calculation algorithms required for Collider operation, is being built.

The constants used in the algorithms are derived from lattice calculations, magnet measurements, or empirically determined from machine data. Circuit configuration information is also included with the calculation constants to indicate which magnets, separator modules, etc. are powered and their polarity. A constants file, which contain all the constants for each unique group defined in a USER FILE, is maintained.

The algorithms and their constants may be viewed and modified during a session. Any modifications may be saved in a constants file associated with each USER FILE.

When the output waveform for a set of devices in the selected ramp is calculated, both the input parameters and output parameters may be plotted on a color graphics screen utilizing a standardized plotting package.

Program Implementation

A crucial aspect in the development of the next generation Collider Software was the early development of a layered set of library routines optimized for the VAX console environment. These routines are built upon existing Console LIBrary routines to interface TV and graphics I/O, the accelerator database (for "static" data) and datapool (for "live" data), central filesharing facility, and network communications.These new libraries provide mid-level set of routines designed to create a richer programming environment and increase the ease and efficiency of writing application programs. In many cases, these routines substantially reduce the amount of code required by application programs for data and screen I/O. [6]

A new era at Fermilab for program control was entered upon the introduction of a new mode of program execution, called scripting.[6] A set of routines has been added to the library which allow the "tape recording" of console programs for later replay. A "script" is a record of the console interrupts and cursor movement while recording. These scripts may be accessible through a menu selection for replay or invoked by a remote task. The CRG utilizes these scripts to allow the user to automate an otherwise complicated or lengthy set of interrupts.

Interface to other Software

A set of library routines have been designed to aid in the communication between programs. These routines utilize VAX VMS mailbox, filesharing files and a routine for starting and passing data to remote tasks. The CRG is currently interfaced to three other software programs; the CBS, the Tevatron Orbit Program (TOP) [7], and the on-line lattice calculation program TEVCONFIG [8].

A communication path between the CBS and CRG provides an easy mechanism for adjustment of the common machine parameters (i.e. tune , chromaticity, and coupling) at injection, flattop, and low beta. The sequencer starts the CRG as a remote task and passes (via mailbox) the values to be adjusted. If the adjustments are successfully loaded in hardware, the CRG returns success and the new values are updated in sequencer files. Instead of passing parameter values, the sequencer can also start a CRG script. This is used for time dependent b2 adjustments, loading a specified ramp, or a file.

The communication between TEVCONFIG and the CRG primarily utilizes filesharing files. As the CRG loads the hardware tables it updates an "operational currents file" to reflect the currents in all Collider devices. Whenever any program requests lattice functions using operational currents, TEVCONFIG will recalculate the lattice functions if the "operational currents file" has been updated since its last calculation. An interactive mode will allow the user to update a "calculated currents file" and then request a lattice calculation. Communication between these programs allows the user to calculate the effect of the change before it is made. In addition, TEVCONFIG will provide the necessary coefficients for the independent pbar tune control algorithm.

The interface between the CRG and TOP also utilizes filesharing files. The primary interaction between these programs is during parsing the squeeze where TOP updates a file with the last sent angles to the dipole correctors. The CRG can read this file to maintain orbit corrections during the squeeze.

Parsing

A technique [9] to step forward or backward through any time ramp one (or more) sequences at a time, adjusting parameters at each step, is referred to as "parsing" a ramp. This technique has been used in building the final low beta squeeze tables for all Collider devices as beam measurements are made.

Continuity between the injection optics and the β^* of .25 meter low beta optics is achieved with a set of 17 "steps". Each of these steps is a solution to a lattice optimization program (i.e. SYNCH) which provide the approximate gradients for the insertion quads. To preserve beam intensity and emittance all parameters must be precisely controlled at each step of the transition to the final β^*. As the CRG loads the hardware to move to the next step, it sends the calculated currents for all devices to TEVCONFIG which will calculate new lattice functions corresponding to actual currents in the magnets. In order for the Tevatron Orbit Program TOP to calculate a correction to a measured orbit distortion at each step , it obtains lattice functions for the current step from TEVCONFIG based upon either the design gradients or the currents sent to the hardware. [Note: these lattice functions are available to any program via interface routines.] Once the desired orbit has been reached the correction angles are passed back to the CRG which saves them for the next execution of the low beta squeeze ramp. After the orbit has been smoothed, the coupling, tune, chromaticity, separators, and feeddown sextupoles may be optimized. When the operator is satisfied with the results, the ramp is parsed to the next step for beam measurements and adjustments.

User Interface

The console interface must be user friendly and provide the user with all possible information to allow intelligent operation. This implies the full usage of user prompts, program messages, error reporting, command logging, on-line program help, plotting functions, and utility routines. The interface is therefore menu driven in a windowed environment. Currently, there are five basic functional windows utilized in the program. They are: STATUS PAGE , DATABASE , RAMP CONTROL, CALCULATION DISPLAY, and PLOT CONTROL. To provide continuity, each window contains a menu bar at the top of the window indicating the possible choices the user may make. Each of the choices in the menu bar will either RETURN to the previous window, open another window, or display a "popup" menu for selection from an allowed set of menu options. Many of the menu bar items have a constant function through the program. Through the menu bar item labeled ACTION (see fig. 1), the user will find all the allowed "actions" that control program flow dependent on the program mode and active window. The OPTIONS menu bar item contains sets of switches or flags which allow the user to modify the default operation of the program in the following areas: plotting, sending to hardware, message display, and error logging.

Current Status

The first version of the CRG program was used during the commissioning of the new low beta insertion at B0. Upgrades to the program structure continue in a effort to produce a flexible, easy to use, menu driven software package for the coordinated control of the time and energy parameters of any accelerator.

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