THE COLLIDING BEAMS SEQUENCER

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Abstract

The Colliding Beam Sequencer (CBS) is a computer program used to operate the pbar-p Collider by synchronizing the applications programs and simulating the activities of the accelerator operators during filling and storage. The Sequencer acts as a meta-program, running otherwise stand alone applications programs, to do the set-up, beam transfers, acceleration, low beta turn on, and diagnostics for the transfers and storage. The Sequencer and its operational performance will be described along with its special features which include a periodic scheduler and command logger.

Introduction

The Tevatron was initially developed as a 800 Gev fixed target accelerator with a cycle time of approximately 1 minute. The evolution to a Collider, with many hour stores of relatively rare pbars, involved many changes in the definitions and implementation of clock events, timer channels, and function generators. All the changes were not immediately apparent during the initial stages of the evolution. The requirements for the operation of the Tevatron as a collider were learned in brief study sessions during the fixed target program. The mechanism to allow the evolution in a smooth and efficient manner was established in the Colliding Beams Sequencer. Once the structure and protocol was established for the CBS, the program evolved to its present state by the addition of new features and commands.

The filling procedure consists of many operations including, but not limited to, the following major operations: safely aborting any existing beam (protons and pbars) in the Tevatron, loading low beta quad parameters for the fixed target lattice, resetting the injection fields of the Tevatron, checking the pbar injection channel into the Tevatron with protons, filling the Tevatron with protons, filling the Tevatron with pbars, coordinating the acceleration cycle to the flattop storage energy, coordinating the parameters required for the low beta lattice[1], and performing beam measurements.

Most, if not all procedures performed by the CBS program could be carried out by the Operations Group using existing programs. To use those programs in the proper sequence would entail many discrete operations where values and/or times would have to be entered by hand or files would have to be loaded at precise times. The programs, files, values and timers are sufficiently different for the various procedures used for colliding beam operation that it would be too time consuming and prone to error for reasonable operation of the Collider. In this respect, the CBS program, is a controller of other application programs. In addition, many tasks that could be constructed as stand alone application programs have been included as commands within the program.

Main page

The main control page image is displayed in Figure 1 to indicate the aggregate commands and some of the individual commands available

```
T48                    COLLIDING BEAM SEQUENCER          ♦FTP♦♦COPIES♦
                            *log      *sched   *miscpar *filedit *COMND
*Help         3/01/89   9:10:13              store 2010
*set at 150/inject protns  16.35  AGC#11 *recover from store
*set up proton injection                                      1 KILLBEAM
* inject protons(p1-p6)                                       2 BLM  EN
*set up pbar injection                                        3 LEAD ON
* pbar pilot shot                                             4 D69 f 11
* inject pbars (a1-a6)                                        5 CNTFMSTP
*ramp to flattop and store 14.57                             6 T48 f  8
*turn on low beta         14.5                               7 T49 f  7
* vary parameters                        Qx    19.443       8 EVT4D EN
-*reccver from low beta                   Qy    19.38        9 T23    4
*recover from store       17.45          Cx    12          10 SCHDS   0
--------utilities---------                Cy    -8
*adjust at 150 gev                       SQ    -2.46
*unsqueeze / freeze squeez               b2mn-3.7
*test rev inj TEV-MR                     Tinj 7
*inj cog - store summary                 Ttop 60
*periodic beam measurement
*misc commands I
*miscellenous commands II
   Log Entry:
```

Figure 1: Main CBS page image showing the *recover from store aggregate command

to the user. Many of the aggregate commands have been discussed elsewhere.[2] A complete list of individual commands, their format and usage, is contained in the help pages discussed below. The aggregate commands appear on the left hand side of the page and begin with an *. The right hand side of the page displays the individual command list for the selected aggregate command. The second line of the page image contains interrupts for access to the subpages of the program. These subpages are discussed in the next sections. The next to last line of the page image displays all command log entries as they are being logged. It also provides a mechanism of manually entering messages into the command logger. The last line is used for program status messages.

The example in figure 1 shows the individual commands for aggregate command #11 labeled *recover from store. This command sets all function generators and timers in the Tevatron to a cyclic ramping mode, which is much like that used for fixed target operation, prior to setting the Tevatron at the injection energy of 150 Gev. When this aggregate command is selected, the program additionally displays the desired 150 Gev values of the tune, chromaticity, coupling, and the value for b_2 which are passed to the program called in command #7. When the command is issued the first instruction (KILLBEAM) aborts any existing beam in the Tevatron. Since the Beam Loss Monitors are disabled during pbar-p stores to prevent accidental aborts due to Main Ring losses, they are re-enabled (BLM EN) during shot set up to prevent an accidental Tevatron quench during shot setup. The cooling for the Tevatron power leads is regulated depending on the current in the Tevatron. If the Tevatron is at the injection level, the next command will increase the cooling (LEAD ON) to the power leads prior to ramping. Otherwise, the command is bypassed. Command #4 (D69 f 11)[3] calls the Accelerator Time Line Generator program which controls accelerator reset events for all Fermilab accelerators and loads the requested file number. When the CBS returns from configuring the accelerator resets, it waits for a time of 60 seconds into the Tevatron acceleration cycle, then instructs the Tevatron energy waveform generator (TECAR) to resume ramping from its current storage level (i.e. CoNTinue FroM SToP). The next command (T48 f 8) loads clock events and timers from the internal data files discussed below. The

next command (T49 f 7)[4] calls the program responsible for generating the time and energy dependent parameters for most of the function generators in the Tevatron to configure timers and function generators for a ramping mode. The next command (EVT4D EN) enables the Tevatron injection clock event. The next to last command (T23 4) calls a comparison program which inspects the values of about 300 devices to verify proper values and display exceptions. The last command (SCHDS 0) disables all sequences in the periodic scheduler discussed below.

Program Features

The set of aggregate commands is constructed on-line from the console and may be general in nature. Each aggregate command is composed from a set of individual commands, which cause some action to be taken. The underlying feature of the program, which ultimately allows its flexibility, is that list of individual commands is read from the console tv page image at execution time. As requirements change, aggregate command titles and the list of individual commands associated with these titles may be constructed and saved without program modification. However, complex commands which do a series of simple commands can be defined by the addition of code.

This command page is always displayed upon the color monitor for inspection or execution of a command by the user unless one of the other sections of the program is being used. Currently, the only constraint upon inspection of the command list for the aggregate commands is that an aggregate command list is not being currently executed.

The set of aggregate commands contains a structure which provides safeguards against illogical execution of commands or selection of commands out of order. For example, the command which causes the Tevatron to ramp from 150 Gev to flattop will be refused if the Tevatron is already at flattop or turning on low beta if the Tevatron is not at flattop. These operational constraints placed on the set of aggregate commands currently require program modification. The program displays the last command issued in contrasting text and indicates (by an arrow) the next logical command to be issued.

The individual command list associated with any aggregate command may be executed in three ways. The entire list may be sequentially executed from the top as a single command; any single command within the list may be executed; or the list may be sequentially executed starting from any point from within the list. The execution of any command may be terminated at any time with the use of an ESCAPE touch panel program switch.

The CBS program, and all of the called programs which send data to hardware, allow commands to be executed in a manner that displays the data to be sent without actually sending the data to hardware. This has been a valuable tool in the development as all the commands may be verified without affecting the hardware or Tevatron operation.

Within the CBS program, one can create files of commands to set delays and references of timers and function generators and to enable, disable, or trigger clock events. The files are easy to modify and greatly facilitated debugging collider operation of the Tevatron.

The CBS program utilizes a console help utility program[5] for on-line program usage documentation including individual command functions and structures; and keep an up-to-date record of the status and changes to the program. The help pages are accessed via a "green function button" located on the console keyboard.

Periodic Scheduler

This feature of the CBS program allows the periodic execution (based on the time of day) of up to 10 sequences, each comprised of a single aggregate command or (set of) individual commands. The program verifies that the command is allowed depending on the current state of the Tevatron. Any or all sequences may be activated individually or as a group. An interval between successive executions of a sequence can be varied between 1 minute up to 2 hours or the sequence may be executed once and then disabled.

```
T48              COLLIDING BEAM SCHEDULER          ◆FTP◆◆COPIES◆
*Return                    *log     *SCHED    *miscpar *filedit *comnd
*Help              3/01/89  9:10:32
       *MODIFY                    *DISABLE ALL
   EN interval last sent next send AGCom  Sc1 Sc2 Sc3 Sc4 Sc5 Sc6  dt
 1 .    5 min 18:23:00    :   :    12     0   0   0   0   0   0   46
 2 E  120 min 08:54:00  10:54:00   16     0   0   0   0   0   0  122
 3 E  120 min 08:56:03  10:54:00   16    10  11  12   0   0   0  ***
```

Figure 2: Page image of the Periodic Scheduler

The scheduler currently has two main functions. Figure 2 shows the page image of the currently defined sequences. The first (sequence #1)and most important for Collider operation, is the control of the sextupole currents for tracking the time dependent b2 fields in the Tevatron dipoles while stored at the 150 Gev injection energy. The program contains an algorithm for the time variation of the b2 field which is used to adjust the sextupole currents depending on how long the Tevatron has been at 150 Gev.[6] The second usage of the scheduler is to make periodic beam measurements during the pbar-p stores and study sessions (sequence #2). The beam measurements consist of closed orbit measurements, beam profiles using the flying wires, bunch intensities, and longitudinal bunch measurements. These data are then written to a database for future store analysis.[7] Several video recorders record the bunch longitudinal profiles and spectrum analyzer tune displays for any post mortem diagnostics of lost stores. These recorders are automatically rewound every 2 hours by sequence #3.

Command Logger

This section of the program automatically logs all commands and instructions executed by the CBS into a data file. This log file also keeps track of any command (aggregate or individual) changes. Figure 3 displays an example of the log file for a period during shot set up for store 2010. This file may be inspected at the console via an interrupt or at any VAX terminal, using a separate FORTRAN program. This feature has been very useful in diagnosing procedural problems that have arisen, especially during periods of development for the commands and command procedures.

```
T48   Help380sequencer Log File  (T48 help pages 30 + )        ◆COPIES◆
*Edit
*Return -381(cntd)
02/28/89  1814 PROTON BUNCH 5  injected at  47.8               2010
02/28/89  1814 PROTON BUNCH 6  injected at  87.933             2010
02/28/89  1816 T49 f   7   19.443 19.38  12  -8   -2.46-2.34 + 2010
02/28/89  1823 T49 f   7   19.443 19.38  12  -8   -2.46-2.34 + 2010
02/28/89  1825 EVT40 DS                                        2010
02/28/89  1825  SDA started                                    2010
02/28/89  1825 T48 f   5                                       2010
02/28/89  1825 D69 f   9                                       2010
02/28/89  1826 D1  f   7                                       2010
02/28/89  1827   0     0                                       2010
02/28/89  1827 FWspec 19 sent to wire  M                       2010
02/28/89  1827 FWspec 09 sent to wire  T                       2010
02/28/89  1827  mask Tev BLMs                                  2010
02/28/89  1827 SCHDS  0                                        2010
02/28/89  1828 waited  80.0 sctime                             2010
02/28/89  1829 PBAR   BUNCH 1  injected at  7.8667             2010
02/28/89  1830 waited  40.0 sctime                             2010
02/28/89  1830 PBAR   BUNCH 4  injected at  87.867             2010
02/28/89  1831 PBAR   BUNCH 2  injected at  7.8                2010
02/28/89  1832 PBAR   BUNCH 5  injected at  47.867             2010
```

Figure 3: Page image of the Command logger file showing log entries for shot setup 2010.

Programs called

There are about a dozen application programs that are currently called by the sequencer. These programs load files to change the accelerator configuration, provide alarm and limit functions, or storage and/or analysis of data from beam monitoring hardware. Programs that are called by CBS are required to contain a small initialization section of code to establish communication with the CBS program. A few of the programs called have been mentioned earlier.

Two programs that keep track of data gathered to monitor beam and accelerator performance are the Sequenced Data Acquisition (SDA)[8] program and the Shot Summary program[7]. The CBS program coordinates data transfer to each of these programs in differently. The SDA is a VAX task which gathers beam intensity and emittance data during the various steps of the filling cycle. The CBS program starts the SDA and requests that specific sets of data be stored. Once the store is underway, the periodic beam measurement aggregate command is issued by the Operator and the Scheduler is enabled to repeat the measurements for the duration of the store at a regular interval. A specific clock event is used to trigger the transfer of the beam quality data to a database to be read by the Shot Summary Program at a later time.

Program Environment

The program runs as a single-user primary applications program on a PDP-11/34 console computer[9,10]. The program memory size for all primary application programs is limited to 20 K words for all code and data structures due to limited address space. The actual size of the program is significantly larger due to the overlay feature of the PDP-11.

As other applications programs are called by the CBS, the CBS program must be terminated and removed from memory while the called program is executed. When the called program is complete, the CBS program is (re)initialized and the program execution is resumed at the point at which it was terminated. This exchanging of programs in memory, which is similar to a FORTRAN subroutine call, is accomplished by a Fermilab Controls Library routine called change program (CHGPGM)[11]. This routine allows the coordinated exchange of primary application programs in memory by passing control information between programs via an 80 byte command buffer.

The Fermilab Control System upgrade[12] plans include replacing the PDP-11 console computers with the more powerful microVAX 3200 computer. This is a virtual memory computer which would eliminate the necessity of complex overlay structures and allow the simultaneous execution of multiple application programs through windowing. Current plans call for implementation of the new consoles by (at least) the beginning of the next Collider run scheduled for mid 1990.

Operational Performance

The operational performance of the CBS program can best be described as a necessary tool for the development of the Tevatron as a Collider. Since its development, it has become necessary for the day to day operation of the Collider. It has spurred the development of additional dedicated sequencer programs.[13,14] At the start of this Collider run, the setup time required for a fill ranged between 4 to 8 hrs. Currently, the filling operation requires less than 2 hours and is frequently on the order of an hour. This decrease in the filling time has come with the experience and constant evolution of the filling procedure. It is hoped by the authors that the present implementation of the CBS program has contributed to this evolution by making the Tevatron filling procedure less ambiguous.

Future Improvements

Some of the planned improvements to the CBS program will be realized as the new consoles become operational. This will free the program from the complex overlay structure now imposed. As this occurs additional aggregate commands and individual commands may be added and more of the hierarchical structure may be brought to the console page images. The addition of additional commands is projected due to the additional low beta interaction region at D0 and the installation of beam separators. Since the microVAX's may execute two primary application programs simultaneously, the CBS program no longer needs to be terminated to call other application programs. This should increase the speed and flexibility of the CBS program.

References

1. D. A. Finley, R. P. Johnson, and F. Willeke, IEEE Trans. Nucl. Sci., NS-32 No. 5 (1985), p. 1678.

2. R. P. Johnson, IEEE Proceedings of the 1987 Particle Accelerator Conference, IEEE Cat. No.87CH2387-9, pp. 8-12.

3. R. P. Johnson, W. R. Knopf, and A. D. Thomas, IEEE Trans. Nucl. Sci., NS-32 No. 5 (1985), p. 2053.

4. R. W. Goodwin and R. P. Johnson, Proceedings of the 12th Int. Conf. on High Energy Accelerators., Fermilab, Aug., 1983, p. 594.

5. B. Joshel, W. Kissel, Fermilab memo (unpublished).

6. D. E. Johnson, et.al. "Compensation of Time Varying Fields in the Tevatron Superconducting Magnets", presented at the IEEE Conference on Particle Accelerators, Chicago, Il, March 20-23, 1989.

7. N. Gelfand, et.al., "Shot Summary System for the Tevatron Collider", presented at the IEEE Conference on Particle Accelerators, Chicago, Il, March 20-23, 1989.

8. R. Gerig, K. Cahill, private communication.

9. J. G. Smedinghoff, "The Fermilab Accelerator Control System Parameter Program and Plotting Facilities", Nuc. Inst. and Meth. A247 (1986), pp.172-175.

10. D. S. Baddorf, "An Operators View on Fermilab's Control System", Nuc. Inst. and Meth. A247 (1986), pp.176-180.

11. A. D. Thomas et al., Fermilab Internal Report, Software Documentation Memo 62 (1895).

12. J. G. Smedinghoff, K. Cahill, private communication.

13. P. Emma, et.al.,"Fermilabs Automated Accelerator Start-up Program", presented at the IEEE Conference on Particle Accelerators, Chicago, Il, March 20-23, 1989.

14. B. Hendricks, private communication.