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FNAL Booster Intensity, Extraction, and Synchronization Control for Collider Operation*

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FNAL BOOSTER INTENSITY, EXTRACTION, AND SYNCHRONIZATION CONTROL FOR COLLIDER OPERATION

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Abstract

Booster operation for collider physics is considerably different than for fixed target operation. Various scenarios for collider physics, machine studies, and P-Bar targeting may require that the intensity vary from 5E10 PPP to 3E12 PPP at a 15 Hertz machine cycle rate. In addition to the normal Booster single turn extraction mode, collider operations require that the Booster inject into the Main Ring a small number of beam bunches for coalescing into a single high intensity bunch. These bunches must be synchronized such that the center bunch arrives in the RF bucket which corresponds to the zero phase of the coalescing cavity. The system implemented has the ability to deliver a precise fraction of the available 84 Booster beam bunches to Main Ring or to the P-Bar Debuncher via the newly installed AP-4 beam line for tune-up and studies. It is required that all of the various intensity and extraction scenarios be accommodated with minimal operator intervention.

Introduction

The demands on the Fermilab Booster accelerator to provide unique types of accelerated proton beam have become increasingly varied and complex with the advent of the Tevatron accelerator, the P-Bar Source, and colliding physics operations. Most importantly, these varied scenarios are often mixed within what is called a "supercycle" of accelerator operations. A supercycle, typically lasting about ninety seconds, is often programmed to include three or four different types of Booster operations. This variety and the desire to optimize available machine time preclude any thought of cycle by cycle manual tuning of the rapidly cycling Booster. Accommodation of these diverse operations has been achieved by an integration of the Tevatron Clock (TCLK), the Main Ring Beam Synchronous Clock (MRBS), specially constructed timing hardware, and various software facilities to existing Booster systems.

Tevatron Clock

The most important element for facilitating these operations is the Tevatron Clock which broadcasts accelerator timing information throughout the accelerator complex. TCLK is a 10 MHz ac line-locked clock that has become the master clock of the accelerator. Up to 256 unique events or timing markers may be encoded onto TCLK with typical resolution of 100 nanoseconds. 142 events have been implemented to date. The devices which listen and respond to events on TCLK now number in the thousands.

The most important of these events are classed as accelerator resets. These resets are programmed into the Time Line Generator (TLG) to occur at specific times within the supercycle. There are presently nine TCLK events defined as Booster resets, each having correlation to specific beam scenarios as well as to no-beam and pre-beam cycles. These events, in conjunction with other events, specify particular operating conditions for the Main Ring, P-Bar source, and Tevatron. It is useful to list the TCLK events which differentiate the demands of the Booster.

* Event $11 - Booster null cycle with no beam.

* Event $12 - Booster pre-pulse cycle with no beam. All pulsed and ramped elements operate on this cycle.

* Event $13 - Successive full turns, at eighty-four bunches each, of high intensity beam for fixed target physics. These full turns are usually loaded in boxcar fashion into the Main Ring - though staggered loading is possible.

* Event $14 - Single full turn of high intensity beam for P-Bar targeting.

* Event $15 or $19 or $1C - Partial turn of high intensity beam for coalescing into single bunch A or B or C for Tevatron colliding physics. Extracted Booster beam may range from seven to thirteen bunches with the center bunch always phased to the Main Ring coalescing RF system. Booster operation is similar for these three resets - though different intensities and number of bunches transferred could be facilitated.

* Event $16 - Partial turn of low intensity beam for the Accumulator. This beam is used to tune the transfer line to Main Ring from the Accumulator normally used by P-Bars.

* Event $17 - Partial or full turn of beam of various intensities for the Debuncher using AP-4 as a transport line. The AP-4 line is direct from the Booster to the Debuncher and is the path taken when Main Ring is not available as a transporter. When the AP-4 line is off, event $17 is often dedicated to Booster studies.

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The five categories of beam cycles may, as operating conditions dictate, also serve other purposes such as Booster, Main Ring, or P-Bar source study cycles.

A variety of hardware and software has been developed over the last several years which is sensitive to generated TCLK events or sequences of these events. Timing modules (CAMAC 177, 287, & 377) that generate a pulse with a programmable delay from a single event or from a combination of TCLK events are the most common implementations of different scenarios. Timing channel outputs are often or'd when different delays from several event references are required. Waveform generators (CAMAC 164 & 365) have been developed that can associate the occurrence of various output waveforms with specific clock events. A vector module (CAMAC 055) can produce different 16 bit digital words or DAC control voltages that are selected by generated TCLK events. Most of the computers in the accelerator control network have facility for "listening" to generated TCLK events. Database entries for control system parameters often include arguments pertaining to TCLK events.

Intensity Control

The intensity of the Booster is controlled by the pulse width of the 200 MeV Chopper power supply. Although the Booster can now accelerate a fractional turn, the Booster typically operates in a range of one to six full input turns. Historically the largest number of turns injected with any success was sixteen turns in 1978. Each different Booster beam reset is now operator defined to have "N" turns. A console application program assists the machine operator in setting associated channel delays for intensity as a function of input turns. Timing modules, which are sensitive to Booster reset events, are or'd to produce five different sets of Chopper times.

As the number of injected turns is changed, it is also necessary to vary the ramped waveforms of the quadrupole and sextupole correction elements. The waveform generators that drive these elements are loaded with different files that correspond to different intensities. The operator may specify which file is played from detection of a reset event. If the intensity is changed for a given reset event, the operators can quickly install the proper machine tune parameters by redefining the event to file relationship without resorting to extensive manual tuning or save files. Currently, operators are required to use different application programs to accomplish this. Modification of the intensity selection application program will, in the near future, obviate this operator task.

It has also been found necessary to vary the machine transition time as a function of intensity. This has also been accomplished with or'd timing channels sensitive to different Booster resets. The Gamma-T Jump system, that is currently being brought on-line, is thought to require time and amplitude versus intensity control. This will be accomplished with a combination of event dependent hardware and software.

Beam Synchronous Clocks

There have been longstanding requirements to have available various beam-synchronous signals to properly control the injection, extraction, and beam monitoring operations of the accelerator complex. A variety of schemes have been implemented in the past, generally unique to a particular requirement. The demands of synchronizing Debuncher and Accumulator operations to the Main Ring have recently presented new requirements that have forced a more coherent systems approach.

The solution has been the development of beam synchronous clocks for the Main Ring (MRBS) and the Tevatron (TVBS). These clocks are similar to TCLK in capability and distribution. Their 7.5 MHz base frequencies are sub-harmonics (RF/7) of the Main Ring and Tevatron low-level RF VCO signals. Encoded on these clocks, at every machine turn, are revolution synchronous (RF/1113) events that are always present without regard to the status of either the presence of beam or the high-level RF system. Also encoded on these clocks are other events, synchronous to the revolution events, that synchronize or initiate beam transfers. New Booster extraction timing hardware makes use of one of these other events, MRBS $77, to effect synchronous transfers of beam to the Main Ring.

Extraction

Extraction of any beam from the Booster is initiated by the Booster Extraction Sync (BES) pulse originating from the Extraction Processor module. BES is always generated with a fixed RF cycle displacement from the MRBS revolution event. This displacement is, however, unique and controllable for each of the five types of Booster beam resets. Primary inputs to this module include: 1) the Main Ring low-level RF VCO signal which is divided by 1113 to form an internal Main Ring revolution marker; 2) MRBS event $77 which synchronizes the internal marker to MRBS as per parameter B:BMBO; 3) a reset dependent digital parameter (B:BMBO), scaled in RF cycles, which determines the displacement of the internal revolution marker from that of MRBS; 4) an asynchronous timing pulse (B:TEXTR) which is synchronized to the next internal revolution marker to form the BES output; and 5) a reset dependent digital parameter (B:BBDL), scaled in RF cycles, which determines the displacement of the next successive transfer of beam from the Booster to Main Ring. These actions all occur near the end of the thirty-three milliseconds of Booster acceleration when the Booster and Main Ring RF systems are phase-locked. MRBS $77 occurs only during the first beam acceleration cycle of a continuous series of beam cycles.

The Booster Extraction Sync and Booster RF VCO signals are distributed over equal length cables to the locations of Booster

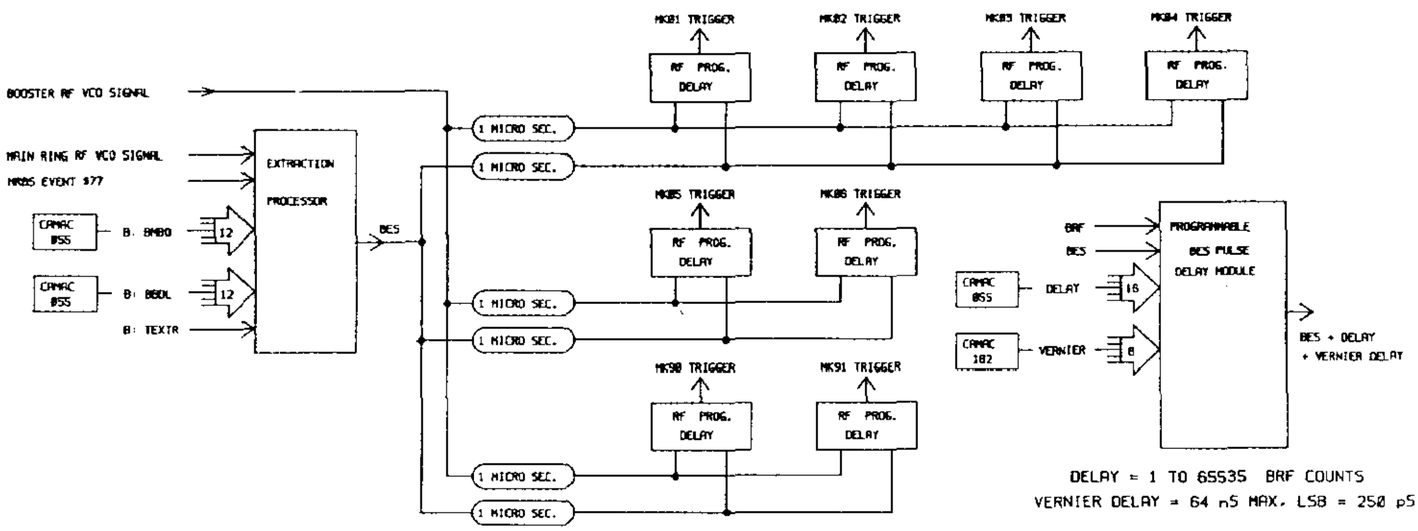

Fig. 1. Elements of the Booster Extraction Timing System.

extraction kickers (MK01 thru MK06), the Main Ring injection kicker (MK90 and MK91), and to associated septa. These devices require exactly timed triggers that are properly phased to the accelerated beam. BES first triggers the extraction and injection septa which have relatively long settling times to nominal field values. The triggers to the kicker elements are then generated, typically delayed by about 300 microseconds from BES. These triggers must additionally vary for different types of Booster beam cycles or, in some scenarios, not trigger at all.

A major improvement to the extraction timing system has been the addition of the Programmable BES Pulse Delay modules. The unique aspect of this hardware is that it provides delay in RF cycles rather than in time. This makes possible the generation of triggers that are in synchronism with the accelerated bunches. This is especially important for the $15, $19, and $1C cycles that must deliver precise numbers of beam bunches accurately phased to the Main Ring revolution event. The net transit time of BES and Booster RF distribution to the delay modules is closely matched to the delay of low-level RF VCO to the accelerating cavity gap. The desired delay in RF cycles presented to the BES Pulse Delay modules is sensitive to generated Booster resets - thereby accommodating different extraction scenarios. Typical programmed delays are in the area of 15,000 RF cycles. If the delay for a particular kicker channel is programmed to zero RF cycles, the kicker will not fire - a definite requirement for certain scenarios.

The eight kicker triggers shown in figure 1. are paired in operation. The timing relationship of Booster extraction kickers MK01-MK02 versus MK03-MK04 determines the number of bunches transferred to Main Ring. This beam is bracketed by the the MK90-MK91 Main Ring injection kicker. The timing relationship of extraction kickers MK05-MK06 versus MK01-MK02 or MK03-MK04 determines the number of bunches transferred to the Debuncher via the AP-4 line. Vernier time control of up to 64 nanoseconds in 250 picosecond steps is provided at each BES Pulse Delay module to compensate for long-term drifts in the kicker power supply circuits.

Conclusion

The varied demands upon the Booster to deliver fractional or full turns of beam of different intensities precisely matched to the Main Ring RF systems has been reliably achieved by judicious use of TCLK, MRBS, and new hardware components as interface to existing Booster systems. Future plans include better integration of the new facilities to existing application programs - especially for intensity control. Work is now in process to remotely monitor the actual delays of the kicker power supply circuits so that fine adjustments of timing related to the extraction process may be automated.

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