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Abstract

Hardware has been built and software written and incorporated in the existing SLC accelerator control system to control injection of beam pulses from the accelerator into the PEP-II storage rings currently under construction. Hardware includes a CAMAC module to delay the machine timing fiducial in order that a beam pulse extracted from a damping ring will be injected into a selected group of four 476 MHz buckets in a PEP-II ring. Further timing control is accomplished by shifting the phase of the bunches stored in the damping rings before extraction while leaving the phase of the PEP-II stored beam unchanged. The software which drives timing devices on a pulse-to-pulse basis relies on a dedicated communication link on which one scheduling microprocessor broadcasts a 128-bit message to all distributed control microprocessors at 360 Hz. PEP-II injection will be driven by the scheduling microprocessor according to lists specifying bucket numbers in arbitrary order, and according to scheduling constraints maximizing the useful beam delivered to the SLC collider currently in operation. These lists will be generated by a microprocessor monitoring the current stored per bucket in each of the PEP-II rings.

Introduction

Filling the PEP-II storage rings using the SLAC linac imposes both hardware and software constraints to achieve the required accuracy and efficiency, and to allow shared operation of the accelerator complex. The injection timing system is required to provide fully-interlaced e+/e- filling at 60Hz/beam with +/-50 psec timing accuracy. The injection control system has been integrated into the SLAC Linear Collider (SLC) controls to allow precise preparation and control of each accelerator pulse, and to easily handle rescheduling of beams as required for research program needs, or for machine or personnel protection.

In this report, the design and implementation of the injection timing system is described. After a description of the control system operation for SLC collisions, the injection control system design and implementation is presented.

Timing System Design

Timing signals in the linear accelerator, the damping rings and the SLC collider arcs are derived from a 476 MHz reference oscillator. An independent 476 MHz oscillator provides the basic frequency of the PEP-II rings. For injection purposes [1], the PEP-II oscillator is locked to the linac reference, and is unlocked only for machine chromaticity measurements. However, to access all of the 3492 PEP-II (2.1 nsec) RF buckets, the linac 476 MHz reference signal must be phase ramped to one of four possible phases. The PEP-II reference oscillator phase is sampled and held during the phase shift operation, while the beam stored in the electron and positron damping rings is phase-shifted in time to match the target buckets.

Programmable Delay Units (PDU's)[2], operating at 119 MHz derived from the linac 476 MHz reference, provide signals precisely timed relative to event markers. In the linac complex, a 360 Hz fiducial marker, obtained from a zero-crossing of phases of the 60 Hz main power source, identifies each possible damping ring injection/extraction time. New programmable delay units for PEP-II (PPDU's) use two markers, generated at 360 Hz, to identify the injected bunch and to provide a "bucket 0" reference.

The circumferences of the PEP-II storage rings and the SLC damping rings are not integrally related, with one damping ring turn exactly 14 "ticks" of 119 MHz, and one PEP-II ring turn exactly 873 ticks of the same frequency. Any group of four consecutive PEP-II 476 MHz buckets can be reached by delaying the fiducial by an integral number of damping ring turns. Individual buckets within a group are accessed by phase-shifting the linac 476 MHz as described above.

Timing System Electronics

For controlling the selection of any bucket group, a PTG (PEP-II Trigger Generator) has been built. The PTG maintains a clock of period corresponding to 873 damping ring turns, which can be offset by a programmable count of damping ring turns. PEP-II injection fiducials are generated by the PTG on scheduled machine pulses. The PTG also contains two TDC's, used for monitoring timing of fiducials.

For selecting individual PEP-II buckets within a group of four buckets, the phase of the two bunches stored in each damping ring will be shifted by as much as three 476 MHz buckets, while leaving the phase of the beam stored in the PEP-II rings unchanged. This phase shifting is accomplished by ramping the linac frequency in sector 0, and by locking the PEP-II 476 MHz with the Linac main drive line 476 MHz during only a fraction of each 120th of a second. At the end of each phase shift cycle, the phases of the bunches remaining in the damping rings will be returned to what they would have been if no phase shift had occurred at all.

Existing SLC Control System

For producing 120 Hz SLC colliding beams, electron bunches are typically damped for one 120th of a second in one

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signal to divert beam pulses for PEP-II injection testing without causing the loss of any effective beam time to SLD.

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One ten-bit field of the 360-Hz 128-bit broadcast message is reserved for the PTG control parameter, the damping ring turn delay count. An additional 4-bit field is interpreted according to the logical expressions assigned to the PAU controlling selection of a PEP-II injection bucket within its bucket group.

In sector 0, one of the PTG's TDC's is used to measure the time from the usual fiducial (which is synchronized with the power line zero crossing) to the PTG output. The PTG's second TDC is used to measure the time from the fiducial to the next zero crossing of the 8.5 MHz damping ring rotation reference. The 360 Hz interrupt routine collects these TDC readouts together with the PEP-II injection control parameters received in the broadcast into a set of buffers whose contents can be retrieved and displayed by the central Alpha.

PEP-II Injection Software

PEP-II injection timing software must support filling or topping-up PEP-II storage ring buckets in any sequence. PEP-II injection will be driven by two injection request queues, one for each of the two rings (HER and LER). These queues are maintained in the MPG and are each fed from either the bunch intensity controller microprocessor (BIC) or the main control program (SCP).

In any MGRP, a variant type of beam code modifier pattern may be specified to control computation and broadcast of the PEP-II injection parameters. The PEP-II bunch intensity controller (BIC) is a separate microprocessor which receives input from the two bunch-by-bunch current monitors, and which can insert bunch injection requests into one of two queues maintained in a shared memory. Each executed instance of these variant modifiers in an MGRP will cause the topmost entry if any in the indicated queue to be dequeued and decomposed into target bucket group number, bucket number within group, and desired bunch intensity. The bunch intensity parameter will apply at bunch creation time either for an e- bunch to be damped and injected into the high energy ring (HER), or for an e- bunch which creates positrons which are then damped and injected into the low energy ring (LER). The bunch timing parameters apply when the desired bunch is to be extracted from its damping ring.

The MPG also contains a ring synchronization routine, whose purpose is to find the phase difference, in units of one PEP-II bucket, between the PEP-II "bucket 0" reference and the PTG's constant clock measuring units of 873 damping ring turns. The PEP-II ring synchronization routine will measure the time from a PEP-II injection fiducial to the next PEP-II "bucket 0" reference. Given the target PEP-II bucket number, this measurement will yield an error indicating "lateness", i.e., time of arrival minus time aimed at, resolved to units of one PEP-II bucket. This error should be zero except at start-up time or after power failure. A second PTG module has been installed in the MPG to make this measurement. The PTG's fast TDC has a resolution of 1/8 PEP-II bucket (262 picoseconds) and a range of more than 16 microseconds.

A display is provided to retrieve executed PEP-II bucket injection requests and PTG TDC readouts for the last full second. One line of this display shows: time (in 360ths of a second relative to the beginning of the second being displayed), HER/LER indication, target bucket number, PTG damping ring turn delay count, 2-bit PEP-II bucket number within bucket group, sector 0 PTG "slow" TDC readout (showing delay from SLC MTG usual fiducial to PTG-controlled fiducial), MPG PTG "fast" TDC readout converted and added to target bucket number (showing "lateness" described above), and sector 0 PTG "fast" TDC readout (showing PTG phase stability). This display is based on a full second's data, retrieved in synchronization from the MPG and sector 0 microprocessors.

Conclusion

The timing accuracy and bucket selection of the injection system has been tested against a PEP-II reference. Beam scheduling tests, for which the SLC beam is turned off after a SLD trigger and a beam destined for PEP-II has been extracted from the damping rings, have been used to validate the control system software.

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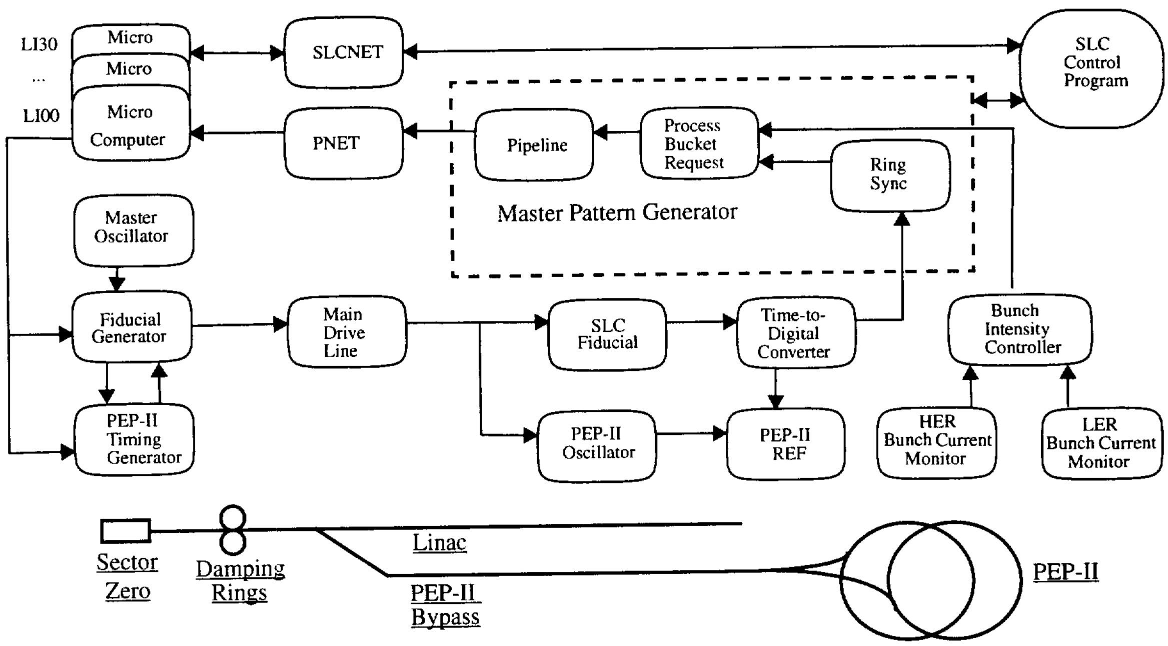

Fig. 1. Major components of SLAC accelerator control system, focusing on PEP-II injection timing and control.

damping ring (north), and positron bunches are damped for one 60th of a second in the other damping ring (south). Each damping ring holds two bunches. On each 120th of a second, both bunches are extracted from the e- (north) damping ring (and new bunches injected), while only one bunch is extracted from the e+ (south) damping ring (and a new bunch injected). The second extracted e- bunch is kicked onto a rotating target yielding positrons, which are collected and accelerated back to the front end of the machine to be injected into the e+ damping ring.

The entire machine is controlled by about 80 distributed microprocessors [3], all running identical software, except one, which produces a 360 Hz control broadcast. This broadcast of a 128-bit varying message drives an interrupt routine in each microprocessor, which in turn issues CAMAC commands to broadcast beam codes to timing devices.

The microprocessors communicate with the central DEC Alpha computer via a dedicated communication link known as SLCnet, Fig. 1. The SLC control system primarily consists of a very large program (known as SCP) running one copy per display terminal on the Alpha. The SCP provides the entire operator control interface, including displays. For synchronizing needed control and readout of devices on a pulse-to-pulse basis, the 360-Hz 128-bit message from the master pattern generator (MPG) is broadcast on a separate dedicated unidirectional channel known as PNET.

The main function of the MPG microprocessor is to produce this control broadcast message, i.e., to schedule beams, and to schedule beam position monitor readout. The desired content of this broadcast is expressed in a scripting language, in which the basic independent entity is known as a BGRP. Each BGRP produces a broadcast on one 120-Hz subset of the 360-Hz output and is, on operator command, downloaded and activated in the MPG.

Each BGRP is divided into an arbitrary number of sections, called MGRP's. Each MGRP represents a possible scheduling state of the machine. Each MGRP consists of three parts: a) conditional GOTO statements selecting on each 120-Hz iteration which MGRP is to be actually executed; b) statements defining the broadcast patterns for one or more beam codes; and c) for each defined beam code, statements defining the broadcast patterns for individually named bits in the broadcast message to regionally modify the effect of the given beam code. These individually named bits, called beam code modifiers, have different meanings depending on their usage in logical expressions separately assigned to individual timing devices.

Conditions tested during MGRP selection on each 120-Hz iteration of a given BGRP include machine protection signals read by the MPG at 360 Hz from digital input modules and from a shared memory written into by the separate machine protection system (MPS). For example, a beam containment fault detected in any part of the machine may be signaled by a single digital input bit read by the MPG, which, depending on how the BGRP has been coded, may cause beam delivery rate to drop to 1 Hz. Protection Ion Chamber processors are read out and analyzed by the MPS microprocessors at beam rate and the summarized result is transmitted to the MPG within a few 360ths of a second after the causing beam pulse; the result may be a lowering of beam delivery rate. Also testable by the BGRP is one bit from the SLD detector signaling the beginning of a time window of about 8 beam pulses during which the SLD cannot collect new data. A BGRP has been written to use this

signal to divert beam pulses for PEP-II injection testing without causing the loss of any effective beam time to SLD.

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