TIMING OF THE ALS BOOSTER INJECTION AND EXTRACTION

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Abstract

The Advanced Light Source (ALS) timing system upgrade introduces a complete replacement of both the hardware and the technology used to drive the timing of the accelerator. The implementation of a new strategy for the booster injection and extraction mechanisms is conceptually similar to the one in place today, but fundamentally different due to the replacement of the technology. Here we describe some of the building blocks of this new implementation as well as an example of how the system can be configured to provide timing for injection and extraction of the ALS booster.

INTRODUCTION

The ALS timing system is currently being replaced as part of the ALS control system upgrade. The current timing system [1] was implemented around 20 years ago based on booster field measurements and the generation of analog triggers to drive the different components of the machine. The timing system upgrade currently undergoing will benefit from 20 years of improvements in the electronics and optics fields.

The solution adopted to implement the new timing system is based on a commercial solution (MRF [2]), which is an event-based system with the ability of distributing RF-synchronous events around the machine from a centralized Event Generator (EVG). At the ALS, the current timing system is very much centralized around the measurement of the booster bending dipole to deduce the appropriate times for both injection into the booster from the linac, and extraction from the booster into the storage ring. A large majority of the rest of the triggers generated by the current timing system are deduced from these fundamental field-based triggers.

The injection and extraction mechanisms are of particular interest in the process of upgrading the timing system due to the change in the technology. We have been evaluating different options and the new architecture really favors a purely time-based system, where instead of having the booster bending magnet drive the start of the injection and extraction sequences, these processes will be entirely predicted and driven having a time base from the centralized Event Generator.

Here we show the different mechanisms involved in the transition from a field-based system to an event-based system putting special emphasis in the injection and extraction sequences which are of special interest.

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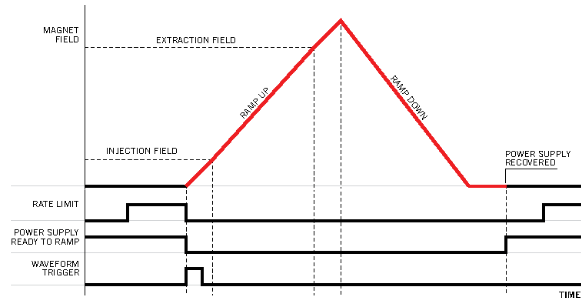

Figure 1: ALS booster bend magnet cycle.

BOOSTER FIELD CYCLE

Figure 1 shows the ALS booster bend magnet cycle, which has a programmable rate limited to around 1 Hz in normal operation. During this cycle, up to 12 bunches are generated at the 125 MHz electron gun and accelerated in the 3 GHz linac for injection into the booster ring. The booster bend magnet has a controlled power supply with a programmable ramp [3] in order to accommodate for different machines modes, however the existing timing system still implements a measurement of the field to generate the main injection and extraction triggers. The reason behind this field measurement was originally that the booster ramp was not controlled and was therefore unpredictable, following the L/R time constant of the magnet along with some shot-to-shot variability due to hysteresis.

Time-based Architecture

The new timing system is entirely time driven, where an event sequencer is triggered in the EVG at the beginning of each booster cycle, and the time that it will take the magnet to reach the appropriate field for injection and extraction has to be predicted. Even though the bend magnet power supply is currently being controlled, we have found that the reproducibility of the actual magnetic field inside the magnet varies considerably in a cycle-per-cycle basis and it is not possible to accurately predict when these field levels will be reached in a time basis.

A field tracking mechanism has been designed in order to monitor the bend ramp for diagnostics purposes, having the capability of modifying the event tables and delays at the receiver ends in order to correct for large amounts of variability in the field measurement with respect to time. The new scheme combining the field tracking mechanism and the MRF based system has already been tested during user operations in the machine and has shown to not provide any degradation in injection or extraction efficiency with respect to the field-based scheme.

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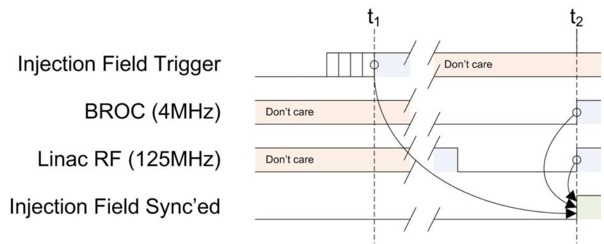

Figure 2: Injection system timing diagram.

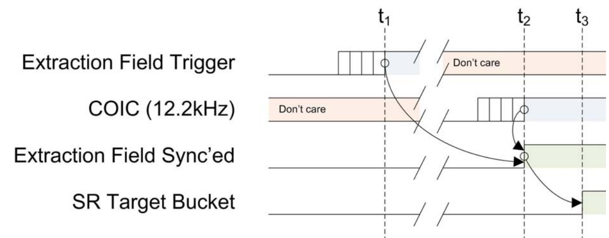

Figure 3: Extraction system timing diagram.

Booster Cycle Repetition Rate Generation

There are several approaches to tackle the task of synchronizing the bunch generation from the electron gun, injection into the booster and extraction into the storage ring. In our case, taking a few precautions on the alignment of the booster and storage ring buckets, where the train of bunches arrive into the booster when the booster and the storage ring bucket 0 align greatly simplifies the ulterior math in order to target a specific bucket in the storage ring.

The booster cycle repetition rate (start of the EVG timing event sequence) establishes the origin of time in the entire event sequence. This cycle needs to be synchronized with the AC line and a multiplexed counter in the EVG is used, where AC line synchronization logic is available. Using this scheme, the repetition rate can be controlled and the resulting trigger to start the event sequence can be generated following multiples of the AC line period.

INJECTION

The injection field trigger determines the matching between the energy of the linac and the booster. As stated before, having the first bunch coming from the linac target bucket 0 in the booster when being injected into the booster simplifies the booster extraction process. This is achieved by synchronizing the injection trigger with the booster orbit clock (BROC, 4 MHz).

The phase of the linac 125 MHz clock and the orbit clocks is then necessary and is achieved by using the same externally divided RF clock (500 MHz RF divided by 4) to pulse the gun bunch trains and drive the event generator. A clock divider is available in the EVG to divide the 500 MHz RF and provide the reference for timing, but using this method would introduce a phase ambiguity between the clock used to pulse the gun and the source of timing for the machine. This scheme is compatible with the current layout of the machine since historically all timing signals in the linac where generated by a parallel timing system using a 125 MHz reference and this will continue to be the case in the new architecture since that part of the timing is intrinsically merged with the linac RF system.

As stated earlier, both the injection and extraction triggers follow a tracking mechanism from a measurement of the booster bend magnet field. This measurement and the corresponding calculation of the time relationship between the start of the booster cycle and the injection trigger is independent of any synchronization mechanisms and therefore the resulting injection field trigger out of that process needs to be synchronized with the coincidence clock. The way this is handled is by using an injection event in the event generator table as a pre-trigger and calculating the actual injection field trigger by aligning the result of the field measurement calculation, the injection field trigger happening N event clock cycles after the injection timing event, where N guarantees that the injection field trigger generated at the EVRs is aligned with the coincidence clock (the coincidence clock period, 82 μs, being a multiple of 8 ns).

The injection sequence generated by the MRF system has not yet been entirely tested, however the MRF system has been used to replace the field-based triggers generated by the current system and results show no degradation in the injection efficiency into the booster.

EXTRACTION

The booster extraction timing system generates timing triggers for the extraction kicker, septum magnets, and storage ring bump. The extraction field trigger is generated using a similar scheme as the injection trigger, where an extraction event is used as a pre-trigger and N event clock cycles are added as a delay to that event in order to establish synchronization with the coincidence clock. The extraction field trigger coming from the booster field measurement mechanism is used to indicate that the booster has attained sufficient energy for extraction into the storage ring and is then synchronized with the coincidence clock (COIC) in software. The synchronized extraction trigger can then be delayed by one to 328 BROC cycles to target a particular bucket in the storage ring, and this value delay is added to the delay synchronizing to the coincidence clock with a 2 ns resolution (RF is 500 MHz) in order to target a single bucket in the storage ring. This resolution is achieved using the fine delay universal I/O modules which are part of the MRF catalog (10 ps resolution).

If we take a snapshot of the booster and storage ring when bucket 0 of the booster coincides with bucket 0 of the storage ring, and we then let the booster bunch complete exactly one turn and we take another snapshot, it will then coincide with bucket 125 (125 being the harmonic number of the booster) of the storage ring. If we repeat this process, bunch 0 of the booster will coincide with bucket 250, 47, 172, etc. of the storage ring. Bunch 0 in the booster will then coincide with all buckets in the storage ring in

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an unrepeated way until 328 booster revolutions after (328 being the harmonic number of the storage ring). The coincidence of bucket 0 in both the booster and the storage ring is marked by the coincidence clock (COIC). Following the process described above it seems clear that we need to delay the extraction trigger by n BROC cycles in order to target a particular bucket in the storage ring, where n is given by:

$$n = (21 \times t)\%328 \quad (1)$$

where t is the target bucket in the storage ring and n is the required number of booster ring revolutions after the COIC necessary to line up the booster beam with the targeted bucket. This mechanism was designed by M. Fahmie in his original ALS timing design and establishes a simple and elegant way for target bucket in the storage ring [1]. The computation of n is managed by the control system (embedded in the timing IOC), which takes the storage ring loading prof le as an input and loads the necessary BROC delays into the extraction timing system in a cycle to cycle basis.

IMPLEMENTATION

The implementation of the injection and extraction functions are performed using a combination of MRF hardware, standard MRF IOC device support developed at BNL and ALS custom logic. ALS has traditionally placed most of the complexity of the different machine modes at a high level using Matlab running in the control room interacting with the original timing system. Relying on high-level applications and the EPICS network for real-time operations such as the injection and extraction mechanisms pose some reliability issues as the sequence of events necessary of the mechanisms to work depend on non-real time systems.

Figure 4 shows the proposed architecture for the interaction of high-level software and the timing system in order to perform the injection and extraction functions. The functionality requiring real-time operations have been brought down to the IOC level, where one can achieve a greater level of reliability than using high level applications communicating with the hardware via Channel Access. The ALS booster cycle is currently no faster than approximately 1 Hz and the cycle to cycle conf guration of the injection and extraction mechanism are perfectly in the range of what the IOC can handle.

High-level controls are provided for Matlab applications to interact with the timing system for conf guration of the machine modes, where the timing system (at the IOC level) provides PVs to conf gure different state machines to switch from one machine mode to another one. According to the mode of operation the timing IOC also provides other levels of conf guration, such as a PV containing a target bucket number for extraction for single injection mode, or a waveform record containing a sequence of target buckets which then the IOC cycles through and updates the extraction delay settings in a cycle-per-cycle basis.

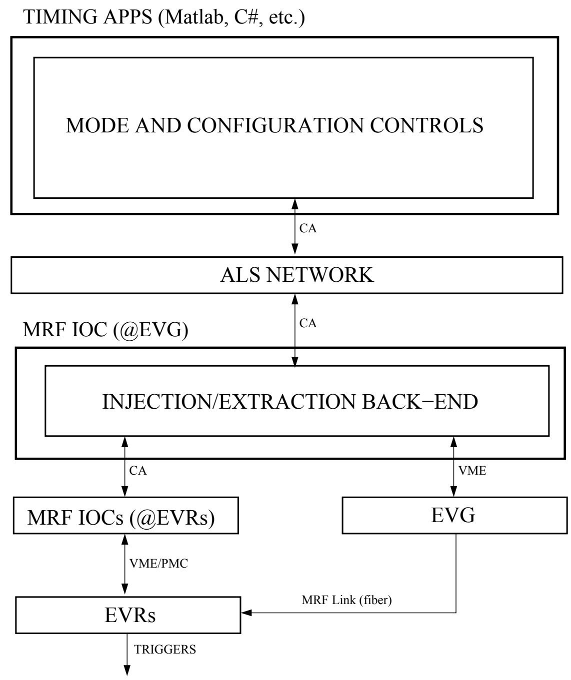

Figure 4: Software integration of the ALS high-level timing applications and the MRF-based timing system.

CONCLUSIONS

The ALS timing system is currently being upgraded to benef t of 20 years of improvements in the electronics and optics f elds. The increase of performance and f exibility will greatly simplify some of the tasks the current system is performing, allowing for a new set of possibilities which were not possible in the past. However some challenges are encountered when changing dramatically the system architecture, where the transition from a purely f eld-based to an event-based system is not obvious and has been achieved with no apparent degradation on injection and extraction performance in the machine despite the non-reproducibility of the booster bend magnet ramp.

The new timing system is still under production but has already been used for user operation in order to test the injection and extraction capabilities with very promising results.

REFERENCES

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