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LEReC TIMING SYNCHRONIZATION WITH RHIC BEAM*

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Abstract

RHIC low energy bunched beam cooling experiment, LEReC, a 704 MHz fiber laser is modulated such that when striking a photocathode, it produces corresponding electron bunches which are accelerated and transported to overlap an ion beam bunched at 9 MHz RF frequency The need for precise timing is handled well by the existing infrastructure. A layer of software application called the timing manager has been created to track the LEReC beam concerning the RHIC beam and allow instruments to be fired in real-time units instead of bunch timing or RHIC turns. The manager also automates set-tings of different modes based on the RF frequency and maintains the timing of instrumentation with a beam. A detailed description of the bunch structure and scheme of synchronizing the RF and laser pulses will be discussed in the paper.

INTRODUCTION

In contrast to previous electron cooling systems that utilized DC beams, the Low Energy RHIC eCooling (LEReC) accelerator has recently demonstrated cooling of RHIC ion beams using bunched electron beams. During the FY2019 RHIC run, cooling was commissioned using electron beams with kinetic energy of 1.6 MeV to cool Au ions at 3.85 GeV/nucleon as well as using 2 MeV electron beams to cool Au ions at 4.6 GeV/nucleon [1].

Cooling a bunched beam of electrons is achieved by illuminating a multi-alkali photocathode, inserted into a high-voltage dc gun with an operating voltage around 400 kV. Light emitted from a fiber laser hitting the photocathode produces individual electron bunches of 40 ps full length at 704 MHz frequency, modulated at a 9 MHz macro-bunch frequency, to match the repetition rate of ion bunches in RHIC. A macro-bunch of electrons consisting of 30 individual electron bunches is timed with each individual ion bunch. The use of such macro-bunches allows the total charge of about 3 nC required for cooling, to be divided into 30 e-bunches with 0.1 nC per bunch. The LEReC beam structure consists of each group of electron bunch spaced by 1.4 ns placed on a single ion bunch, with ion bunch repetition frequency of 9 MHz [2].

The desired timing parameters for generation of bunched beam of anticipated characteristics are given in Table 1.

Generation of Triggers

As depicted in Fig. 1, the triggers for various instruments are generated by two main RHIC timing modules namely Beam-synchronous Trigger (V124) and Timing Decoder (V202) VME boards that are programmed to generate fine timing triggers for accelerator operations and also have software interfaces [3].

Table 1: Machine Timing Parameters

Name	harmonic	Frequency (Hz)
Frev	1	7.82e4
28Mhz Bsyn	360	2.82e7
704 Loopback	1944	1.52e8
704 Laser IF	1944	1.52e8
140Mhz Dig Clk	1800	1.41e8
Nominal 9Mhz	120	9.39e6
704Clk/9Mhz		75

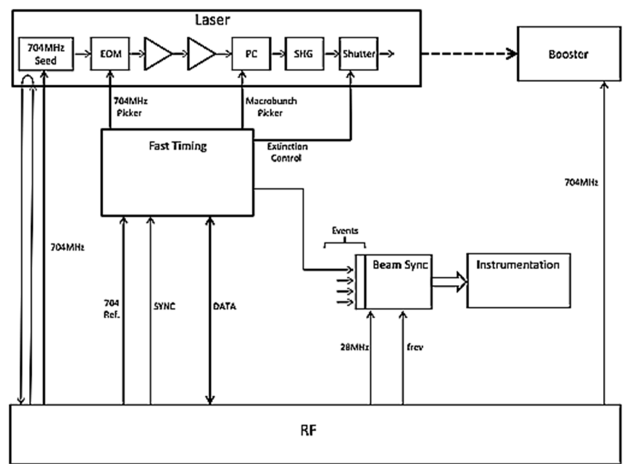

Figure 1: Trigger generation scheme for RHIC and LEReC beam phase synchronization.

The key elements of timing and synchronization are a distributed 100 MHz clock and the Update Link [4], which is a deterministic data and control link that ties systems together whether in the same rack or halfway across the facility.

Each low-level RF system creates a 400 MHz clock from the global 100 MHz clock. The phase advances every 2.5 ns is calculated from the harmonic and revolution frequency. Since T (the clock period) is the same for every system, the frequency ratios are whole numbers. The RF output comes from a lookup table for sine and cosine values the frequency ratios are whole numbers. The RF output comes from a lookup table for sine and cosine values.

When the ratio between 9 MHz and 704 MHz is not an integer, we need to change the number of “off” bunches between macro bunches.

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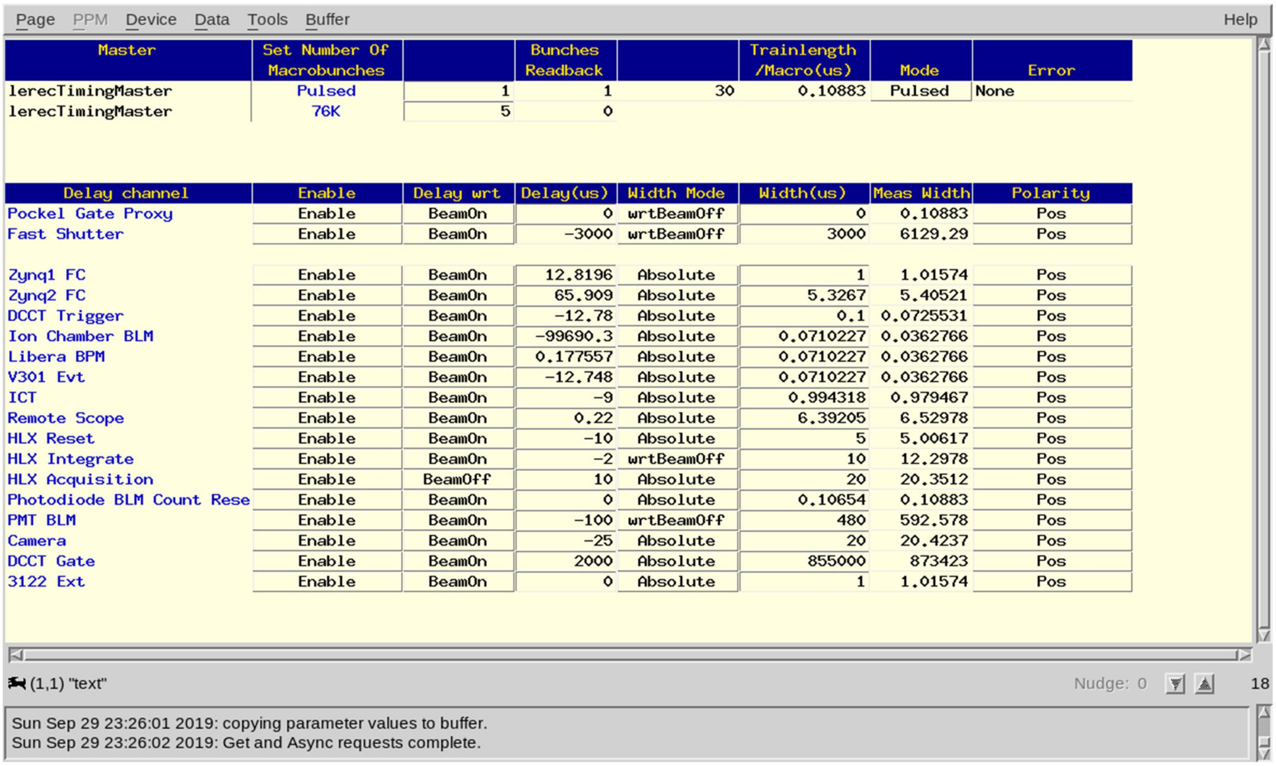

Master	Set Number Of Macrobunches		Bunches Readback		Trainlength /Macro(us)	Mode	Error
lerecTimingMaster	Pulsed	1	1	30	0.10883	Pulsed	None
lerecTimingMaster	76K	5	0				

Delay channel	Enable	Delay wrt	Delay(us)	Width Mode	Width(us)	Meas Width	Polarity
Pockel Gate Proxy	Enable	BeamOn	0	wrtBeamOff	0	0.10883	Pos
Fast Shutter	Enable	BeamOn	-3000	wrtBeamOff	3000	6129.29	Pos
Zynq1 FC	Enable	BeamOn	12.8196	Absolute	1	1.01574	Pos
Zynq2 FC	Enable	BeamOn	65.909	Absolute	5.3267	5.40521	Pos
DCCT Trigger	Enable	BeamOn	-12.78	Absolute	0.1	0.0725531	Pos
Ion Chamber BLM	Enable	BeamOn	-99690.3	Absolute	0.0710227	0.0362766	Pos
Libera BPM	Enable	BeamOn	0.177557	Absolute	0.0710227	0.0362766	Pos
V301 Evt	Enable	BeamOn	-12.748	Absolute	0.0710227	0.0362766	Pos
ICT	Enable	BeamOn	-9	Absolute	0.994318	0.979467	Pos
Remote Scope	Enable	BeamOn	0.22	Absolute	6.39205	6.52978	Pos
HLX Reset	Enable	BeamOn	-10	Absolute	5	5.00617	Pos
HLX Integrate	Enable	BeamOn	-2	wrtBeamOff	10	12.2978	Pos
HLX Acquisition	Enable	BeamOff	10	Absolute	20	20.3512	Pos
Photodiode BLM Count Rese	Enable	BeamOn	0	Absolute	0.10654	0.10883	Pos
PMT BLM	Enable	BeamOn	-100	wrtBeamOff	480	592.578	Pos
Camera	Enable	BeamOn	-25	Absolute	20	20.4237	Pos
DCCT Gate	Enable	BeamOn	2000	Absolute	855000	873423	Pos
3122 Ext	Enable	BeamOn	0	Absolute	1	1.01574	Pos

Figure 2: The user interface for LEReC timing manager used by the machine experts to perform various mode studies.

DISTRIBUTION OF TRIGGERS

The timing manager layer acts as an orchestrator to distribute the relevant beam timing triggers to diagnostic devices and synchronize their acquisition with beam's arrival. It is a desired characteristic of the LEReC beam to operate in three different modes. A continuous-wave (CW) mode provides close to DC beam, whereas a pulse train is produced in Pulsed mode by introducing a half-wave plate in the laser trajectory and produces beam of the desired number of bunches at 9MHz rate. A recently introduced third mode produces macro-bunches at a repetition rate of 76 kHz.

The software architecture consists of two main concrete container classes referred to as Accelerator Device Objects (ADOs), in the Collider-Accelerator Department's Control Systems infrastructure [5]. These two classes share a master-slave topology, with there being as many instances of the slave ADO as many diagnostic instruments.

The properties of LEReC timing that are central to all of the associated devices are either set via user input or received and processed by the master ADO class called lerecTimingCtrl. Once the beam's profile in terms of macorbunches is translated to microsecnonds, it is then broadcast to all of the slave ADOs. that the slave ADOs allow the users to compensate for the timing properties of each type of instrumentation. The master ADO is the human-machine interface that translates the desired beam train structure time into RF buckets and electron bunch characteristics. It is a direct client of the Low-Level RF assembly and keeps track of the changes in critical parameters such as revolution frequency.

The two types of timing modules, Beam Sync and Delay Channel used for distribution of triggers operate at different native clock frequencies and hence use different underlying time units for determining trigger output properties. To make it convenient for machine operators and instrumentation engineers, the timing manager serves as a layer of abstraction and allows for an interface to enter trigger properties such as pulse width of the trigger and time of the trigger with respect to end and the start of the ion bunch.

As seen in Fig. 2, the trigger delay and pulse width of diagnostic instruments can be specified with the following modes:

- Pulse Delay modes: BeamOn, BeamOff
- Pulse Width modes: Absolute, wrtBeamOff

The provision of these modes allows for trigger definition that ensures tracking of the beam envelope. It is extremely powerful in scenarios of when switching between modes modes (CW, Pulsed, 76 Khz) and handling changes in bunch train length. The slave ADO class, lerecTimingCh, has logic inbuilt to prevent situations of invalid or NaN type of numeric calculations that get applied to lower level ADOs using inter ADO communications.

The master ADO being the first client of the change in electron bunch scheme, also assists in automating the task of setting up machine parameters that need to be adjusted when mode of operation of beam changes. Some examples of these are set up of DC gun current threshold, Beam Position Monitors' (BPM) number of samples based on current measured by the fast current transformer (FCT).

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RESULTS

Fig. 3 and Fig. 4 depict the triggers generated as specified by machine operators in actual time units. The distribution system successfully produced synchronous triggers necessary to align 704 MHz warm RF cavity to accelerate laser-generated electron bunches.

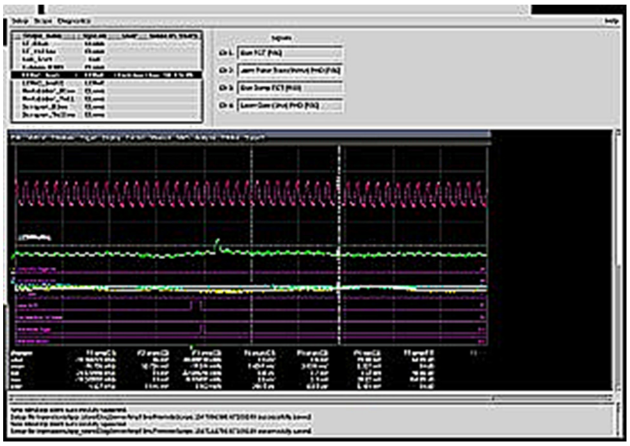

Figure 3: Digital scope used at LEReC to depict instrument trigger gates and analog signals. Taken at the beginning of LEReC project.

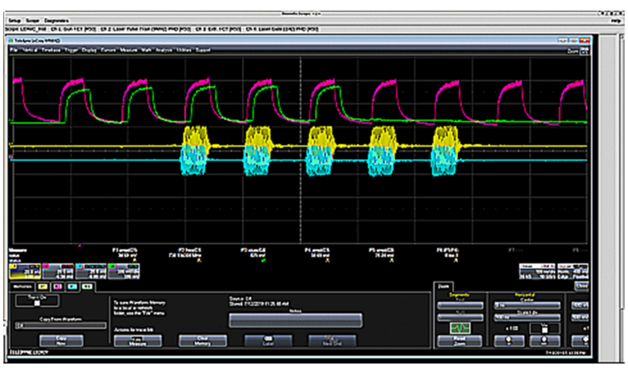

Figure 4: Bunched LEReC beam in pulsed mode with 5 macro bunches.

CONCLUSION

The low energy cooling of RHIC beam was successfully demonstrated at an energy of 1.6 MeV without any magnetic field in the cooling section. Various existing pieces of CAD timing infrastructure were used to generate the desired alignment of RHIC and LEReC beams. Management software was used for the purpose of user aide and automation. The primary features and algorithm employed in this tool have been outlined.

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