BEAM BASED FEEDBACK FOR THE LINAC COHERENT LIGHT SOURCE*

D. Fairley, S. Allison, S. Chevtsov, P. Chu, F.J. Decker, P. Emma, J. Frisch, T. Himel, K.Kim, P. Krejcik, H. Loos, T. Lahey, P. Natampalli, S. Peng, D. Rogind, H. Shoaee, T. Straumann, E. Williams, G. White, J. Wu, M. Zelazney
SLAC National Accelerator Laboratory, Menlo Park, California, U.S.A.

Abstract

Beam-based feedback control loops are required by the Linac Coherent Light Source (LCLS) program in order to provide fast, single-pulse stabilization of beam parameters. Eight transverse feedback loops, a 6x6 longitudinal feedback loop, and a loop to maintain the electron bunch charge were successfully prototyped in MATLAB for the LCLS, and have been maintaining stability of the LCLS electron beam at beam rates up to 30Hz. In the final commissioning phase of LCLS the beam will be operating at up to 120Hz. In order to run the feedback loops at beam rate, the feedback loops will be implemented in EPICS IOCs with a dedicated ethernet multi-cast network. This paper will discuss the design of the beam-based Fast Feedback System for LCLS. Topics include MATLAB feedback prototyping, algorithm for 120Hz feedback, network design for fast data transport, actuator and sensor design for single-pulse control and sensor readback, and feedback configuration and runtime control.

INTRODUCTION

The Linac Coherent Light Source at SLAC requires several beam-based feedback systems to stablize electron beam parameters. For the first three years of commissioning, the LCLS beam has been operating at rates up to 30Hz. During this time the required beam-based feedbacks were prototyped in MATLAB, which allowed great flexibility to rapidly react to changing requirements, and to test feedback algorithms. In April 2009 the LCLS will begin operating at a 120Hz. beam rate. This paper discusses the components of the LCLS Feedback system and the architectural changes required to achieve single-pulse stabilization at the 120Hz beam rate.

FEEDBACK REQUIREMENTS

The LCLS feedback systems are required to provide fast, single-pulse stabilization of several electron beam parameters. This stabilization is realized through several feedback systems of three basic types, a longitudinal feedback loop, multiple transverse feedback loops, and a few simple single parameter general feedback loops.

Longitudinal Energy and Bunchlength Feedback

The longitudinal feedback is responsible for single-pulse stabilization of the beam energy at four locations along the LCLS linac, and the bunch length at two locations along the linac. This feedback maintains all six parameters simultaneously using a 6x6 matrix of transfer coefficients [1]. Figure 1 .is a schematic of the longitudinal energy (δ) and bunchlength (σ) feedback. The longitudinal feedback operates at beamrate, up to 120Hz.

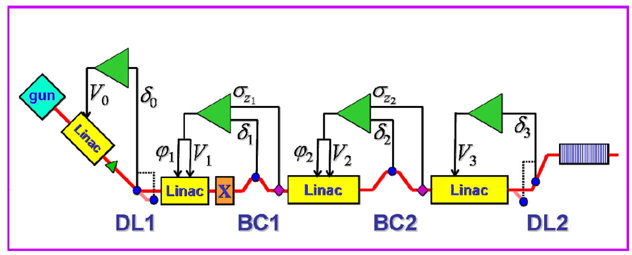

Figure 1: Longitudinal feedback [2].

Transverse Trajectory Feedbacks

Transverse trajectory feedbacks are used in eleven locations along the linac where the launch into the downstream section is important. They stabilize the X and Y position and angle of the beam. The majority of them run at 1Hz or 10Hz rep-rate. The LTU Feedback operates at beam rate, up to 120Hz, for single-pulse stabilization of the beam position and angle before entering the undulator region. More of these feedbacks are planned for the near future. See Figure 2.

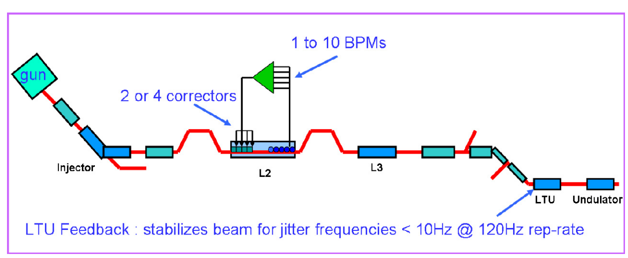

Figure 2: Transverse feedbacks.

Bunch Charge Feedback

A beam position monitor (BPM) near the RF gun measures the total charge of each electron bunch. The Bunch Charge feedback adjust the laser intesity in order to maintain a constant bunch charge. This is a simple single sensor, single actuator feedback and an example of several other simple feedbacks planned for the LCLS. Figure 3 is a schematic of the Bunch Charge Feedback.

*Work supported by U. S. DOE Contract DE-AC02-76SF00515

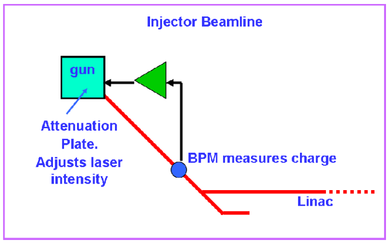

Figure 3: Bunch charge feedback.

Additional Requirements

The LCLS has additional features that prove challenging for continuously running feedback loops. Figure 4 shows where the final energy can be set automatically to a value anywhere between 4.3 GeV and 14GeV. The linac configuration can change using bend magnets to direct the beam into dumps at various locations along the linac, or to move the chicanes. A kicker magnet upstream of the undulator region can kick out pulses on a pulses-by-pulse basis, and is used to protect the undulator magnets.

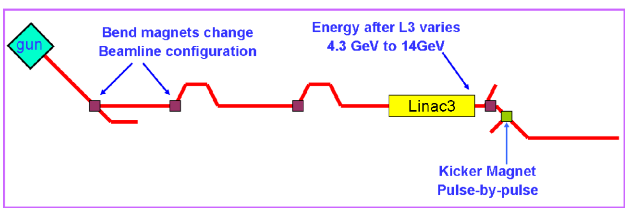

Figure 4: LCLS changing beamline.

The final and most challanging requirement is the 120Hz operation, to begin in April of 2010.

PROTOTYPES

The above feedbacks were first prototyped in MATLAB using simple PID control. They use Channel Access; reading from sensor PVs, writing to actuator PVs. These are currently working at rates up to 10Hz. The MATLAB prototypes have allowed us to keep up with rapidly changing requirements through 3 years of commissioning. This early prototyping proved to be extremely useful in defining the important components of the feedback systems, testing algorithms, and identifying techniques for managing energy changes and beamline changes.

120 HZ FEEDBACK SYSTEM

In April 2010 the LCLS will begin operating at up to 120Hz beam rate. 120 Hz beam operation draws power from two interleaved 60 Hz powerline phases. Beam generated on different 60 Hz powerline phases have differing noise characteristics. The noise on each powerline "timeslot" must be corrected independently by the feedback.

Feedback System Architectural Changes

In order to meet the 120Hz single-pulse stablization requirement, and correct for the 60Hz differences the final production feedback system will require several architectural changes and additions to the LCLS. The significant changes include:

- Faster network communications
- Timing pattern based processing
- Faster feedback processing
- Modular design for future growth

The following sections describe the architectural changes and additions made to the LCLS to support a 120Hz feedback system, and describe the important components of the system.

Dedicated Network

A dedicated gigabit Ethernet network is added to the LCLS infrastructure, to isolate the feedback communications from Channel Access and other network traffic. The feedback IOC applications will communicate over this new network using an IP-Multicast/UDP based protocol developed at SLAC [3]. The network interface software provides a simple API and has been developed as a module that can be added to any IOC that must become part of the LCLS Feedback system. Figure 5 show the added network. Each IOC used in feedback communicates on this network via a second on-board NIC.

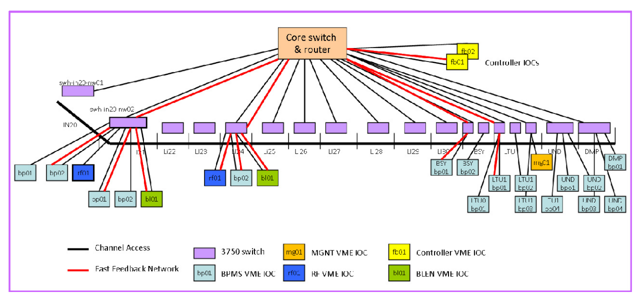

Figure 5: An isolated feedback network added to the LCLS infrastructure, shown in red.

The Feedback Network is defined as a separate VLAN and includes it's own uplinks from the LCLS sector switches to the main switch and router. This network design allows for growth by adding uplinks, and by splitting the sector switches, as more IOCs are added to the fast feedback network.

Timing System Interface

An interface to the timing system allows synchronization between feedback and beam pulses generated on different powerline phases. The LCLS timing system assigns a 'pattern' for each pulse that indicates from which "timeslot" the pulse is generated.

The feedback loop IOC application, and the feedback actuator devices, such as corrector magnets, need to be integrated with the timing system to synchronize their processing with the pulse, and to discover the 'timeslot' pattern assigned to each pulse, in order to handle the noise on separate timeslots. The timing system interface includes an Event Receiver and interface software module that can be integrated into the feedback loop Controller IOC and actuator (magnet and RF) IOCs.

Actuator Devices

LCLS feedback actuator devices, such as RF stations and corrector magnets, are integrated with the feedback network, and the timing system. They also include an additional 'multiplexer' software module that allows the actuator IOC to accept setpoint values per timing pattern. This software module registers with the timing system to receive a fiducial event. It queries the timing system for the current pattern pipeline and chooses the correct setpoint based on the current pattern. See the diagram in Figure 6.

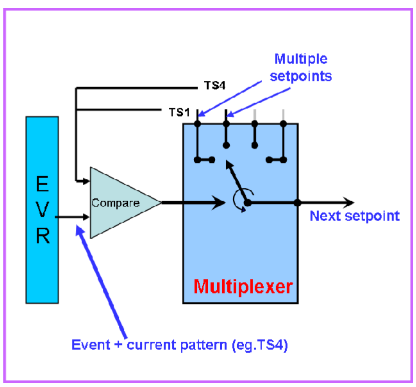

Figure 6 Setpoint multiplexer. Each input has an assigned timing pattern and actuator setpoint.

Sensor Devices

LCLS sensors, such as beam position monitors (BPMs) and bunch length monitors, (BLENs) are made available to the Fast Feedback by integrating the BPM and BLEN IOCs with the fast feedback network. These sensors already have an EVR and are interfaced to the timing system.

Feedback Controller, algorithms, and software Framework

In order to gain processing speed, as well as interface to the timing system and the new network, the feedback loop calculations currently done in MATLAB are ported to an LCLS EPICS IOC. The LCLS IOCs consist of a VME6100 processor with two NICs, an EVR, and run the RTEMS realtime operating system.

The Feedback Loop Controller IOC application is uses EPICS records for data and configuration storage, and is a multi-threaded application using the EPICS OSI library. This Feedback Controller application can run one or more feedback loops. There will be two Controller IOCs installed initially. Growth can be achived by adding loops to an existing Controller IOC, and by installing additional Controller IOCs.

The Controller IOC application is developed as a software 'framework' that handles common functions, such as:

- Error checking
- Managing operational limits on sensor readings, actuator setpoints, feedback calculated states
- Managing gains and averages
- Receiving sensor data and sending actuator setpoints
- Managing changing machine conditions

It will also support feedback algorithm testing by including a set of algorithm functions that can be configured into a feedback loop.

Configuration Tool

For the LCLS, it is imperative to have a feedback configuration tool to allow the user to change a feedback configuration off-line. This Java application interfaces to the Controller IOC PVs via channel access, as well with the LCLS RDB in order to get matrices from the LCLS Model Database, and save configurations. This tool allows the user to get new matrices when the model changes, choose different actuator or sensor devices, set up timing patterns, change the feedback algorithm, perform load balancing between Feedback Loop Controller IOCs, and create new feedbacks for test.

Runtime Control and Display

EDM displays are used to display the performance of the feedbacks. Feedback data is plotted at 1Hz to provide a near real-time performace display. Alarms and warnings are also displayed on these screens.

EDM displays also allow the operator to change feedback operational parameters while the feedback is running. For the LCLS, feedback operational limits, state setpoints, and gain values can be changed on-the-fly.

REFERENCES

[1] P. Krejcik, "Controls Requirements for LCLS Feedback Systems", LCLS Physics Requirements Document #1.1-304. August 2005.

[2] J.Wu et. al., "Linac Coherent Light Source Longitudinal Feedback Model", 2005 Particle Accelerator Conference, Knoxville, TN. USA, May 2005.

[3] T. Straumann, "LCLS Fast Feedback Communication Infrastructure Interface Control Document", *Draft*, July 2009.