Lawrence Berkeley National Laboratory
Advanced Light Source

Memorandum

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1 Executive Summary for Controls System Upgrade Requirements

The original ALS control system was developed using ILCs, multibus I hardware (e.g., the collector micro module (CMM)), and multibus II hardware (e.g., the display micro modules (DMMs)). The communication between ILCs and CMM is provided by a 2 Mb/s serial link which is capable of linking up to 20 ILCs. CMM provides a shared memory architecture for the the real time control. Compared to today's standard switched Ethernet at 100 Mb/s, the data rate in such systems is rather limited due to the bottleneck of the slow serial link. Most importantly, the present shared memory system is not capable of providing real-time synchronization across the distributed system. Instead, polling has been the standard method used extensively to coordinate reads and writes in the accelerator control.

The future control system for ALS based on a standard frame work with modern communication and control hardware should deliver much higher data rates, provide better signal coordination and synchronization of large number of channels, and implement a set of standard control functionalities used by other major accelerator facilities around the world.

1.1 Types of Hardware Involved

The present control system supports the following types of IO hardware:

- analog to digital converters (ADCs) of various bit resolution;
- digital to analog converters (DACs) of various bit resolution;
- digital (binary) inputs and outputs;
- serial buses such RS232C and GPIB;

The control systems for new accelerator subsystems and control upgrades in general are expected to use some modern real-time systems. Device drivers will be needed to drive all the existing types of hardware IOs. In addition, drivers for the following types of hardware will be needed as demanded by the the accelerator system upgrades:

- video capture and analysis boards;
- fast ADC boards;
- others to be determined.

1.2 New Capabilities To Be Delivered

Besides a high data rate, the upgraded control system should provide us a set of new capabilities:

- Low-level capabilities:
  - a fully distributed but integrated system to allow the control of the accelerators using any control computers in a uniform manner;
  - a software ramping program to perform the tight-loop ramping for each step in the ramp at up to 100 Hz (preferably up to 200 Hz) with capabilities to set the ramp rate and ramp time constant:
    e.g. magnet ramping, orbit feedback, feed-forward systems;
  - synchronized writes across the distributed system at 10 Hz (mandatory), and preferred up to 50 Hz. All synchronized writes should be carried out within 10 ms, preferred within 5 ms;
    e.g. magnet ramping, orbit feedback, feed-forward systems;
  - synchronized reads across the distributed system at 10 Hz (mandatory), and preferred up to 50 Hz. All synchronized reads should be carried out within 10 ms, preferred within 5 ms;
    e.g. magnet ramping, orbit feedback, feed-forward systems;
  - switching between synchronized reads/writes and periodic reads/supervisory writes:
    e.g. magnet ramping, orbit feedback, feed-forward systems;
  - a fast local-loop control using one real-time host at > 100 Hz:
    e.g. EPU feed-forward;
  - fast data acquisition and waveform capabilities:
    e.g. FADs, BPMs, QFA current read-backs;
  - in-memory short-history data capabilities with selectable word length from 1024 to 10000:
    e.g. most of channels;
  - 10 Hz periodic update capability for any analog monitors and up to 50 Hz periodic update capability for a few selected analog monitors:
    BPMs and power supplies;
  - generic GPIB interface for programming GPIB devices in the control room:
    e.g. beam-line 3.1, RF system;
  - sum-junctions for control channels which need to be controlled by different subsystem:
    e.g. correctors, QF and QD families;
  - software implementation of direct reads and averaged data on the same analog device:
    e.g. BPMs, power supplies;
  - the sequential control capability using state machines:
    machine status updates;

  - time-stamps for controls system data.

- High level capabilities:
  - a better name convention for all control signals and a method for name aliasing;
  - an alarm capability for trouble shooting:
    e.g. vacuum, cooling, superbends;
  - data logging and long-term archiving capabilities for most of channels;
  - an easy-to-use and easy-to-configure graphic user interface (GUI):
    e.g. operation, beam physics studies;
  - a simple process (e.g. web-based system) for adding and deleting software channels:
    e.g. beam physics studies;
  - a simulation environment with soft channels and read-only access to the controls system for new control subsystem/application development and prototyping with no impact on the operation of the accelerators;
  - software support for linking the control system with other software packages, such as matlab, labview, tcl-tk, etc. and accelerator modeling programs, such as TRACY (details to be determined).

2 Hardware Systems

2.1 Magnets

In general, the future control system should provide better control and synchronization for performing magnet ramping and orbit correction.

- capability to set ramp rate and a ramp time constant for every step in the ramp and for all magnets to be ramped. When there is no ILC dedicated for ramping a power supply, each ramping step should be carried out by an equivalent software ramping program in the IOC to complete the step at 100 Hz, preferably at 200 Hz;
- a mandatory 10 Hz (preferred up to 25 Hz) data rate for ramping magnets via synchronized writes;
- fairly precise coordination of all magnet power supplies during the ramping. All ramped magnets should respond to a set-point change within 10 ms, preferably within 5 ms;
- a reset of the power supplies should ramp the control voltage to zero;
- a mandatory 10 Hz (preferred up to 50 Hz) data rate for orbit correction via synchronized writes;
- fairly precise coordination of all corrector magnets to be used for the orbit correction. These correctors should respond to a set-point change within 10 ms, preferred within 5 ms;
- if upgrading DACs, the corrector magnets need 18-bit DACs.

2.2 BPMs, IDBPMs, New IDBPMs

Most of the electron beam motion in the ALS ring is less than a few Hertz. Having a 10 Hz data acquisition has proven to be very effective for orbit correction and monitoring. The next frequency range of interest is 10–50 Hz. Access to this frequency range would allow accurate monitoring of orbit perturbations due to ground vibrations and uncompensated insertion device motion up to 25 Hz.

- for synchronized BPM reads, all BPM data should be read at 10 Hz (mandatory), preferred up to 50 Hz. All reads should be synchronized within 10 ms, preferred within 5 ms;
- when a BPM channel is not used for orbit correction, this channel should be periodically updated at 10 Hz (mandatory), and possibly updated at up to 50 Hz;
- 16-bits ADCs are OK;
- both direct monitoring data and averaged data on the same BPM channel;
- time-stamps for data;
- new IDBPMs will be added to the system and they should be implemented with the same capabilities as existing BPMs. These new IDBPMs will be integrated with the present BPM system for orbit correction and feed-forward.

2.3 QFA Shunts

At present, the same ILCs are used for controlling QFA family and monitoring ion gauges and pumps. This makes controlling the shunts very slow with up to 8 second delays. Reloading this ILC to perform vacuum work had caused a beam dump during user operation.

- separation of QFA controls from ion gauge/pump controls if possible during the upgrade;
- 2–10 Hz update rate on QFA shunts.

2.4 Pinger and FAD Systems

Presently, there is no good synchronization between the pinger system and the FADs. Wait statements have been used to make sure that FADs are ready. Overall it takes more than 20 seconds to ping the beam and read back all FADs. The goal is to make this system a regular diagnostic tool integrated with the control system and with 1 Hz performance.

- to make the FAD data accessible via channel access;
- better synchronization between pingers and FADs;
- 1 Hz operation for the pinging and FAD reading cycles;
- an integrated and local solution using one IOC for pingers and FADs controls may be worth consideration for better synchronization. In this arrangement, the FADs data can be dumped to a local disc for later retrieval;
- an improved trigger system (not fixed to the booster trigger) is desirable.

2.5 Special BPMs

The special BPMs are under development with fast analog-to-digital conversion capability to replace a few existing BPMs. This system must be digitized by fast ADCs and turn-by-turn synchronized to the revolution frequency. Long data buffers are preferred. To use this system for beam dynamics measurements, the BPM reads should be triggered by the pinger like the FADs (see the pinger and FADs systems). From setting the pinger amplitude to read out the orbit from special BPMs, it should take less than 1 second. And the system should be operated at 1 Hz.

- 12-bit or 14-bit ADCs with 1024 word buffers, preferred with $10,000$ word buffers;
- turn-by-turn synchronized with the revolution frequency.
- triggered by the pinger;
- a repetition rate of 1 Hz or faster;

2.6 ID Controls

The present ID control works fine for the slow orbit feed-forward. However to make use of the possible movement speed of the IDs, the feed-forward algorithm should be sped up. To accomplish this, a faster read-back rate is necessary.

- a faster read-back rate at 30 Hz (mandatory), preferred at 50 Hz;
- the velocity profiles should be made modifiable and readable;
- with the optimized orbit feed-forward, the ID gap operation is expected to be sped up.

2.7 Beam-line 3.1 and Streak Camera

- drivers for 6 stepper motors;
- four generic GPIB interfaces with ability to read waveforms;
- about 10 analog inputs with 16-bit resolution;
- video digitizer at 60 Hz (or fastest within reason);

2.8 RF System

- duplicate existing channels with existing read-back rates;
- generic GPIB interface capability;
- provide a high bandwidth trip diagnostic system with 8 input channels. This system would record a few signals with a high sampling rate (20 kHz or so) and stop recording when a beam trip signal is present.

2.9 Harmonic Cavities

- duplicate existing capability;
- generic GPIB interface capability.

2.10 RF Synthesizer

Currently, the user operation of ALS uses a high performance HP synthesizer, HP8644B, to minimize the RF phase noise. However, without FM-ing, this synthesizer cannot change the RF frequency without causing beam losses. The goal is to use the same synthesizer for all modes of operations including user operation, ring setup, and beam dynamics studies.

- to use HP 8644B for both the user operation and accelerator physics experiments. An external DC source from a 16-bit DAC will needed to continuously FM-ing the frequency;
- to calibrate the frequency control channel using a high precision frequency counter;
- to provide controls of HP 8644B in the control system.

2.11 Video Interface

The present video signal related system is capable of remotely switching most video signals. The video signals can be captured using a frame grabber on a PC in the control room. The video image analysis is provided by the Spiricon Laser Beam Analyzer (module LBA-100A) and the result is displayed by a PC monitor. The Spiricon solution is unacceptable because it has current dependency, provides no real tilt information, and is difficult to optimize.

The future video subsystem should support the following functionalities:

- capturing and digitizing any selected video images;
- displaying a subset of "live" video images on any control computer;
- saving/retrieving video images and video sequences into/from files;
- analyzing any selected lived video images and making the result of the video analysis available within the control system.

2.12 Tune & Chromaticity Measurement System

The existing tune measurement system is a stand-alone system implemented on a PC using labview via GPIB interface. This tune measurement cannot be remotely started and the system provides no information about when a tune measurement has been completed. A user typically combines waiting and polling technics to insure a correct measurement. Due to the lack of synchronization with the main control system, the present tune measurement is very slow and unreliable.

- the existing tune measurement system should be fully integrated into the control system;
- the control system should be able to set the measurement parameters and start the measurement;
- the revolution frequency should be read into the system for computing tunes;

In the future, two new tune measurement systems will be developed:

- a phase-locked loop system for continuous tune measurements (details to be determined);
- a pinger based tune measurement system to measure both tunes and chromaticities. Some software development efforts are needed (see Pinger and FAD systems).

2.13 General Purpose Channels

Although some spare control channels are physically available in the control racks, they are not present in the control system. In the future, a number of different types of general purpose channels should be readily available in the control system. The upgrade requirement includes:

- to implement several (4–8) DAC and ADC channels per group of control racks inside the shielding wall. On the hardware side, to implement some standard connectors (such as BNC) for connecting signals to the control system. On the software side, all general purpose channels should be implemented in the database with assigned signal names.
- to implement several waveform read-back channels using fast ADCs at selected locations;
- to develop a general purpose GPIB device/driver program for controlling GPIB devices as needed;
- to establish several general purpose GPIB connections and related hardware at selected locations.

2.14 Injector System

Sooner or later, the booster control system must be upgraded as it is almost 10 years old. As found out many years ago that the linear correction for the magnet ramping is not sufficient. Currently we have 100 ramp points at 3 ms per step.

- for the booster, to provide for the linearity correction for the quads and correctors. A 1024-step ramping table should be developed and all controls be set within 300 μs.
- to investigate ramping the main booster magnets using controlled waveform generators;
- more diagnostics are needed for the booster ring and linac (to be determined);
- for linac, a live monitor in the control room for the phase relation between the injected beam and the accelerating RF wave is desirable.

2.15 Vacuum, Cooling, and Interlock Systems

Most of the vacuum and cooling system channels are now accessible via Channel Access (CA). However, there are a few channels which remain unaccessible via CA.

- make all existing channels accessible via CA;
- add all interlock system states to the control system for monitoring;
- set proper alarm states for the vacuum and cooling system signals and to use an alarm handler to monitor the changes of the alarm states of these systems as well as the changes of state in the interlock system.

3 Control Applications

3.1 Machine Operation and Setup

Machine operation and setup require a set of critical systems to be operational (see the list below). However, a good operation depends on all the systems mentioned in this document to be functional.

- Hardware systems:
  - Magnets;
  - QFA shunts;
  - BPMs and IDBPMs;
  - Tune measurement system;
  - Main RF controls;
  - Harmonic cavity controls;
  - Insertion device controls;
  - Analog read-backs for magnets, vacuum, etc.;
- Control Applications:
  - ramping application;
  - orbit and tune feed-forward system;
  - slow orbit feedback;
- Other dedicated systems:
  - transverse feedback system;
  - longitudinal feedback system;

3.2 Slow Orbit Feedback

Slow orbit feedback corrects for orbit distortions caused by magnet field drifts due to temperature variation, errors in the insertion device feed-forward tables, etc.. Presently running at 0.1 Hz, the future system should be capable of correcting at least 10 Hz (mandatory) and preferred 50 Hz orbit errors by coordinating the BPM reads and corrector writes. See Magnet and BPM systems for requirements on the BPM reads and corrector writes requirements.

- summing junctions for corrector channels so that feedback and feed-forward systems can use the same magnets.

3.3 Orbit Feed-forward

The orbit feed-forward system is currently used to compensate the local orbit change due to the operation of the insertion devices. Without knowing the computer delays in the feed-forward system (sequencer, IOC, CMM, ILC, power supplies), the feed-forward algorithm has not been optimized to allow faster movement of the insertion devices. Using the measured orbit perturbation due to the existing feed-forward system, the insertion devices have been slowed down to about 1 mm/s.

- a need to quantify the time delays in the orbit feed-forward system;
- to optimize the feed-forward algorithm;
- to provide software adding junction (**a very high priority**) to allow the correctors in the orbit feed-forward system to be used in the global correction scheme at the same time;
- EPU and similar future insertion devices require a fast feed-forward at 100 Hz, which could be realized locally.

3.4 Tune Feed-forward and other Feed-forward Systems

The tune feed-forward is a new application to be implemented to compensate for the tune changes due to the operation of the various insertion devices. This system will read back the insertion device positions, compute the necessary changes needed for quadrupole magnets, and then change their settings. The tune feed-forward system can be implemented using a local scheme for each insertion device or a combination scheme of local/global corrections. In addition, this system may be coordinated with other systems to provide chromaticity correction, coupling correction, etc.. Because of the complexities of this system, prototyping of the feed-forward algorithm should be worked out first by the physics group, and the significant level of involvement from the physics group will be needed in implementing this system into IOC.

- the opening/closing of the insertion devices should cause the tune feed-forward program to be activated;
- a local or local/global tune forward algorithm to be developed;
- sum junctions for controlling QF, QD, correctors, etc..
- other feed-forward systems for correcting chromaticities, coupling, etc. (details to be determined).

4 High Level Control Applications

4.1 Data Acquisition and Archiving System

Currently, there is no waveform capability and short history data capability in the EPICS based control system. Almost all ALS channels are archived every 3 minutes. The archived data are not available for analysis on the same day.

The future control system should provide the following three different levels of data acquisition: waveform data, short history data, and archived long-term data. The waveform provides a way to acquire fast data for short durations. The set of data are read out by the a fast data acquisition system deployed for a particular application. The software support should provide a uniform interface to deliver scope traces (read by a scope and interfaced by a serial bus such as GPIB) and the waveform data from a fast ADC and/or transient digitizer. The short history data sampled at a few Hz would extend the coverage to tens of minutes to provide for the recent history of the operation. The short history data can be cached in the real-time host main memory and delivered through the same waveform interface to the operator interface (OPI). An archiver is used to log the long-term data at much lower data rate. The user should be able to access the logged long-term data using the same interface as for the live data.

- Waveform data:
  - hardware drivers for various scopes, fast ADCs, and transient digitizers;
  - the data rate should be determined by the hardware used;
  - a standard software interface to read and display any number of waveforms;
  - a waveform tool to analyze the waveform data with FFT and correlation analysis capabilities.
- Short history data:
  - sampled at a few Hz (1 to 10 Hz) for any analog and digital channels;
  - with a very low overhead by collecting data from the existing channels;
  - selectable data length (from 1024 to 16384);
  - time-stamps for data array;
- Archiving data:
  - time-stamped data;
  - archiving using a real database for easy retrieval;
  - providing a standard interface to the OPI;
  - configurable update intervals for archived channels.

4.2 Alarm Handler

The alarm handling capability is not available for the signals in ILCs and not implemented for the signals under the EPICS control. In the future, alarm states will be used to prevent hardware trips and to diagnose beam loss events.

- to provide alarm capability for all control channels;
- to implement alarm states in all control signals when appropriate;
- to implement an alarm handler to monitor the alarm states;
- to implement state machines to analyze and report complex state changes to the alarm handler.

4.3 User Interface

The Web based interface between the users and operations is not adequate. A high performance interface between the beam-lines and accelerators should be developed to facilitate the sharing of the information.

- the important beam-line data (such as the beam motion) should be made available to the accelerator control system;
- critical accelerator operation data should be shared with beam-line users;
- most of the data sharing will be read-only and a dedicated IOC can be used to provide cached data for sharing, an additional level of security, and easy configuration changes.

4.4 Operator Interface

Presently, a large number of OPI programs used for the daily operation depends on DMM. Recognizing that DMM will be retired in the near future, efforts will be needed to make sure that all OPI will access data via channel access.

- a set of standard libraries in C for access the control system (e.g. libraries for CA and SCA);
- to use the standard EPICS GUI tool to develop/redevelop the operator interface.

4.5 Machine States

Many instruments at ALS have to be put into a known state for them to function properly. Examples include BPMs, IDBPMs, DCCT2, tune measurement system, BL 3.1, etc.. Therefore setting, recalling, and archiving these states are critical to reliable operation of ALS. At present it is quite difficult to recall the state of the accelerators. Basic states such as what is the energy or whether the storage ring is set up for injection or for a production user run can be guessed from settings of various control system channels (or from saved files by matlab applications). However, since the present control system is not designed in an object-oriented manner, there is no systematic way to associate system states with a particular hardware instrument. In addition, the accelerator operation generates a number of higher level states in high level applications which typically control a set of channels from several hardware subsystems. For example, when all magnets are normalized a high level state of normalized magnets is generated. There is no mechanism in the present system to record such a high level state.

- implement more low level states when possible for hardware instruments;

- implement soft channels for recording the high level states;
- use machine states for alarm handling;
- archive machine states.

4.6 Signal Name Convention and Name Server

The present signal name convention was adopted in the early stage of the accelerator construction and controls system development. The name convention has served the PC based control system reasonably well since a small number of developers who need to use it on the regular basis can afford the time to get familiarized with the convention. However, for accelerator physicists, operators, and beam-line users who do not have extensive knowledge of signal names, the signal names remain too abstract and too short. To further complicate the matter, meaningless underscores have been used to fill the name fields in the channel access signal names when mapping the signals from CMM to EPICS.

It is the time to develop and adopt a new name convention which is based upon the accelerator sub-systems and beam-lines so that signals can be named according to their primary uses in the control system. In addition, a name aliasing procedure should be developed for the compatibility between the old and new signals names, and for the individual beam-lines to use a set of local names. In addition, a name server (with a web based interface) should be developed to resolve the individual fields in the signal names and to provide detailed information about the signal (such as the full content of the process variable as seen by the real-time system).

- to develop and adopt a new control signal name convention;
- to develop an easy-to-use name aliasing mechanism;
- to develop a name server to resolve signal names, provide searching capabilities, and to supply a complete set of the information for a signal to be queried.

5 New Systems and Operation Mode

5.1 Superbends

The details of the superbend control have been documented by the superbend power supply controls specifications of 5/17/99 version 0.90. A brief summary of the control requirement according to this document is here:

- the control interface is DeviceNet 2.0;
- binary controls for switching on/off, reset, reboot the power supply and related binary monitors;
- 18-bit DACs and 16-bit ADCs;
- a software record to perform ramping;
- related PLC interface.

5.2 Top-off Mode Operation

The top-off operation is a new mode of operation. To successfully operate the storage ring and its injector in the top-off mode, the injection to the storage ring has to be completely automated.

- Upgrade requirements for the booster:
  - a tune and chromaticity measurement system for the booster;
  - orbit measurement and feed-forward system;
  - a current measurement systems;
  - an optical diagnostic system for monitoring the beam trajectory and beam profile in BTS;
  - an improved feedback for the beam transport line;
  - improved ramping procedures using new ramping tables with more points;
  - the control of the bunch current in the booster;
- Upgrade requirement for the storage ring:
  - a upgraded injection timing system with the computer interface;
  - a “bunch current equalizer” which measures the bunch pattern and fills the buckets with the lowest current;
  - an interlock system for bad injection;
  - better controls for the injector bumps, and controls for potential new injection kicker(s);

5.3 Narrow Gap ID

A narrow gap insertion device is a future insertion device used to produce ultra-short pulse X-rays.

- most of the control will be the same as the other IDs, details to be determined.

5.4 Photon BPMs

The photon BPMs are very important diagnostic tools to be developed to provide live data on the transverse beam profiles and beam center movement using synchrotron radiation. This system consists of a pinhole array imaging system for beam profile measurement and a double-blade system for vertical beam motion measurement. The control system requirement details for this system are still to be worked out. However, the following controls features are required:

- controls for filter motors;
- controls for a framegrabber;
- video image analysis capability;
- full integration of this system with the rest of the controls system.