The SSCL LINAC Control System

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I. INTRODUCTION

The SSCL Linear Accelerator (LINAC) consists of an Ion Source, Low Energy Beam Transport (LEBT), Radio Frequency Quadrupole (RFQ), Drift Tube LINAC (DTL), Coupled Cavity LINAC (CCL), CCL Transport and LINAC to Low Energy Booster (LEB) Transfer Line. The Ion Source generates H^- ions and accelerates them to 0.035 MeV. The LEBT transports and matches the beam to the input of the RFQ. The RFQ bunches and accelerates the beam to 2.5 MeV. The DTL and CCL accelerate the beam to 70 and 600 MeV, respectively. The Transfer Line routes the beam from the CCL Transport Line to the LEB.

The Ion Source/LEBT, RFQ, DTL and CCL support systems consist of vacuum, cavity temperature control, beam instrumentation, RF power, and magnet subsystems. Each of these sections is capable of stand-alone operation.

The SSCL Global Accelerator Control System (GACS) is a standard multi-layered system. Figure 1 illustrates the six levels of functional hierarchy used to specify and describe the GACS. Level 6 provides information exchange services. No true control functions are performed at this level. This level is used to provide a pathway for the exchange of information between the Control System and SSCL computer services. Level 5 is the machine integration level of the system. At this level, controls for all SSCL machines, i.e., LINAC, LEB, MEB, HEB and Collider, are integrated into a single unit. This level includes a central control room for operations. Level 4 is the machine control level. At this level all module level controls are integrated into an SSCL machine, in this case the LINAC. Level 3 is the LINAC module controls. The function of Level 3 is to tie the various subsystem controls together into stand-alone modules, i.e., Ion Source, RFQ, etc. Level 2 controls are defined as those which logically combine a group of front-end systems into a control unit. Subsystem controls such as vacuum and RF are performed at this level. Level 1 is the front-end controls. This level provides interconnections between sensors and controls, signal conditioning, I/O module interfaces, front-end processors and local operator stations used for system maintenance and commissioning.

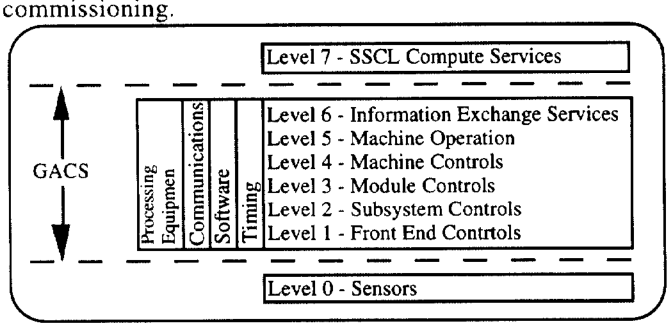

Figure 1. GACS Levels

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II. LINAC CONTROL SYSTEM ARCHITECTURE

A. *Communications*

Figure 2 is a block diagram of the LINAC controls communications infrastructure.

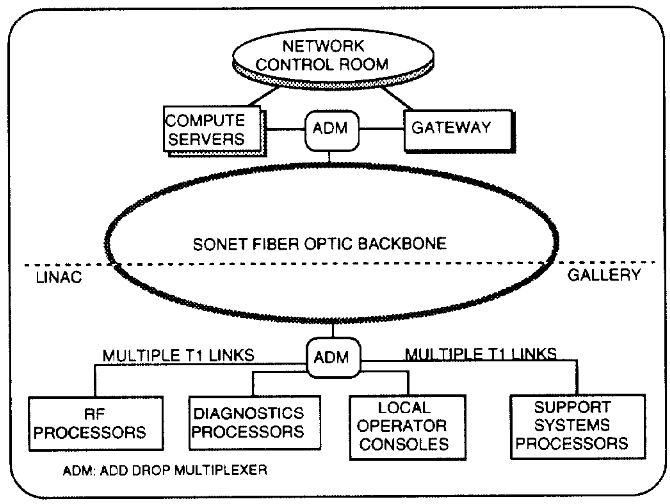

Figure 2. LINAC.Communications Infrastructure.

The communications backbone is a SONET fiber optic network that interconnects the LINAC Gallery and the Accelerator Main Control Room (AMCR). Add-Drop Multiplexer (ADM) equipment is installed in the LINAC Gallery and the AMCR to interface the SONET backbone with T1 telecommunications links. Communication interface modules are provided to interface the T1 links from the ADM with the front-end equipment in the Gallery. Communications gateway equipment is provided at the AMCR to connect the ADM to the standard communications network of the AMCR.

B. *Front End Systems*

The SSCL has chosen EPICS (Experimental Physics and Industrial Control System) as the front-end control software. The primary hardware supported by EPICS is VME and VXI based. Commercial and custom modules mounted in VME and VXI crates are used to interface the control system to the various sensors and systems of the LINAC.

A minimum of four operator workstations, used for checkout and commissioning, will be located in the Ion Source, DTL, CCL and Transfer Line sections of the LINAC Klystron Gallery. The operator workstations will have a direct connection to a SONET backbone through an ADM or a commercial router. In addition, each workstation will act as a data server for the section of the LINAC to which it is connected. This will be accomplished by additional Ethernet connections to the building Network. In this manner, additional workstations may be connected and obtain access to the LINAC Control System.

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C. Machine Synchronization

The LINAC Control System provides synchronization of the front-end processors used to control each of the LINAC sections. The system is capable of delivering synchronizing messages to the processors within a 10-millisecond window before the start of each LINAC pulse. Typical messages will indicate the operating mode of the machine, i.e., LEB injection, medical facility operation, test beam operation, etc. The Global Controls Message Broadcast System (MBS) is used to provide this capability. The message indicating that the LEB is ready for a LINAC pulse will originate in the LEB Control System and be passed to the LINAC Control System by the MBS. LEB Injection will be the top priority mode of operation and will override all other LINAC operating modes.

D. Control Room Systems

The LINAC compute servers shown in Figure 3 and described below are located in the AMCR.

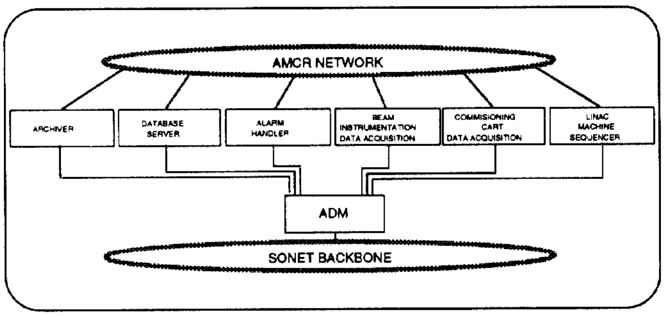

Figure 3. LINAC Compute Server.

LINAC Archiver – This computer performs the functions of archiving machine settings and slow (10 Hz) status information, along with operator actions.

LINAC Alarm Handler – The LINAC alarm compute server is used to log and alert the operator of any alarm conditions.

LINAC Database Server – The LINAC database server is used for storing and loading control application tables and software, and saving/restoring machine configurations.

LINAC Data Acquisition – Data acquisition here is defined as blocks of data read from various systems, often at high rates. This is data that may require further analysis and is of a type not covered by the data archiver. The primary subsystems that supply this type of data are the LINAC beam instrumentation system and the LINAC "Commissioning Cart." The LINAC Control System will supply a compute server or servers with sufficient compute capacity to perform analysis of data and sufficient disk capacity to archive the data. Analysis and storage of the data will be limited to that required for proper LINAC operation.

III. OPERATIONAL SEQUENCES AND CONTROL

The levels of control described in the preceding sections can be used to describe the types of control sequences and applications used within the LINAC Control System.

LINAC CONTROL APPLICATION (LEVEL 4)

The state machine for the LINAC can be described using sequential function charts (SFC) common in many industrial control systems. Each instance of an SFC is considered to be an application. The highest level of control in the LINAC is the actual machine sequence that leads to a beam pulse. In turn, each module of the LINAC would have a control application and each subsystem of each module would have an application. Devices within each subsystem can even have applications. The LINAC Control Application SFC is shown in Figure 4. Each state and transition event is described in the following text.

OFF State – Control power to the VME/VXI crates, CPUs, racks and operator consoles is on. Code is executing in the LINAC Control System CPUs. Beam Permit is "Off".

Event A – The operator or an automatic sequence has commanded that the LINAC start.

Start-up State – The operator or an automatic sequence has issued the "start LINAC" command. In this state the operator will be able to direct the desired destinations for the beam (i.e., LEB, Medical, DTL Tank 1, etc.). When this state is entered from the OFF state, the operator will be prompted. The logic will then issue the appropriate start-up commands to the various LINAC modules. All modules required for each destination will be commanded to start.

Event B – The LINAC modules ready status is equal to the required module ready status.

Event F – The LINAC "off" command has been issued.

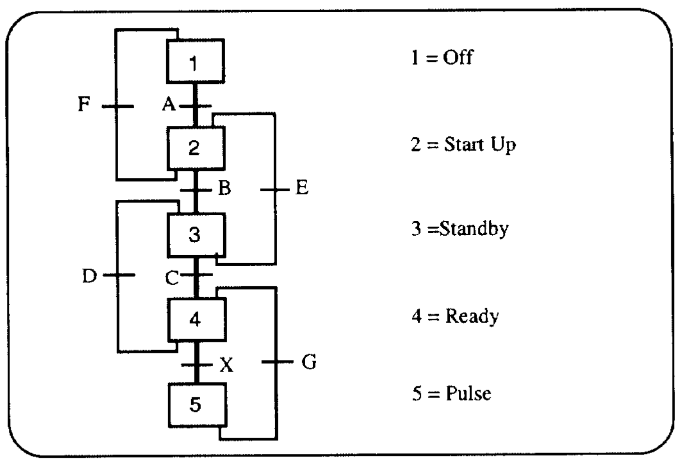

Figure 4. LINAC Control Application.

LINAC Standby State – In this state, the ready status of the LINAC modules is equal to the ready status for the anticipated beam destinations. This is a hold state, waiting for an operator or automatic sequence command to commence LINAC beam operations.

Event C – The LINAC "Go to Ready" command has been issued.

Event E – The LINAC module ready status is "not ready".

LINAC Ready State – In this state the "beam ready" status of each LINAC module is compared with the required module status for the particular pulse destination. In effect, this allows a Beam Permit for the pulse. If the beam ready status equals the required module ready status, the Beam Permit is granted. If the beam ready status does not meet the required status the timing delay for the RFQ is set and the LEBT chopper is not pulsed. The timing pulse for the other LINAC RF modules is not affected.

Event X – The Beam Permit for the pulse has been granted.

Event D – The LINAC modules ready status is less than required.

LINAC Pulse State – The LINAC pulse command is given to the ion source. The proper timing for the LEBT, RFQ and other LINAC modules is set such that beam is accelerated. Note that the LINAC state will cycle between Pulse and Ready on a pulse-to-pulse basis, even when the LINAC is running to the same location on every pulse.

Event G – The LINAC pulse is complete.

Implied Events – For the sake of clarity, the implied transitions from one state to another have been omitted from the drawing. These events would be operator or automatic sequence events that would command the LINAC state to a lower state than it is presently in. For example, the LINAC can be manually moved from the READY state to the STANDBY state by the operator. The LINAC can also be switched completely off from any state by the operator.

MODULE CONTROL APPLICATION (Level 3)

Each module of the LINAC (Source, RFQ, DTL, etc.) will have a module level control application. The purpose of this application is to transition the module from the OFF state to the MODULE READY state. In this state the module is ready for beam. The module level application SFC for the DTL Input Matching Section (IMS) is shown in Figure 5. It is a representative example of the application used for each module. The module states and transition events are described in the following text.

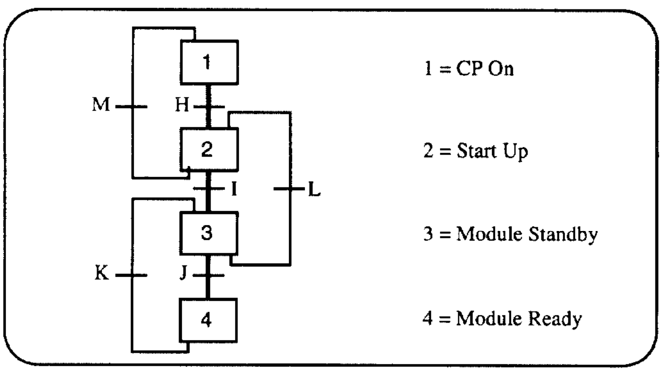

Figure 5. LINAC DTL IMS Module Application.

Module Control Power On State – This is the lowest state that a module control system can reach. In this state the control power is turned on to the VME/VXI crates, processors, racks, etc. Code is executing in the module control CPUs.

Event H – The "module start" command is received from the LINAC Application.

Event M – The "module off" command is received.

Module Start-up State – In this state the module control application will command its various subsystems to begin turning on and preparing for beam. Vacuum systems will begin the pumpdown process, the Temperature Stabilization System (TSS) will begin to function and regulate cavity temperature, magnets will move to their nominal beam positions (focus and steering), RF systems will turn on, etc.

Event I – All module subsystems are ready for beam.

Event L – All module subsystems are not ready for beam.

Module Standby – All module subsystems are ready and operational. This is a hold state, waiting for an operator or automatic sequence command to move the LINAC to beam operations. In this state the module status is reported as "Ready" to the LINAC Application.

Event J – The "Go to Beam Ready Command" is received.

Event L – All subsystems are not ready.

Module Beam Ready – All module subsystems are ready. In this state the module status is reported as "Beam Ready" which also implies "Ready".

Event K – Subsystems are not "beam ready".

Implied Events – For the sake of clarity, the implied transitions from one state to another have been omitted from the drawing. These events would be operator or automatic sequence of events that command the module to a lower state .

SUBSYSTEM CONTROL APPLICATION (Level 2)

Each subsystem of the module will have a subsystem level control application. The purpose of this application is to transition the subsystem from the OFF state to the SUBSYSTEM READY state. In this state the subsystem is ready for beam. The subsystem level application SFC for the DTL IMS vacuum system is shown in Figure 6. It is a representative example of the application used for each subsystem. The subsystem states and transition events are described in the following text.

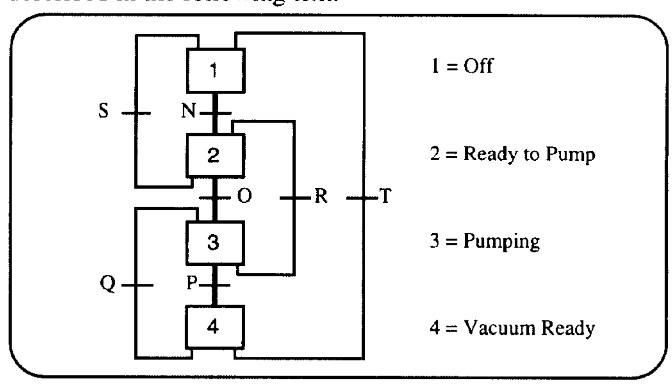

Figure 6. LINAC DTL IMS Vacuum Application.

Vacuum System Off State – The vacuum system is in the off state. Ion gauges and ion pumps are turned off and gate valves are closed.

Event N – The vacuum system is manually roughed down. This event occurs when the Convectron gauge pressure is measured to be less than 10^{-2} Pa.

Vacuum System Ready to Pump State- – Ion gauges are on, Ion Pumps are off, and gate valves are closed.

Event O – The "Pump" command has been received from the module control application.

Event S – The Convectron gauge pressure is above 10^{-2} Pa.

Vacuum System Pumping – Ion gauges, and Ion Pumps are on. Gate valves are closed.

Event P – The DTL IMS Ion Gauge pressure is less than 10^{-5} Pa.

Event R – The DTL IMS pressure is greater than 10^{-4} Pa.

Vacuum Ready State – Ion pumps, Ion gauges are on. Gate valve enables have been granted.

Event Q – The DTL IMS pressure is greater than 10^{-5} Pa.

Event T – The "vacuum off" command has been received from the module application.