# DEALING WITH CHANGE WHILE MAINTAINING OPERATIONAL RELIABILITY OF THE ADVANCED PHOTON SOURCE LINEAR ACCELERATOR

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*Abstract*

In recent years, many changes have been made to the Advanced Photon Source (APS) linear accelerator (linac) to support multiple tasks. The primary purpose of the linac is to provide beam to fill the APS storage ring, which is done using new thermionic cathode rf guns. At the same time, we have had to provide support for research, including the free-electron laser (FEL) project and a new facility for testing injector components. With each operating gun and research project requiring a different lattice and timing configuration, while at the same time using a common rf system, the complexity of operations increased significantly with even greater demands on reliability and performance. In addition, personnel safety and equipment protection concerns grew as the machine operation became more complex. Our approach to these challenges involved three developments: a high degree of automation in linac operation, using APS's Procedure Execution Manager (PEM) software; a new interlock system based on programmable logic controllers; and use of an automated S-band rf switching system. In this paper, we discuss how these developments have or will improve the flexibility and reliability of linac operations.

## 1 INTRODUCTION

The Advanced Photon Source at Argonne National Laboratory is a high-brightness, third-generation synchrotron light source. It is operated in top-up mode 75% of the time, which entails injecting beam every two minutes to maintain a current of 102 mA to 1% tolerance. When top-up is not being performed, the ring is filled twice per day. The APS linac consists of 13 S-band, 3-m-long, constant gradient, traveling-wave accelerating structures, five 35-MW klystrons, three SLEDs, three electron guns, a complex S-band rf switching system, and timing, water, and vacuum systems.

The APS linac is now configured to support multiple functions in addition to storage ring top-up and fills. This was accomplished by the addition of three new subsystems: an interlock system based on programmable logic controllers (PLCs), an automated S-band rf switching system, and a graphical user interface called the Procedure Execution Manager (PEM). This paper will discuss in detail these important features that support highly reliable storage ring filling as well as research and development work.

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## 2 LINAC AUTOMATED OPERATIONS

The APS linac is made up of five modulators and klystrons, three SLEDs, three electron guns, and a complex diagnostic and lattice arrangement. In addition, there are various subsystems, like water, vacuum, and timing, that are incorporated into various operating screens that hold hundreds of read-backs and controls for every aspect of operation.

Originally, when making changes in the linac, the operators had to switch back and forth among many control screens and perform procedures from memory or with the aid of written procedures. To say the least, this was a very time-consuming, error-prone task. PEM software procedures [1,2], when configured properly, follow the same steps an operator would take during equipment start-ups and reconfiguration. The main difference is that PEM has the ability to repeat steps faster, more consistently, and with less possibility of error.

After implementing the PEM system for the linac, linac operators found it provided the ability to make changes to linac configuration while maintaining safe operation of the subsystem equipment. When using PEM procedures, the operator no longer has to open numerous control screens and work on one task at a time. Rather, the PEM is able to efficiently use multitasking to alleviate the burden on the operators in what can often be a stressful situation. The operators can read corresponding descriptions and view the steps of a PEM procedure to become familiar with it. This is not intended to reduce operator training, but it does serve as an additional source of information that may be valuable to operators.

Complex PEM procedures are constructed by combining simpler PEM procedures in a series and/or parallel fashion. The PEM interface is expandable, simple, and consistent, so operators often do not need to learn anything new in order to correctly use a new procedure. Using the PEM's ability to execute steps in parallel can decrease the execution time and further enhance productivity. In addition, the PEM has error trapping and reporting to help machine managers and software developers diagnose and respond to errors.

The dialog screen (Fig. 1) for power supply start-up allows the operator to select a snapshot file to be restored at the end of a magnet conditioning. A snapshot file (Fig. 2) is a database files that includes all the settings necessary to reproduce the conditions existing when the snapshot was recorded. Once executed, the PEM procedure opens another display window that shows each step as it occurs and reports procedure status (Fig. 3).

There are two principal difficulties with the PEM

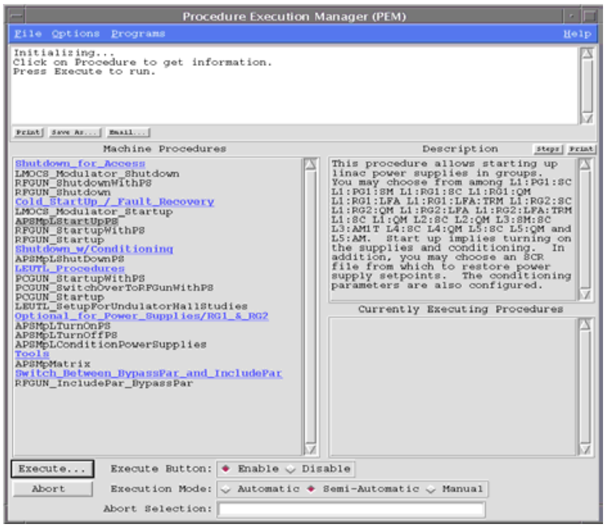

Fig. 1: Procedure Execution Manager for the APS linac.

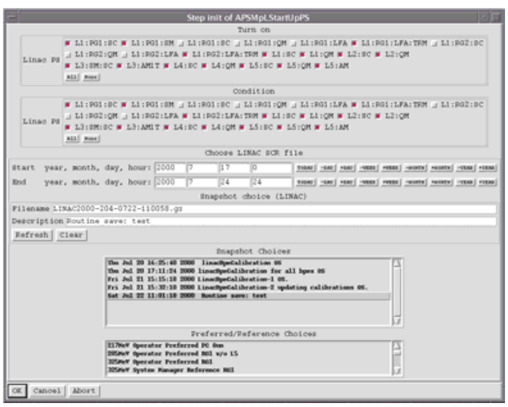

Fig. 2: Initial dialog screen.

Fig. 3: Status monitor.

process. First, changes in the controls system or hardware can cause the procedures to fail. This problem has been managed by the use of administrative controls and a device layer between the PEM procedures and EPICS. Second, thorough testing of these procedures requires machine time, which is in very high demand for storage ring top-up and experimental programs.

## 3 NEW SUBSYSTEM INTERLOCKS

### *3.1 Interlock Support*

A milestone was reached this year with the completion of the linac programmable logic controller (PLC)-based interlock protection system. The original interlock system for the linac was a hard-wired, relay-based one. For the most part, the system was very reliable. However, when additional interlocks were needed, it proved very time consuming to make changes.

### *3.2 PLC Selection*

The 205 Direct Logic Controller, known as the world's most powerful micromodular PLC was found to meet or exceed all our requirements. This Direct Logic Controller uses a remote master eight-slot I/O crate with a DL250 controller-processing unit (CPU). The wiring between the I/O card and the terminal strips were completed using the ZIP Link system, which eliminated the tedious process of running one wire at a time from the PLC to the terminal blocks. Using this type of system has saved many hours not only during the initial installation of the hardware but also in programming and debugging time. The DL250 was found to also interface very well with our EPICS system, in that it provided additional diagnostic information to the control room via standard MEDM screens.

### *3.3 Interlock Function and MEDM Displays*

In EPICS, equipment is controlled from workstations that communicate over a network with local computers called input/output controllers (IOCs). All systems in the linac that require or use an interlock for equipment or personnel safety protection require a latching function independent of the IOCs. Once a latch has been made, operator intervention is required to reset the interlock.

Each klystron requires a 400-watt power amplifier to provide rf input at sufficient levels to drive the klystron. Each amplifier is potentially inhibited by two signals. The first originates in the personnel safety system, known as the Access Control Interlock System (ACIS). The second signal, independent of the ACIS, is provided by the PLC Direct Logic system. The PLC monitors the status of equipment that must function in order to enable the klystron drive without the possibility of damaging the klystron or the equipment it powers.

Using the PLC's ability to monitor each interlock signal separately, the MEDM screen developer is now able to design a thorough diagnostics display for operations. In the event of a trip, a quick glance at this screen shows the general source of the problem in an easily understood graphical fashion.

## 4 RF SWITCHING SYSTEM

Because of top-up operation, the requirements for reliability and availability of the linac are even greater now than in the past, when the linac was only needed for an hour twice per day. In addition, linac systems are under greater stress due to continuous operation, making failures more likely. The first part of the linac, consisting of the rf guns and four accelerating structures, requires two klystrons (designated K1 and K2) for operation. A waveguide switching system is now in place that permits switching power from a third klystron (K3) in place of either K1 or K2. This system relies on a series of electropolished S-band switches that are configured using 340 waveguide pressurized with sulfur hexafluoride (SF6) to 30 psi [3,4]. The system also supports research and development by providing rf power to a gun test area and to the photoinjector (which is needed for FEL research).

### *4.1 Switching System Description*

The linac rf switching control system is responsible for monitoring and controlling eight rf switches connected to various waveguide sections in the low-energy section of the linac (sectors L1 through L3). The switches are used to reconfigure the operation of the Linac with respect to gun operation and klystron sources. The switching system communicates to a variety of field devices including switch mode interfaces, modulator interlocks, VSWR fault switching, sector interlocks, and Bitbus (via serial BUG).

In general, the switching system will monitor the rf switch position, command the switches to move when necessary, and provide the proper handshaking signals to insure that no damage to equipment will occur due to an improper switch configuration or uncommanded switch motion. The switching system will also notify each individual sector interlock system of the switch configuration in order to route faults to the proper destination. This is accomplished by a variety of handshaking signals to and from the switching system.

### *4.2 Modes*

The following mode descriptions are used:

Mode 0 – K3 Down    Mode 1 - K1 Down
Mode 2 - K2 Down    Mode 3 - Test Room
Mode 4 - Normal

Using Mode 1, as an example, assumes klystron one (K1) has failed and is no longer able to support its normal operating functions. In this case, K1 normally provides rf power to the RG1 thermionic rf gun. Utilizing the switching controller and selecting the K1 Down Mode reconfigures the switching system to direct klystron three (K3) output power to drive the RG1 thermionic rf gun, while the output power of the failed klystron will be directed to a 50-MW water load for testing (Fig. 4).

## 5 CONCLUSION

The new linac interlock upgrade and the use of the PEM procedures for equipment startup and configuration switching have proven to be very reliable. Without these tools, it would be difficult if not impossible to provide operational reliability, ensure equipment safety and provide consistent beam. The job of the control room operator is now much easier. In addition, this work has contributed significantly to the success of experimental programs by permitting rapid, reliable switching among various operating modes.

The waveguide switching system promises to contribute significantly to this process by providing the ability to rapidly respond to problems with specific rf systems. We are presently in the process of developing PEM procedures that will manage the rf switching system and bring it fully into operation.

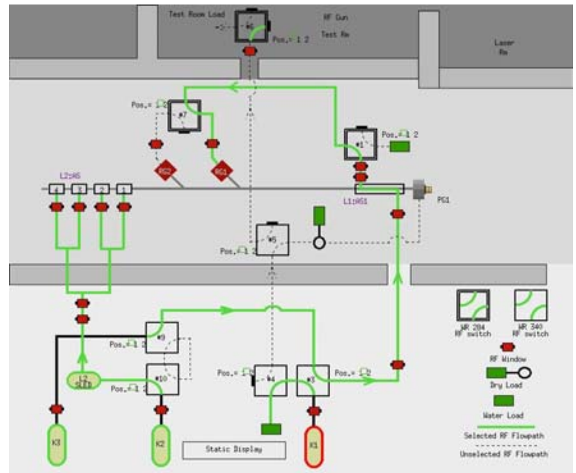


Fig. 4: S-band switching display.

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