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SLAC KLYSTRON TEST LAB BAKE STATION UPGRADE

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Abstract

The Klystron Bake Station at SLAC is a facility for baking out klystron tubes (high power RF amplifiers) among other large equipment in preparation for installation in the linac. The scope of this project was to upgrade the 30-year-old controls (based on VMS and CAMAC) to utilize PLC automation and an EPICS high-level user interface.

The new system allows for flexible configuration of the bake out schedule that can be saved to files or edited real time both through an EPICS soft IOC as well as a local touch panel HMI. Other improvements include active long term archiving of all data, COTS hardware (replacing custom-built CAMAC cards), email notification of fault states, and graphical user interfaces (old system was command line only). This paper discusses the improvements made and problems encountered in performing the upgrade.

BACKGROUND

Figure 1: Bake station 5 with oven shell removed (device in center is klystron tube awaiting bake-out).

Production and fabrication of most chambers and in-vacuum devices naturally leads to many undesirable contaminants building up on and in their surface. Such contaminants such as hydrocarbons will lead to outgassing under very low pressures, which makes pumping down a high vacuum system very difficult if not impossible. Additionally, such contaminants in high voltage gradient devices such as klystrons can lead to arcing once voltage is applied which can damage the hardware. In order to remove these contaminants, a combination of high heat and vacuum pumping needs to applied under highly controlled conditions over a long period of time (up to a week or more).

The klystron bake stations (Figure 1) at SLAC were originally built over 30 years ago and whereas some minor elements have been upgraded over the years, the hardware and controls have largely remained unchanged. Control of the heaters and pumps were all handled through FORTRAN scripts running on a VMS operating system that in turn communicated with a CAMAC crate loaded with custom SLAC-designed I/O modules. Interlocks were handled entirely through hard-wired relay circuits that also read back through CAMAC modules.

Not only was much of the hardware for the heater and vacuum systems much in need of modern replacements, the CAMAC and VMS systems are no longer being supported at SLAC and therefor a full upgrade was necessary.

REQUIREMENTS

Upgraded stations provided must be robust, stable, reliable, and serviceable. Mechanical and electromechanical hardware shall have a service life of 10-20 years. Electronic hardware shall have a service life of 20 years. After a power outage, the system shall default to a predefined safe condition upon reset or restart.

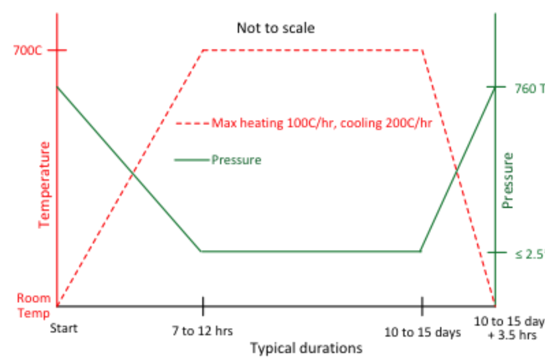

Figure 2: Example vessel temperature and pressure vs. time profile (not measured data).

In order to prepare new klystrons and chambers ready for use in High Vacuum, the Vacuum Microwave Devices Department (VMDD) at SLAC needs to be able to pump down the oven vessel, klystron tube, and RF window to at least the 2.5x10-5 Torr range while simultaneously raising their temperatures to as much as 700°C [1]. Temperatures for these regions are ramped up and down via heat tape according to predetermined profiles created by the expert users. These profiles (Figure 2) can be saved and loaded both directly via the PLC interface as well as remotely for offline filing and log reports.

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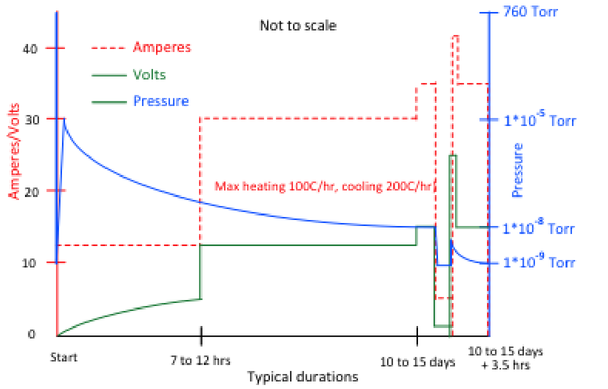

Figure 3: Example klystron filament voltage and current profile (not measured data).

Similarly, the voltage applied to the filament within the klystron tube shall be ramped up and down with its own predefined profile to assist in the cleaning of contaminants within the tube (Figure 3). The combination of the filament and temperature ramp times and rates as well as interlock setpoints is called the "Bake Schedule" and is designed and loaded into the PLC on per-use basis. Some Schedules are standard and should be saved and loaded as needed, but custom Schedule also need to be facilitated.

ARCHITECTURE

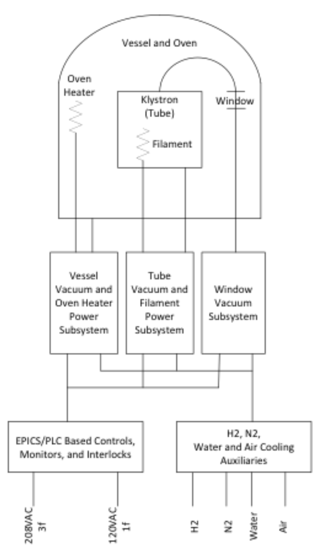

Figure 4: Generalized hardware architecture.

Hardware

The Bake Station consists of the Oven Vessel, Klystron Tube, and RF Window systems (Figure 4). Each of these systems has their own isolated vacuum, heating, and cooling systems.

The main driver for the operation and interlocks of the upgraded Bake Station comes from an Allen-Bradley Compact-Logix PLC utilizing 1769-L33ER processor (Figure 5). This PLC uses a variety of analog and digital modules to readback interlocks, monitor readbacks (such as temperature, pressure, and water flow), and control PID feedback loops. Additionally the PLC is connected to a 15" PanelView touchpanel HMI for local operational control and readback.

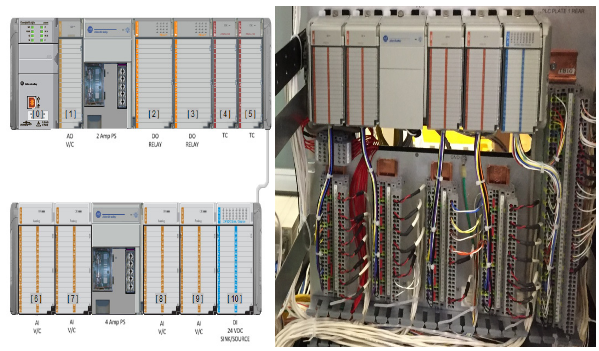

Figure 5: Bake station PLC.

The PLC is wired to a variety of sensors and controllers used regulate the temperatures and pressures in the various subsystems. For the temperature, a Eurotherm EPower controller is used to regulate the current to heater tape wrapped around the Vessel. A Eurotherm EPack controller drives the Filament inside the tube.

For the vacuum, Ion Pumps are used on the Tube and Window lines whereas a diffusion pump backed by a scroll pump is used to pump out the Oven Vessel itself. A cold trap is used to catch as much of the oil from the diffusion pump as possible from back propagating into the chamber. A Gamma MPCe (standard COTS controller for SLAC) is used to control all of the Ion Pumps, while the diffusion and its backing pump (which themselves were out of scope for this upgrade) are controlled via hardwire relay-based interlocks only. Cold Cathode and Convectron gauges are used on all three subsystems for pressure readback and interlocking and the Granville-Phillips 370 controller is used for these. Finally, the pneumatic valve solenoids are driven directly via outputs from the PLC.

In addition to the PLC interlocks however, there are also a series of hardwired relay-based interlocks installed as a redundant fail-safe system to ensure that power to the various power supplies and pumps is shut off in a safe manor should a major fault occur. These relays can be reset through a digital output from the PLC only if all of the hardwired interlock signals are clear.

Software

As mentioned above, all critical control for the Bake Station takes place locally on the PLC independent of network availability (Figure 6). It was decided that remote access and control of the Bake Schedule was highly desirable given the long runs of a given bake out, however nothing in the Bake Station should depend upon the controls network being actively connected. To accomplish this, the Bake Station PLC stores up to 10 different bake out profiles that can be saved and loaded locally from local touchpanel HMI.

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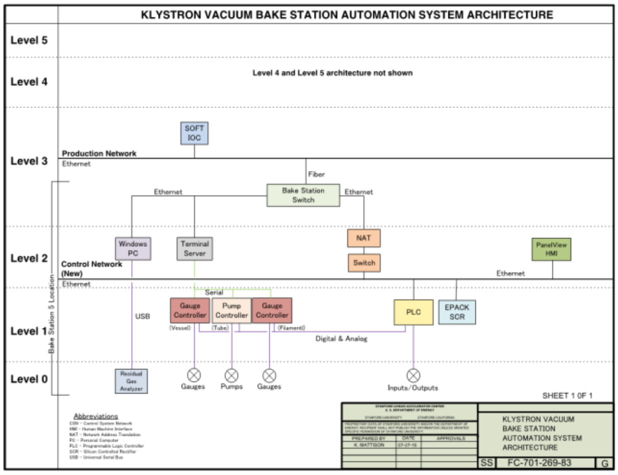

Figure 6: Bake station network architecture.

Remote readback and control then is provided through an EPICS 3.14.12 Soft Input/Output Controller (SIOC) running on the test facilities production network. There is no Autosave functionality as once again the PLC is intended to be the Master for purposes of configuration control. A user interface is provided through EDM (Figure 7) and is designed to largely reflect the layout and design of the PLC HMI screens. An Alarm Handler is also implemented in order to send out emails to specified individuals in the even of a major fault.

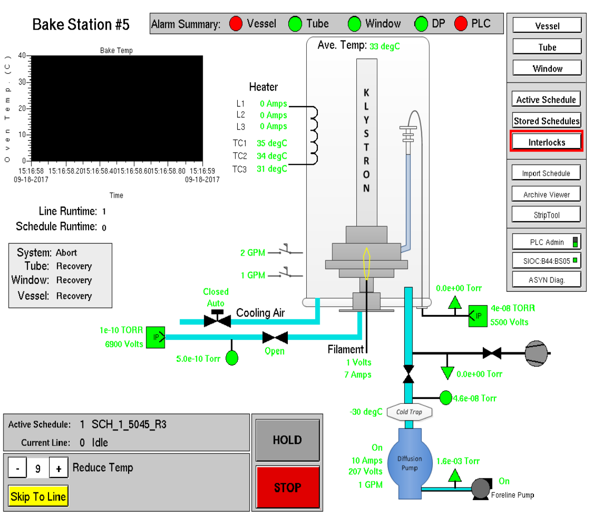

Figure 7: Bake station 5 home screen.

The SIOC communicates with the PLC over the network using the EtherIP protocol. Additional redundant communication is established with RS232 via a Digi terminal server to the vacuum gauge and ion pump controllers to aid in troubleshooting and some optional controls and readback no available for access by the PLC.

One of the requirements outlined by the users was that they wanted to be able to take tables of setpoint data from Excel and load it directly into the PLC as a Bake Schedule. To facilitate this, a Python application (Figure 8) was written using PyEPICS to talk to the PLC and PyQt4 as the user interface. This GUI takes formatted Comma Separated Value (CSV) tables and parses it out to a specified Schedule on the PLC. It is also capable of downloading the active or stored schedules from the PLC to be saved on a group network drive or appended to a logbook entry. All Schedule data can be edited on the fly within the Python GUI or additionally through an EDM interface.

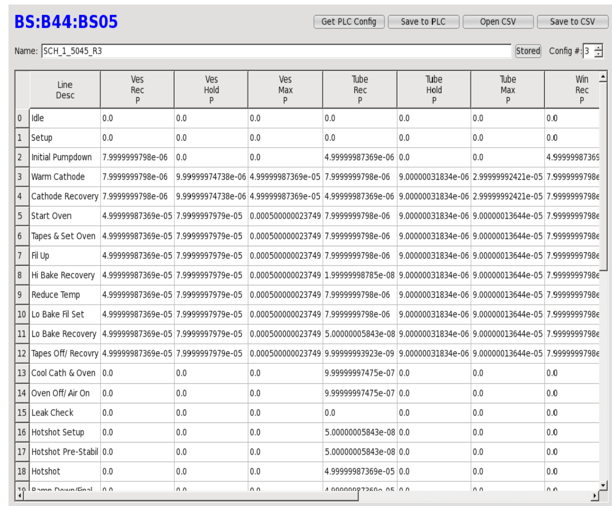

Figure 8: Python bake schedule interface.

All data in the SIOC is stored were possible via the Test Facility Archive service. The standard SLAC Archive Viewer Java application can be used to plot and correlate history data.

ISSUES

As was to be expected, the PID loops for the temperature and filament controls took quite a bit of time to properly tune. Using generic industrial "furnace" type PID parameters managed to get pretty close to the correct tune, but some long term running and iteration was necessary to smooth out the response.

Additionally, an issue was encountered with the current supply to the Tube filament. All of the original Bake Stations were designed to use old type 132-135 filament power supplies with a stepper motor driven Variac and diodes on the output. For the station 5 upgrade this was changed to an SCR controller employing phase angle control. During testing with oven chamber removed, we noticed an audible hum of filament at 35 ARMS. The measured oscillogram of the filament voltage (current) is shown in Figure 9 below.

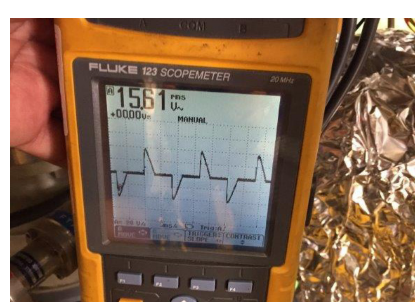

Figure 9: Filament Voltage Oscillogram.

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It is believed that this is caused by the chopped waveform produced by the Eurotherm controller. This chopped current causes high electromagnetic fields and/or thermal stresses that flex the filament at 60Hz. Flexing degrades the filament and the sintered support material mechanically (Figure 10).

Figure 10: Flexed tube filament.

A new automated solution involving a sinusoidal AC Variac transformer is currently being tested in the hope that a cleaner full waveform will work better.

RESULTS

Despite the issues encountered above, we have found that the PID loop, interlocks, and Schedule management have worked quite well. Several klystrons and other equipment have successfully been baked out and made ready for full production use (Figure 11).

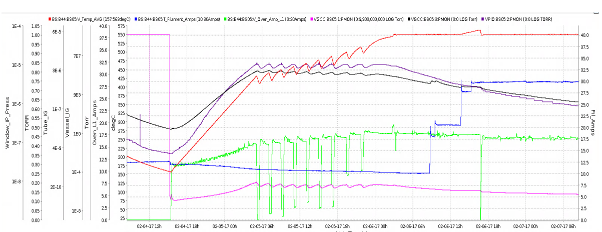

Figure 11: Archived data from successful klystron bakeout.

Testing is still ongoing on trying to clean up the voltages for the Tube filament. Instead of the Eurotherm EPack, we are currently testing whether a Variac transformer will provide a more steady and cleaner waveform.

In general though, the new system is far maintainable utilizing largely Common Off The Shelf (COTS) hardware with a ready available spares pool (Figure 12). Additionally the new graphical interface provides for a much more intuitive method for controlling and interacting with the station than the old command line based script system.

Figure 12: Bake station 5 before (left) and after (right).

ACKNOWLEDGMENT

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REFERENCES

[1] P. Bellomo, "Klystron Vacuum Bake Station Description and Requirements", SLAC, Menlo Park, USA, Rep. SLAC-I-090-001-001-00