BAKE-OUT MOBILE CONTROLS FOR LARGE VACUUM SYSTEMS

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Abstract

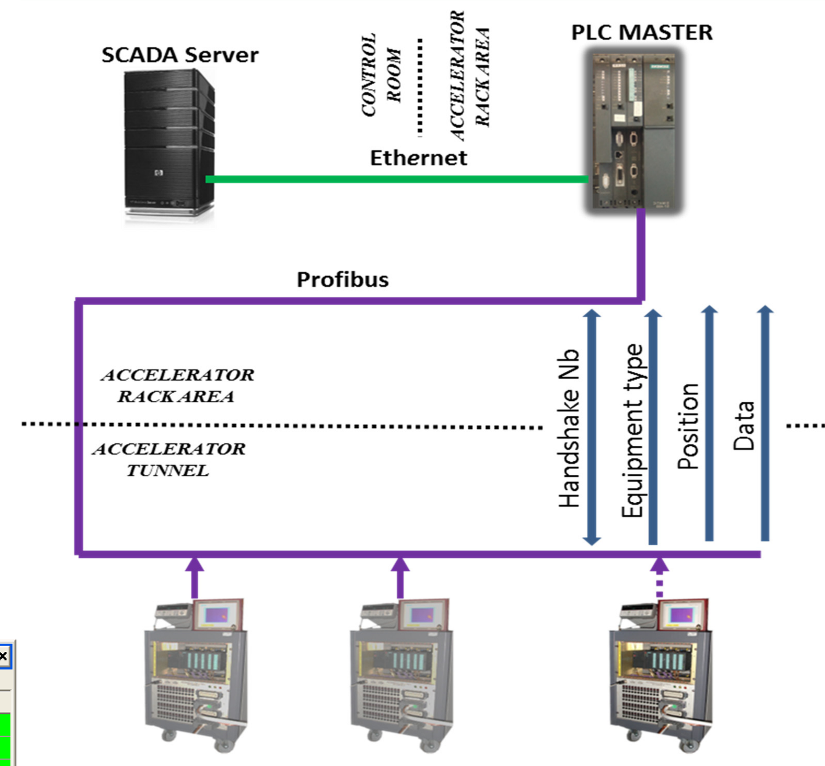
Large vacuum systems at CERN (Large Hadron Collider - LHC, Low Energy Ion Rings - LEIR...) require bake-out to achieve ultra-high vacuum specifications. The bake-out cycle is used to decrease the outgassing rate of the vacuum vessel and to activate the Non-Evaporable Getter (NEG) thin film. Bake-out control is a Proportional-Integral-Derivative (PID) regulation with complex recipes, interlocks and troubleshooting management and remote control. It is based on mobile Programmable Logic Controller (PLC) cabinets, fieldbus network and Supervisory Control and Data Acquisition (SCADA) application. The CERN vacuum installations include more than 7 km of baked vessels; using mobile cabinets reduces considerably the cost of the control system. The cabinets are installed close to the vacuum vessels during the time of the bake-out cycle. Mobile cabinets can be used in any of the CERN vacuum facilities. Remote control is provided through a fieldbus network and a SCADA application.

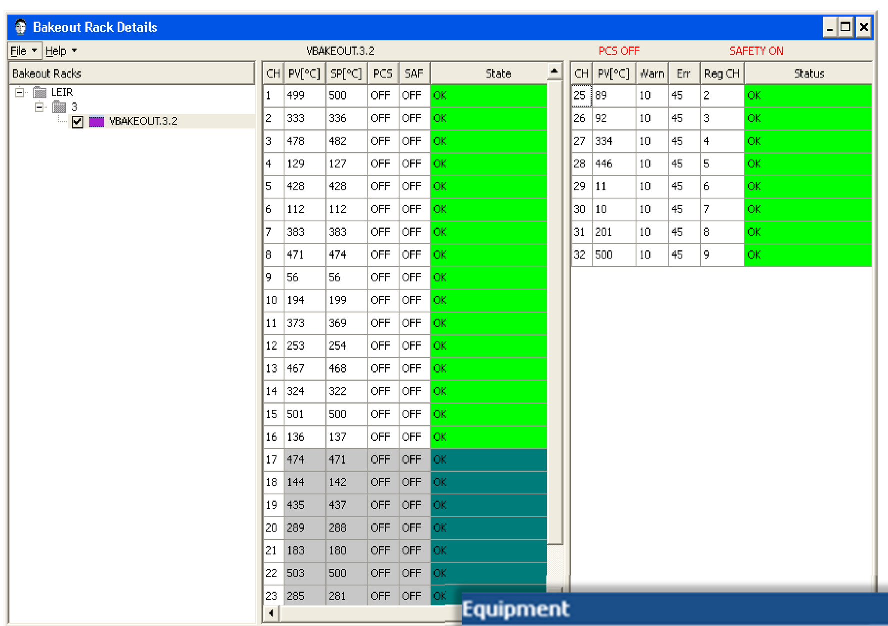
Specifications

- **MOBILITY**: considering that bake-out cycles are non-recurrent, short in duration (4 days in average), and take place in very different locations, the local control cabinet must be mobile. This reduces substantially the global number of required cabinets.
- **THERMAL REGULATION**: the control cabinet has to regulate a wide variety of heating systems, with very different thermal properties. Pre-defined recipes shall be available to adjust the temperature set-points of the complex thermal cycle required for the NEG activation.
- **DIAGNOSTICS AND ERROR MANAGEMENT**: Bake-out is a critical process. Over-temperature may damage components of the accelerator. Reliable diagnostics and error management are required.
- **LOCAL CONTROL**: a touch panel shall be added to the cabinet. Operators shall be able to locally set-up the Bake-out control parameters.
- **REMOTE CONTROL AND LOGGING:** the Supervisory Control And Data Acquisition (SCADA) application for vacuum systems shall include remote control and data logging for the Bake-out cabinets

Human Machine Interface

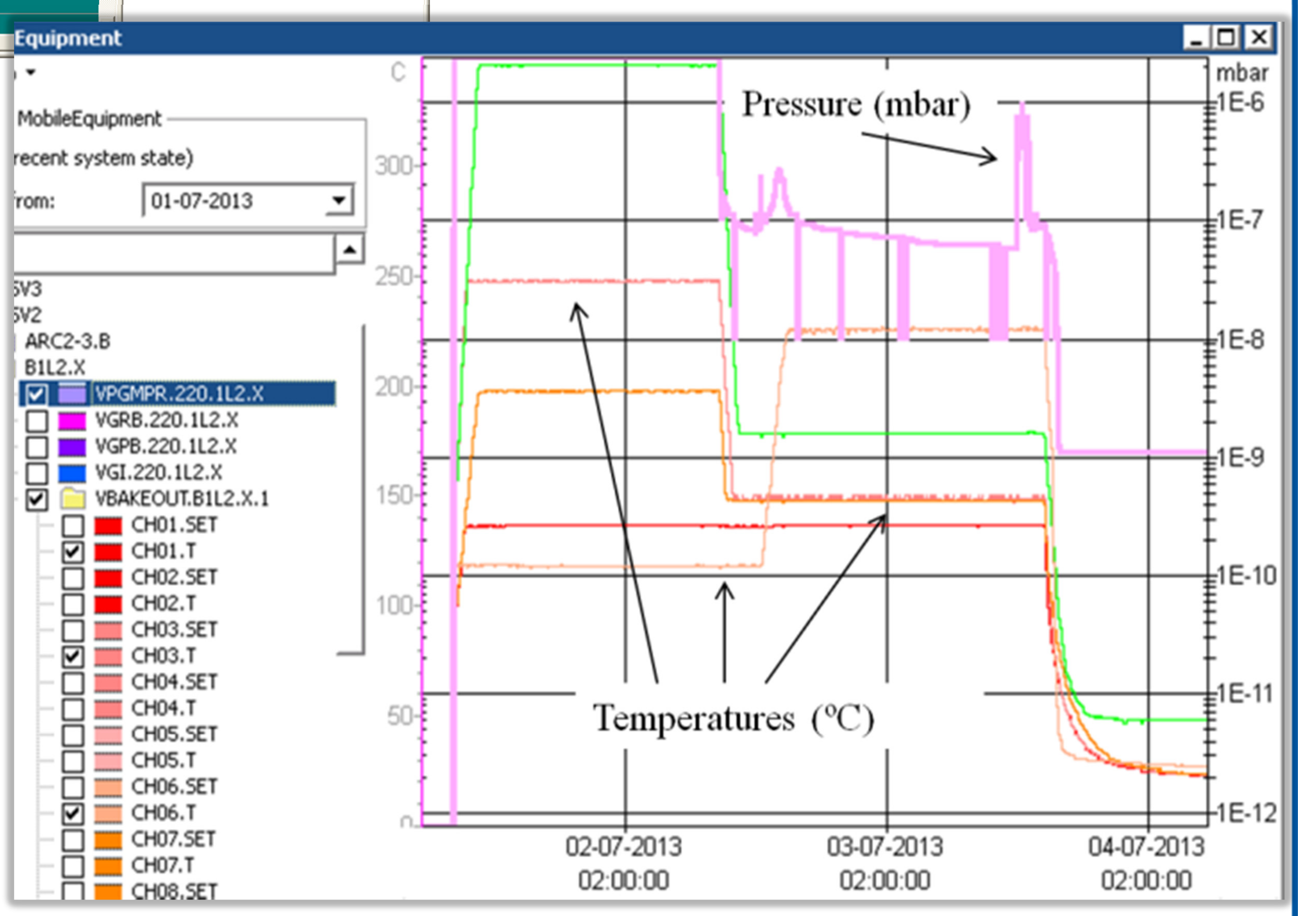
14 fieldbuses for mobile controllers have been installed in all CERN Accelerators.
The presence of equipment on the fieldbus is analysed by the Master PLC. When a new hardware connection is detected, a communication is set-up. As absolute time is not critical for bake-out process, the data is not time stamped on the cabinet, but only on the SCADA at reception.
The SCADA has a generic e-mail/SMS messaging system. It can be parameterized to notify operators in case of bake-out channel error.





SCADA Status Panel: real time status (state, process value, set point value and safety level) is shown for each bake-out channel.
This information is sorted by vacuum sectors and bake-out cabinets.

SCADA History Panel: process values, set-points and vacuum-sector pressures can be shown in a same graph and so operators can follow the correlation between temperatures and pressures, and notice any unusual behavior.

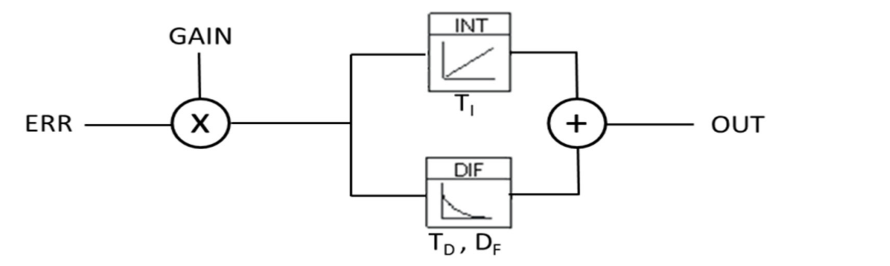


Hardware

The bake-out cabinet is a CERN design based on Siemens® Programmable Logical Controllers (PLC) S7-300 series, comprising a CPU, Input/Output modules, Profibus® and Ethernet interfaces. The bake-out cabinet has 24 regulation channels and 8 control channels integrated in a standard 13-unit high and 19 inch width rack, mounted on wheels.

Thermal Regulation

The thermal regulation of the vacuum vessel heaters is based on a Proportional, Integrated and Derivative (PID) regulation.



The step response in the time range is:

$$OUT(t) = GAIN * ERR\left(1 + \frac{1}{T_I} * t + D_F * e^{-\frac{t}{T_D} * D_F}\right)$$

Where OUT(t) is the manipulated output variable in automatic mode of the controller; ERR is the step change of the normalized error (i.e. the relative difference between set-point and process variable); GAIN is the controller gain; T_I is the integral time constant (seconds); T_D is the derivative time constant(seconds); D_F is the derivative factor.

Diagnostics and error management

Unexpected events are classified from "warning" level (minor events, no action needed) to "critical error" level (major events, with actions needed). A regulation channel has 5 warning status, 2 error status, 1 critical error status and 3 user-defined (warning, error, and critical-error) status.

Next table describes the resulting actions in case of an error, where ΔT is the absolute temperature difference between set-point and process value.

Channel Status (Error Code)	ACTIONS			
	SAFETY LEVEL 1	SAFETY LEVEL 2	SAFETY LEVEL 3	SAFETY LEVEL 4
OK	No Error/Warning, no action			
Output calculated power = 0%	Warning, no action			
Output calculated power = 100%				
Control sensor overshoot warning threshold				
ΔT > 15°C				
ΔT > 25°C				
Regulation sensor open cable	ERROR, STOP CHANNEL			
Control sensor overshoot error threshold				
Output calculated Power= 100% longer than 10 minutes	Warning			
Control sensor Interlock remaining even after channel stopped			CRITICAL ERROR, SHUT DOWN ALL POWER RELAYS	
ΔT > 50°C				
External digital input interlock				

Conclusion

A total of 88 bake-out control cabinets have been manufactured and more than 160 bake-out cycles have been foreseen for the 2013-2014 CERN accelerators long shutdown. The new application for bake-out control has been used during the 30 cycles already performed. This new application has improved: the safety, the regulation accuracy and the parameters set-up time. The remote monitoring access allows post-mortem diagnostics, logging for follow-up reports and error notifications.

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