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THE STATE MACHINE BASED AUTOMATIC CONDITIONING APPLICATION FOR PITZ

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Abstract

The Photo Injector Test Facility at DESY in Zeuthen (PITZ) was built to test and to optimize high brightness electron sources for Free-Electron Lasers (FELs). In order to achieve high accelerating gradients and long RF pulse lengths in the normal conducting RF gun cavities, an extensive and safe RF conditioning is required. A State Machine based Automatic Conditioning application (SMAC) was developed to automate the RF conditioning processes, allowing for greater efficiency and performance optimization. The SMAC application has been successfully applied to RF conditioning of several gun cavities at PITZ.

INTRODUCTION

The PITZ [1] has been established to develop, test and optimize sources of high brightness electron beams for FELs like FLASH [2] and the European XFEL [3]. Essential requirements of an electron injector for FELs are the ability to generate a reliable electron beam with a very small transverse emittance (e.g. <1mm-mrad, 1nC bunch charge) and a reasonably small longitudinal emittance. The primary goal at PITZ was to facilitate stable and reliable operation with 60 MV/m accelerating gradient at the photo cathode at 650µs RF pulse length and 10Hz repetition rate. To achieve this, a new RF feed system with two RF windows was installed at PITZ in 2014.

The RF Setup

The gun prototype 4.5 conditioning setup consisting of a 10-MW multi-beam klystron, an upgraded RF waveguide distribution system with SF_6 and Air parts, two 10-MW THALES [4] vacuum RF windows, directional couplers, Ion Getter vacuum Pumps (IGP) and a Pressure Gage (PG), photomultipliers (PMT) and electron detectors (e-det) located around the gun coupler is shown in Figure 1.

The Gun

The PITZ photo electron gun is a 1.6 cell normal conducting L-band cavity, with cathode located at the back wall of the half-cell. The electron beam is generated at the cathode by a laser pulse and then accelerated by RF fields and focused by the solenoid fields.

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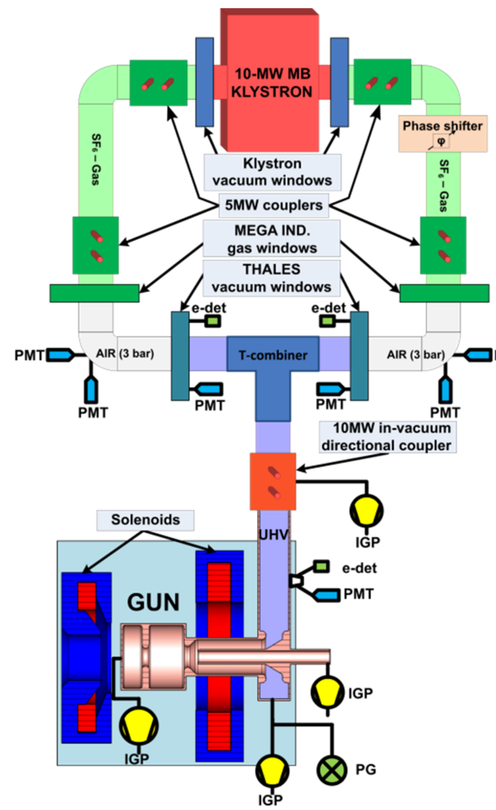

Figure 1: The PITZ RF setup (version 4.5, 2018).

Conditioning

The main goal of the conditioning process is to improve the vacuum in the cavity and the surface condition of the cavity, while applying the RF power is slowly increased in steps up to the operating gradient. During the conditioning process breakdowns may happen with a sharp rise of the pressure in the cavity. In such event the voltage in the cavity is dropped to some initial value and then slowly increased again. The final goal of the gun conditioning is to achieve stable operation at the maximum power level in the gun with solenoid fields.

The State Machine based Automatic Conditioning application (SMAC) was developed to automate the conditioning process for the RF cavities. The application was designed to replicate the operator behaviour during conditioning an RF cavity, allowing for greater efficiency and performance optimization. The interface for the SMAC application has been designed to be user-friendly and intuitive. It provides the user control of the conditioning process and relevant monitoring data.

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THE STATE MACHINE BASED AUTOMATIC CONDITIONING APPLICATION

SMAC is written in Java and uses State Chart XML (SCXML) [5-7] as the finite-state machine execution environment based on Harel state-charts [6]. It employs the Distributed Object-Oriented Control System (DOOCS) [8] and Three-fold Integrated Networking Environment (TINE) [9] for the communication with the control systems of PITZ such as RF System, Interlock System [10], Alarm system, Water Cooling System (WCS), etc. The graphical user interface (GUI) is created by using the Java Swing toolkit and available via Java Web Start (JWS) [11] which provides a simple way to launch an application via a network. Communication between GUI and SXML processing layer is performed via Document Object Model [12] (DOM) events. A pure Java design makes the application extremely portable across computing environments. In the end SMAC produces very detailed logs in order to see how the workflow has progressed from step to step and observe any errors that may have occurred. The overall structure and data flow of SMAC application is shown in Figure 2.

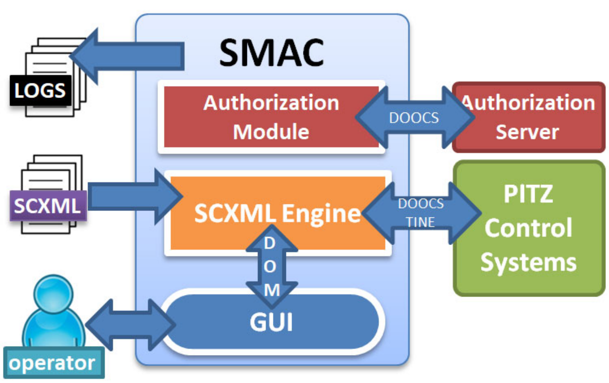

Figure 2: Overall structure and data flow of SMAC.

The Authorization Module

The authorization module with a help of the Authorization server guaranties that only one instance of SMAC is working at the same time. This will prevent concurrent conditioning processes that would lead to application malfunction and even cavity damage.

The SCXML Engine

SCXML engine capable of executing a state machine defined using a SCXML document that describes the application flow. Figure 3 shows a SCXML file segment that defines top-level states of the RF conditioning process. The main advantages of the SCXML approach are listed below:

- Legibility: the whole application flow is easily visible by looking at the flow definition files.
- Flexibility: using only the SCXML document the application control logic can be extracted out of the source code and specify very modular components into an SCXML.
- Standards-based solution: specified by W3C the SCXML is becoming a standard way to represent state charts in XML. It is part of Unified Modeling Language (UML) [13].
- Any SCXML can be easily parsed and interpreted by other software. An SCXML document can be created even using various graphical tools.

Figure 3: Segment of SCXML code.

The GUI

Figure 4 shows a screen snapshot of the SMACs interface whilst running.

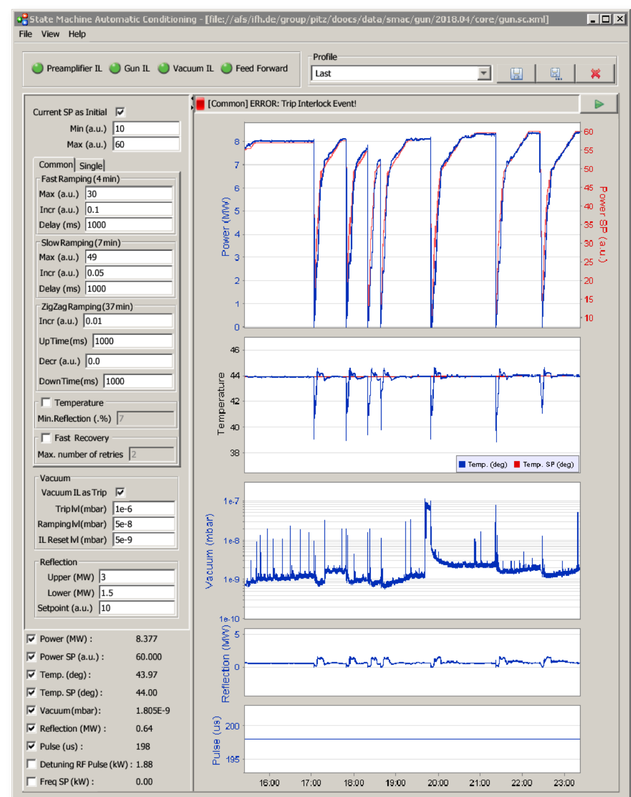

Figure 4: A screenshot of the GUI.

The panel on top-left shows the feed-forward signal and the Interlock system statuses. The profile panel on the top right allows operator to pre-configure the conditioning settings in order to quickly apply them to a new run. The plots on the right present the history of the RF power, water temperature, vacuum pressure, reflected power and the RF pulse length. The bottom left displays the current values of monitored parameters. Parameters of the condi-

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tioning procedure can be set at the middle left of the screen. The main parameters set by the user are:

- RF power range and ramping speeds.
- Vacuum upper/lower thresholds.
- Reflected power thresholds.
- Enabling WCS temperature control.
- Enabling "Fast Recovery" [14] procedure after each breakdown.

Default values for these parameters were set based upon prior experience of the operators.

CONDITIONING ALGORITHM

The conditioning algorithm consists of gradually increasing the RF power and the RF pulse length but keeping a low rate of vacuum spikes in the cavity in order to prevent any damage from breakdowns. The algorithm based on conditioning requirement of the THALES windows and adopted for the gun cavity conditioning. It follows simple rules:

- RF pulse length: 10 – 650µs.
- Vacuum pressure: below 10^{-7} mbar.
- RF power ramping speed: maximum 0.2MW every 15 minutes for each new RF pulse length, when the RF window has seen this power level the first time.
- In the case of significant vacuum spikes or breakdowns:
  - Reset the RF power to initial value.
  - Reset pulse length to minimum value (10µs).
  - After reaching the maximum RF power, increase the pulse length in reasonable steps.
- Initially, the RF gun solenoid is off.
- Achieve the maximum RF power level with a negligible breakdown rate (aim for less than one breakdown per week).
- Finally repeat the conditioning procedure with sweeping RF gun solenoid currents.

However such a conditioning algorithm might be complicated since it involves simultaneous monitoring and controlling various operating parameters (e.g. interlock/feedforward/feedback statuses, RF power, gun temperature, RF frequency, etc.). Figure 5 shows a segment of the RF ramping flow diagram.

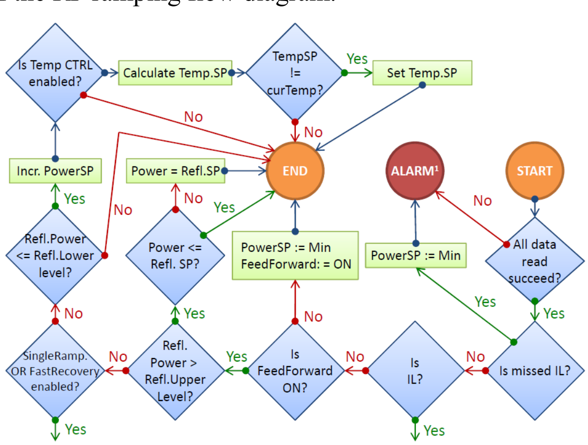

Figure 5: Segment of the RF ramping flow diagram.

The current version of the SMAC application implements two ramping modes:

1. Single mode: based on the "Fast Ramping" algorithm [14]. Thus the RF frequency is changed to follow the resonance frequency and the temperature of the gun cavity is continuously adjusted for slightly overheated operation. This process is continued until a certain power level is reached or a breakdown occurs.
2. Common (or continues) mode is shown in Figure 6: RF power is steadily increased until a significant vacuum spike or until breakdown occurs. The common mode consists of several stages ("fast", "slow" and "zigzag") with different RF ramping speeds. In case of relative high level of pressure in the cavity or high level of RF reflected power:
   - Suspends increasing of RF power until suitable ramping conditions.
   - Decreases RF power to initial value, if reflected power or pressure in the cavity is too high.
   - After each breakdown SMAC attempts to reach the last power level applying the Fast Recovery procedure if enabled.

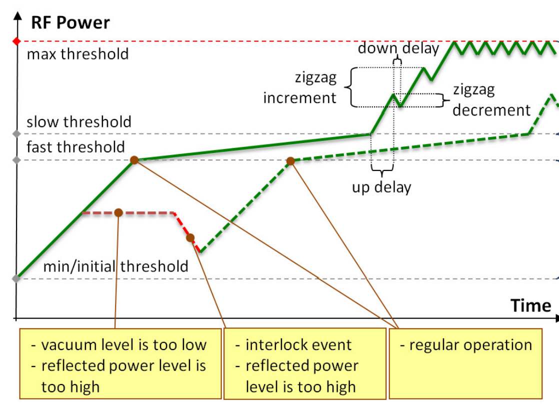

Figure 6: Common mode of the RF power ramping.

CONCLUSION

In this paper, we have presented the main design features and the current implementation status of the SMAC application. This implementation was intended as a proof of concept, applying a state-chart approach toward the development of the automatic conditioning application. The state-chart approach has been found particularly useful because of its appealing hierarchical, communication and concurrency constructs. The use of Java SCXML engine was very encouraging and we intent to explore the use of it with advantages offered by the Java technology. The SMAC application was brought into operation in 2010 and has been used at PITZ very successfully for all RF cavities. Since then the application is left to run unattended overnight. The RF conditioning strategy is based on recommendations from physicists of the PITZ group. The SMAC continues to be improved by feedbacks and suggestions from the physicists.

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