THE FINITE STATE MACHINE FOR KLYSTRON OPERATION FOR VUV-FEL AND EUROPEAN X-FEL LINEAR ACCELERATOR

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Abstract

In order to provide a pulsed RF power signal that fulfills all designers and users demands the development on power supplies, pulse transformers, wave-guides, and klystrons has to be well coordinated. Because operators and not experts engineers will operate the user facility therefore software has to be implemented in order to automate the enormous quantity of hardware operation accompanying regular operation of *linear accelerator*. A finite state machine provides an adequate formal description of reactive systems that has become starting point for designing our control software. To present the complexity of the task that establishing a FSM for klystron and modulator system would be, one has to become acquainted with the complexity of the system itself. Therefore this article describes the construction and principles of the klystron and modulator as well as ideas concerning the implementation of a FSM for such a system.

INTRODUCTION

In present time all this equipment, which work for VUV-FEL and X-FEL together with hardware control systems, has to be monitored and operated through a computer system. At DESY DOOCS has been developed (Distributed Object Oriented Control System DOOCS [3]) that is a computer system of multi layer servers working together for optimal operation of the whole system. Beside the typical hardware servers like ADC or DAC servers, there are also servers designed especially for Finite State Machine purposes. Such FSM allows minimizing user intervention during system operation to "one button" action. One of the part of the whole system that requires such a structure is a system responsible for supplying cavities with energy necessary for particle acceleration.

Superconducting cavities are supplied with RF power needed for electron acceleration from multibeam 10MW klystrons working in pulse mode.

KLYSTRON SYSTEM DESCRIPTION

In order to provide a pulsed power signal that fulfils all designers and users demands the work on power supplies, pulse transformers waveguides and klystrons has to be well coordinated. As in the phase of commissioning the device (like VUV-FEL) such a system can be operated manually that in a final solution operator has to be replaced by robust FSM software working in the DOOCS environment

In the whole klystron and modulator system one can distinguish several subsystems that form main sections. Each of this section has to be carefully managed to achieve best system performance.

Modulator - High Voltage Power Supply (HV-PS)

HV-PS is a section responsible for high voltage (HV) pulse for klystron. There is possibility to regulate HV pulse parameters as duration or voltage level and repetition rate in order to achieve requested portion of the energy for the klystron.

Electrical power is delivered to the system as AC 440V 50Hz signal in 3 phases. After conversion (in a transformer) the signal is filtered and the energy is stored in 1,4mF capacitor (*Cap Bank*). Next to the capacitor *the crowbar* system is installed. If there is an arcing effect in the klystron tube this system makes a short circuit for the Capbank and sends the energy from the capacitor to the ground. This system is not used during normal operation.

The switch is present for releasing the energy from capacitor bank. This *main switch* is based on seven Integrated Gate-Commutated Thyristors devices.

This power is send to *the pulse transformer*.

Because of the slope that occurs on a high voltage envelope there is compensation needed. In order to achieve a flattop the bouncer system is used. A bouncer is a resonance circuit that stores energy and when triggering signal appears this energy is released in order to compensate the slope on the main circuit signal. Bouncers counterbalance signal minimizes the fluctuations of the high voltage signal to the level of +-0,5 %.

Pulse Transformer

The *pulse transformer* (PT) is a subsystem that converts signal achieved from HVPS to the HV signal that supplies the klystron tube [4]. For the efficient use of magnetic core, there is also biasing introduced through one of the section of the secondary windings.

In order to decrease thermal power losses, the whole pulse transformer body is cooled by mineral oil. The level, temperature and also humidity of the oil are monitored at all times.

Klystron Section

The HV pulse is delivered to the klystron, where *collector* is grounded and high voltage is applied to the *cathode*.

To achieve sufficient electron emission from the cathode, this part of the klystron must be heated to the particular temperature. *The filament* subsystem is responsible for this process. A heater subsystem contains special controller hardware for slow increasing the temperature that is necessary for efficient and longtime filament and cathode use.

According to the data achieved from cathode examination the pearvance of the klystron is measured. Afterwards some correction of the filament preparation process can be performed (like increasing heating time or increasing current step level).

When filament heating is finished and all security systems are ready HV can be applied into the klystron.

In order to achieve focused beam current *external solenoids* are installed. Information about the voltage and current of the PS powering the solenoid are given.

For XFEL purposes the klystron will work up to 10Hz pulses with 1.7ms time of power release.

The Drive RF Signal Delivering

The small RF drive signal is introduced to the klystron tube with an antenna placed before first bunching cavity of the klystron. The signal from this antenna causes beam modulation with 1,3 GHz and shape bunches in such a way to achieve signal responding required RF envelope shape. Then in the following cavities – resonators the bunching process is continued and finally with another coupler (in the last klystron cavity) power is coupled out and distributed in wave-guide system through the two arms of the klystron. The gain of the power is determined by DC power from HVPS subsystem and signal efficiency by bunching process.

Klystron cavities as well as a wave-guide system and the output coupler from the klystron are designed and made in such a way that the signal of the output of the klystron is a 1,3 GHz signal.

Klystron Machine Protection and Safety Subsys.

In the klystron section there are a couple of security interlocks systems that examine the online klystron environment and provide necessary information about overcoming fault thresholds or even activate the interlock.

- Vacuum pump system

In order to keep high vacuum in the klystron tube there are three pumps installed. In case of not clean environment the pump starts to evacuate the tube. If the device overcome specified current level appropriate action in interlock take place.

- Solenoid status check

For convenient beam focusing voltage and current of solenoid have to be checked. Monitored signals have to be compared with the technical specification.

- Cooling system check:

Because of low efficiency of the klystron and the magnets (about 50-60%) this parts are heated during operating time and have to be equipped with a cooling system. All the parts are cooled by water flow.

- RF Leakage subsystem:

Because of the waveguide power distribution system complexity it is not possible to keep the system completely shielded for RF signal. That is why dedicated subsystems monitor the RF leakage level. Subsystem gives information to the interlock channel if safe leakage level has been overcome. This signal can be read as well from DOOCS interlock server. If RF leakage will be detected at the excessive leakage interlock protection will switch off all the other subsystems.

RF Signal Distribution – Klystron Driver

After achieving modulated and corrected RF signal from the Low Level RF control system *klystron driver* section amplifies this signal in an RF amplifier.

There is also a RF switch present that allows switching off the RF signal during some stages of klystron operation, for example during changing the HV level or if interlock action occurs.

OPERATION AUTOMATION

In order to achieve system automation a *Distributed Object Oriented Control System (DOOCS)* has been designed and developed. A finite state machine [2] is the adequate formal description of reactive systems. Therefore two very helpful tools - *FSM server* and *FSM C++ server code generator* have been included in *DOOCS* environment. As the *FSM DOOCS server* one understand a computer program that is compatible with DOOCS and its algorithm is based on FSM formalism. The standard graphical editor DOOCS Data Display (DDD)[1] developed to display and control the TTF equipment has been extended to allow the creation of FSM designs. The FSM code generator can generate a template for the FSM server straight from *state charts (Fig.1)*. Foregoing scenario is a usual way of creating applications that drive subsystems of *linear collider*. The following part of the article presents some new ideas, which will be realized during the development of the FSM for *klystron subsystem*.

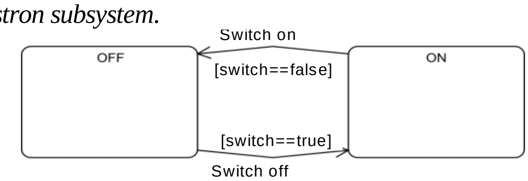

Figure 1: State chart - representation of FSM formalism.

Requirements Analysis

One has carried out the requirement analysis, which revealed that the main difficulties in case of *klystron FSM* creation could be the changes in the hardware and software during FSM development and maintenance.

Because this software will work for at least 10 years challenges related to long-term maintenance would be present. Next problem concerns documentation management. It would be very helpful if FSM were "self-describtive". For the time being FSMs are mainly made as monolithic programs. A new approach considers creation of small (and common for all klystrons) generic FSM's and set of binaries that will work as drivers for particular subsystems. These components will be implemented as independent processes but connected with each other with communication channels. This solution aims to create a machine that will consist of a many well programmed and tested binaries (*subsystem drivers*) that will work under the command of one generic state machine. To make FSM more flexible and easy configurable one consider whether is not better to move all configuration which is related to DOOCS environment to plain XML files, definitions of DOOCS members as well as definitions of the simple algorithms.

Modularization and Interface Generalization

Proposed approach aims to create a reliable set of well-tested small applications. Additional advantage is that several people can work on one FSM independently. It also means that each *subsystem driver* can be written and maintained by person who understands relevant subsystem. In order to simplify the development process one has to design common and simple interface between the FSM and the generic *subsystem driver*. It will make it possible to easily extend number of subsystems that will be driven by the FSM without recompiling it. Only changes in the FSMs configuration file will be necessary. The crucial task in the achievement of such solution is to apply inter-process communication protocol that will be able to handle inter-object communication with sufficient efficiency and reliability.

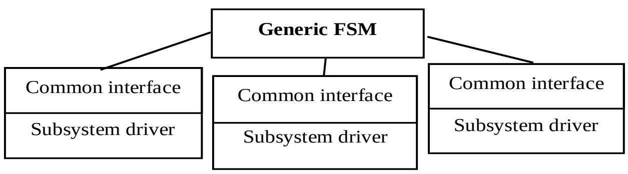

Figure 2: Modular architecture of FSM.

Hierarchy and Dependency

From observations that has been taken (one has observed how engineers work with klystrons) follows that *the klystron system* should be divided into several dependent subsystems i.e. cooling, vacuum, plenty of power suppliers, personal and hardware interlocks etc. Dividing software into modules supports this aspect of structure, but additional effort in designing object-oriented structure, which can handle such dependencies, has to be made. If we can represent such dependencies as tree-like structure it will help in system error handling, since errors affect "parent" systems in case of affecting "child" ones.

Configuration Instead of Recompilation

One considers design structure of XML document that will be the configuration file for *subsystem driver*. Maybe not all issues can be solved this way. Still remains difficulty with using the algorithms which are performed by special software i.e. Matlab. But it can help in case of change *DOOCS* property name or meaning or even in change in some algorithm (which can be represented as series of reads and writes to certain properties). By the way well formed XML files can very precise describe functionality of its binaries. Therefore one considers creating fully automated solution that will generate documentation from those configuration files and store this data in the easy readable form.

Taking Advantages of Existing Solutions

Because the FSM will be incorporated in the DOOCS environment one cannot omit solutions developed so far. To communicate between the state machines ClientLib will be used. Also FSM will need to be controlled somehow even if it has only a few control buttons. Therefore main FSM will be implemented as regular DOOCS FSM server. One consider to include DOOCS server interface in every *subsystem driver* in order to use existing watchdog to improve reliability of the system.

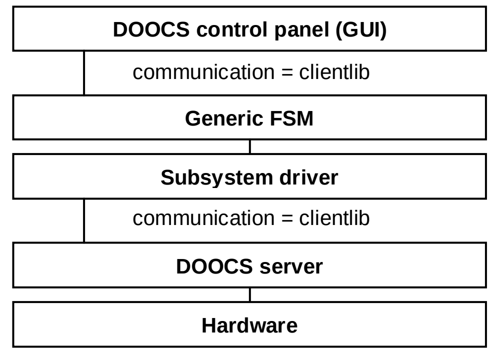

Figure 3: Communication between DOOCS and new FSM.

CONCLUSIONS

The requirement analysis revealed several problems like for example a need for ease software modifications during accelerator operation and development without compromising machine work or well-defined and efficient way for a new part of the system description. In order to solve them one has to design new architecture for the FSM for klystrons. First idea is to split the FSM for one generic FSM for all klystrons and set of programs will act as drivers for relevant klystron subsystems. To handle dependencies between subsystems a hierarchical tree-like structure class structure has to be designed and implemented.

Because the klystron equipment will work in radiation environment for at least 10 years one cannot omit challenges related to long-term maintenance. Therefore software which is designed have to be flexible, easy reconfigurable and well documented.

ACKNOWLEDGEMENTS

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