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THE STATE MACHINE FOR THE ACCELERATOR SYSTEM WORKING IN THE NATIONAL SYNCHROTRON RADIATION CENTRE SOLARIS

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Abstract

A state in which accelerator system works at a given moment of time is determined by the state machine. The idea of the project has been based on FSM – finite state machine, in which each of the states is precisely determined by assigned specified operations on subsystem devices of the accelerator system such as e.g. magnets of storage rings, RF transmitters etc. To ensure high reliability, the main part of the project has been based on PLC – Programmable Logic Controller. StateMachine wich is a TangoClass has been written in Python using the facadedevice library, that allows information from the control system to be delivered to the PLC system. By using an universal Tango Class AllenBradleyEIP the state machine shering an informationa about accelerator system to the Tango control system. This information is archived in Cassandra database system by using the Tango HDB++ archiving system.

DESCRIPTION OF ACCELERATOR'S SYSTEM WORKING IN SOLARIS

The Linear Accelerator with the Transfer Line

The linear accelerator working in Solaris has the lenght of 40 m and is capable of accelerating electrons from initial energy of 2.8 MeV (energy after leaving the electron gun) to maximum energy equal 600 MeV. After leaving the linear accelerator electrons are transferred to the storage ring by the transfer line. A system of two dipole magnets placed on ends of the transfer line provides for beam deflection in the vertical plane at an angle 27°, whereas six quadrupole magnets are responsible for beam focussing. The transfer line is ended by the septum magnet which connects the injector with the storage ring.

The Storage Ring

The storage ring in Solaris has been created in DBA technology (double-bend achromat), thus making possible to accomplish the design assumptionsit in which the small as possible emittance at the smallest size of the machine. The storage ring has circumference of 96 m and is capable of accumulating the current up to 500 mA at energy of 1500 MeV. For the construction of the storage ring, twelve of DBAs were used, connected with 3.5 m straight sections. Ten of straight sections are reserved for insertion devices and the other two are intended for beam injection and RF systems. The main Solaris storage ring parameters are presented in Table 1.

Table 1: The Main Storage Ring Parameters

Energy	1.5 GeV
Nominal current	500 mA
Circumference	96 m
RF frequency	99.931 MHz
Natural emittance	5.598 nmrad
Energy spread	$0.745 \cdot 10^{-3}$
Radiation losses/turn	114.1 keV
Betatron tunes (H/V)	11.22/3.15
Corrected chromaticities (H/V)	+1/+1
Momentum compaction factor	$3.055 \cdot 10^{-3}$
Total lifetime	13 h

THE IDEA AND A SCHEME OF THE STATE MACHINE

Operation of the accelerator system is characterized by its states, which enable or deny specific actions on the accelerator system. In Solaris for specifying a state of the accelerator system the state machine is responsible for, which has been implemented in based on finite state machine model [1]. In this implementation 11 states have been defined:

1. **Shutdown** - all devices of the accelerator system are switched off;
2. **Ring off** - no beam in the storage ring. After passing to this state, all subsystems of accelerator system are switched on and requirements of PSS - personal safety system and MPS - machine protection system are checked. At the moment of positive information about correct switched on of all systems and fulfillment of requirements PSS and MPS systems, there is automatic transition to **Ring standby** state;
3. **Ring standby** - all devices of the accelerator system are switched on, but an electron beam is not accumulated in the storage ring;
4. **Ring preparation for injection** - all insertion devices are open, in turn safety shutters are closed;
5. **Injection** - a state in which injection and electron accumulation are made;
6. **Ramping** - a state in which electron beam energy is increasing;
7. **Beam delivered** - the state machine comes to this state automatically from the **Ramping** state after energy of a beam is equal 1500 MeV;

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8. **Beam for beamlines** - an electron beam is accumulated with intended for beamlines;
9. **Beam for storage ring optics** - an electron beam has been accumulated with intended for carry out diagnostic measurements of the storage ring;
10. **Beam lost** - a beam has been lost due to the errors. At the moment of transition to this state, a watchdog is switching on, which has to be canceled during the set time. If cancelation does not occur, the system automatically moves to **Ring off** state;
11. **Beam dump** - no beam in the storage ring due to intentional removal by an operator.

The graph describes dependencies between the states have been shown on the Fig. 1.

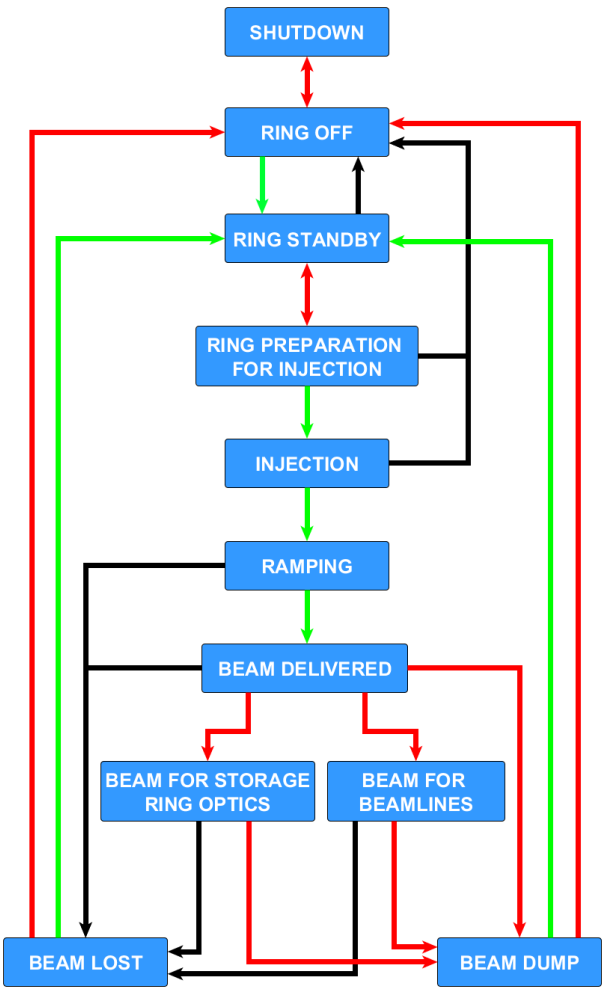

Figure 1: Schematic diagram presents all states of the state machine with set transitions. The color of the connection/transition: red - transition triggered by an operator or watchdog, green - transitions is triggered automatically after fulfilling specified conditions, black - transition has been made automatically in a case of lock comes from the PSS or MPS system [1].

DESCRIPTION OF THE IMPLEMENTATION

Presented project of the state machine has been divided in the two blocks:

1. PLC - Programmable Logic Controller block,
2. StateMachine block - instance of a TangoDevice.

The implementation of the main execution block of describing state machine has been created in PLC - Programmable Logic Controller technology. This choice has been dictated by the need to ensure the reliability of the device. In the project a driver ControlLogix 1756-L72 by Rockwell Automation has been used, which is a part of the protection system of vacuum. The code has been mostly developed in Ladder Diagram and also in Structured Text. The interface betwen PLC and main control system Tango has been created using universal TangoClass the AllenBradleyEIP. TangoDevice which is an instance of this class has 11 attributes of boolean types, which correspond to the eleven states of the state machine. Each of the attribute is archived by the Tango HDB++ system in ChangeArchiveEvent mode, with 1 s period of checking a change. The Solaris HDB++ as database system used the Cassandra [2].

The second part of describing state machine is the StateMachine block. This block has been developed in Python using the FacadeDevice library [3] and fully double role. From the one hand, it is responsible for transition information from the Tango control system to the PLC block. On the other hand, it enables transition of information about the state of accelerator system collected in one unit to the operators and BMS - building management system.

The StateMachine class allows the following commands to be performed:

- **Init** - initialization of the state machine, it creates connections with devices from which data will be downloaded or will be sent,
- **Reconnect** - restore a lost connection with devices, which were connected during initialization,
- **AcknowledgeWatchdog** - cancellation of a watchdog which was started in a **Beam lost** state,
- **StartCycling** - starting of a cycling magnets procedure,
- **StopCycling** - stopping of a cycling magnets procedure,
- **State** and **Status** - commands that returns the information about a state and status of the state machine.

Attributes of this classes are:

- **MachineState** - a current state of the accelerator system;
- **WatchdogStatus** - a status of a watchdog in case of transition to the **Beam lost** state;

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- **BeamWatchdog** - a amount of time remaining to auto-transition from the **Beam lost** state to the **Ring off** state;
- **BeamCurrent** and **BeamEnergy** - a value of current and energy of a beam acumulated in the storage ring - attributes transferring to the PLC system;
- **CyclingIsRunning** and **MagnetsCyclingDone** - informations about state of the cycling magnets procedure - attributes transferring to the PLC system;
- **RampingStatus** - information about state of the Tango Device responsible for procedure of increasing energy of an electron beam - attribute transferring to the PLC system;
- **PowerSuppliesReset** - a flag informing about the transition to the **Ring off** state, it is calling by the watchdog.

CONCLUSION

In the National Synchrotron Radiation Centre Solaris, the project of state machine has been developed which determine in the current moment of time state of the accelerator system. The discussed state machine has been mostly developed in PLC – Programmable Logic Controller technology, thanks for that it has stability and operational reliability. It may be proven by the fact that the device tested phase was launched in March 2017 and has been working properly since then. On 21.09.2017 the State Machine has been started in daily operations routine of the facility. The information about a state of accelerator system is collected by the Tango HDB++, thus it is relatively easy to determine the statistics of the utilisation of the Solaris research infrastructure. The use of a four-color signal column integrated with the state machine enables fast visual rate of a state of the accelerator system both by support of the experimental hall and measurement line users for greater productivity and comfort. The project will be expanded in the future by blocks that perform automatic statistical calculations on collected data.

REFERENCES

[1] W. Kitka, "Automation of electron beam injection to the storage ring of synchrotron," M.Sc. thesis, Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering, AGH University of Science and Technology, Poland, 2017.

[2] Tango HDB++, http://www.tango-controls.org/community/project-docs/hdbplusplus

[3] Tango FacadeDevice, https://github.com/MaxIV-KitsControls/tango-facadedevice