OVERVIEW OF CONTROL SYSTEM FOR 30MeV RF SOURCE

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Abstract

Control system for RF source of 30 MeV, 3 kW RF Linac for neutron generation is being developed. The system consists of two 15 MeV linac structures, each powered independently with klystron rated for 7.5 MW(pk)/7.5 kW(avg). Two klystron modulators of 160kV, 110A, 7µs and 250Hz feed pulsed power into the klystron, which produces RF power at 2856 MHz. The klystrons will be driven by low power RF driver amplifiers programmed for matching phase, frequency and power into the linac. Both the driver amplifiers are controlled through RS-232 Protocol. The HV pulsing and RF drive for the klystron has been interlocked with water flow, arc detector, SF6 gas pressure etc. The control system is designed using Real time embedded controller, where pulses for synchronization are being generated in FPGA. Most of the power supplies like electromagnet, HVDC, etc. are on RS-232 protocol. These power supplies are controlled via suitable RS-232 to Ethernet converter. State machine topology is being used to design the logic. The database for logging data is developed in SQL. This paper describes the details of the software implementation and hardware used to realize the control of the RF power source.

INTRODUCTION

A 30MeV, 3kW Linac is being developed. The thermionic diode gun of 85 kV, 1 A based on indirectly heated LaB_6 cathode of pierce geometry will be directly coupled to the linac system, which will inject a train of pulses into the linac at the rate of 250 PRF, each having a pulse width of ~ 7µs. The beam will be further accelerated to 30MeV by two 15MeV RF coupled cavity linac structures, each powered independently with klystron rated for 7.5MW (pk)/7.5kW (avg). The RF power at 2856MHz to the linac will be fed via a wave guide, Circulator, Dual Directional Coupler, H Bends and E Bends. Arc detector is located at the bend of the RF line to detect any arc in the RF Line. SF_6 gas at 28 psi pressure is maintained in the RF waveguide line to withstand high RF Power. A vacuum of ~ $4x10^{-7}$ torr will be maintained with the help of a turbo/sputter ion pump (TP/SIP) combination system.

SYSTEM REQUIREMENT

The major tasks to be accomplished in control system of RF Source include:

i) Generation of pulses with synchronization
ii) Monitoring in real time mode of all the interlocks / critical parameters like vacuum, Arc, water temperature etc
iii) Control / monitoring of High voltage supplies, e-gun supplies, Electromagnet power supplies, etc.
iv) Monitoring of RF Microwave parameters like forward power, reflected power, etc.
v) Transmission of the trigger pulses through EMI prone area.
vi) Protection of the controller from radiated and conducted noise.
vii) RF phase matching between both the linacs
viii) Data logging of the parameters

Figure 1 shows the schematic of 30MeV RF source.

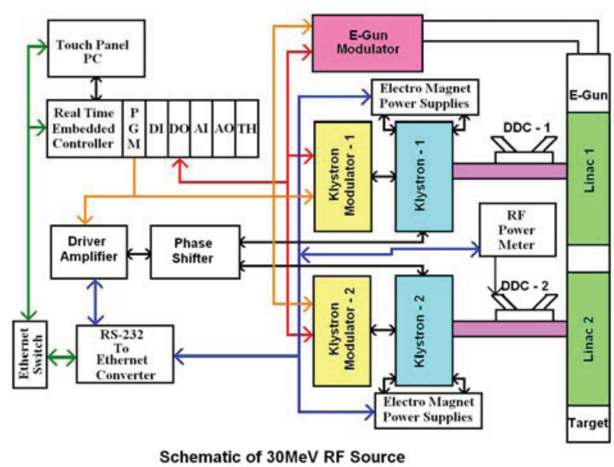

Figure 1: Schematic of 30MeV RF Source.

DESIGN ASPECTS

Hardware

The system consists of Real time embedded controller with FPGA for pulse generation logic. The controller is connected to the input output modules with 8 slot chassis. As per the requirement provision for 1PGM (Pulse Generation Module) 16DI, 16DO, 8 AI, 4 AO and 4 Thermocouple channels has been given. Two 4-ports RS-232 to Ethernet converter is used for controlling RS -232 protocol devices like electromagnet power supplies, driver amplifier, RF power Meter etc.

Software

The design is based on State Machine Architecture. It gives an abstract description of the behavior of the system. This behavior is analyzed and represented in series of events that occur in one or more possible states.

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The state transition diagram for the control was prepared. It consists of 7 states viz Initialize, OFF, Warm up, Ready, HV ON, Trigger ON, Fault state and Shut down. Based on state diagram logic/flowchart was designed. Figure 2 shows the state machine diagram for implementation of the algorithm for the control system.

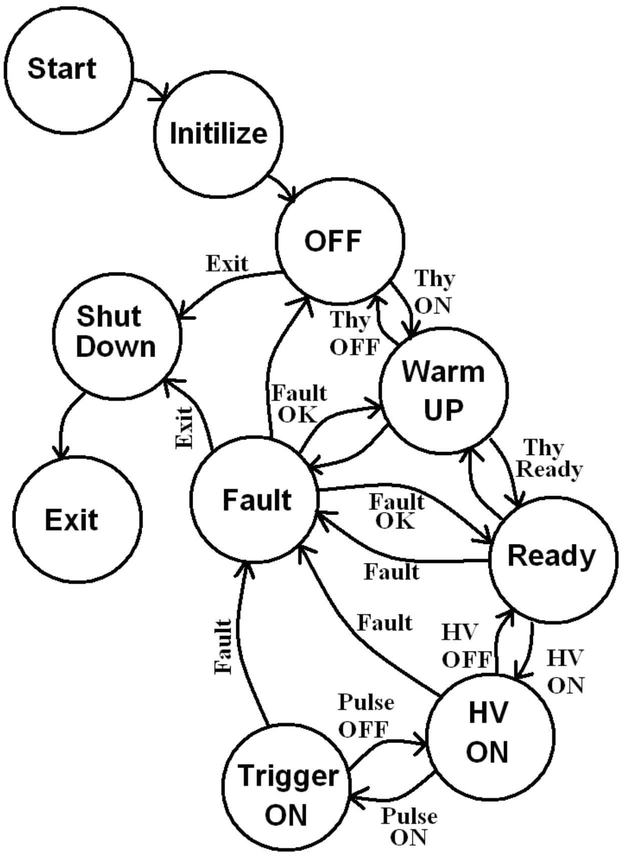

Figure 2: State Machine Diagram.

Initially all the ports are configured and variables are initialized. In the OFF state, it constantly monitors the user interface for the next action to take. It transits to Warm UP state upon response from the user for thyratron heating. Once the thyrtaron heating is completed, it automatically moves to Ready State. Further it moves to HV ON and Trigger ON state as per the response from the user. In any state, if fault occurs, it moves to fault state. On rectification of the fault, it moves to other state depending upon the status. The State machine algorithm was implemented using While loop and Case Structure.

There are 3 modes of developing the software (i) FPGA, (ii) Real Time and (iii) HMI (PC).

In FPGA, pulse generation logic is developed using flat sequence structure and case structure and all the I/O Nodes of the modules are accessed. The FPGA loop is timed to 40MHz to get a clock pulse of 25ns. The PRF, Pulse width, the delay and pulse Start/Stop values are received from HMI to RT program. In RT, the TON and TOFF period of the Pulse are calculated. These values are passed to FPGA. When the user clicks the Pulse Start button to generate the trigger pulses, in first cycle of pulse generation, the delay is generated in order to synchronize the output of e-gun modulator and the klystron modulator to get the accelerated beam, and then the TON and the TOFF is generated. In subsequent cycles only TON and TOFF is generated. When the PRF is changed, only TOFF is changed to achieve the desired PRF. When the command for stopping the pulse generation is issued, it completes the current cycle and stops generating the trigger pulses. The PRF can be changed in steps of 1 Hz. The delay between the two pulses can be adjusted in steps of 0.1µs.

All the I/O Nodes of the modules are connected to the controller via chassis accessed through FPGA. The FPGA code is complied and converted to bit file to access the I/O nodes in real time module. The path of the complied bit file is given to “Open FPGA Reference” to generate the reference. To get the access to the I/O nodes in the RT, FPGA Read/Write Control commands are used. Finally to close the reference “Close FPGA Reference” is used. The variables like TON, TOFF and Delay is passed to the FPGA using FPGA Read/Write Control.

Timed loop is used in Real time module for deterministic action. In this loop, we can set the priority of the loops, execution time, etc. Code for monitoring all the interlocks is developed in timed loop. If any of the interlocks gets activated the pulses to the driver amplifier and the e-gun modulator are disabled. Hence, no RF and no high voltage output are available. The interlocks are identified and the logic is implemented in the timed critical loop of 10ms in real time embedded controller, where it ensures that the action will be taken within 10ms. 4-port RS-232 to Ethernet converter is used for controlling various RS-232 protocol devices. Each power supply is controlled in independent loop having independent queues for each device. These queues are used to store the events generated by the user on the GUI. If no event is generated, it reads the current parameters and updates it. Initially the port is open and configured with required parameter. The query / commands are sent to the power supplies in the loop for the control / monitor of the power supply. Query is sent to acquire and the command is sent to set the parameter of the power supply. Each loop is executed every 1s. This code has been developed in RT and only the parameter values of the power supplies are sent to the PC.

Finally to transmit and receive the data between real-time controller and the HMI (PC), TCP/IP Protocol is used. Here the controller is a server and the PC act as a client. TCP Listen command is used in the RT waiting for any in coming request. The PC sends the request to the controller with parameter (IP address of the controller and the port number). Once the request is accepted by the controller further communication can achieved using TCP Read and TCP Write commands. Touch screen PC is used for human interface. GUI for the human interface has been developed. All the values are transferred from RT to PC and are displayed on the GUI.

The database for storing the data like PRF, Vacuum, RF Gain, forward, Reflected etc with Date and Time is developed in SQL. The data to be stored in database is stored in local variable. These values are inserted in the database with proper SQL Query containing table name and column details. The time interval between the data storing is variable from 1s to 5mins. The numeric box is provided for selecting the time interval. The database has separate loop running at every 500ms. To display the stored data user selects the date and the data of that particular date is displayed in the grid. The data displayed in the gird can be exported in DOC / XL.

Analog – Digital Isolation

ADAM 3014 signal conditioning isolation module is used for protecting analog processed signal from ground loops, other electrical interferences. It provides channel - channel optical isolation of 1kV DC.
Relay is used between digital channel and the field signal. It provides physical isolation between the signals.

Fiber Optic ulse ransmission Circuit

For transmitting the TTL trigger pulse Fiber optic pulse transmission circuit was designed and developed. The TTL pulse generated by pulse generation module is fed to HFBR 1412 – Transmitter and the signal is transmitted over fiber optic to HFBR 2412 – Receiver kept near the trigger circuit of the individual system, where the fiber optic signal is converted back to electrical signal.

EMC Enclosure

As the controller will be placed in areas which have high radiated fields and conducted noise, proper EMC enclosure was selected. The rise time of 10μs pulse is ~500ns. Hence the maximum frequency component of the radiated noise is Fh = 0.35/500ns = 700 kHz. To protect the controller from the radiated noise Rittal compact Enclosure AE with 100dB attenuation from 700 kHz – 1MHz was chosen. The enclosure size of 600mm W X 600mm H X 210mm D was selected in order to enclose the controller with its I/O protection circuits. Proper EMC glands are selected for taking out the cables out of the enclosure.

TESTS

Pulse generation logic was tested for synchronization between e-gun modulator, driver amplifier and klystron modulator. The pulses have adjustable pulse width from 0.1μs to 4μs and adjustable pulse delay with steps of 0.1us. Faults were simulated and the logic of the interlocks was tested successfully.

CONCLUSION

The development of the above described control system is complete. Control of few supplies is being done remotely through PC. The testing of the system with Klystron modulator on actual operating conditions is awaited.

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