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Study of 3MeV DC Electron Beam Accelerator to implement Distributed Control System

C. Arnold Charles*[1], L. K. Ragha[1], Vijay Sharma[2], R. I. Bakhtsingh[2]

[1]Electronics Engineering Department, Terna Engineering College, Nerul, Navi-Mumbai, India

[2]Accelerator and Pulse Power Division, Bhabha Atomic Research Centre, CBD Belapur, Navi-Mumbai, India

**Corresponding author E-mail:* c.arnoldcharles18@gmail.com

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Abstract

Electron beams with beam energy in the range of 0.2 to 10 MeV have found a large number of industrial applications such as cross linking of plastic film, foam and cables, degradation of scrap Teflon, sterilization of medical products and food irradiation. Keeping these industrial applications in mind, the development and commissioning of a 3 MeV accelerator is being done at Electron Beam Center at Kharghar, Navi Mumbai. The accelerator comprises of several sub systems such as Scan magnet supply, Chiller unit, Vacuum unit, High voltage unit and other support sub-systems. All the above subsystems have to be controlled from central location in order to operate and monitor the accelerator safely. Each of the sub-system is controlled by a Programmable Logic Controller (PLC) independently and their control and safety is ensured by the program logic. After each subsystem is tested separately all the PLCs are connected to the central PLC via Modbus RS232 and Modbus TCP-IP to implement the technology of Distributed Control System (DCS). A DCS refers to a process in which elements from different locations can be controlled by inputs from a remote place by different modes of control implementation.

Keywords: *Distributed Control System, Electron Beam Accelerator, Modbus RS232, Modbus TCP-IP, PLC*

1. Introduction

Accelerators are devices that accelerate charged particles to high energies and generate ionizing radiation from the interaction of energetic particles with matter. Electron beam processing is a process which involves using electrons, usually of high energy, to treat an object for a variety of purposes. This may take place under elevated temperatures and nitrogen atmosphere. Electron energies typically vary from the keV to MeV range, depending on the depth of penetration required. The irradiation dose is usually measured in Gray but also in Mrads, where 1 Gy is equivalent to 100 rad [1]. The basic components of a typical electron beam processing device are an electron gun (consisting of a cathode, grid, and anode) used to generate and accelerate the primary beam. A magnetic optical (focusing and deflection) system is used for controlling the way in which the electron beam impinges on the material being processed (the "work piece").

The development of a 3MeV, 30 kW DC industrial electron beam accelerator has been taken up as a part of the "Indigenous Industrial Electron Accelerator Development Programme at BARC" and is being developed at Electron Beam Center, Kharghar, Navi- Mumbai [2]. The Schematic of Electron Accelerator is as shown in Figure 1.

2. Accelerator Sub-Systems

The accelerator and its high voltage power supply are housed in a pressure vessel filled with SF_6 gas as the insulation at 6 kg/cm^2. The accelerator is a vertical assembly housed in a concrete building where the accelerator is located in the upper cell and the product irradiation facilities in the lower cell. A triode electron gun using LaB_6 cathode generates the electron beam and injects into the accelerating column at 5 keV. This beam is accelerated through a 3.5 m long accelerating column assembly. Vacuum pumping systems are attached on this beam line. Apart from vacuum system there is a thermal based beam locating aperture, a focus coil, and two sets of beam steering coils. Before the beam enters into the scan chamber it can be aligned by adjusting current in these coils. The beam is then scanned at 100 to 200Hz to cover over 1m width uniformly using a bipolar magnet and brought out to the atmosphere through 120 cm x 7 cm, 50 micron thick titanium window for product irradiation and radiation processing applications [3-4].

Other than the core systems described above there are many other sub-systems which are essential for reliable and safe operation of the accelerator. This includes radiation shielding, vacuum system, SF_6 storage & transfer system, ozone removal system, product conveyor system and cooling systems. For radiation shielding the accelerator is housed in concrete building. Accelerator is located on the upper floor above the irradiation cell isolated one another with 1 m thick concrete slab to protect the sensitive components from high intensity X-Rays. Ozone exhaust duct is fitted with blowers to remove the Ozone gas produced in air by electron beam impact. This ensures ozone level in the cell below 0.1 ppm within 5 minutes of switching off the beam. Two chiller type heat exchangers, one at the top of the accelerator and the other in the RF transformer side tank removes heat generated within the accelerator tank.

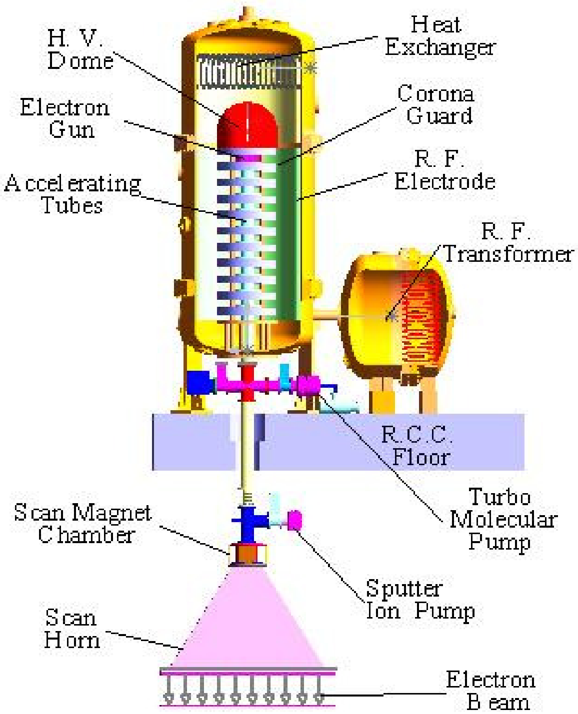

Figure 1. Schematic of 3MeV 30kW Electron Accelerator.

Cooling of scan horn, beam dump, vacuum system and oscillator components are with low conductivity water. Forced air cooling system is incorporated for the beam aperture. A cooling system is used for the accelerator and transformer vessel to remove heat dissipation due to joules heating. Electrical currents flowing in the accelerating structure and in electromagnets coils are high enough that this heat must be carried off by a cooling system. The use of chiller allows the design engineer to produce chilled water in a central building location or even on the roof and distribute the water economically as chilled water provides accurate temperature control. A SF_6 handling system consists of two storage tanks and a handling cart that can transfer the gas from accelerator tank to the storage tank and back to accelerator tank during maintenance. This system is also capable of evacuating the tanks up to 0.1 torr in either direction and also can remove dust, breakdown products and moisture through filters built in the handling cart.

Vacuum system comprises a turbo-molecular pump, sputter ion pumps and a rotary pump to produce and maintain a vacuum of 10^{-6} Torr in the gun, beam transport column and scan horn. Roller Conveyor System is used for carrying products to be irradiated into and out of the accelerator cell area. This system comprised of series of rollers which is continuously moving in the loop and carrying the tray of products which is to be irradiated.

All doors in the restricted area should be physically checked by the operator and the search & secure switch closed before switching ON HVDC to prevent any person got trapped in the accelerator area. The radiations produced within the shielded area of this accelerator are dangerous because of their energy and intensity and they can only be detected by some instruments such as area monitors, survey meters, etc.

3. Problem Formulation

The main problem with the above sub-systems is that they all are stand alone i.e. they do their individual process of operation correctly but the feedback from the other sub-system is not accessed by any sub-system. So a need arises to link the sub-systems with each other so as to achieve better performance and reliability. Fully automatic operation of the accelerator will only be achieved when all the sub-systems have been linked to each other in a closed loop. This linking of the sub-systems can be accomplished in the master PLC logic. And this interlinking is possible in the sub-systems by introducing the technique of Distributed Control System in Electron Beam Accelerator.

To enable maintenance of the subsystems under the supervision and knowledge of the central control system, additional digital signals generated by local-remote panel locks are also required. These signals need to be developed by designing and making the logic implementation for the same, due to which the technology of Distributed Control System needs to be installed in the above sub-systems.

4. Distributed Control System

A distributed control system (DCS) refers to a control system usually of a manufacturing system, process or any kind of dynamic system, in which the controller elements are not central in location but are distributed throughout the system with each component sub-system controlled by one or more controllers. The entire system of controllers is connected by networks for communication and monitoring. DCS is used in variety of industries, to monitor and control distributed equipment [5]. A DCS typically uses custom designed processors as controllers and uses both proprietary interconnections and communications protocol for communication. Input and output modules form component parts of the DCS. The processor receives information from input modules and sends information to output modules. The input modules receive information from input instruments in the process (or field) and transmit instructions to the output instruments in the field. Computer buses or electrical buses connect the processor and modules through multiplexer or de-multiplexers. Buses also connect the distributed controllers with the central controller and finally to the Human–machine interface (HMI) or control consoles [6]. DCSs may employ one or more workstations and can be configured at the workstation. Local communication is handled by a control network with transmission over twisted pair, coaxial, or fiber optic cable. A server may be included in the system for extra computational, data collection, and reporting capability.

5. Interfacing

All the accelerator subsystems have been independently developed by the experts. The interface between subsystems and control system are grouped according to the following categories:-

5.1 Digital inputs

A digital input detects if a voltage is above/below a specific threshold. If the voltage is higher than some value, the computer will detect the digital input as high/set/1. If the voltage is lower than some value, the computer will detect the digital input as low/clear/0 [7].

5.2 Digital outputs

A digital output allows you to control a voltage with a computer. If the computer instructs the output to be high, the output will produce a voltage (generally about 5 or 3.3 volts). If the computer instructs the output to be low, it is connected to ground and produces no voltage.

5.3 Analog inputs

An analog input is a measurable electrical signal with a defined range that is generated by a sensor and received by a controller. The analog input changes continuously in a definable manner in relation to the measured property. An analog input is converted to a voltage level and finally into a digital value that can be stored and processed in a controller [8].

5.4 Analog outputs

An analog output is a measurable electrical signal with a defined range that is generated by a controller and sent to a controlled device, such as a variable speed drive or actuator. Changes in the analog output cause changes in the controlled device that result in changes in the controlled process.

5.5 Serial Communication

In RS232 Standard, Communication is defined as an asynchronous serial communication method. The word serial means, that the information is sent one bit at a time. Asynchronous tells us that the information is not sent in predefined time slots. Data transfer can start at any given time and it is the task of the receiver to detect when a message starts and ends.

RS-422 and RS-485 are the common names for two serial communications standards. Communications systems based on RS-422 and RS-485 communicate digital information over twisted pair wire from transmitters to receivers. RS-422/485 systems can communicate at rates up to 10 Mbps. RS-485 are used as the basis for many commercial and industrial data communications systems [9].

5.6 Modbus

The Modbus protocol was developed in 1979 by Modicon, Incorporated, for industrial automation systems and Modicon programmable controllers. It has since become an industry standard method for the transfer of discrete/ analog I/O information and register data between industrial control and monitoring devices [10].

Modbus devices communicate using a master-slave (client-server) technique in which only one device (the master/client) can initiate transactions (called queries). The other devices (slaves/servers) respond by supplying the requested data to the master, or by taking the action requested in the query. A slave is any peripheral device (I/O transducer, valve, network drive, or other measuring device) which processes information and sends its output to the master using Modbus.

5.7 Modbus TCP/IP

Modbus TCP/IP is simply the Modbus RTU protocol with a TCP interface that runs on Ethernet. TCP/IP refers to the Transmission Control Protocol and Internet Protocol, which provides the transmission medium for Modbus TCP/IP messaging. TCP/IP allows blocks of binary data to be exchanged between computers. It is also a world-wide standard that serves as the foundation for the World Wide Web. The primary function of TCP is to ensure that all packets of data are received correctly, while IP makes sure that messages are correctly addressed and routed. Modbus TCP/IP uses TCP/IP and Ethernet to carry the data of the Modbus message structure between compatible devices. That is, Modbus TCP/IP combines a physical network (Ethernet), with a networking standard (TCP/IP).

6. Conclusion

By introducing the technique of Distributed Control System, a fully automatic operation of the 3MeV Electron Beam Accelerator can be achieved which will reduce the operator burden heavily by performing a sequential operation of the accelerator based on the timing of each sub-system as well as the system parameters.

REFERENCES

[1] http://en.wikipedia.org/wiki/Electron_beam_processing.

[2] K.C. Mittal, K. Nanu, A. Jain, K.V. Nagesh, S. Acharya, R.I. Bakhtsingh, S.R. Barje, A.S. Chawla, A.R. Chindarkar, S.R. Ghodke, D. Jayaprakash, S. Khole, Mukesh Kumar, Mahendra Kumar, R.L. Mishra, G.P. Puthran, R.N. Rajan, P.K. Sarma, P.C. Saroj, D.K. Sharma, Vijay Sharma,S.K. Srivastava and R.C. Sethi, 'Design and Development of 3 MeV, 30 kW DC Industrial Electron Accelerator at Electron Beam Center, Kharghar', SEBTA, 2005, 476-486.

[3]K.C.Mittal, K.Nanu, A.Jain, K.V.Nagesh, S.Acharya, G.P.Puthran, R.I.Bakhtsingh, P.C.Saroj, D.K.Sharma, R.N.Rajan, Mukesh Kumar, S.K.Srivastava, A.S.Chawla, A.R.Chindarkar, S.R.Ghodke, D.Jayaprakash, Mahendra Kumar, Rajesh Barnwal, R.L.Mishra, Vijay Sharma, S.Dewangan, S.R.Barje, R.M Agarwal, M.K.Pandey, S.R.Raul, D.P.Chakravarthy and A.K.Ray, 'Development of 3 MeV, 30 kW DC Electron Accelerator at EBC, Kharghar', APAC 2007, Raja Ramanna Centre for Advanced Technology(RRCAT), Indore, India, THPMA043.

[4]R. Majumder, K.C. Mittal, K.Nanu et al, 'Design and Development and Status of 3 MeV, 30 kW DC Industrial Electron Accelerator at Electron Beam Centre, Kharghar', InPAC-2003, CAT, Indore, Feb. 3–6, 2003, p-241.

[5] P. Holecko, 'Overview of Distributed Control Systems Formalisms', Department of Control and Information Systems, Faculty of Electrical Engineering, University of Žilina.

[6] http://en.wikipedia.org/wiki/Distributed_control_system

[7] http://www.omega.com/literature/transactions/volume2/digitalio.html.

[8] http://www.omega.com/literature/transactions/volume2/analogio.html.

[9] http://en.wikipedia.org/wiki/RS-232,RS-485.

[10] http://www.acromag.com/IntroductionToModbusTCP/IP