DEVELOPMENT OF DISTRIBUTED DATA ACQUISITION AND CONTROL SYSTEM FOR RADIOACTIVE ION BEAM FACILITY AT VARIABLE ENERGY CYCLOTRON CENTRE, KOLKATA

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Abstract

To facilitate frontline nuclear physics research, an ISOL (Isotope Separator On Line) type Radioactive Ion Beam (RIB) facility is being constructed at Variable Energy Cyclotron Centre (VECC), Kolkata. The RIB facility at VECC consists of various subsystems like Electron Cyclotron Resonance (ECR) Ion source, analysing magnet, Radio Frequency Quadrupole Linear Accelerator (RFQ linac), Rebunchers, Inter-digital H-mode Linear Accelerators (IH linacs) etc which are required to produce and accelerate radioactive ions for different experiments. To facilitate the smooth operation of this RIB facility by way of monitoring, supervision and control of all the important parameters associated with its various sub-systems, a "Distributed Data Acquisition and Control System (DDACS)" is being developed at this Centre. This paper briefly describes the design philosophy, basic architecture and various functional components of the DDACS.

INTRODUCTION TO RIB FACILITY

The RIB facility (Fig. 1) at VECC is an ISOL type RIB facility. Radioactive isotopes are first produced in a target from nuclear reaction with the primary beam coming from K-130 Cyclotron operational at this Centre. Radioactive atoms diffusing from the target are ionized initially in an integrated 1^+ ion-source and then in a 6.4 GHz Electron Cyclotron Resonance Ion source (ECRIS). After mass separation, the low energy RIB is accelerated from 1.75 KeV/u to about 100 KeV/u in Radio Frequency Quadrupole Linear Accelerator (RFQ linac). Three Inter-digital H-mode Linear Accelerator (IH linacs) modules raise the energy up to around 415 keV/u. Subsequent linac modules are to be used to achieve the final beam energy of 1.3 MeV/u [1].

DESIGN PHILOSOPHY OF DDACS

The DDACS for RIB facility, like any other control systems of large accelerators, is not only a vital means of monitoring the status of the machine at any point of time during operation, but also a tool for achieving desired beam. A detailed requirement analysis was done for the design of the control system. Following are some of the guidelines which are followed in global stages and have also been appropriately adopted in the design of DDACS.

- The control system should have multi-layered architecture. Entire task of data acquisition and control would be shared by different control modules distributed in all layers [2].
- The control system must be modular, incrementally upgradeable and extendable to fulfil the future requirements as machine grows in scale [3].
- The modules of the control system must be individually usable in case of testing, installation and commissioning of a subsystem.
- The control system must have provision to accommodate various kinds of heterogeneous equipments manufactured by different companies and hence characterised by different operational requirements.
- Variation in design of individual control modules should be minimized. Homogeneous design of control modules must be of paramount importance for the ease of maintenance and replacement.
- Use of state-of-the-art technology.
- The control system should be expandable in terms of addition of similar modules for similar subsystems.

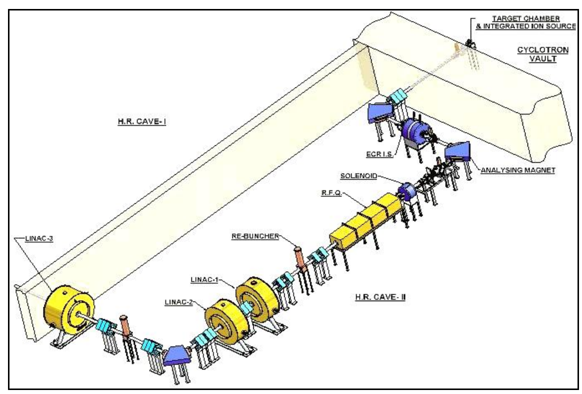

Figure 1: Layout of RIB facility (up to LINAC-3).

ARCHITECTURE OF DDACS

Based on the above design philosophy, RIB control system is being developed using 3-layer architecture: a) Equipment Interface Layer b) Supervisory Control Layer and c) Operator Interface Layer. The control system is composed of a number of functional modules distributed over these layers which are connected through suitable communication network and protocol.

The Equipment interface layer consists of different Equipment Interface Modules (EIMs) which are directly connected to the accelerator equipments through various interfaces. Each EIM is a microcomputer based intelligent unit with front-end analog/ digital electronics. Each of the EIMs is separately connected to the supervisory computer through fibre optic link in a star topology.

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The Supervisory layer has been realised using Embedded Controllers (EC) designed around Single-Board-Computer (SBC) with Embedded XP operating system. This controller, interfaced with EIMs through fibre optic cables, performs supervisory task of continuously sending command and acquiring data from lower level EIMs and reporting to the operator interface layer as and when requested.

Operator interface layer consists of operator console formed with another embedded controller and high performance PCs/ Workstations for controlling and monitoring machine parameters. The data acquired and analysed at the supervisory layer can be displayed at the operator console and operators can control the whole facility from the user friendly graphical interfaces.

A schematic diagram of the architecture is shown in Figure 2.

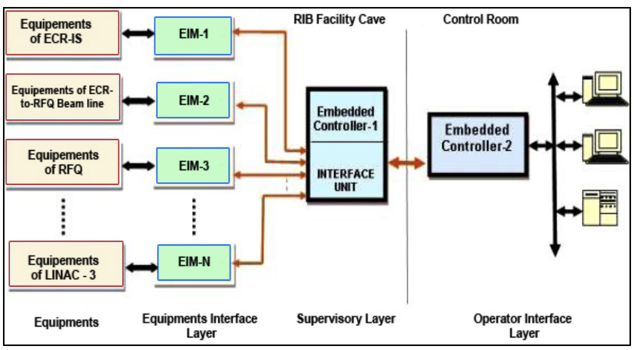

Figure 2: Schematic diagram of DDACS.

DESCRIPTION OF DDACS

For the development of data acquisition and control system, entire RIB facility has been viewed as a composition of following subsystems and their interconnected beam lines (as per present status of RIB facility).

a) Electron Cyclotron Resonance Ion source (ECRIS)
b) ECRIS to RFQ Beam Line
c) Radio Frequency Quadrupole (RFQ)
d) RFQ to Rebuncher Beam Line
e) Rebuncher
f) Rebuncher to Linac-1 Beam Line
g) Linac-1
h) Linac -1 to Linac-2 Beam Line
i) Linac -2
j) Linac -2 to Linac -3 Beam Line
k) Linac -3

These subsystems and their interconnected beam lines are associated with various kinds of equipments like High Current Magnet Power Supplies, High Voltage Power Supplies, Klystron High Power Amplifier (KHPA), RF Transmitters, Vacuum Pump Controllers, Vacuum Gauges, Gate Valves, Faraday Cups etc. DDACS is intended to monitor and control important parameters of these equipments and thus help smooth operation of machine.

The three layers of DDACS are detailed in the following sections.

Equipment Interface Layer (Layer-1)

The Equipment Interface Layer is the lowest level of control system which is directly interconnected to the accelerator equipments. It consists of multiple microcomputer based modules named as "Equipment Interface Module" (EIM) (Fig. 3) which form the basic foundation of this data acquisition and control system. The multiple equipments associated with each subsystem are physically connected to their respective EIM module through a variety of interfaces which actually governs the design of the EIM. Wide range of computer/remote interfaces available with the equipments from different manufacturers has been extensively studied and EIMs are finally designed to support multiple analog/ digital input/ output channels and RS-232/ RS-485 ports suitable for connecting all the equipments. Following a generalised hardware architecture, EIMs are indigenously developed around 32-bit ARM controller with analog/ digital front-end electronics (ADCs, DACs, Opto-isolators, Multiplexers etc.) and RS232/ RS-485 level translator. It also consists of a touch-screen display (Fig. 4) using which, equipments, connected to it, can be locally controlled and monitored. This feature immensely helps in tuning of the control system during installation and also in testing and commissioning of many subsystems.

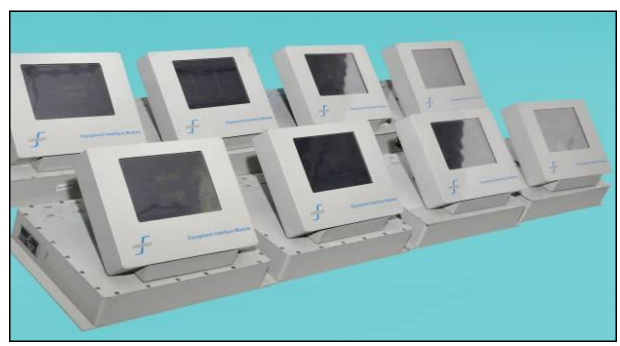

Figure 3: Snapshot of Equipment Interface Modules (EIMs).

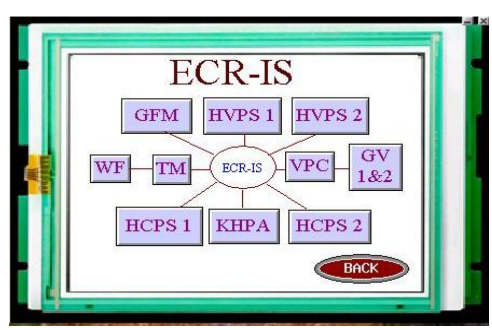

Figure 4: Snapshot of a typical touch-screen based local display panel of EIMs.

Some of the equipments such as RF transmitters, Faraday cups and Slit controller do not have compatible remote interface to connect them to EIM. Hence, suitable interface units are introduced to enable them to get connected to their respective EIM.

Each of the EIMs is individually connected to the Supervisory Layer computer through fiber optic link in a star topology which has helped in reducing the overhead of address checking.

Software in EIM performs predetermined tasks either on request or on regular basis and confines to a group of instruments. For getting access to the equipment parameters, various proprietary command-response based communication protocols of different equipments have been implemented in EIM software. It periodically scans all equipments, connected to it, to read the status of their parameters and stores parameter values in its local buffer. It finally sends these values to the upper layer on demand. It also issues required control commands to the individual equipment for changing value of their parameters as desired by the operators. The task of handling data exchange between EIM and Supervisory Computer (SC) is performed following a customised protocol. The message received from SC is parsed and appropriate action is taken according to the command. Thus, dedicated software at this layer in coordination with upper layer provides total accessibility of equipment at remote control location.

Each EIM also handles safety interlocks associated with the subsystems it deals with and informs the interlock status to the upper layer.

The software for this layer is written in C language and after cross-compilation, the executable code is downloaded to the EIM controller.

Supervisory Layer (Layer-2)

The Supervisory Layer of DDACS has been realised by a system, developed using single board computer with Embedded XP operating system (OS) and named as Embedded Controller-1 (EC-1). The EC-1 (Fig. 5) is physically located at the cave of RIB facility, but away from the machine and interfaced with all the EIMs through fibre optic link to ensure necessary isolation and noise immunity. EC-1 performs the task of supervision by way of delivering the operator commands to the EIMs for controlling field equipments and receiving status information from them to report to the operators.

The Embedded Controller is built around a VIA processor operating at 800 MHz. However, the processor architecture is optimized for low power operation and reliable performance to meet the requirements of industrial applications. The embedded controller board supports operation over a wide temperature range of -20 to 70 deg. The controller runs on Embedded XP operating system which is built with minimum kernel resources, drivers and occupies minimum foot print when compared to the conventional Windows XP operating system. The OS, drivers and application software are embedded in a Flash memory. The board supports 512 MB of SDRAM and 512 MB of Flash memory. The controller board is operated from a DC supply of 5 - 28V DC. All the secondary DC supplies and the power management circuitry are built on-board. The Controller module has been tested and qualified for the environmental standard as per JS 55555 and Electromagnetic Compatibility (EMC) standard as per MIL STD 461.

The EC-1 system rack contains a Data Interface Unit (DIU) which physically connects EC-1 to all the EIMs. This unit mainly converts the fibre optic signals to the appropriate electrical signals and vice versa.

Main functions of this supervisory level controller are:

- To acquire data from EIMs (Layer-1), process the same and communicate the relevant data to control console at Layer-3.
- To receive the control messages from the control console, parse the same and distribute those to related EIMs to make effective on the equipments.

The application software, running in EC-1, is developed using Labwindows™/CVI and continuously sends commands to and acquires data from lower level EIMs. A customised command-response based protocol with 16 bit Cyclic Redundancy Check (CRC) has been adopted for reliable data communication between EC-1 and EIMs. Each equipment attached to an EIM is identified by unique “Instrument ID”. This instrument id along with specific “Function Code” in a command message issued by the EC-1 uniquely define a particular operation (such as setting a voltage, reading a voltage, making a power supply on/off etc.) on a piece of equipment connected to a particular EIM.

Figure 5: Snapshot of Embedded Controller-1 System Module.

The EC-1 is connected upward to an Operator Interface Layer controller, named as Embedded Controller-2 (EC-2) through a pair of optical link. It receives operator commands and provides corresponding responses like transmitting a block of data or initiating the action to change the status or set the values of parameters of different equipments.

Operator Interface Layer (Layer-3)

Operator Interface layer handles operator interaction and provides a means of communication between operators and the accelerator machine. It mainly deals with data representation and responds to each of the user actions. This layer has been realised by another embedded controller named as EC-2 and multiple PCs/ Workstations. These all are physically located in the RIB control room and form user friendly operator console.

EC-2 is similar to EC-1 in respect of hardware, but is functionally different. EC-2 is interconnected with different monitoring units (PCs/ Workstations) through a Local Area Network (LAN). All the status information of different equipments received from all EIMs by EC-1 are sent to EC-2 and finally displayed at PC/ Workstations. Any control action (for changing status of equipments) initiated at this layer finally reaches to the intended equipment through EC-1 and respective EIM. The response to user interaction has been kept within the human acceptable limits (500 milliseconds to 1 second).

Application software in EC-2 communicates with the supervisory layer embedded controller i.e EC-1 for data acquisition and control initiation. It communicates with the monitoring units using UDP protocol for displaying machine information in user friendly Graphical User Interface (GUI) (Fig. 6).

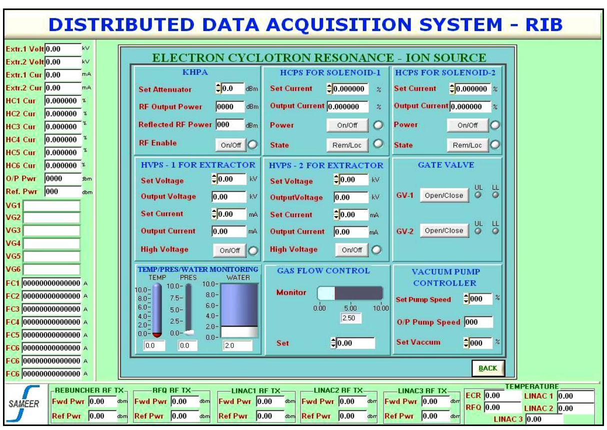

Figure 6: A typical GUI for ECR-IS Subsystem.

PRESENT STATUS

All the data acquisition and control modules have undergone functional performance check and EMI/ EMC qualification tests at Society for Applied Microwave Electronics Engineering & Research (SAMEER), Chennai before installation at RIB facility at VECC. Functional performance of the modules has been checked using a simulator system developed indigenously. Radiated Susceptibility test, Conducted RF Immunity test and Power Frequency Magnetic Immunity test have been carried out as per IEC 61000 standards on the modules to qualify them to be used in an accelerator environment. Presently, all the EIMs are installed and rigorous testing of the modules with the different sub-system has been carried out successfully at the RIB site. Embedded Controllers are also installed and thorough testing of those with EIMs produced expected results.

CONCLUSION

The RIB facility at VECC is under development and it is growing step-by-step towards its complete shape. The multilayer architecture of this data acquisition and control system is ideally suited for the RIB facility growing in phases. It has been envisaged to deploy a database server to be connected to the LAN at operator interface layer for data archival and off-line analysis.

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