THE DISTRIBUTED LOCAL CONTROL SYSTEM FOR A LEP-RF UNIT

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Summary

Each unit for the LEP-RF system comprising 16 cavities, 2 klystrons, high voltage interface and low-level controls equipment forms a complete and essentially autonomous part of the RF system. A modular approach to digital control has been adopted. The equipment for each element is interfaced to its own dedicated microprocessor controller. The 23 Equipment Controllers within each unit are linked by two separate IEEE488 buses to a VME based multiprocess unit controller (Data Manager). The functions of the Equipment Controllers and the Data Manager are summarized and the software described. The transfer of information and commands to and from the data manager and the means of bus control for parallel processes is described. The use of distributed control, showing the partition of control functions between Data Manager and Equipment Controllers, is illustrated by a description of the procedure for switch on of an RF unit. The inherent flexibility of a modular approach has resulted in straightforward adaption for the introduction of superconducting RF cavities for the LEP energy upgrade.

Introduction

The accelerating system for LEP is made up of separate, independent and identical RF units driven from a common frequency source. The presently installed RF system (LEP Phase 1) consists of 8 such units grouped in pairs around interaction points 2 and 6 of LEP. An RF unit consists of two 1 MW klystrons driving 16 coupled cavity assemblies through circulators and a system of waveguides. It also includes power converter for the DC supply of the klystrons, cavity vacuum equipment and low level controls. The klystrons, high voltage interface and group of 22 racks of electronics are housed in a separate underground klystron gallery parallel to the machine tunnel. Each RF unit can be operated individually, either from a local control point in the racks, or remotely via the control system from the Prévessin Control Room (PCR).

RF Unit Control Configuration

The control configuration of an RF unit reflects the structure of the unit. It has been attempted, as far as possible, to provide modularity by grouping together all functions associated with each individual element of the unit. This allows the use of local intelligence at the level of each element, permitting a large degree of autonomy and simplifying the overall control of the unit. The overall management of the RF unit is done by a multiprocessing VME based Data Manager (DM) [1]. It provides facilities for local operator control of the unit via a touch screen and a colour graphics display. It can run locally resident procedures for overall unit control and surveillance. It provides the connection to the general control system of LEP via the MIL-1553 multidrop, an interface to the General Machine Timing (GMT) system and direct connection to the token ring of LEP via Ethernet for remote data acquisition.

The functions of each element of the unit are handled by an intelligent G64 bus based Equipment Controller crate (EC) [2], there being one for high voltage equipment (HV), one for each klystron, (K1 and K2), one for each of the 16 cavities (C1 to C16), two for low level RF controls and timing (LL1 and LL2), one for equipment associated with the waveguide system (RFD - RF Distrbution) and one for cavity vacuum (CV). Each EC contains interface harware for all associated equipment and software for control, acquisition, surveillance and local data display (on a small monochrome monitor). The Data Manager communicates with the ECs, grouped on two separate IEEE488 (HPIB) buses. Separate links provide connection to the klystron power converter (RS232) and cavity vacuum equipment (RS422).

Equipment Controller Functions and Software

The EC consists of a 6U crate with a G64 backplane bus. It contains a Z80 processor module and clock, video controller driving a 5 inch monitor, IEEE488 interface and RS422 interface modules. As far as possible the input and output to the hardware is done using a restricted set of standard I/O modules. The ECs provide the lowest level interface to the equipment of the RF unit. Through them all of the 2400 hardware states, settings and readings provided for the running of the unit can be made directly available to the the Data Manager or to a remote console for operation, monitoring or diagnostics. This is particularly important in view of the large distances involved in LEP. As far as possible specific details about the hardware e.g. interface addressing, configuration, calibration factors etc. are handled by the EC. All requests or commands result in the return of a reply state orrequested data in ASCII form. The sending or return of bit patterns or other specific low level data is deliberately avoided at higher levels.

Similarly for changes of equipment states or values any low level procedures required for the interface or for the equipment itself are handled internally by the EC. Relatively complex procedures can therefore be initiated by simple commands. Local surveillance of equipment data is continually carried out and any abnormal change in state timestamped and stored, e.g. an interlock trip or an overtemperature. The EC allows local display of blocks of equipment

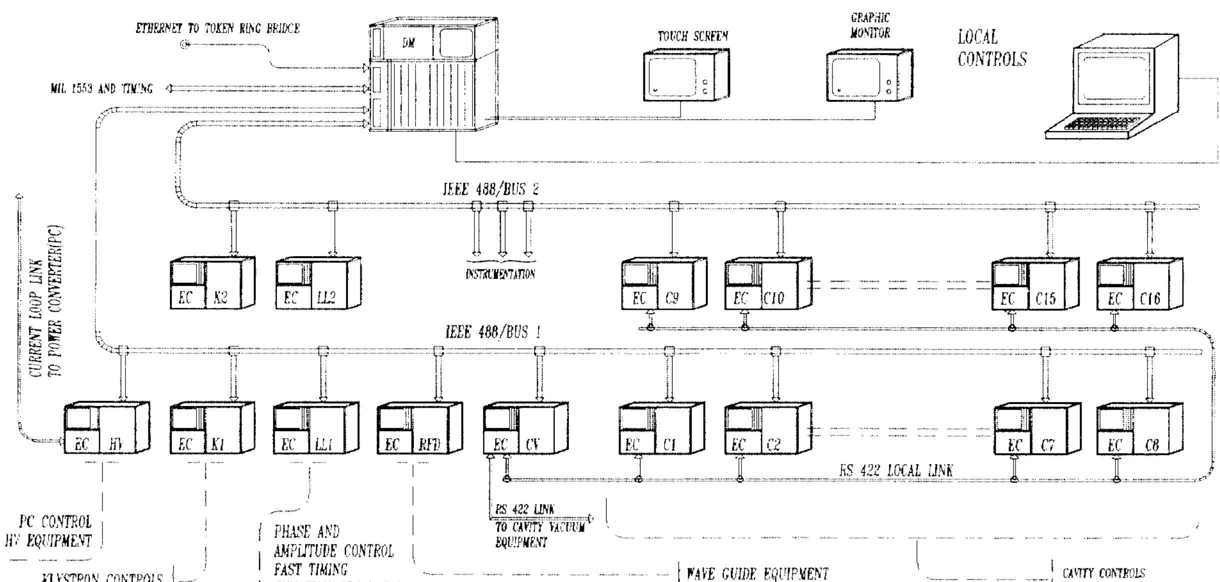

Fig. 1 RF Unit Control Layout

data and command activity on its monitor, up to 9 pages of data being selectable. This is convenient for local test or fault finding. To facilitate overall surveillance of the RF unit, a survey list of the most important data for the equipment can be returned by a single command. Logging of specific data with storage in local memory and readback of data is implemented in some cases. Specific characteristics and functions of each EC type are outlined below.

The High Voltage EC contains the control interface to the equipment making up the high voltage system, i.e. thyratron (klystron protection), klystron modulators and related components. This comprises status readings, cooling temperatures, protection interlocks, voltage measurements etc. The HV controller has access to the klystron power converter, situated in a surface building, via a point to point RS232 link. The klystron power converter has its own local intelligence [3] and is controlled by the transfer of simple messages over the link. The HV controller can therefore monitor the operation of the high voltage system and the klystron power converter.

The Klystron ECs (K1 and K2) in a similar manner, contain the interface to equipment related to each klystron, e.g. filament and focus supplies, RF drive amplifier, klystron modulator and loop controls, DC voltage and current measurements, klystron input and output power measurements, temperatures and interlocks.

The Cavity ECs (C1 to C16) interface equipment specific to each cavity, i.e. the cavity tuning system, RF power measurements, interlocks and temperatures. The cavity tuning interface comprises detector readings, set points, 'slow sum' signals and direct control of the drives of the three tuner pistons. Local software permits auto zeroing of detector errors to facilitate initial setting up of the tuning system. Local software is also used to bring the tuners to locally stored nominal starting values when the RF unit is switched on. Each cavity EC is supplied with cavity vacuum data from the cavity vacuum controller. This permits local logging of vacuum data and RF power which is of particular interest during cavity conditioning.

The first Low Level EC (LL1) handles the analog and RF electronics for voltage and phase control of the unit, i.e. the amplitude control system, klystron drive level controls, RF switch and its interlocks, RF/LF phase shifters and the function generator [4]. EC LL2 is assigned to tcontrol RF regeneration electronics, beam synchronized timing, the longitudinal feedback systems and fibre optic signal selection.

The RF Distribution EC monitors equipment associated with the klystron circulators and the waveguide system, e.g. circulator power supply, RF power measurements, circulator and load temperature measurements, waveguide and circulator interlocks and summary interlocks from each cavity.

The Cavity Vacuum (CV) EC allows data acquisition from and limited control of cavity vacuum equipment (guages and pumps), which in common with the rest of the vacuum components in LEP have their own resident intelligence [5]. It links to the local area network of the vacuum system. It passes any commands it receives to the relevant piece of vacuum equipment. Interrogation of all cavity vacuum guages and distribution of readings to the Cavity Equipment Controllers is undertaken automatically.

The EC Software handles local bus communications, local graphics, and I/O modules. Each EC type has its own equipment library and specific command interpreter. The software is single task only. The main program is a loop which carries out surveillance, acquisition and logging. The software which handles IEEE488 and RS422 communications is interrupt driven and written in Assembler to assure rapid response to external commands. Practically all of the software was written in Turbo Pascal running on CP/M. This allowed rapid, straightforward development and debugging of all software, important in view of the large number of specific equipment functions

Data Manager Functions and Software

The Data Manager is a 9U crate with a VME bus backplane containing a main 68020 CPU with hard disc and onboard Ethernet interface, two slave 68000 processors to handle the IEEE488 buses, two graphics modules for touch screen and display monitors, MIL-1553 interface and GMT timing module.

The Data Manager provides facilities for local operator control of the unit and remote control via the 1553 multidrop. It has access, via the IEEE488 buses, to the ECs and can therefore access all hardware states, settings and values in the the unit. The local operator accesses equipment via a touch sensitive screen and graphics display monitor. A menu tree based on selection of equipment type and function provides an easy to follow structure giving access to all aspects of the unit. For remote control a command interpreter directs the command to the equipment concerned. An important function of the Data Manager is to execute sequential control procedures which involve several elements of the unit, e.g. switch on/off procedures, asynchronous ramping and cavity conditioning tasks. The running of these tasks may be controlled locally from the touch screen or remotely from the PCR.

A background surveillance program runs permanently in the Data Manager which updates at an interval of 15 seconds. This monitors the overall state of the unit and around 200 of the most critical individual equipment states, values and settings. It displays information the colour graphics monitor and stores it in a data module. This can be returned in block form to the PCR to simplify surveillance of the overall RF system. In the event of loss of RF power or klystron DC power due to a fault, interlock information, such as current status and fault history is obtained from the ECs in order to to determine the cause. A diagnostic message is displayed on the monitor and a message containing the diagnostics is sent over the LEP general alarm system. Other surveillance programs can be run to perform continuous acquisition and display of given states or measurement values related to groups of equipment, e.g. all cavity vacuum readings, temperature measurements for all cavities or both klystrons, cavity power readings etc. For units with superconducting cavities critical data such as cavity temperatures, cryostat levels and pressures are logged on the hard disc. An Ethernet interface and TCP/IP communications software are installed in the Data Managers and will be used to simplify the transfer of logging and surveillance data.

The main CPU of the Data Manager must handle several concurrent tasks and a resident real time multi-tasking operating system is required. The OS9-68020 operating system was chosen. All the software is written in 'C'. This includes software for graphics, touch screen control, MIL-1553 communications and timing, as well as the application software. The slave CPUs are single tasking, with no resident operating system, but the programs which they run were developed in 'C' under OS9.

Communications

Communication between Data Manager and the ECs is based on simple command response transfer of ASCII strings. On receiving a request from the Data Manager an EC carries out an action then returns a reply string. The command format originally used [2] has been replaced with one in which the command message transmitted resembles the corresponding Data Manager 'C' language function call. E.g. **dsum()**, **s_focus(K2,ON)**, and **m_tunp(C16,AT,50.0)** to read the RF voltage detector sum, to set the klystron 2 focus supply on and to move all tuners of cavity 16 to 50 % result in the ASCII strings "**dsum()**", "**s_focus(ON)**" and "**m_tunp(AT,50.0)**" being sent to Low Level 1, to klystron 2 and to cavity 16 EC respectively. This approach gives consistency and is also convenient in view of the fact that most of the large number of function calls required in the Data Manager for 'C' language programs are simply defined as macros in which the command string is declared. The underline character '_' denotes that the command is something other than a passive read and its presence can be used by a simple equipment protection system.

The IEEE488 bus being byte parallel has a rapid data tranfer rate. The total duration of a transaction is determined mainly by the the time taken for the interpretation of the command, the carrying out of the action and the forming of the reply. Overall transaction times are generally between 10 and 50 milliseconds. A disadvantage with command/response is that during this time the bus is blocked for other activity. The number of transactions needed can be minimized by making maximum use of local intelligence in the ECs. For multiple transactions, when the same command is sent to a group of ECs, the Data Manager first distributes the command before sequentially collecting the replies. In this way a multiple access takes the same order of time as a single access. In addition, multiple commands over the two separate buses can be handled simultaneously by the two Data Manager slave CPUs. Extensive use is made of multiple commands in the local surveillance program where every 15 seconds a mixture of 200 data values, including reals, integers and strings is aquired in less than two seconds.

The Data Manager runs concurrent processes, several of which may require access to the equipment over the IEEE488 buses. Simultaneous access of the buses by several processes must be prevented. A

means of bus control, allowing ordered interleaved access for each process, is required such that all processes can continue in a parallel and regular manner. The two IEEE488 buses are handled independently of the main CPU by their own slave CPU modules, communication between the main CPU and the slave CPU is by common memory buffer. This buffer permits a simple means of control of bus usage for the various tasks. It is organized as shown in Figure 2.
The concurrent tasks which can run on the Data Manager are grouped into 8 types, e.g. local acquisition, remote acquisition, surveillance, conditioning etc. Only one process of each type is allowed to run at a time. Eight buffers are allocated in the common memory, one for each type of process. A process requiring an IEEE488 access loads the command string, sets the elements of the 32 byte device array according to the device or devices to be accessed and sets the appropriate command pending flags. The program in the slave CPU loops continuously checking these flags. If one is set it sends the command to the devices specified, puts the replies from each device accessed into its corresponding reply string area and sets the reply ready flag. This indicates to the waiting main process that data is available. All process types are serviced in sequence and have the same priority. Conversion to required data types, single or multiple is performed by a set of library routines called by the main process.

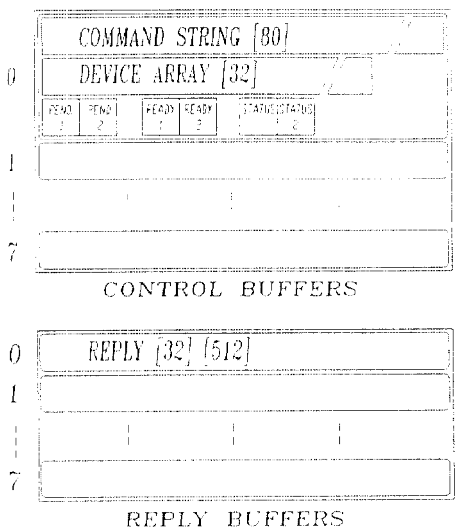

Figure 2 IEEE488 Common Memory Buffer

Use of Distributed Control

It has been attempted to make maximum use of distributed control and available local intelligence in order to obtain best efficiency in the control procedures used for operation of the RF unit, e.g. for surveillance, switch on, ramp preparation, conditioning.
The overall procedure of switching on the RF unit from cold consists of four phases, each corresponding to a separate local Data Manager procedure. For local control, operator intervention is required to initiate each phase. In the PCR, however, this is usually handled by an application program.
The actions carried out and the ECs accessed are shown in the diagram. Most of the steps involve a single EC access. Actions such as switch on of filaments, focus supplies and drive amplifiers, or setting up the klystron loops at present done in 3 steps could be done using a single command.

Upgrading for Superconducting Cavities

Twelve new RF units with 16 superconducting cavities (4 cryostats each containing 4 cavities) will be progressively installed over the next 3-4 years for the upgrade of LEP to higher energy. The high power RF system will be similar to that of the present units, as well as all related low power and controls equipment. At present one new unit with 4 superconducting cavities is being put into operation. A new cavity EC is required for these units. Four more ECs will be added per unit for cryostat functions. Facilities for local logging of cryostat data and cavity temperatures are important for superconducting cavities, paricularly in the initial stages of operation.

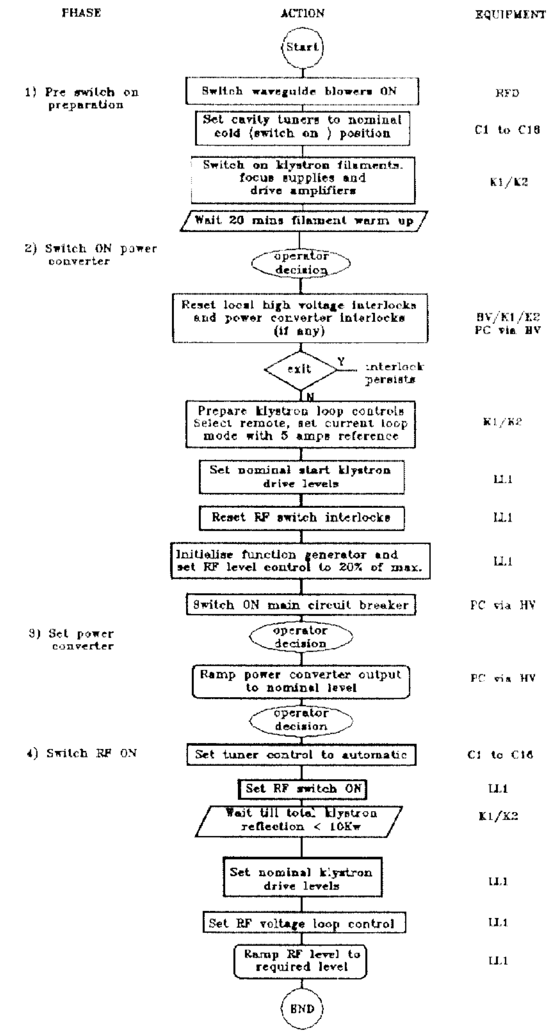

Figure 3: Flow Diagram of RF Unit Switch On Procedure

Conclusions

Distributed local intelligence and assoicated modularity have provided the necessary degree of flexibility and efficiency. Implementation of the IEEE488 bus standard has resulted in straightforward communications with minimum software overhead. In addition direct connection of instrumentation is possible. Modularity permits the separate testing of individual elements and subsystems. Modification or introduction of functions can be made at the equipment level without major software changes at higher levels.

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