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Digital Control of the Superconducting Cavities for the LEP Energy Upgrade

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Abstract

The superconducting (SC) cavities for the LEP200 energy upgrade will be installed in units of 16 as for the present copper cavity system. Similar equipment will be used for RF power generation and distribution, for the low-level RF system and for digital control. The SC cavities and their associated equipment however require different interface hardware and new control software. To simplify routine operation control of the SC cavity units is made to resemble as closely as possible that of the existing units. Specific controls for the SC cavities at the equipment level, the facilities available and the integration of the SC cavity units into the LEP RF control system are described.

I. Introduction

The RF system for LEP phase 1 consists of a total of 128 RF accelerating/storage cavity assemblies operating at 352 MHz, providing a total circumferal voltage of 400 MV. The cavities have been installed around interaction points 2 and 6 in the form of eight individual RF units. Each consists of 16 cavities, two 1 MW klystrons, DC high voltage power converter, low-level electronics and controls. For the LEP200 energy upgrade to 90 GeV, requiring 2000 MV, a further 192 superconducting (SC) cavities will be installed in 12 new RF units, two at each of points 2 and 6 and four at each of points 4 and 8. The RF frequency for the SC units is the same as for the copper units and as far as possible they will use identical equipment i.e. klystrons, power converter, low-level equipment and controls.

The SC cavities are housed in groups of four in a common cryostat to make up an "RF module". Initially only one klystron will be installed per unit but there is provision to add a second for higher beam intensities.

Control of the SC cavities and associated equipment is based on the same principles as for the copper cavities with the same type of interface equipment and software. To render overall operation as straightforward as possible differences between the two types of RF unit are taken into account by local software. Unlike the copper cavity units the SC units can be run in different configurations e.g. four, eight, 12 or 16 cavities and with either one or two klystrons per unit. The configuration must be taken into account by the local software. With two klystrons SC cavity units could be operated more effectively as two "sub-units" of eight cavities and one klystron sharing the common HV power supply. This option is allowed for in the hardware layout and software.

At present one unit with 12 SC cavities is operational in LEP and further units will be installed gradually up to the completion of the project, planned for the beginning of 1994.

II. Controls and Instrumentation for the LEP SC Cavities

Within the RF unit the various pieces of equipment associated with each major element of the unit are grouped together and controlled by a G64 bus standard based 'Equipment Controller' (EC). As for the copper cavity units there is one EC for each SC cavity but for each RF module there is an additional EC for cryogenics data. The EC is of modular construction and maximum use is made of a small range of interface cards. Standard modules are used to interface the following equipment :

- Cavity tuning systems,
- RF power measurement,
- RF window and helium gas return heating,
- HOM coupler fundamental mode power measurement,
- Helium gas pressure measurement,
- Helium gas valve control,
- Cryostat insulating vacuum,
- Cavity vacuum.

Interlock protection systems exist to switch off cavity tuning, RF or the HV power converter in the event of a fault or unsafe condition. These systems are largely contained within the ECs in the form of standard interlock modules and G64 readout interfaces which provide fault status and record trip sequences. For the SC cavities a "beam dump" interlock has been added. In the event of very high helium gas pressure or low liquid helium level, RF is switched off in all RF units.

For temperature measurements in the cavity a dedicated module inside the cavity EC measures up to 32 temperatures from signals from Pt100 sensors at various critical points. Conversion of voltage levels to temperature values in degrees Kelvin is done by the EC. Independent hardware logic inside the module triggers RF or tuner interlocks in the event of a change outside preset levels stored in EPROM. Fault information is stored and can be read via the the G64 bus.

A dedicated module in the cryostat EC provides a readout of liquid helium level in the cryostat. This, together with the gas pressure readings and RF levels, is made available via hard wired links to the regulation system of the cryogenics plant.

The design of the above equipment and interface hardware has been finalised and the material for the 180 cavities yet to be installed is being manufactured in outside industry.

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III. Local Control

The control layout for the equipment of the RF unit, situated in racks underground in the klystron gallery beside the LEP machine tunnel, is shown in Figure 1.

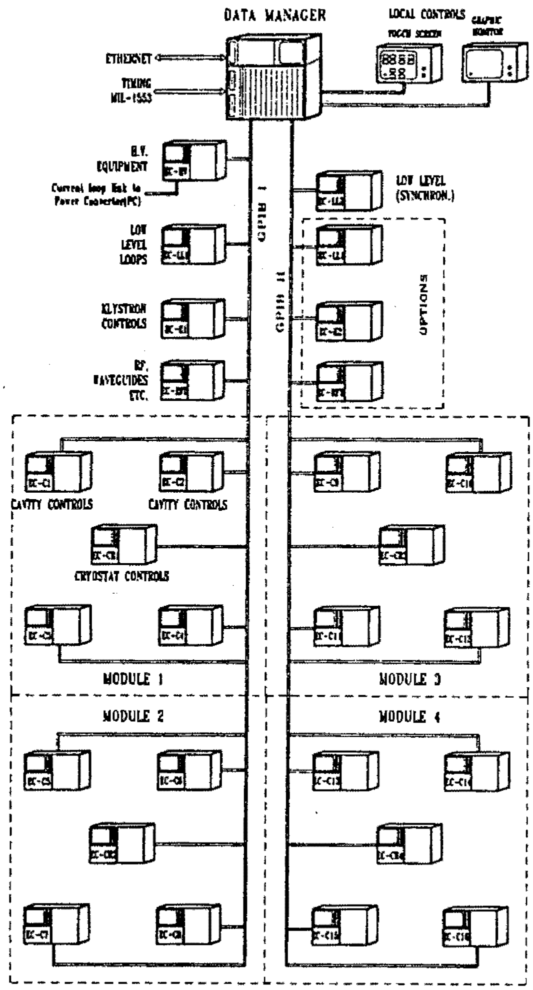

Figure 1 Control Layout within an SC Cavity RF Unit

An EC is dedicated to each major element of the unit i.e. HV equipment, klystron(s), low-level equipment, waveguide system, cavities and cryostats. For the SC units one or two klystrons can be installed, depending on available beam intensity. Second low-level and waveguide system ECs are allowed for to give independent RF operation of two [illegible]ht-cavity sub-units if two klystrons are used. Overall co[illegible] each RF unit is provided by a VME based "Data M[illegible] (DM) running a multitasking operating syst[illegible] It communicates with the ECs via two local IEEE [illegible] (GPIB) buses.

The DM provides remote and local access to all equipment parameters via the ECs either singly or in groups. The DM equipment access functions have been modified for the case of the SC unit in order to cope with the various configuration possibilites. The low-level bus access routines make use of a preset array stored in battery-backed-up memory which indicates active ECs. The DM also executes control procedures involving access to various pieces of equipment, for example HV switch-on, RF switch-on, RF ramping and local surveillance.

For example the RF switch-on procedure for the SC cavity units involves the presetting of the various control loops, setting of initial klystron input drive level and cathode currents, clearing of any RF interlocks, setting the tuning to the correct mode and setting nominal tuning system reference values. After RF switch on klystron drive level and current are slowly increased to a given value of total forward power, sufficient to allow the cavity tuning systems to operate in the presence of LEP beam. As the cavities approach resonance they are slightly detuned by introducing a tuning reference offset to avoid producing full RF voltage and resulting large variation in synchrotron frequency. Once all cavities are in this state the voltage control loop is switched on, the tuning of all cavities returned to nominal and the starting RF voltage set.

While this and other procedures can be different from those of the copper cavity units they are called up in exactly the same way. All equipment and hardware dissimilarities are handled as far as possible by the DM and the ECs.

IV. Overall Control of the LEP RF System Including SC Cavity Units

The DMs at each point equipped with RF are interconnected by an Ethernet segment and to the general LEP control system Token Rings by bridges.

The principles of operation for the SC units are exactly the same as for the copper cavity units. Direct remote access must be provided for all equipment functions in view of the large amount of equipment and the long distances from the control centre. At the same time maximum use is made of local intelligence at the levels of the DMs and ECs to reduce the amount of accesses required for standard operational procedures, such as switch on and setting up the RF voltage ramp for acceleration. These procedures are initiated by simple commands, the same for both SC and copper cavity units, and are normally carried out simultaneously in all units.

The Apollo workstations used for LEP operation in the Prevessin Control Room (PCR) communicate with the DMs and ECs over the network and local buses. Network communications are based on standard TCP/IP socket library routines[2]. Simple protocols based on command response using strings of ASCII characters are used throughout. The command formats sent resemble their corresponding equivalent "C" language functions with additional information denoting the unit and equipment EC to be accessed. The equipment access functions are implemented as simple macro definitions which invoke command response and appropriate data conversion procedures.

For example in a local DM program the "C" language function "s_valve(C9,3,40.0)" will cause the string "s_valve(3,40.0)" to be sent to the EC of cavity 9 requesting it to set helium gas valve 3 to 40 per cent of its range. The

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EC carries out the action and returns a reply in string form e.g. "OK" for successful completion. Similarly the corresponding function at the level of the PCR workstation, "LRFSetValve(LRF_233,C9,3,40.0)", causes the string command "C9_RS,0_0,s_valve(3,40.0)" to arrive at the DM of LEP RF unit 233. The command format is compatible with the LEP standard command format intended for communication over the MIL-1553 bus : C9 is the device to be acted on in member 233 of family LRF and RS denotes that a reply in string form is expected. The reply is always in string form and when a numerical reply is to be returned it is converted at the source, the appropriate function being part of the macro definition.

This method first of all allows simple direct command response for remote access to equipment. This low-level access is essential in initial commissioning and has proved to be of value later on for troubleshooting. The command format reflects the logical path to the equipment and the function itself can be clearly understood and easily remembered by the equipment specialist. The underline character in the example given is included in all commands which change equipment states or values to permit a simple equipment protection system.

Secondly, the method of implementing equipment functions as macros based on the same simple direct command/response communication protocols allows straightforward build-up of more complicated software, both at the levels of the DM and the PCR workstations. The total number of functions defined both for the DM and for the PCR workstation is over 300, of which around 50 are specifically related to SC cavity control and data acquisition. The initiation and monitoring of DM procedures is done in the same way, in this case the equipment accessed is the DM itself.

PCR application programs for overall RF operation are based largely on the use of these DM procedures. They are essentially data driven. Use is made of a table called the RF current data set (CDS) which is set up by the operator to indicate to the program which units are to be acted on. The table is stored in the standard Table File System (TFS) format used for LEP applications software data. The RF CDS also contains data such as HV settings and available RF voltages for the various RF units. This means that one piece of application software can handle both SC and copper cavity RF units without the type of each unit having to be checked.

For the copper cavity units a large amount of software, based on interactive graphics packages, has been provided for the RF equipment specialists to show the detailed state of operation of the various pieces of equipment. The preparation of equivalent software to handle SC cavity and cryostat equipment is in progress.

V. SURVEILLANCE AND DATA LOGGING

In the same way as for the copper cavity RF units a DM background local surveillance program gathers the most important states, settings and readings from the SC cavities and other equipment in the RF unit. The data is stored in an operating system "data module" in the form of a structure. The unit configuration must be taken into account by the surveillance program and it deduces this from the contents of the active EC array. The data structure contains approximately 300 integers, strings and floating point values and is updated every 15 seconds. The information is also stored in a cyclic buffer in the local memory of the DM. At present up to one hour of data can be stored, but this will be increased by adding more memory to the DMs. The structure is transferred to the control room on request using TCP/IP protocols directly over Ethernet and Token Ring. It is used for overall logging of RF system performance and also for a permanently updating PCR display of RF system status.

The DM also carries out logging of parameters of special interest for cryogenics. Helium levels and pressures, RF powers and cavity temperatures are measured every 15 minutes by a background program and stored in ASCII form on local hard disc in TFS format. These files can be read remotely using Telnet or copied using FTP.

VI. OPERATIONAL EXPERIENCE AND CONCLUSIONS

The incorporation of the first SC cavity RF unit and its operation with the rest of the RF system has proved straightforward. The SC cavity unit is now routinely used during the running of LEP and its operation is treated in the same way as the copper units. As in the case of the copper cavity units the response time overall of the control system is adequate and its reliability good.

Whilst the software facilities for PCR operation are as complete as those for the copper cavity units, those for the presentation of collective data and detailed equipment states for the specialist await completion. In addition initial running-in experience has shown a need for more rapid monitoring, for example to help in the diagnosis of certain faults or when *in-situ* conditioning has to be carried out. The possibility of logging helium gas pressure and RF level for example and the detection of transients is envisaged. Special instrumentation, connected via the GPIB buses, to measure such parameters will be installed.

The gradual introduction of more SC cavity units will require practically no modifications to existing operational procedures. The control system hardware is finalised and in production and software facilities will be expanded as LEP200 installation progresses.

VII. REFERENCES

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