MICRO-COMPUTER CONTROL SYSTEMS FOR THE HERA 52 MHz RF SYSTEMS

M.S. de Jong and A.B. Hood
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0

ABSTRACT

MULTIBUS I based control systems using the iAPX186 processor have been developed for both the PETRA II and HERA 52 MHz rf systems. These control systems monitor and control all aspects of system operation except for personnel safety and fast interlocks. The hardware and software design will be detailed and our operational experience with these systems will be described.

INTRODUCTION

CRNL has built two 52 MHz rf systems for the PETRA II and HERA proton synchrotrons at DESY as part of the Canadian contribution to the HERA project. These systems have been described in some detail at the previous EPAC conference[1,2], but the basic characteristics are repeated here. Each system consists of 2 rf amplifiers, cavities and all power supplies, rf fast feedback and tuning loops, and computer control systems. The PETRA II system was delivered, installed and commissioned in 1988 June and has been used in the initial commissioning of the PETRA II accelerator for protons in 1989 November. The HERA system was delivered, installed and commissioned in 1990 March. This paper describes, in more detail, the computer control system used on each rf amplifier-cavity assembly.

DESIGN REQUIREMENTS

These rf systems were delivered as essentially "turn-key" systems. This occurred because a complete system was required, instead of just individual components. There was a requirement that all the system acceptance tests to be performed at DESY during commissioning be initially performed before shipping from CRNL. This placed an initial requirement for a stand-alone control system that was available at CRNL during assembly and testing. Since a control system was required in any case, a computer-based system was selected to provide the broadest flexibility during system development. Furthermore, such a computer system could replace many of the hard-wired control functions usually found in such rf systems. Consequently, all control and interlock functions were implemented by the computer except those involving personnel safety or those requiring very fast time response. In practice, only the high-voltage interlock chain and the high-voltage crow-bar circuits do not go through the computer. In spite of the stand-alone nature of the control system, it was necessary to provide a connection to the main DESY control computer system so that the rf systems can be operated remotely from the main control room. Effectively, the computer systems make the PETRA and HERA rf systems look like large "smart" instruments. At the same time, the systems provide all the signal conditioning, digitizing, and scaling to engineering units.

These considerations led to the following general requirements for the computer systems:

(1) They must provide a local control console, used for monitoring the rf system during operation and for maintenance and commissioning tests.

(2) They must provide all hardware interlock protection of the rf systems except for the high-voltage interlocks and the high-voltage crowbars. All other hardware protection is performed by software in the computer.

(3) They must automate operation of the entire rf system. A single command can start the rf system from completely off to an operational state with all rf control loops closed and the desired rf fields in the cavities.

(4) They must handle communications with the main DESY control computers via a SEDAC[3] link, permitting remote operation of the system from the main control room.

HARDWARE

Hardware selection was determined largely by our previous experience with INTEL MULTIBUS systems, the availability of software development tools and a desire to purchase commercial equipment suitable for industrial applications as much as possible. The main requirement is for reliable hardware systems that can be easily configured to suit an application where the computer is to run a fixed ROM-based control program. A separate computer is used for each rf amplifier-cavity assembly to simplify the system configuration. A VT-100 compatible terminal is used as the local control console. No sophisticated user interface is necessary since the computers are normally operated remotely from the DESY control computers.

The hardware of each MULTIBUS computer system consists of INTEL's iSBC 186/03A processor board and iSBC 519A 72-channel digital input-output board, and Data Translation's DT 712 64-channel analog input board and DT 728 8-channel analog output board. These are supplemented by a custom interface to the SEDAC system in use at DESY, and by appropriate signal conditioning hardware. However, details of the systems are different between PETRA and HERA.

In PETRA, which was the first system built, a 4-slot chassis with serial priority resolution is used. The processor board uses 128K EPROM and 128K RAM. This is just adequate for the final hardware configuration, but during system development it was not sufficient. Software and hardware development is much easier when software can be loaded from a disk, and more memory is available for software diagnostics. Thus an 8-slot chassis was used during the development phase with a floppy disk controller and additional memory.

PETRA uses a standard analog input and output range of 0-5 V, with custom signal conditioning designed to convert all analog signals to this range. A voltage standard for signals is adequate in this case, since the control system is located only a few metres away from the amplifier, reducing stray electrical pickup. All digital signals are optically isolated from the computer for electrical transient protection.

In the HERA system, which was started 2 years after the PETRA system, an 8-slot chassis with parallel priority resolution is used. In this case, the processor board uses 128K EPROM and 256K RAM with a floppy disk and controller designed into each computer system. This has proved to be sufficient for all software development and testing.

The HERA rf computer systems are located 300 m from the rf amplifiers and cavities, which presents more difficulties in signal conditioning, especially for the analog signals. After much consideration, 4-20 mA current loops were selected for all computer control analog signals. Analog Devices 3B series of isolated modules are used for all analog signal conditioning. These are available for a wide range of input signal types and provide complete filtering, isolation, and conversion to current loops. Consequently, no significant additional design work was required for signal conditioning. Similarly, all computer control digital signals are isolated using standard CRYDOM (similar to OPTO-22) modules.

SOFTWARE

The software is completely written in PLM-86, INTEL's system programming language, and the iRMX-86 real-time multi-tasking operating system is used on each of the computers. Software was developed using an INTEL 310 development system for editing, compiling and linking. The computer control system then loaded the linked modules from a bootstrap floppy disk. After all the testing was complete, the final software was burned in EPROM's. EPROM's were used for the production version of the software because of their long-term reliability. In addition, there is no need for an operator to load the software after a power failure so that remote restart is always possible.

Software Structure

The software is broken down into 4 main components: a memory-resident data base and associated tasks, a set of tasks for implementing a finite-state machine, local control tasks and remote control. The data base contains the current status of all digital and analog input and output values, along with information on trip conditions, engineering unit conversions for analog signals, signal names and error messages. All digital values are updated every 20 ms and all analog values are updated every 100 ms. The finite-state machine concept permits a simplification of the operation of the rf system. The control system only permits the rf system to be in a specific set of different states. Only a limited number of transitions between the states are permitted, and almost all control functions are based on these transitions. Fault trip response was limited to selecting the safe state in the event of a fault. The local control tasks handle operator commands from the local control console, allowing the operator to display the system status, choose an operating state for the rf system, and update selected output values. The remote control tasks permit a similar set of operator commands from the main DESY control computers.

Software Tasks

Each of the major software tasks is now described in more detail.

Digital I/O Task: This task reads the status of all digital inputs every 20 ms and updates the data base accordingly. The data base indicates those inputs that must have a specific value in the current state. These inputs are checked to ensure this. If a digital input does not have the correct value, a fault condition exists and a message is sent to the Fault Task. The data base is then checked for digital output values that must change, and these outputs are updated.

Analog I/O Task: This task reads the value of all analog inputs every 100 ms and updates the data base. Each input is checked if the data base indicates that these inputs must be in a specific range. If a value is outside the required range, a fault condition exists and a message is sent to the Fault Task indicating that the value is either lower or higher than the desired range. The data base is then checked for analog output values that must change, and these outputs are updated.

Display Task: The local console status display is controlled by this task. The display indicates the current state of the rf system and any selected set of signal input or output values. If a fault condition occurs because an input signal has a wrong value, this task can display the status of all inputs at the time the fault condition occurred. This has proven very useful for diagnosing problems in the rf system.

Command Task: This task handles all operator input from the local console. The operator can select a desired operating state for the rf system or a set of status displays for the local console. The operator can also control a variety of utility tasks for logging the system status, conditioning the rf system or simulating acceleration cycles.

System Task: This task is started each time the rf system must make a state transition and exists until all requested state transitions are complete, at which time the task deletes itself. The state transition requests may come from the Command Task, the Remote Operation Tasks, or the Fault Task, depending upon the circumstances.

Fault Task: This task waits until it receives a message from either the Digital I/O or the Analog I/O tasks indicating that a fault condition exists. The Fault Task aborts any operator-selected state transition that may be underway by deleting and the recreating the System Task, and then sending a message to the System Task specifying the state to which the rf system should go for this fault condition. The task sends the error message associated with the fault to the local console and the main DESY control computers.

Remote Operation Tasks: This set of 4 tasks handles the SEDAC communication link between the DESY main computers and the rf control computers. The tasks provide the main control room operators with most of the functions that the local command task provides, along with appropriate error and status reporting.

State Description

The following is a more detailed description of the 5 possible states for the rf systems.

OFF: In this state, only power for the computer and some essential signal conditioning is on. All other systems are off. This is the condition when the main power breaker is turned on.

Power On: Most of the low-power equipment and signal conditioning is turned on in this state. Checks are enabled to ensure that most sensors are functioning properly. High voltage interlocks are checked to ensure they are open and the high voltage is off.

Standby: The cooling to the amplifier and cavity is turned on. The filaments to all amplifier tubes is also turned on and the high-voltage interlocks are now checked to ensure they are closed.

High Voltage On: The high voltage is turned on to all amplifier tubes and, in HERA, dc power to the solid-state driver. The entire system is operational but the rf is switched off.

Rf On: The rf is switched on and the fast feedback and tuning control loops are closed. The amplitude and phase in the cavity is regulated at the selected operating points. These points can be changed at any time now by the operator, either locally or remotely.

OPERATIONAL EXPERIENCE

The operation has proven to be very reliable. On PETRA, only one computer-based hardware fault occurred, and that during a power surge in a lightning storm when the system was off. In that case, a RS-232 line driver was damaged. No hardware faults of any kind occurred on the HERA system.

Overall fault response time is 50 to 70 ms for digital trips and 150 to 200 ms for analog trips, indicating a response latency of about 50 to 100 ms. These response times were determined using a digital oscilloscope to measure the time between the occurrence of a spark in the cavity and the rf drive being switched off.

There were some early difficulties with the software during the development phase on PETRA. These were traced to incorrect use of some operating system features that were difficult to find in a multi-tasking environment. More care, and use of real-time debugging tools, significantly reduced the problems in HERA. Significantly, although the rf system relies almost completely on the computer systems for all interlocking, no damage has occurred to the rf system because of computer failures. The computer systems have been used frequently for unattended operation overnight and on weekends, even during the rf system testing phase in HERA.

The conceptual simplification produced by using an extended finite-state machine model for the rf system kept the breakdown of rf system sequencing and error handling to a very manageable level. This provided a clear analysis essential for everyone who worked on the development of the rf system. The importance of this cannot be underestimated when trying to produce a control system with high reliability.

REFERENCES

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