© 1981 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

TEVATRON SATELLITE REFRIGERATION CONTROL SUBSYSTEM

J.R.Zagel, D.Bogert, L.J.Chapman, R.J.Ducar, J.C.Gannon, M.Harrison, G.Johnson, M.Martin and S.Segler
Fermi National Accelerator Laboratory*
P.O. Box 500
Batavia, Illinois 60510

The Refrigeration System

Refrigeration for the Tevatron is provided by 24 satellite refrigerators distributed around the ring and a Central Helium Liquefier which acts as a reservoir of liquid helium. The 24 satellite refrigerators are designed to operate as independent entities without attendant personnel. Accordingly, it is appropriate to have distributed local control and monitoring, and also to provide remote monitoring and control capability for central operations personnel. Remote control and monitoring from the main control room of the accelerator is made possible via a high speed link which allows information exchange with the central host computer.[1]

Local control is achieved by means of 24 individual self-cycling microprocessor systems which allow automatic local operation of each refrigerator. This includes operation of 12 control loops, each consisting of a controlled variable (temperature or pressure at a given point) and a process variable (valve position or engine speed).[2] (See Fig. 1.) In addition, there are a number of other monitoring points giving a total capability of 112 digitized analog signals and 64 bits of digital status. For the 24 refrigerators, this capability is already comparable to the total number of monitor points for the entire 400 GeV main ring.

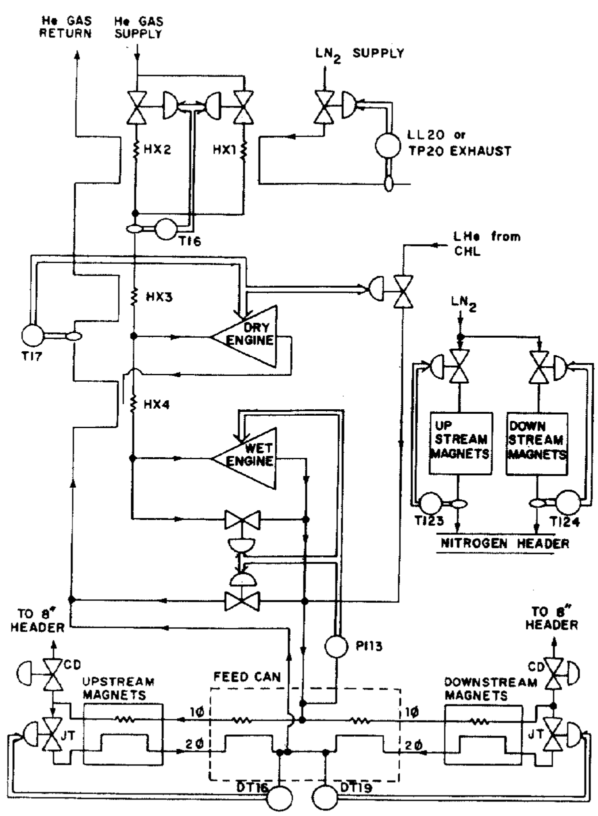

Fig. 1. Refrigeration System Control Points.

*Operated by Universities Research Association, Inc. under contract with the U.S.Department of Energy.

Satellite Refrigerator Control Hardware

The intelligence to control each satellite is provided in an Intel Multibus standard chassis. The microcomputer, memory expansion, and ADC/DAC board are commercially available units modified to adapt to this specific system. Also resident in the chassis are Fermilab designed actuator driver boards, a digital status and control board, and temperature resistor interface boards. Communications with the host computer system is accomplished through a CAMAC 080 (PIO/DMA Interface) module. (See. Fig. 2.)

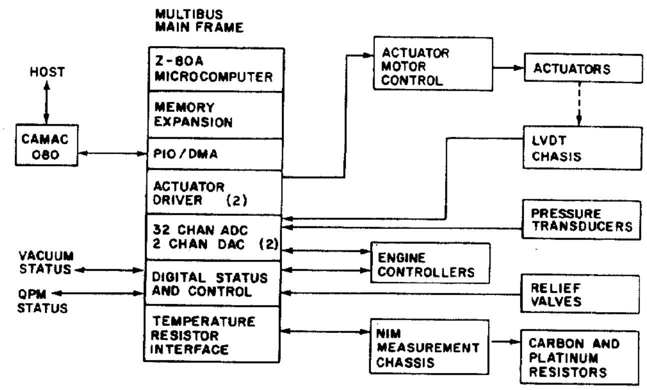

Fig. 2. Satellite Refrigerator Control Block Diagram.

The microcomputer board provides a Zilog Z-80A CPU, 6K bytes of program memory using 2716 EPROM's, 4K bytes of random access memory, both serial and parallel input-output, and floating point capability using an AMD 9512 IEEE format processor. Memory expansion is provided to allow an additional 16K bytes of EPROM and 16 bytes of RAM.

Each actuator driver board is capable of controlling eight actuators. The output consists of a direction and a duration provided as both a dc level and a pulsed 50 ms square wave. The output may be varied from as short as 50 ms to as long as 10 seconds for each actuator command. A level is provided from each actuator to provide for local/remote operation of each control loop. In the local mode, control system outputs to the actuators are inhibited. All signals between the driver board and the individual actuators are optically coupled to eliminate noise problems. The digital status and control board provides 40 bits of input status (24 optically coupled and 16 TTL) and 24 bits of control outputs (eight relay outputs and 16 TTL latches).

The temperature resistor interface board controls the NIM module temperature resistor measuring circuitry. Twenty-four platinum and/or carbon resistors are normally scanned at a one second rate and data are stored in the Multibus system. A single resistor may be scanned at a programmable interval from 50 ms to 54 minutes between measurements.

Satellite Refrigerator Software

The software is designed around a data pool containing many types of data: analog readings, digital status, mode indicators (e.g., "cooldown in progress"), closed loop parameters, and others.

The software comprises three modules. The first module simply initializes and cycles the other two. The initialization includes loading part of the data pool with default values stored in EPROM so that control can be quickly resumed after a power-down. The second module handles all communications with master computers (host and resident local intelligence),[1] by keeping status bits current and by processing General Host and Subsystem Protocol (GHASP) commands. This module is also present in other Tevatron subsystems and makes communications transparent to the rest of the software. The third module contains the refrigeration control software and operates on a two second cycle. These routines are either simple device drivers written in assembly language, or more "intelligent" routines, written in FORTRAN. The higher level functions include closed loops,[2] various long term control sequences (such as cooldown and warmup), alarms generation, and emergency handling interrupts. (See Fig. 3.) FORTRAN is used to simplify the initial coding of the relatively complex logic involved, and to simplify future modifications.

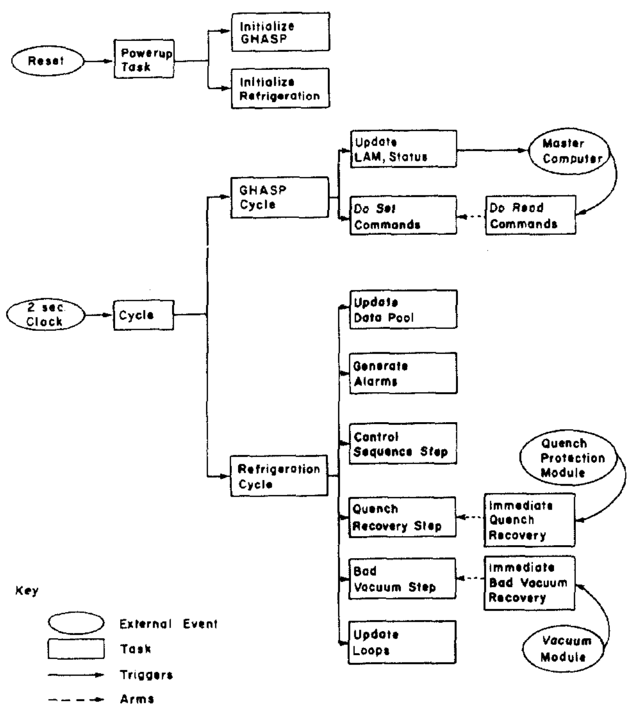

Fig. 3. Refrigeration Subsystem Software Task Structure

Refrigerator Controls Development

The complexity of the software development project was sufficient to suggest that it was advisable to study the control algorithms in an environment that permitted data logging and display facilities as well as rapid and easy alterations to code and parameters. The Research Division at Fermilab has used the Digital Equipment Corp. PDP-11 family of computers to provide these capabilities. A PDP-11/34 was acquired and existing software systems transferred with only very slight modification for the purpose of studying control algorithms. The PDP-11/34 was coded to transmit all logical control commands (in GHASP) to the Z80 microprocessor, which then issued the actual control instructions. Conversely, the microprocessor scanned the ADC channels and delivered voltage readings to the PDP-11/34 on receipt of a GHASP command. The Z80 was an integral part of the test loop, but the logic was placed in the higher level of the PDP-11/34 for the purposes of development. Once algorithms were defined, they were transferred to microprocessor control.

The PDP-11/34 system at the above ground full scale test facility (B12) includes 124K words of memory, one TU-10 tape drive, two DEC tape drives, one Versatec printer, one Tektronix 613 storage scope, one hardcopy terminal, one CRT terminal and a Jorway 411 CAMAC branch driver. The operating system is RSX 11-M. The multi-tasking capability of RSX 11-M is fully utilized since every subsystem is controlled by its own task. There are also special tasks devoted to command dispatching, data logging, and data analysis.

The refrigeration task, RCLOOP, allows the user independently to control the closed loops, with facility to examine and modify any parameter. The values of the controlled variables and valve positions can also be examined. The loop parameters for each closed loop are stored in a disk file which the user may update with new values. Any valve in the system may be positioned on command, independent of any closed loop operation. RCLOOP can log information to the disk about one or more closed loops. This information includes data, time, set value, value of controlled variable, valve position, and corrective action. Another option allows some loops to be placed in an automatic, four-stage cooldown sequence.

Much of the power and usefulness of the B12 facility is due to the data analysis tools which are available on the PDP-11. These tools are contained in an analysis package known as MULTI.[3] MULTI, which consists of one overlayed FORTRAN task and four small MACRO tasks, interacts only with the data logger; therefore, its operation is transparent to RCLOOP and other data acquisition tasks. MULTI obtains data for analysis by reading the logged files, and can produce x-y plots and histograms based on the data, including user defined algebraic expressions. A powerful dictionary facility is available which allows the user to reference the raw data and other variables symbolically. It is possible to perform the analysis either in real time or later in "playback" mode.

System Testing

The test facility at B12 was operated for several weeks while developing the control algorithms. After this time, enough was known to permit the transfer of the control logic into the Z80 microprocessor. This has been accomplished. Testing at B12 and in a string of magnets in the accelerator tunnel is scheduled to begin in March 1981. The tunnel test will utilize the new Tevatron serial link to bring control information back to the host computer system.[1] The satellite refrigerator performance will be monitored and controlled from the main control room.

References

1. D.Bogert, et al., "The Tevatron Control System," paper E-24 of this Conference.

2. M.Martin, et al., "Quasi-Optimal Algorithms for the Control Loops of the Fermilab Energy Saver Satellite Refrigerator," paper K-18 of this Conference.

3. J.F.Bartlett, et al., "TR/RSX MULTI: Packages for Data Acquisition and Analysis in High Energy Physics," IEEE Trans. Nucl. Sci., Vol NS-26, #4, August 1979. Adapted for use at B12 by D.Ritchie, Fermilab.