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THE MICROPROCESSOR-BASED CONTROL FACILITY OF THE He REFRIGERATOR SYSTEM USED IN THE 1000 GeV FERMILAB SWITCHYARD

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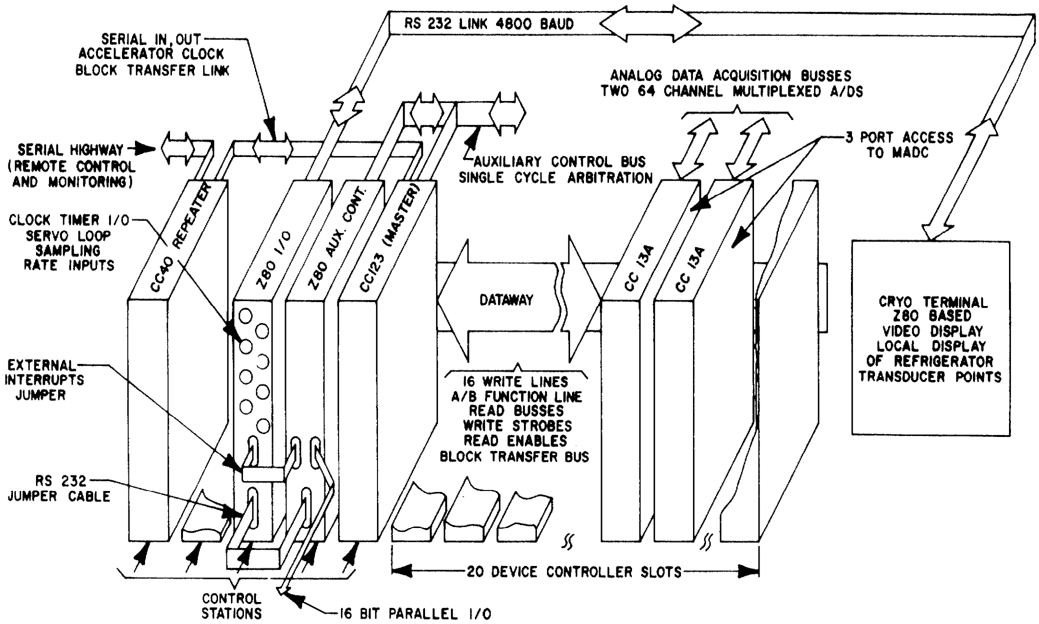

Figure 1. Liquefier Control System.

INTRODUCTION

Because of Fermilab's early commitment to computer control and monitoring, several very large control systems have evolved. The continually expanding size of these systems has begun to tax some of the central computers almost to their limits. These limitations of the central system became very visible when a helium liquefier system that would provide the necessary cryogenics for the upgrading of the Fermilab Switchyard to 1000 GeV needed to be incorporated into the existing Switchyard control system. The control and monitoring requirements of the refrigeration system were of such a nature that distributed processing became an attractive way to alleviate the overloading of the central computer that the helium liquefier would have presented. The purpose of this paper is to give a description of the hardware and software that were necessary to implement the distributed processing concept.

SYSTEM REQUIREMENTS

The following features were deemed necessary in the Helium Liquefier control system:

1. Central computer system access to approximately 100 analog transducer readings.
2. Access to these same transducer readings at the liquefier site.
3. Digital control (ON/OFF) of about 15 points in the liquefier system from both the central system and the local site.
4. A method of displaying long term changes in liquefier operating conditions.
5. Closed loop control of several liquefier parameters.
6. Any implementation must minimize or eliminate the need for modifications to the existing control system.

The first of these requirements was easily met using the existing switchyard control system hardware. Requirements 2 and 3 could be handled in the same manner, by using gauges in addition to the transducers on the liquefier system and switches for ON/OFF control. However, as the transducers were already needed for central system access, the use of gauges appeared to be an unnecessary duplication. Item 4 was satisfied by the existing central system data logging facilities. Implementation of Item 5 through the central control system would have severely taxed an already overburdened system, and required major changes in existing software.

A solution to this problem was found by using a local intelligent controller, and the Switchyard crate system's capability for a master/auxiliary mode of operation. This feature, along with an intelligent display terminal, also allowed the on-site transducer displays to be grouped in one location, in contrast to a plethora of gauges scattered throughout the system.

CONTROL STATION MODULES

CC123: Master Crate Controller

This module provides access to devices in the crate from two possible sources. The primary, or "master source" of access is the central computer system. The secondary source is the local, or auxiliary controller. The central computer system access is via a serial highway structure. The CC123 decodes the serial transmission relayed to it by the CC40 (repeater module), and acts upon the transmission when an address field contained within each transmission coincides

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with its own unique address. The remaining information within each transmission consists of a device station, a bit selecting A or B modes, a READ/WRITE flag, and in the case of a WRITE operation, 16 data bits. The time between reception of an address and decoding of the rest of the function to be performed is used in resolving simultaneous requests for dataway access between the central computer system and the local auxiliary controller. This time amounts to approximately 18 micro seconds.

The auxiliary crate controller gains access to the crate devices by requesting a dataway operation through five memory referenced registers on the CC123. Four of the five are used for data transfer, two eight-bit registers each for read and write data. The remaining register passes control and status information regarding dataway operations. Addressing of these registers is via the crate dataway lines, with data and control paths via the auxiliary controller bus.

Simultaneous requests for the crate's dataway are resolved in the following manner. Due to the serial nature of the transmissions from the central computer system, 18 micro seconds elapses between the arrival of the address field and the time when the dataway access is performed. When an address field match is detected by the CC123, a flag is set. The combination of this flag, and a second flag indicating a write operation is to be performed, sets the bus request line going to the auxiliary controller. The auxiliary has 18 μs to release the pertinent crate lines. With the Z80 auxiliary controller, in the worst case, the bus lines are released within 8 μs, well within the limit of 18 μs. This technique provides for arbitration on a single dataway cycle basis only; therefore if a module required two successive operations, conflicts could still arise, and must be dealt with in another fashion.

CC40: Composite Repeater

This module is the interface between the central system's serial highway and the master crate controller (CC123). The CC40 translates the high level, bipolar, serial highway signals into the unipolar TTL level signals that the CC123 requires.

Z80 Auxiliary Controller

As the name implies, this module is designed using the Zilog Z80 microprocessor. The module contains 4096 bytes of erasable read only memory (2716), 3074 bytes of static random access memory (2114), and two Zilog clock timer chips. The clock timer chips are used to control the sampling rates of the servo loops used in the liquefier system. Also on this module is a Zilog Programmable Input Output chip (PIO). The PIO's external device lines are brought out through the front panel of the Auxiliary Controller, along with an RS-232 serial port. The RS-232 port is driven by a Signetics 2651 Programmable Communications Interface (PCI). The crate configuration allows further memory expansion by a combination of an extension of the auxiliary controller bus to an empty device slot and use of the write data lines in the crate as address bus lines in the microprocessor system.

The Z80 bus request and bus acknowledge lines are interfaced to the auxiliary controller bus. This provides the necessary signals for dataway arbitration of simultaneous dataway requests from the two sources.

Z80 I/O

The I/O module provides an in-crate connection for easier hookup of external interrupts. It also provides a jumper path for the RS-232 link between the auxiliary controller and the local display terminal.

DEVICE CONTROLLERS

Standard switchyard controls system device controllers were used in this implementation, with one exception: the CC13A, which is a modification of the CC13 used elsewhere in the system. The new A/D controller resolved the access conflict between the master and auxiliary controllers. The standard module, or CC13, controls a 64 channel multiplexed analog-to-digital converter. Using this device requires two dataway operations when reading a channel, a write to select a channel, followed by a read which returns the data. As the CC123 only resolves access conflicts on a single cycle basis, a new means of avoiding conflict was required.

The CC13A was designed so that no changes in the central system access procedure were required. The new controller uses the A/B bit included in each dataway cycle as a flag to indicate which system is accessing the controller. The CC13A will return, in response to a Read "A" operation, the channel selected by the last Write "A" operation. Read and Write "B" operations are also paired in this manner. The central system already used "A" operations in accessing the CC13, so the "B" operations were assigned to the auxiliary controller. The CC13A gives highest priority to central system requests, requiring that the auxiliary controller check a flag bit, returned with the data, to determine when its request has been processed.

One other device controller used in this implementation was the CC16, a stepping motor controller. Stepping motors were used in this system where loss of power to the crate would be disastrous to the liquefier. The stepping motors drive potentiometers which provide the control voltages to the liquefier, thus if power is lost in the crate the potentiometer setting is not disturbed. These control voltages are returned to the A/D converter, providing for access by the auxiliary controller when power is restored.

INTELLIGENT DISPLAY TERMINAL

The display terminal, another Z80 based device, provides full graphic and alphanumeric display capabilities, along with the necessary computing power to convert and display the liquefier transducer readings. The terminal contains 16 kilobytes of EPROM for program storage, 32 kilobytes of RAM, an RS-232 port, keyboard interface, and a leverwheel switch. To help the Z80 with floating point calculations, an American Micro Devices 9511 Arithmetic Processing Unit (APU) was added. Twenty-four kilobytes of RAM are scanned by a video generator to produce a matrix of 512 by 384 points, each corresponding to one bit. Each bit is set under software control to produce the desired display on a standard video monitor. The remaining eight kilobytes of RAM can be used by the program.

Z80 AUXILIARY CONTROLLER SOFTWARE

The Z80 controller has two main functions: closed loop control of the helium liquefier system, and to gather or to change control parameters of the system. The closed loops are implemented in a table driven form, allowing for easy changes in loop parameters. These tables are presently held in RAM to facilitate modifications. With more experience in operation of the liquefier system, it is hoped that loop parameters can be fixed, thus simplifying operation. Each loop is driven by an interrupt, the rate of which can be software controlled. After each interrupt the loop software will read an A/D channel, compare the reading to a desired value, and if the difference exceeds a second parameter, (used to prevent the loop from hunting due to noise), modify a liquefier parameter by an amount proportional to the difference. Two such loops are currently being used. One controls the input temperature to a heat exchanger, the other controls the temperature of the gas returning to a compressor.

Communications with the display terminal are in the form of serial ASCII commands initiated by the display terminal. These commands allow the terminal to read an A/D channel, the contents of a "data pool" in the auxiliary crate controller, or a device in the crate. Also provided are commands to change the "data pool" or write directly to a device in the crate. A time of day clock is also available in the auxiliary controller for use by the display terminal. The timing for the clock is derived from a CTC.

DISPLAY TERMINAL SOFTWARE

The liquefier display terminal provides six different sets of information to a local user of the helium liquefier system. The first of these is an index to the rest in the form of a graphic representation of the liquefier system, with labels showing the regions covered by the other displays. Selection of these displays is accomplished with a leverwheel switch. The other five pages display up to 22 different transducer readings, each scaled into appropriate units, along with a short description of the transducer. Transducer readings can also be displayed directly in volts by flipping a toggle switch. This feature has proved useful in isolating problems with transducers and scaling software. Since many of the transducers used in the liquefier system give non-linear readings, often involving transcendental functions, an AMD 9511 Arithmetic Processing Unit (APU) helped simplify the software. In cases where the transfer function of the transducer was not known, curve fitting was used. Time and date information is also provided for convenience when video hard copies of the display screen are made. Control of closed loop parameters is accomplished using a keyboard to type commands which are relayed directly to the auxiliary crate controller.

CONCLUSION

The implementation of the liquefier control system required no changes to the central computers. Although this was a desirable feature in this case, new installations could use this structure to assist the central system. A year's operating experience with the structure has proven its versatility and reliability.

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