To the Graduate Council:

I am submitting herewith a thesis written by William Darrell Corpening entitled "Development of a Distributed Microcomputer Based System to Control Thirty Batch Reactors." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Electrical Engineering.

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DEVELOPMENT OF A DISTRIBUTED MICROCOMPUTER BASED SYSTEM TO CONTROL THIRTY BATCH REACTORS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

William Darrell Corpening

December 1980

ACKNOWLEDGMENTS

The author wishes to thank the members of his committee, Drs. R. E. Bodenheimer, D. W. Bouldin, and R. W. Rochelle. Special thanks to Dr. Bodenheimer, the thesis advisor, who went out of his way to be available for advise on the writing of the thesis.

The assistance of Mr. James C. Stapleton in developing the control algorithms and suggesting possible improvements to the distributed system is greated appreciated.

Final thanks must go to the author's wife, Karen, and daughters, Kimberly and Kelly, for their understanding for the many hours spent away from home pursuing the Master's degree.

ABSTRACT

A microcomputer based control system was designed, developed and assembled to control a single batch chemical reactor. This system employs a complex adaptive control algorithm which was arrived at empirically. This sytem was then duplicated 29 more times so that a total of 30 reactors could be controlled. The capacity was added to allow a reactor to be controlled by any one of three microcomputer systems. The 30 individual microcomputer control systems were tied to a central monitor microcomputer system using an RS232C communication link. The central monitor system allows further development, printouts of batch parameters, and a sophisticated operator interface. The distributed architecture was chosen because of the modularity of the reactor system to be controlled and because a high degree of immunity from control failure was desirable. The completed distributed system meets all criteria for reliability, response, and flexibility.

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CHAPTER I

INTRODUCTION

Why a Distributed System?

Computers are becoming an increasingly important part of every industry [14]. The advent of the microcomputer had reduced the installed cost of a small computer installation dramatically. Computers are now applied in any application that can benefit from their power and flexibility. Microcomputers are powerful tools in their own right; but when they are connected via a communication network, the power of one unit is summed with the next such that a truly powerful distributed system can result.

A distributed computer system is a network of smaller computers, each accomplishing a portion of the total task. Each individual small computer, called the node processor, can accomplish a different function, such as control or data collection or operator interface. In some distributed systems, several nodes may be used to accomplish one major system function. In most distributed systems employed in process control, the control function is delegated to many nodes.

The distribution of the control function means that hardware failure has a minimum affect on the total system control. The nightmare of the huge "number crunchers" of the 1950-1960s was the reliability problem. The failure of a single component meant hours of system downtime which in turn meant lost dollars in a data processing application and meant possible catastrophe in a process control application.

The distributed computer system concept substantially reduces this reliability problem. A failure causes the loss in only that small portion of the total system.

As a bonus of distributing the system to several independent pieces of hardware to decrease overall system risk, the node systems can be physically and electrically remote from each other. In some applications, for example--data collection systems, remote physical location of each node may be the primary reason to apply distributed type architecture.

Distribution of the control function is not a novel idea in the process control industry. Traditional process controllers have long been used to implement one loop or perhaps combinations (cascade, ratio, etc.) thus distributing the risk of failure but sacrificing the size and complexity needed to solve comprehensive control problems. Large digital computers have been overlayed on the conventional analog instrumentation in a supervisory control scheme to add the power necessary to solve these more complex control problems and to add a data processing capability. Considering the cost of both the analog instrumentation and the computer together, this supervisory computer control scheme is a very expensive venture. The distributed computer system offers simplicity and distribution of risk similar to conventional analog instruments and the power to handle complex control and data acquisition problems similar to the large supervisory computer. Figure 1 illustrates the conventional, supervisory, and distributed schemes for comparison.

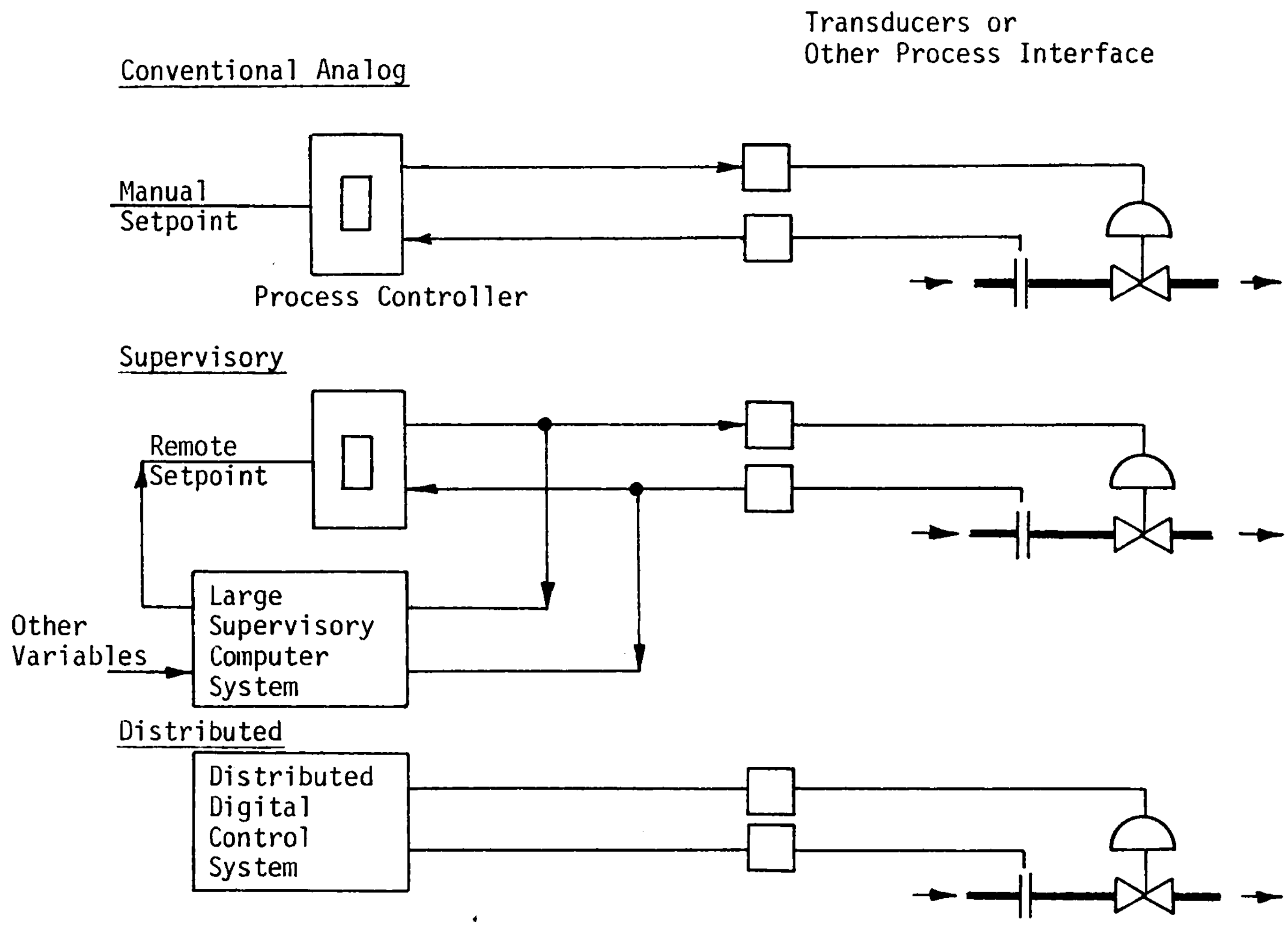


Figure 1. Conventional Analog, Supervisory, and Distributed Control Concepts.

Advantages and Disadvantages of a Distributed System

The distributed control system offers the following advantages over other types of systems. A particular application may not realize every one of these benefits.

1. The system components may function independently, therefore the distributed system has better overall reliability when compared with a large centralized system.

2. Because each node of a particular network is most probably driven with a general software package and because this software is very similar (often exactly the same) from node to node, the overall software effort is reduced when compared with a central computer concept.

3. There is a lower cost associated with the design of a prototype unit, because a distributed system is very modular and easily expandable.

4. Hardware duplication within the system and the associated parts interchangeability allow a much lower cost for replacement parts inventory and education of maintenance personnel.

5. Because system objectives for a given unit or function are usually closely kin to a particular piece of hardware and in a particular physical location, a distributed system makes individual justification of each node objective easier and more necessary.

6. The distributed control system often realizes a savings of hardware cost, electrical wiring, and physical space when compared with conventional instrumentation.

There are also a few disadvantages to a distributed architecture:

1. Some distributed systems may require more equipment than an unconnected, fragmented system.

2. Compromises are usually made in application of hardware and software at a node level so that the economy of similar equipment and programming can be realized. These compromises usually tie the user to a single vendor.

3. There is often an urge to apply a distributed system without carefully evaluating the process to be controlled or function to be accomplished. Not all problems fit well into a distributed system application.

Plant Characteristics that Make Distributed Control Suitable

In order for a distributed computer system to be easily applied and realize the stated advantages of such a system, the job to be performed by the system must have a good deal of inherent modularity. Two important yardsticks of this modularity are horizontal independence and vertical independence at the node level.

A group of batch reactors in a chemical plant can be said to display a high degree of horizontal independence if the control or sequence of one batch reactor has little or no interaction with reactors in the same group which are performing similar functions. If a reactor can be charged, controlled, and dumped without regard for timing or control of adjacent reactors, the system function being performed by this reactor is highly independent in a horizontal sense. Similarly, a system of reactors would be highly independent in a vertical sense if operations both upstream and downstream from a reactor have little or no effect on control or sequence of that reactor.

The advantages of the distributed computer system are much easier to achieve if the application or problem is easily divided into small, simple unit functions. The distribution of risk associated with a highly distributed system is reduced when the node computer must be large due to the complexity and magnitude of the function to be performed at that node.

Correctly matching the degree of distribution of the control system to the controlled process is paramount to having a reliable system that is at the same time economical. Rarely would economics dictate additional expenditures for distributed modules when the process was dependent on some portion of the system for operation of the whole. If the system is distributed to a degree less than the process to be controlled, the advantage of increased reliability due to distributed hardware is reduced somewhat.

The thirty batch reactors to be controlled by the proposed distributed system show a very high degree of both vertical and horizontal independence. The group of reactors is highly modular and fits well into the distributed type architecture. A requirement that the hardware be highly reliable and that the system bend so that hardware problems have minimal impact also dictates a distributed approach.

CHAPTER II

DESCRIPTION OF THE PROCESS AND CONTROLS

General Process Characteristics

The process to be controlled is a purely batch chemical reaction. There are 30 reactors which are essentially the same both in design and operation. Each reactor is virtually independent of the others operationally. From a control standpoint each reactor is independent from the companion processes upstream and downstream. Charging or dumping a reactor may be affected by availability of other equipment but this does not affect control during the reaction phase. Many different products may be made in any reactor, but the method of control is very similar.

Each reactor is manually charged with any number and combination of raw materials and chemicals depending on the recipe to be made. The completion of the manual charge marks the start of the batch reaction control. During the reaction phase two types of chemicals (each may be a mixture of several chemicals) are added to the batch on a time controlled basis. One type of these chemicals causes an increase in reaction rate and the other causes a temporary decrease in heat generated by the reaction. When laboratory analysis of a batch sample indicates a completed reaction, the control room operator manually terminates the batch by initiating timed addition of the finals chemicals. The reactors use common headers for charge chemicals, chemicals to be added during the process, and coolant. These headers are large enough that use of a header by one reactor does not prohibit use by any or all of the others.

Each reactor is jacketed and coolant is run through the jacket to remove heat from this highly exothermic process. Two temperatures of coolant are available on separate headers to the jacket and are separately controlled by on-off type valves. Either type of coolant may be flowing through the jacket at any instant but both headers may not be used simultaneously. A given batch usually uses only the colder coolant during the entire batch or uses the colder during the early portion of a batch and switches to the warmer coolant to complete the reaction. Cooling capacity is varied by adjusting the duty cycle on the coolant supply valve. The frequency of the change of state of this valve is kept as low as possible so that value wear is minimized. A reaction may use the coolant headers as much as deemed necessary for that batch; however, an attempt is made to minimize use of the coolant for economy.

The type of chemicals used on the initial reactor charge, the type and quantity of the chemicals added to the batch during the reaction phase, and the time-temperature curve for that batch all combine to fix the quality and properties of the reacted product. Additionally the final batch control temperature serves to "fine tune" the desired properties of the reacted product.

Since the reaction is highly exothermic and because of the reactor design and cooling capacity, the rate of heat production by the reaction may exceed the rate at which heat can be removed by the coolant system. This condition is called thermal runaway. When a batch goes into thermal runaway, a product which is of poor quality, often completely unusable, is produced.

The phases of the production cycle are defined as follows:

Procool--Coolant is run through the jacket of the empty equipment to remove latent heat left by the previous batch.

Initial Charge--Loading the reactor with product from the production step immediately upstread. This product will not react until chemicals are added to the batch. A charged reactor may wait indefinitely for the start of the reaction phase.

Initial Chemical Addition--This marks the start of the reaction. Chemicals to cause the product to react are added to the reactor.

Control Phase--Starting five minutes after the initial chemical addition, secondary additions of reactant chemicals may be made to control the temperature of the reaction such that a predefined time-temperature curve is followed as close as possible. Coolant flow to the reactor jacket is also controlled.

Temperature Lineout Phase--During the last stages of reaction a constant, somewhat elevated temperature is used as the control temperature. Reaction at this elevated temperature serves to "fine tune" the properties of the product.

Finals Addition--A judgment on whether a reaction is satisfactory and should be stopped is determined by human interpretation of laboratory data from periodic batch samples. When the product is deemed ready, chemicals are added to neutralize the reaction.

Dump--Moving the reacted product from the reactor to the next stage of processing immediately downstream. In general the finals addition and the dump are done simultaneously.

Idle--After a dump but before a new batch is ready, the equipment may wait to be charged again.

Description of Existing Controls

The physical equipment to be controlled has been installed for many years, although the age of each reactor varies. Historically, control of each reactor has been done manually using an array of timers to meter and limit the chemical additions and a controller with a manually adjusted setpoint to control coolant flow to the reactor jacket. This method requires constant, errorless adjustment by the operator.

At the beginning of a new batch, each chemical timer is set by the operator to limit the amount of time the valve controlling flow from the chemical header to the reactor is allowed to be open. Under conditions of a constant, reasonably high header pressure, this is approximately equivalent to adding a constant volume of that chemical during the batch. There is one timer per chemical additive. The selection of the type and volume of these chemicals in addition to the characteristics of the initial charge materials dictates the type of product to be made. If a particular chemical is not included in the recipe for a particular product, that timer can be set to zero. At the completion of a batch the timers are automatically reset so that if the next batch is to be the same product type as the previous batch, no manual setting of the chemical timers is needed.

The coolant controller is not a traditional analog process controller, but is simply an instrument to read process temperature and turn coolant on or off based on the sign relationship of the manually adjusted setpoint and the reactor temperature. The temperature read by the probe is not always a true indication of the average batch temperature. Because of the characteristic viscosity of the product, a substantial temperature gradient may exist within the batch. Every reactor is agitated to reduce this affect and to increase heat transfer; but generally, the temperature profile at the probe will lag the average batch temperature by a range of several seconds to several minutes. This is yet another consideration in control of the batch.

Figure 2 shows a diagram of a batch reactor.

Description of Previous Control Schemes

Two previous control schemes have been used on this group of batch reactors. Originally manual control of the chemical addition and coolant flow was used. This scheme still serves as a reliable, albeit labor intensive, backup for automatic controls. In the late 1960s a PDP 8/I minicomputer system was installed to handle some chemical additions and control flow of the coolant to the reactor jacket.

In manual operation the operator periodically adds chemicals to the batch using the timers. The schedule of these additions is based on the standard timetable for that product type and his observations of the progress of the reaction. He turns coolant on or off in an attempt to force the batch temperature along a time-temperature curve also dictated by product type. The curve he uses is generally very flat so that there is no large increase in temperature over a short period of time thus reducing the chances of thermal runaway. Experience in running a given reactor or a particular product may allow the operator to adjust the control curve upward in an effort to reduce batch time. Manual control of this sort has proven generally very

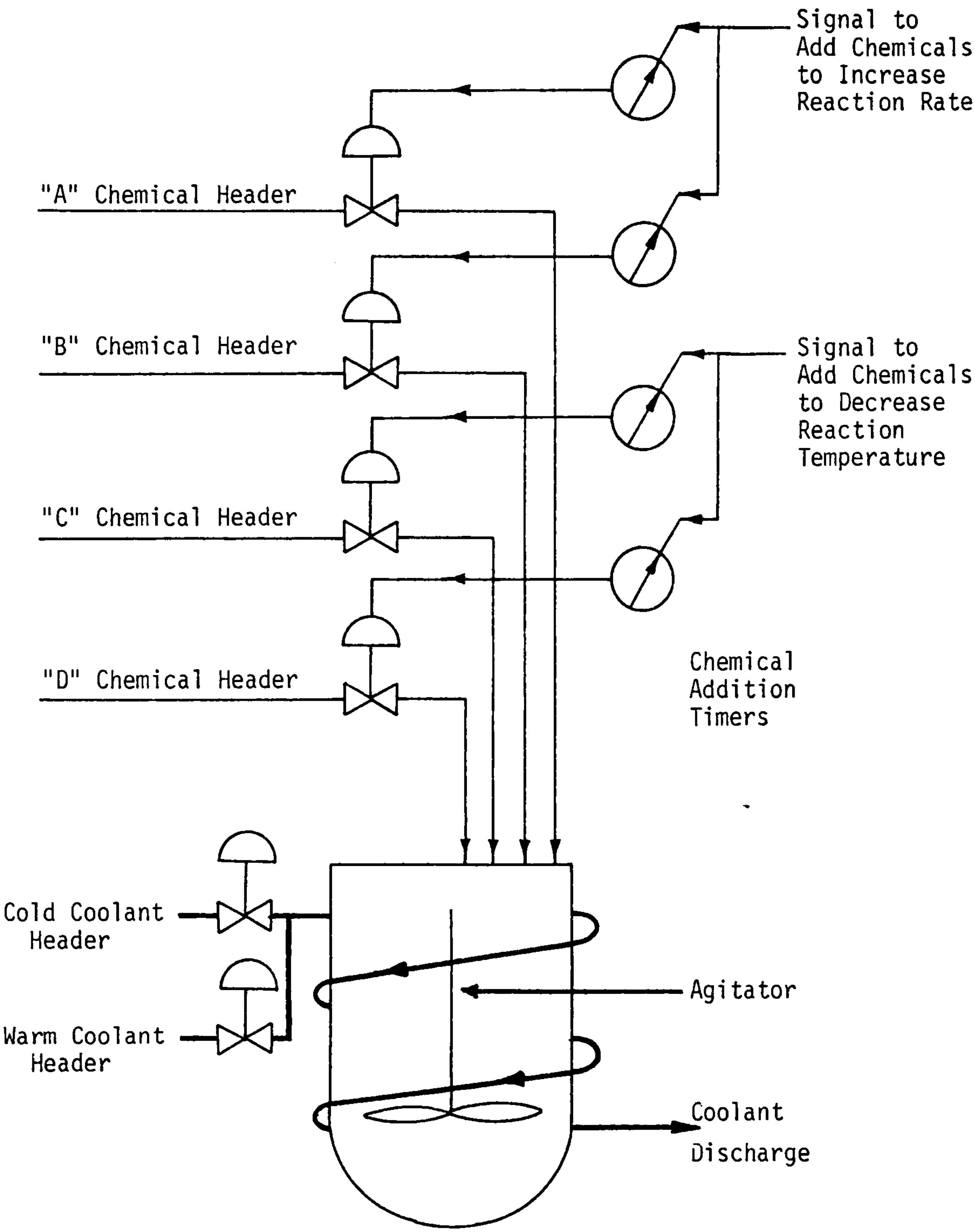


Figure 2. General Batch Reactor Schematic.

reliable but is quite labor intensive. Product quality tends to vary as a function of the experience and attentiveness of the operator. The time needed to complete the reaction is longer implying a corresponding increase in cost of production.

A Digital Equipment Corporation PDP 8/I minicomputer system was added to the existing manual controls in an attempt to decrease batch reaction times. Additionally the computer was to collect data about the batches and print reports based on this data. The supervisory computer mimics the timetables and curves used in manual operation to automatically control the reaction. Contact outputs from the computer wired in parellel with manual pushbuttons allows the computer to start stop timers at will. This scheme went a long way in reducing batch times, primarily because the computer could be very attentive. This system did not have the operator's ability to use experience from previous batches and other inputs to control adaptively. The minicomputer system also suffers from the fact that a failure in the PDP 8/I means loss of automatic control of all thirty reactors. Figure 3 shows how the manual controls, the minicomputer, and the proposed microcomputer system are electrically connected.

Objectives of the New System

In an attempt to reduce production cost, the possibility and feasibility of installing a new control system was explored. The objectives of the new control system are:

1. Reduction in batch reaction time
2. A control system that is highly reliable
3. Better control of batches characterized by a reduced number of thermal runaway batches

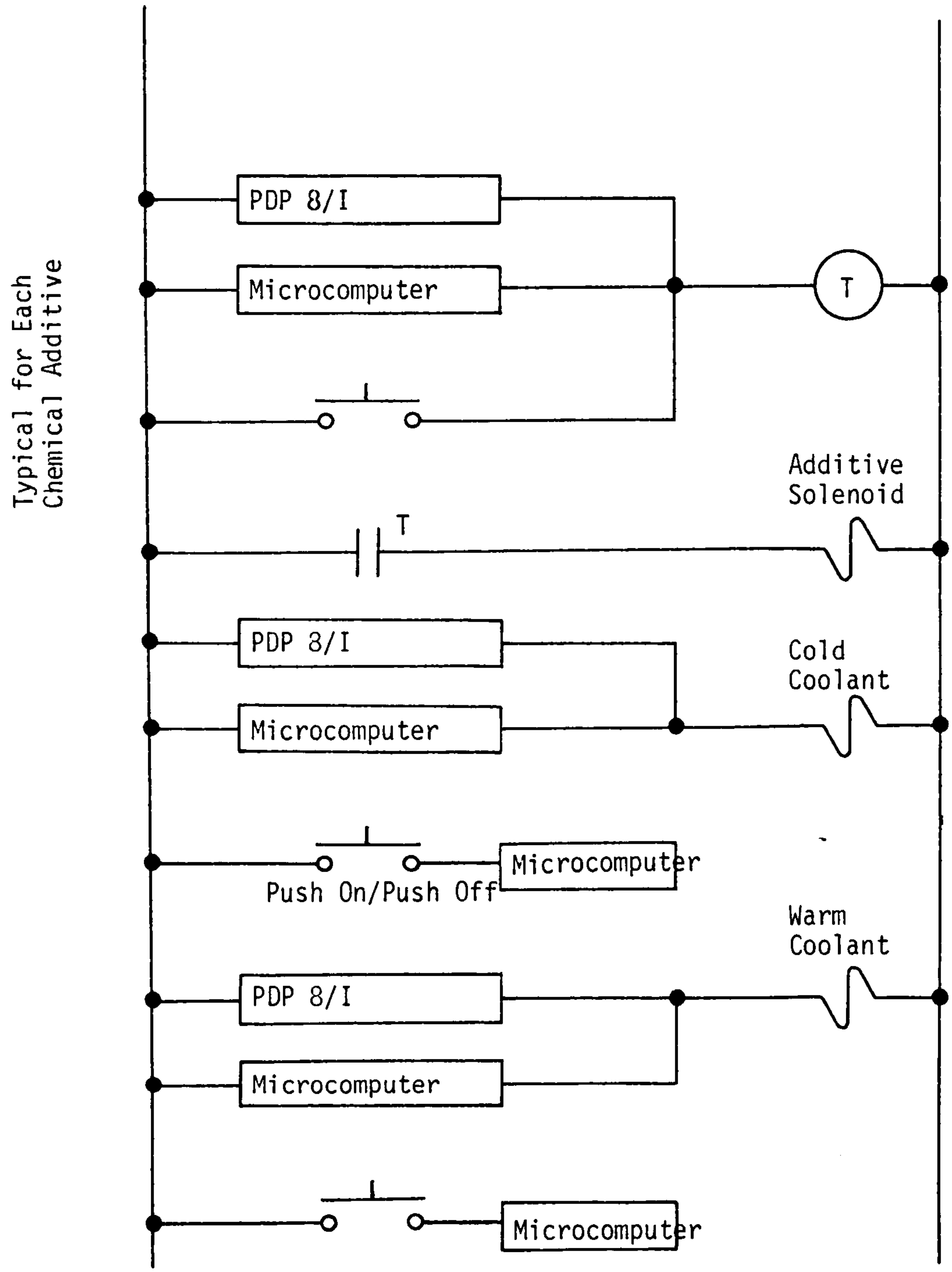


Figure 3. Ladder Diagram of Typical Electrical Controls.

4. A system that is acceptable and useable by the present operators

5. A system that draws on operator knowledge, experience, and observations about parameters affecting control performance.

Reduction of batch times has the greatest potential to save money because of the deferred capital investment in equipment to make more product. The reliability of the controls impacts this savings on an availability basis. For example, a system to reduce batch times by 20% that is available only 80% of the time is worth less than a system that reduces batch reaction times by 18% and is always available.

Observed Improvements and Additions to Previous Schemes

In an effort to thoroughly test new ideas that might be incorporated into the proposed new control system, dedicated manual control was used. One or more engineers would test each new idea by "nursing" the reaction while carefully observing the progress of the reaction and the effect the new control idea had on the reaction parameters. Any idea that showed promise in helping to meet one or more of the system objectives was tested on many batches. This method worked well because the progress of the reaction moves slowly enough that human response to the batch parameters was adequate. After testing all ideas manually a small microcomputer prototype system was installed to test each idea dynamically. These tests showed that even automatic control using the PDP 8/I could be significantly improved upon.

Various control ideas and variations were tried in an effort to improve both control and quality. The following descriptions characterize the improvements in the control algorithms and system deemed necessary to realize the design criteria and objectives.

At the end of a batch, the coolant is usually turned off so that viscosity of the batch will remain high enough to "dump" the product quickly. If the empty reactor is cooled at the completion of this dump, latent heat will not contribute to the amount of heat needed to be removed during the initial phase of the next reaction. In general, equipment upstream from the reactors are ready to charge new reactants within a very short time after completion of the previous batch. Because of this fact, a decision was made to cycle the coolant on for a five minute interval 15 minutes after the dump of the previous batch had started. This interval gives time for the dump to be completed and allows the equipment to be cooled satisfactorily before the next batch. The five minute interval was arrived at empirically since the temperature probe was useless to sense reactor temperature in the unfilled reactor. Consideration was given to having the coolant cycle on for five minutes every twenty minutes until a new start signal was received, but continuous cycling was found to be wasteful of coolant (and therefore energy) if there were a prolonged idle period between batches. Additional cooling cycles were found to be unnecessary since the temperature of the cooled, unfilled reactor would not rise above ambient.

A manual pushbutton to control coolant was needed so that the operator could manually precool prolonged idle equipment and so that the operator could take over manual control of the coolant during the reaction phase if necessary. A visual indication of the coolant on-off status was also deemed necessary since this information was available to the operator only after careful inspection of the coolant controller.

Rather than add most of the reactant chemicals which cause a reduction in heat generated by the batch during the initial chemical addition phase, a decision was made to hold out a larger portion of these chemicals. The later addition of these chemicals could be used to correct imbalances and reduce chances of thermal runaway. The amount of time necessary to complete a reaction is proportional to the area under the time-temperature curve actually followed by the batch. Keeping more chemicals back to be used in control of the reaction allows a hotter time-temperature curve to be used. This in turn allows the reaction to progress more quickly and complete the reaction in a shorter period of time. The additive holdout control idea was most responsible for helping realize the objective of reduced batch time.

A decision was made to meter all additives in smaller cycles to give better control. An addition of a chemical would dictate that there would be no new additions of that chemical for a short period. This allows time for mixing of chemicals and some initial reaction before taking further control steps. This is necessary primarily because the average batch temperature is not immediately available at the temperature probe.

CHAPTER III

THE DISTRIBUTED CONTROL SYSTEM

Choice of System

Since the Digital Equipment PDP 8/I minicomputer was already in place, making changes to that system would seem to have been an easy way to implement the new system. The PDP 8/I was not used because the software was implemented in INDAC, a BASIC-like language for which programming expertise did not exist; because the processor was already taxed both in memory capacity and speed; and because this particular system, while well designed, had a particularly poor maintenance history.

Because of the success in testing new control strategy on the prototype microcomputer system and because of the reliability such a system would afford, a distributed microcomputer system was implemented.

System Architecture

One microcomputer was installed for each reactor. After some testing using a modified prototype microcomputer system which controlled four reactors simultaneously, it was decided that three reactors could comfortably be controlled by a single microcomputer system without expansion beyond the basis processor board chosen. A switching network was proposed to allow control of the reactor by the processor associated with that reactor or by the processors that were associated with the reactors on either side. This gave excellent reliability. Each reactor could completely and independently be controlled by any one of three different processors. At least three processors would have to fail before automatic control of a reactor was lost. Under ideal fault distribution, two-thirds of the system processors could fail and the system will still maintain full automatic control of each reactor.

Each node processor is connected via a communication link to a monitor processor. The monitor stores data about each batch and the operator can observe the system through a printer console.

A system block diagram is shown in Figure 4.

Hardware Considerations--Node

A computer system consisting of a National Semiconductor Rack Mounted Computer (RMC 80/10) [1] and a Datel Systems Model 800 analog to digital expansion board [4] are the heart of the node processor. The RMC 80/10 system uses the Intel 8080 microprocessor integrated circuit.

The RMC 80/10 system consists of a BLC 80/10 processor board, a BLC-635 power supply [3], and a BLC-604 four slot card cage and backplane all in a 19 inch rack mountable enclosure [2]. The BLC 80/10 is limited to 4K PROM, 1K RAM, 48 configurable digital input/output points, and one configurable RS232C or current loop serial interface. Figure 5 shows the BLC 80/10 board in block form. This computer system was chosen because of the familiarity with this system, because of the availability of a development system for the 8080 microcomputer, and because maintenance experience and inventory spares for this hardware were already available within the plant.

A Datel Systems Model ST-800 analog to digital convertor board

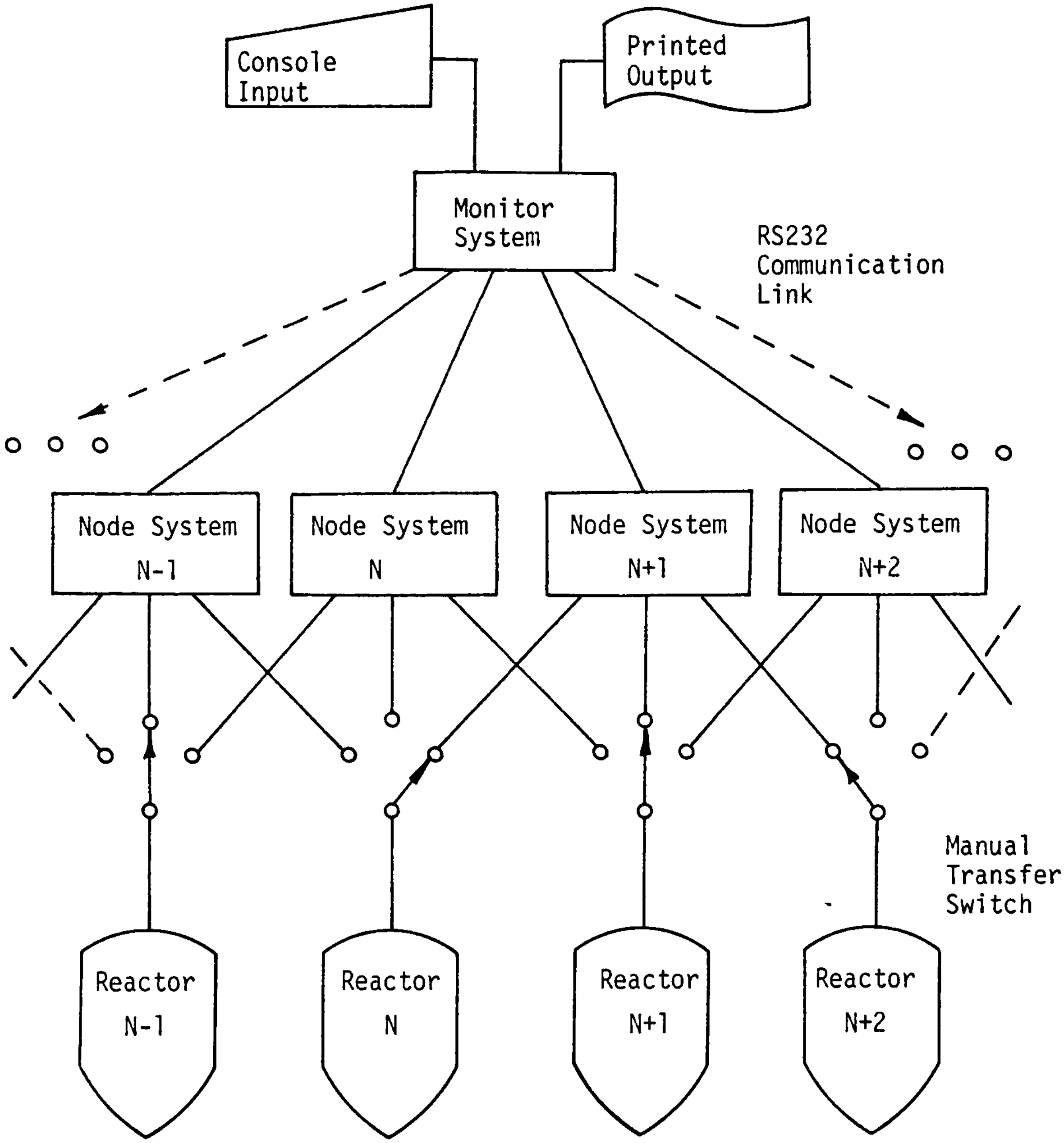


Figure 4. General Distributed System Architecture.

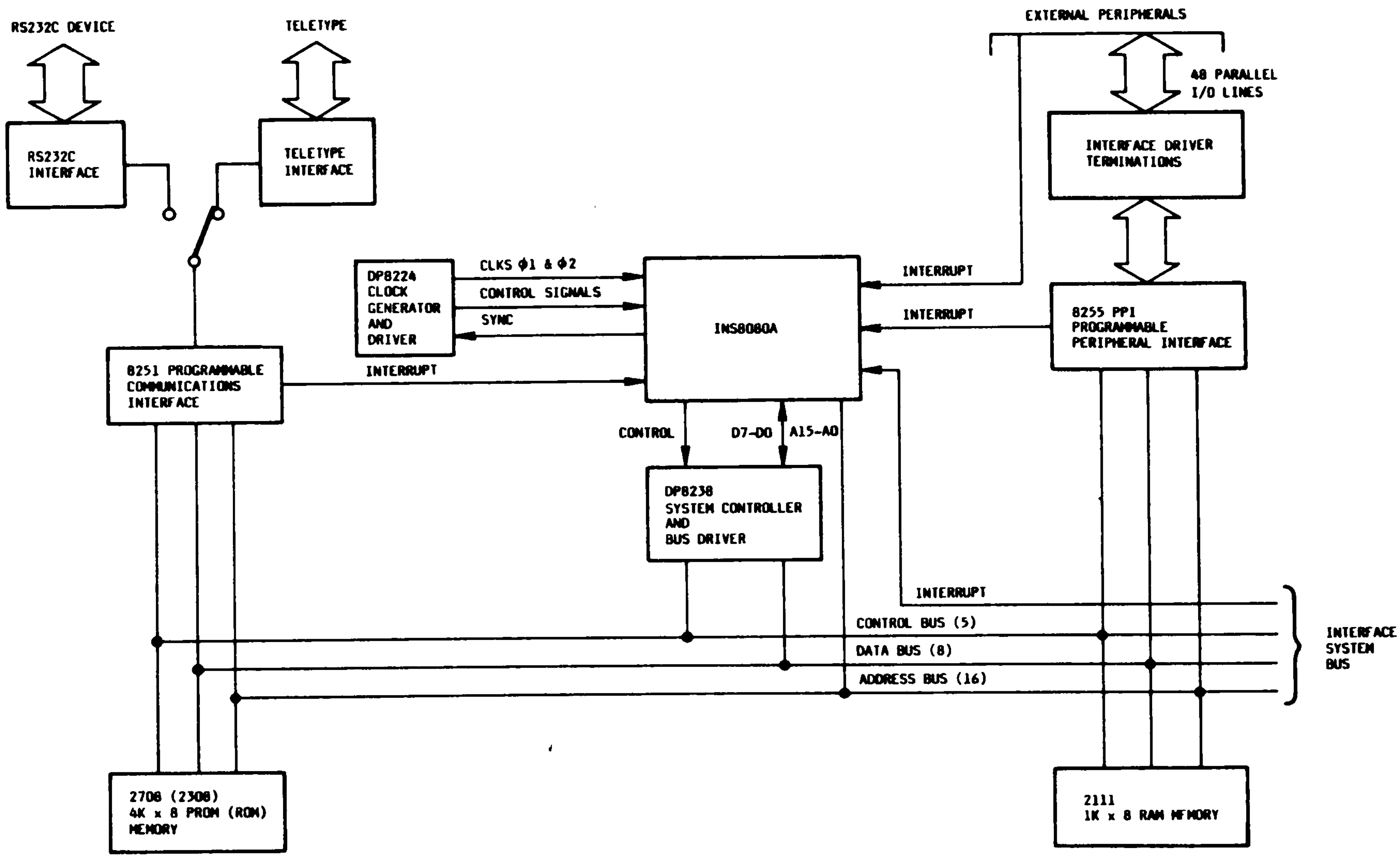


Figure 5. Board Level Computer--Block Diagram.

was used to interface the reactor temperature signals to the node processor system. This board is compatible with the RMC 80/10 system both physically and electrically and accepts up to 16 differential channels of analog input. The digitized signal is 12 bits wide which gives a resolution of one part in 4096. The range of each temperature probe signal is 170 degrees fahrenheit which means the analog board can read these signals to at least the nearest tenth of a degree. This resolution is significantly better than the other instrumentation associated with the temperature loop. The board can be configured for either memory mapped or input/output port access. The memory mapped configuration was chosen for no particular reason.

Each reactor was fitted with a microcomputer interface station which was physically located on the control panel with the existing manual controls. Included as a part of this station are eight Digitran model 9015 thumbwheel switches [6] and three Microswitch AML22 LED backlighted pushbuttons [7].

The eight thumbwheel switches are used to allow the operator to specify the absolute final control temperature, the time-temperature curve, and the chemical addition schedule to be followed for a batch. These BCD-encoded thumbwheel switches are read by a microcomputer through a diode multiplexing scheme. One of eight outputs from the microcomputer selects the switch to be read. The BCD code for that switch goes through a diode network before being read by the computer using four bits of digital input. The diodes keep the selected thumbwheel from being affected by the state of any other switch. This multiplexing scheme is illustrated in Figure 6. Use of the diode multiplexing scheme allows four inputs and eight outputs from the computer to read all eight

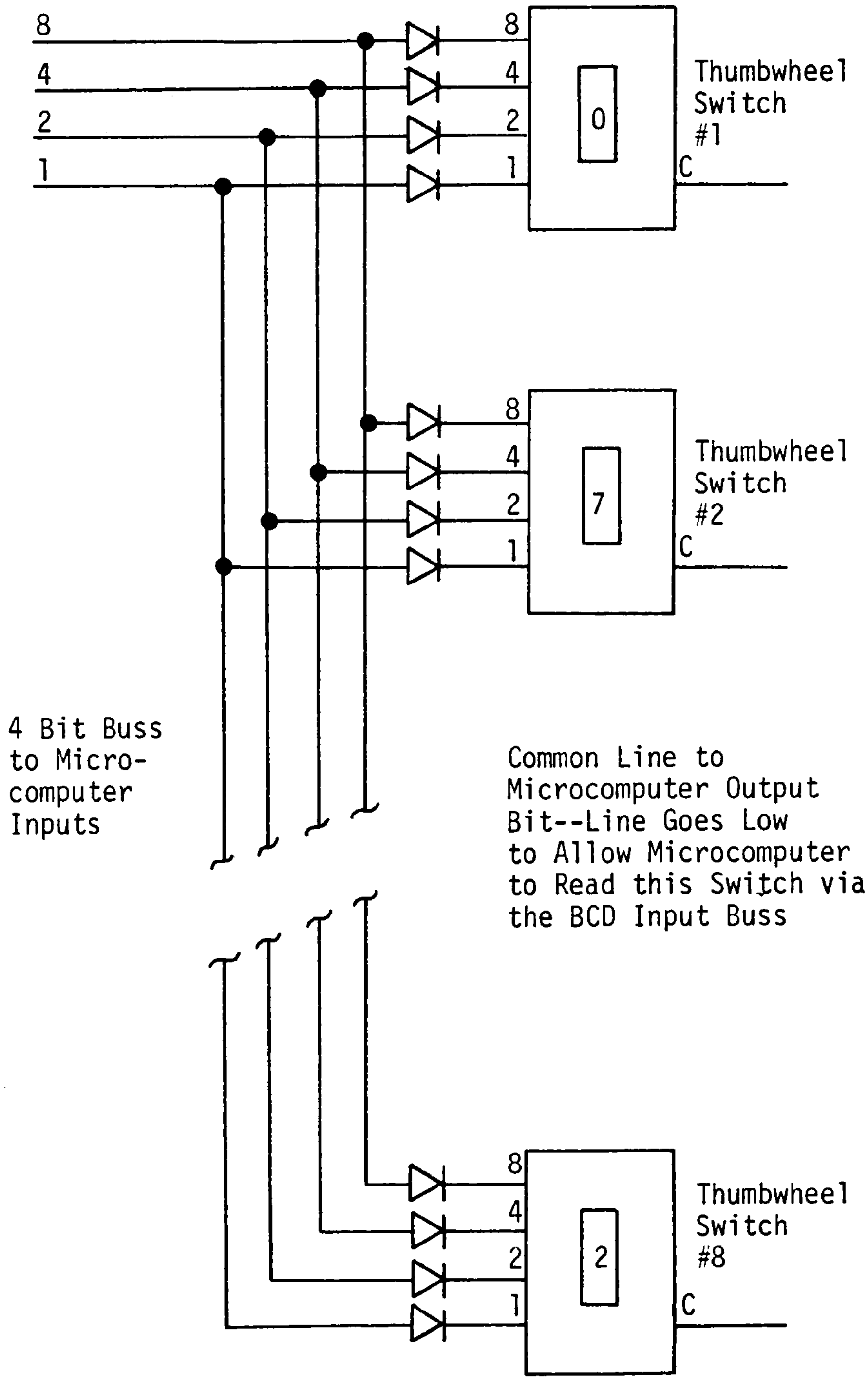


Figure 6. Thumbwheel Switch Multiplexing Scheme.

switches versus 32 independent inputs with no multiplexing.

One of the lighted pushbuttons allows for manual control of the cold coolant both during or after a batch. The pushbutton works in a push-on/push-off arrangement to toggle the cold coolant supply valve. The LED on the switch shows the state of this valve at any instant.

The second lighted pushbutton has a dual function. During the first 30 minutes of a batch, this switch serves to stop the batch time. This is sometimes necessary due to logistical problems during the early stage of the reaction. When a batch is holding, the LED blinks constantly to alert the operator of the hold condition. Very late in the batch this switch is used to manually control the warm coolant valve and show the state of the valve. In either case this switch also works in a push-on/push-off arrangement.

The third lighted pushbutton is used only as an indicator. The state of the watchdog timer circuit on the processor assigned to that reactor is shown on the LED. The same type of switch was used rather than a simple indicator for astetic reasons and to minimize the number of different spares to stock.

Figure 7 shows a front view of the entire operator station.

All inputs and outputs from the operator station go to the microcomputer only. Although some of these controls are for manual override, they do not function unless the associated microcomputer is functioning.

In addition to the thumbwheel switch and the two pushbuttons on the operator station, two additional inputs come into a processor from a reactor. The batch start signal, which is triggered by the start of the initial chemical addition timers and the final signal, which is triggered by the start of the final chemical addition timers are both

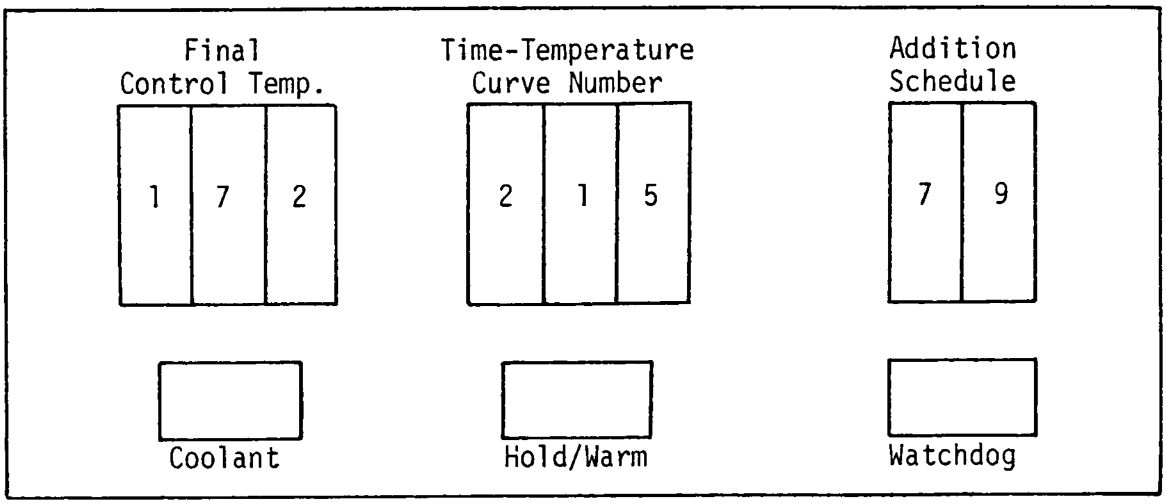


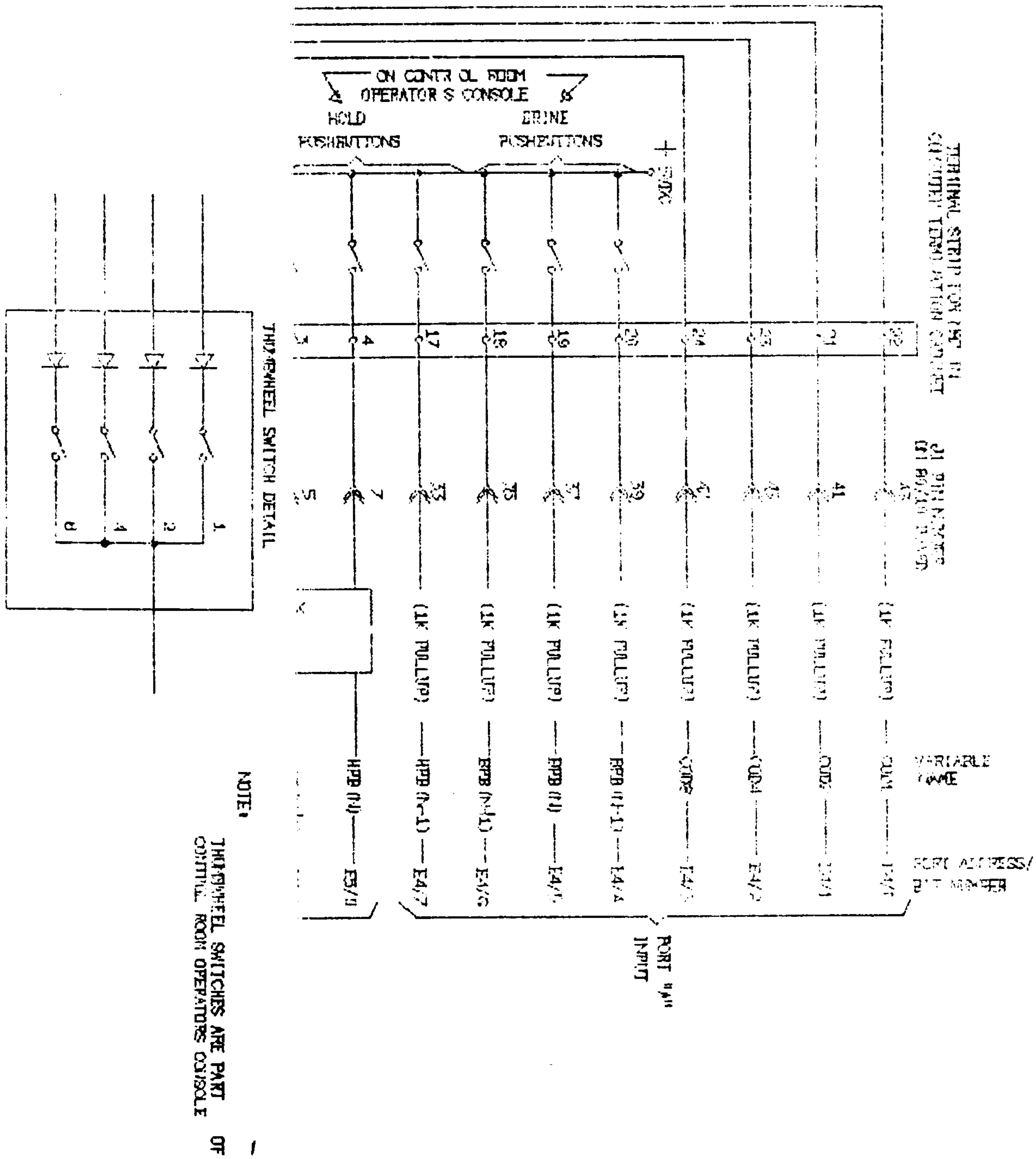
Figure 7. Operator Station.

110 volt AC signals. They are interfaced through Teledyne model 671-1 solid state relays [8]. The output from a solid state relay goes directly to a digital input on all three processors capable of controlling that reactor.

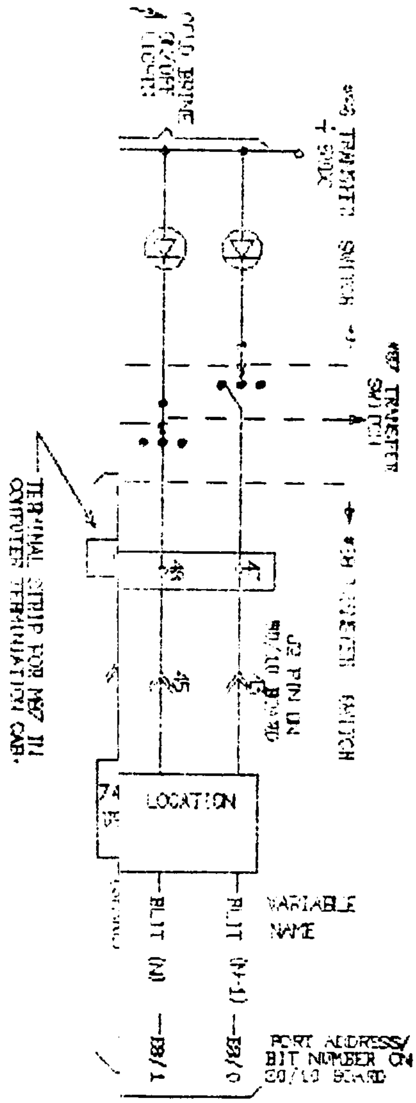
In addition to the three LEDs on the operator station, four outputs per reactor are produced by each processor. Two of these outputs cause timers to run which add chemicals during the batch--one causing one or more timers to run which adds chemicals to increase the reaction rate and the other causing one or more timers to run which adds chemicals that cause a temporary decrease in the batch temperature. The other two outputs drive solenoids which control the state of the cold and warm coolant valves. Each of these four outputs is converted to a 110 volt AC signal by a Teledyne model 671-4 solid state output module [8]. The digital output signals do not go directly to the output relays; but go through the manual transfer switch encoute. The digital output from the processor will be electrically connected to the solid state output modules affecting control and the LEDs on the operator station only if the transfer switch selects that processor for control. Figure 8 diagrams the entire node processor I/O.

Rather than use power from each node processor, a separate five volt power system is used to supply source voltage to all the solid state input/output modules. This five volt system consists of three DC power supplies connected together but isolated from each other using diodes. Each supply is connected to a separate AC power circuit. Since one supply is sufficient to drive all modules for all 30 systems, the theme of double redundancy of hardware remains consistent.

Each node processor and the monitor processor has an additional


HOLD
PUSHBUTTONS
THUMBWHEEL SWITCH DETAIL
NOTE:
THUMBWHEEL SWITCHES ARE PART OF
CONTROL ROOM OPERATORS CONSOLE

Figu


LOCATION
VARIABLE NAME
PORT ADDRESS/
BIT NUMBER ON
TERMINAL STRIP FOR M87 IN
COMPUTER TERMINATION CAB.
#87 TRANSFER
SWITCH

F

custom circuit board containing two 74123 dual monostable chips [9]. This board, called the real time clock/watch dog timer board, accomplishes two distinct functions. One 74123 chip and associated components shape a low voltage AC sine wave length leached from the power supply to produce a narrow five volt pulse which is connected to the processor interrupt input. Using this signal the processor can count time. The other 74123 chip and associated components comprise the processor watch dog circuit. A pulse from one of the processor's digital outputs is stretched by the monostable to about two seconds and is used to keep the watch dog indicator from lighting. Since this monostable is retriggerable, if the processor pulses the digital output bit more often than every two seconds the fault LED will not light. A schematic of the real time clock/watch dog timer circuit is shown in Figure 9.

The complete input/output wiring for a node system is shown in Figure 8.

Hardware Considerations--Host

The monitor or host system is exactly like the node processor, using both the RMC 80/10 computer and the combination real time clock/ watch dog timer custom board. Additionally the host uses an Intel SBC-094 4K battery backup memory board [13], an Intel SBC-108 combination memory and input/output expansion board [12], and two custom circuits built on an Intel SBC-905 universal prototype board.

The Intel SBC-094 battery backup memory board is used to store all parameters from each node processor so that, in the event of power failure, the parameters may be reloaded. A custom circuit built on the prototype board and using CMOS chips for low power drain, constantly counts at a rate of once per second. The power for these CMOS chips is leached from the battery backup board. Digital inputs to the host

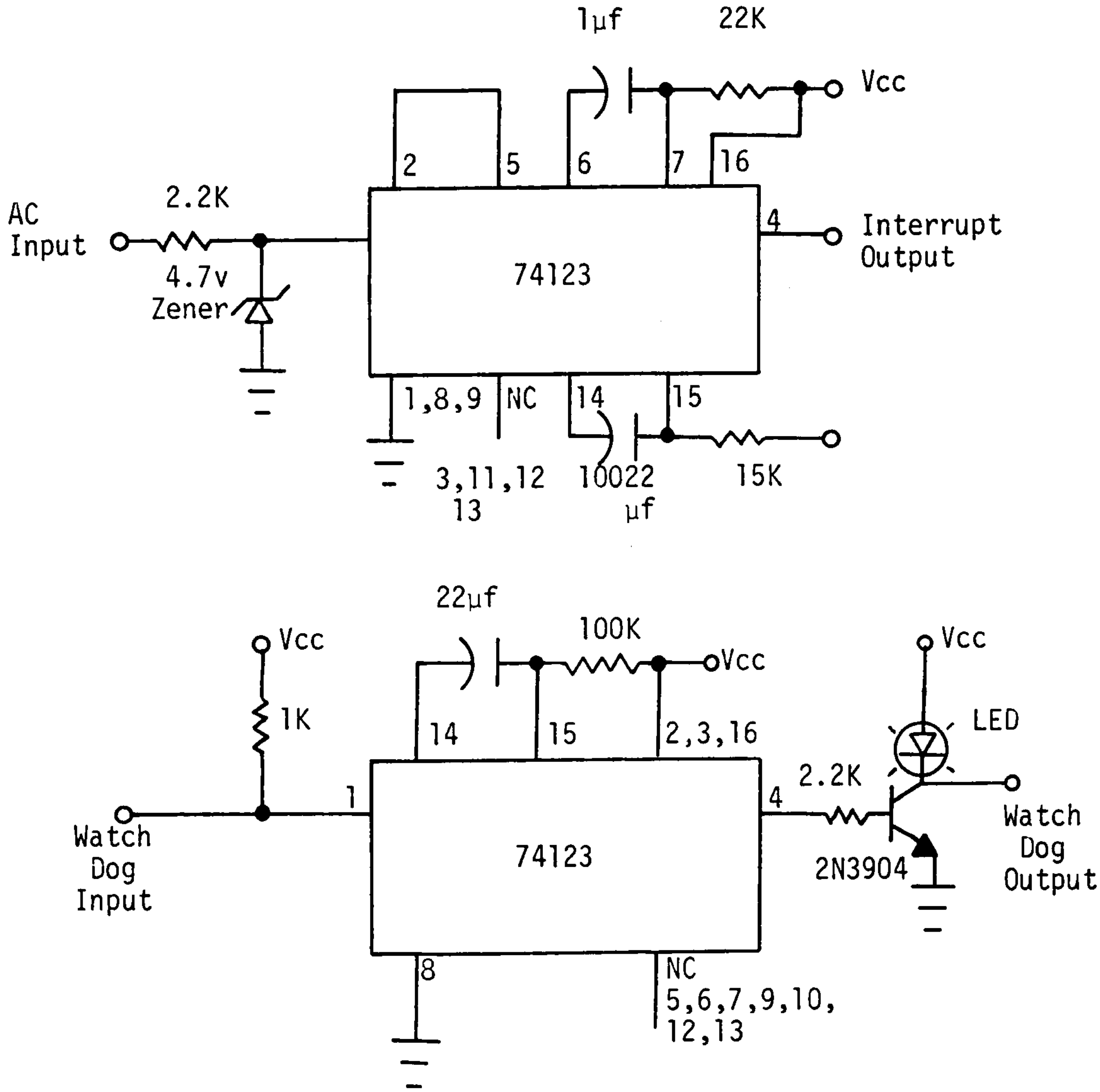


Figure 9. Real Time Clock/Watch Dog Timer Schematic

processor board constantly read the count of this circuit. When power returns after an outage, the host can derive the length of the outage by reading the new count and subtracting the count just prior to the outage. Figure 10 shows this custom circuit.

The Intel SBC-108 board can accommodate up to 8K PROM, 8K RAM, 48 configurable input/output points, and an RS232C serial link. The ROM and RAM expansion on the SBC-108 is used in addition to the facilities on the processor board for the large host program. The RS232C serial input is fed by a multiplexer on the prototype board which allows the host to specify, using digital outputs to the multiplexer, the node to be received. The multiplexer is simply an array of DS1488 receiver chips [10] selected by a 7442 chip [9]. The RS232C serial output on the SBC-108 board goes through a circuit on the prototype board before driving all the node processor serial inputs. The custom circuit serves to give the signal coming from the serial output extra drive. Both custom circuits for the host RS232C link are shown in Figure 11.

Digital outputs and inputs on the SBC-108 board are also used to read the position of every reactor manual transfer switch.

The serial interface on the processor board is used to drive a Digital Equipment Corporation LA36 console [11] for hardcopy output and keyboard input.

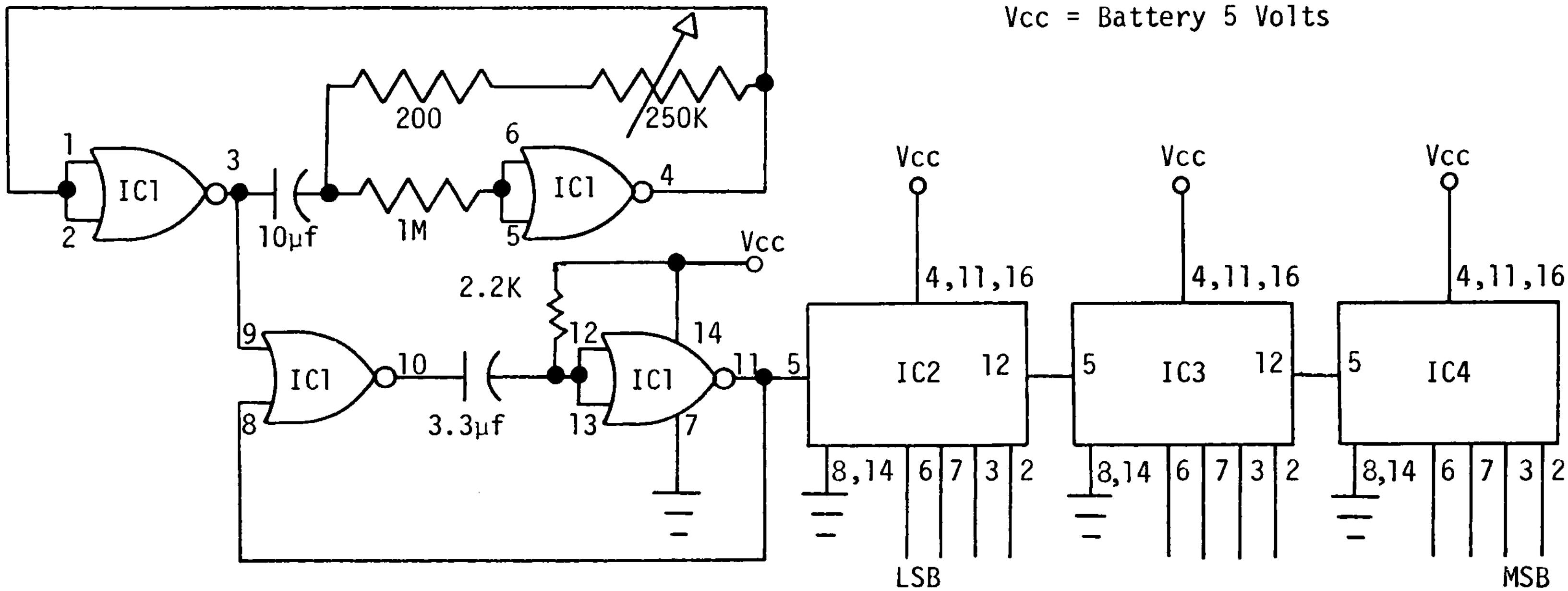
Software Considerations--Node

Every node system uses exactly the same software. A single byte in PROM serves to indicate the node address for a specific system. This byte is needed so that a communication message from the monitor may be decoded by only the addressed system. This byte difference would have

IC1 = 4001

IC2-4 = 74C193

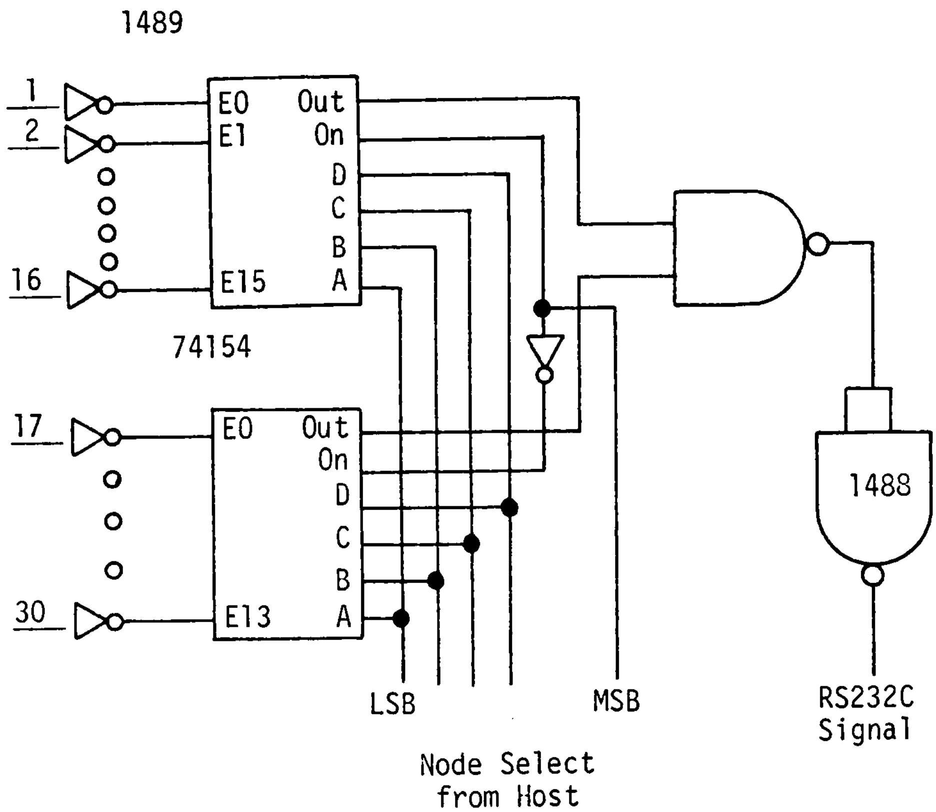
Vcc = Battery 5 Volts



One Hertz Oscillator

12 Bit Count to Microcomputer

Figure 10. Power Down Count Schematic



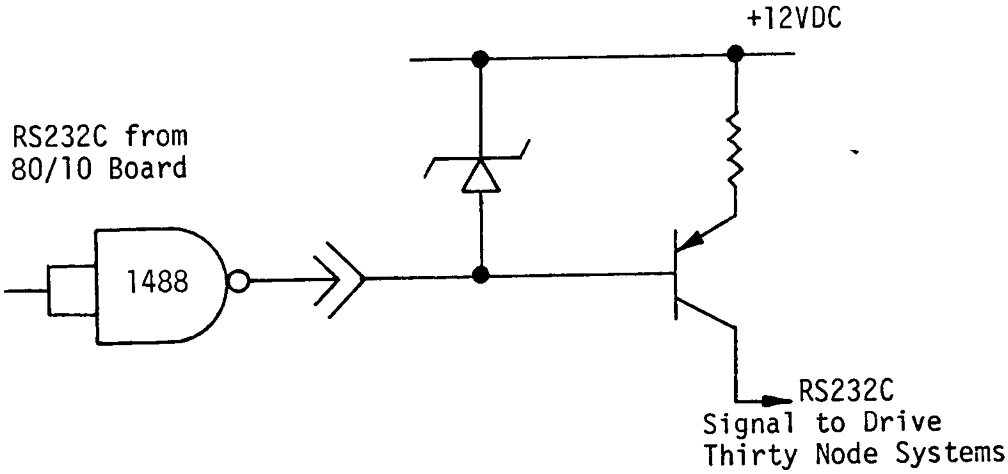


Figure 11. Custom Circuits for Host RS232C Links

been unnecessary if an arrangement to use switches through an input port could have been used to indicate system address. This was not possible because of the limited number of input/output bits available.

The instructions were programmed in 8080 assembly language. The source program was edited, assembled, and placed in four 2708 PROMs using an Intel MDS-800 development system [14]. The hardware capacity of 4K PROM, 1K RAM, and 48 I/O points were used to their full capacity. Because of the hardware limits of the RMC 80/10 and because the volume of systems made assembly language attractive, a high level language was not used for the node software.

The mainline program is flowcharted very roughly in Figure 12. The program services each reactor, fulfills communication requirements with the monitor system, and begins again. The program must service all three reactors that the node is capable of controlling since there is no indication at the node to give the state of the manual transfer switch. The control program assumes that it is controlling all three reactors at all times. In addition to the mainline, an interrupt service routine keeps track of relative time using the 60 hertz signal from the real time clock circuit.

The reactor service routine is flowcharted in more detail in Figure 13. There are not three distinct control routines. All control routines in the node software are reactor independent. Control input and output handlers are the only routines which must know the actual reactor with which to communicate.

The time-temperature curves are stored with the program in the PROMs, in compacted form. Several different storage schemes were considered with the accuracy of the curve and the storage requirements of

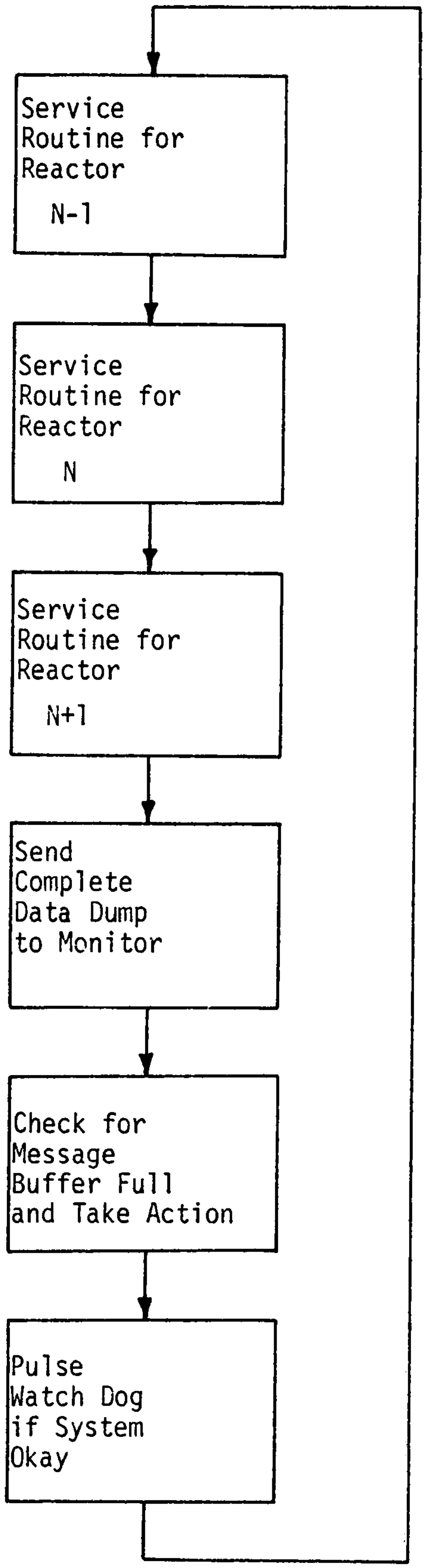
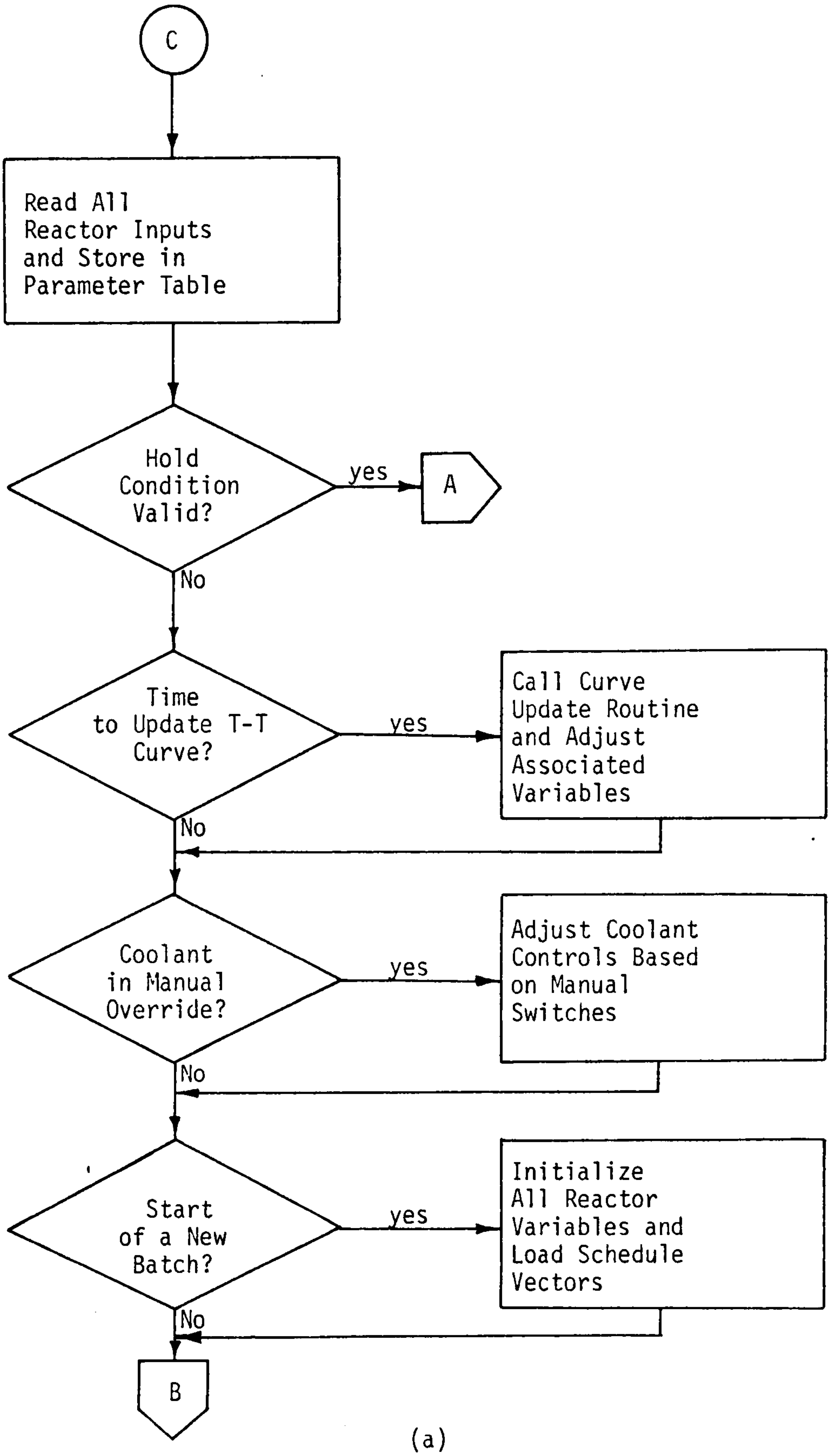
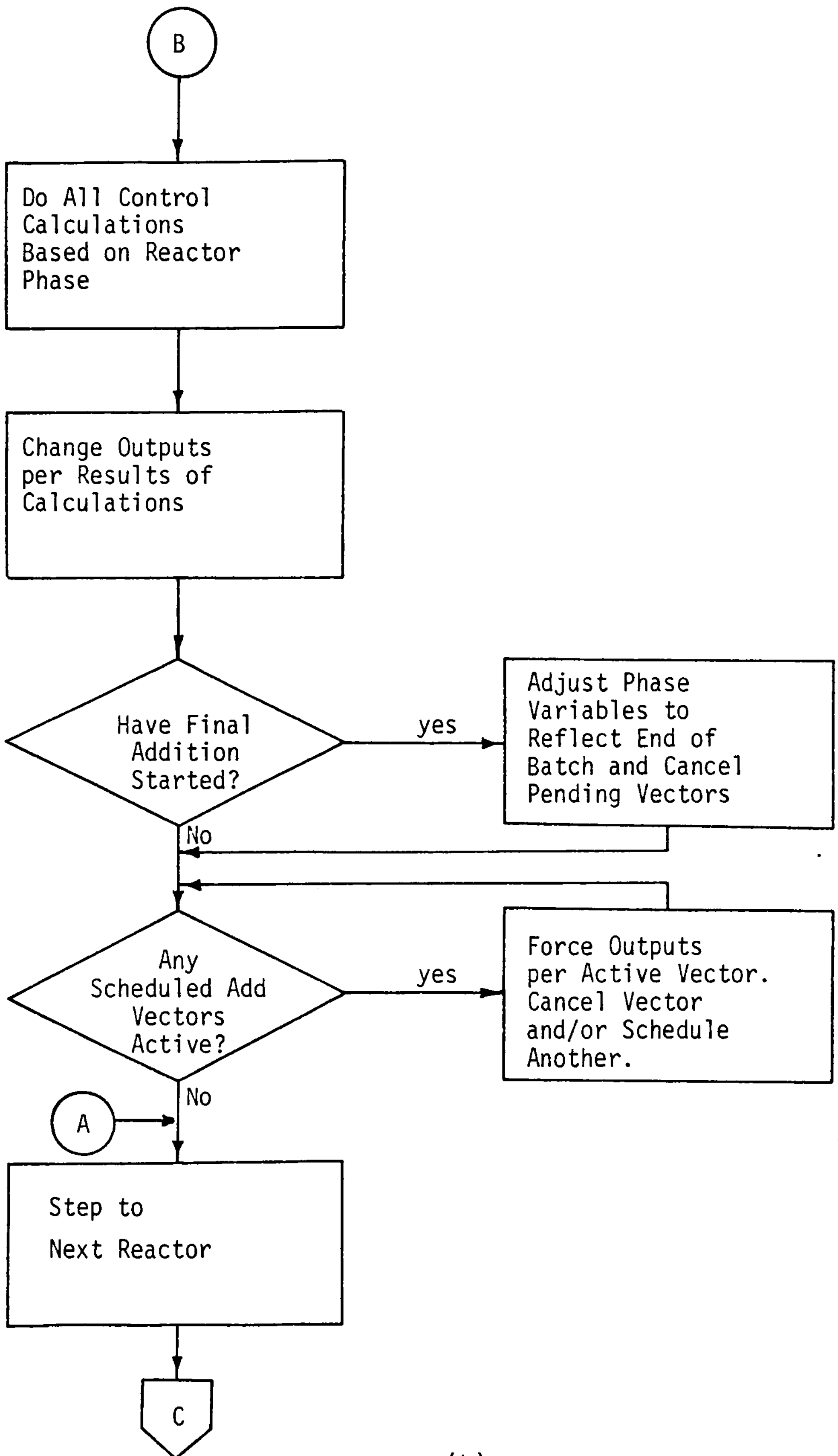


Figure 12. Node Software Mainline.



(a)

Figure 13. Reactor Service Routine Flowchart.



(b)

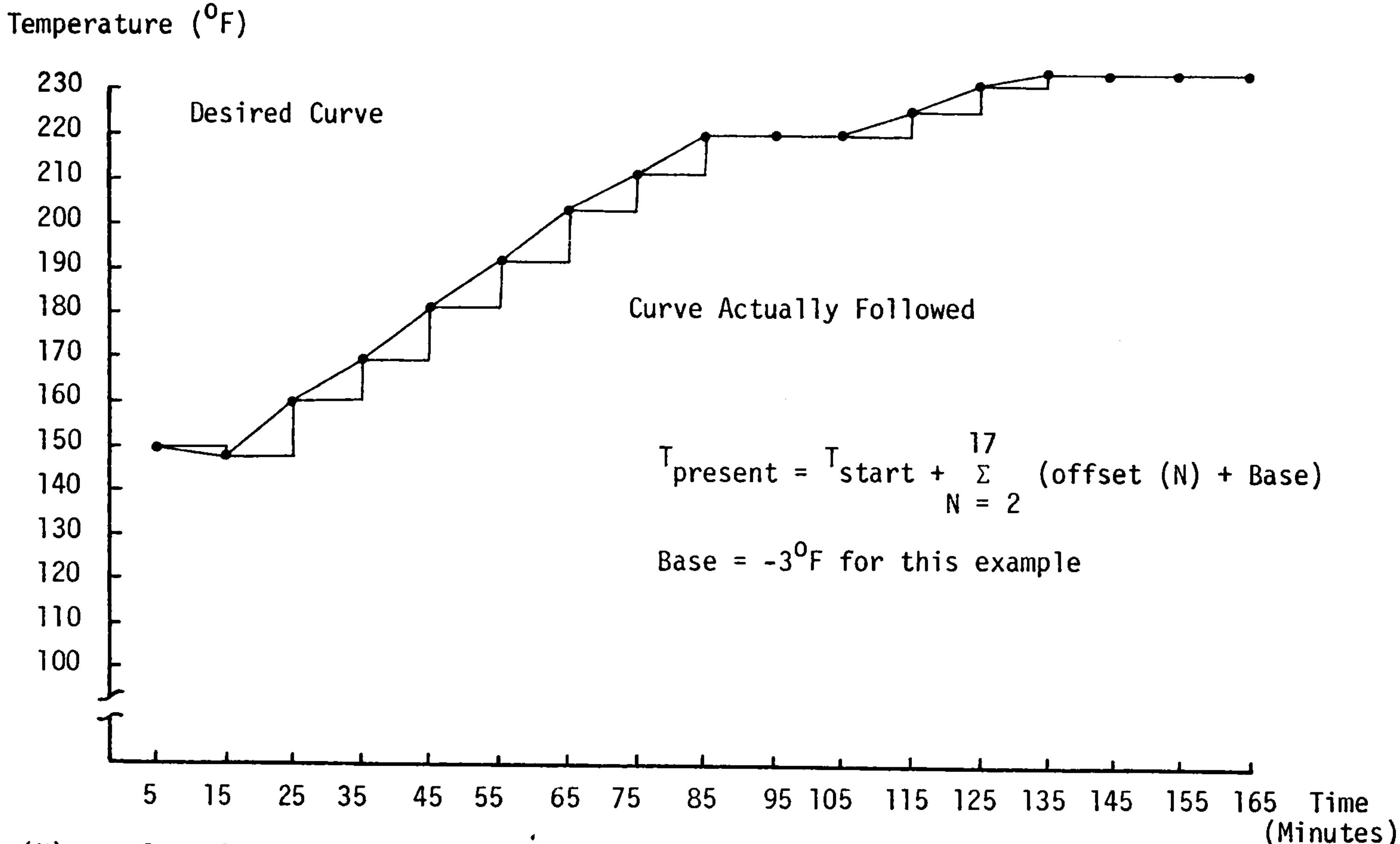
Figure 13 (continued)

primary importance. A decision was made to use a set of temperatures at even time intervals to define a curve. Storage of the curves is simplified by the fact that adjacent temperatures are not widely different. Each curve is stored as an absolute initial temperature and 16 evenly timed offsets from the previous temperature. Figure 14 illustrates this idea.

To simplify conversion of the curve data to compacted form, a FORTRAN program was written to run on a Digital Equipment Corporation PDP 11/70. This program allows entry of curve data in standard time-temperature form and produces a file of compacted curve data. The compacted data can then be downloaded to the MDS-800 Development System where the data can be concatenated with the assembler language source file. This program reduces the time needed to make changes to curve data.

Software Considerations--Host

The monitor system software is rather lengthy. Essentially the monitor program simply accesses each node in a round-robin fashion, stores the node data while always analyzing the reactor state, and sends data to a node in case of power outage. The monitor may also send data to a node because of a request by the operator through the host console to download a development time-temperature curve or chemical addition schedule. Additionally the monitor software must provide a primative interface for the operator to request and view data about any reactor.



Sequence(N)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Temperature	150	148	160	170	181	192	204	211	220	220	220	225	230	232	232	232	232
Offset	-	-2	+12	+10	+11	+11	+12	+7	+9	0	0	+5	+5	+2	0	0	0
Storage	096H	01FH		0DEH		0EFH		0ACH		033H		088H		053H		033H	

Figure 14. Time-Temperature Curve Representation and Storage.

CHAPTER IV

THE COMMUNICATION NETWORK

Objectives

A communications link to connect the node processors to the monitor system was deemed desirable. The purpose of the link is to allow transfer of information from each node to the monitor system for power-fail retention and for report data to be printed or stored by the monitor system. Additionally, in order for the monitor to change parameters in the node processor and download recent variable data to the node in the event of a power outage, the monitor must have a link with each node. During the early stages of development, this link was also used to download programs to a modified node processor for testing purposes.

The primary factor in evaluating possible link arrangements is that a single failure at a node or between a node and the monitor should not cause loss of communication with other nodes. This is in keeping with the system objective of overall system reliability.

Each microcomputer system has, as a part of the processor board, a serial interface. This UART driven interface can be easily hardware configured for either RS232C or current loop standards using jumpers. An entire range of baud rates is also jumper configurable. A decision was made that each node interface to the communication link should use this single interface so that extra hardware interfaces would not be needed. Within the constraints of the other communication objectives, the smallest amount of hardware outboard to the processor board was the most desirable.

Types of Linkages Considered

A fully distributed network was not considered because of the number of interfaces needed and the complexity of the software required. A hierarchical or tree network was also not considered because there are only two distinct levels of control within the system and because several serial interfaces would be required at each node.

An unidirectional loop system, where any system could talk with any other by sending an addressed message around the loop, was considered. In a system such as this, a failed node could stop all communication if it were unable to pass a message to the next node. A logic circuit or relay, triggered from a watch dog circuit in the event of system failure, could be used to break the serial link through that node and make a bypass connection from input to output around the failed node. This solves the problem of loss of the entire communication system but requires additional hardware. A bidirectional loop network was not considered because two serial interface would be needed at each node.

A data highway or multidrop arrangement is often used on commercially integrated systems. In order to allow others to use the highway, a high impedence state must be output when a node is not using the highway. Not only would this approach need additional hardware but certain failure modes could lock up the buss and stop all communication. Because of the objective of overall system reliability and independence from node failures, this scheme was dropped.

A star linked system is a very reliable alternative since failures within the system causes only loss at the failed unit. In this arrangement the monitor system or host controls all resources in the communication system. Each node system can be quite simple both in hardware and in the amount of software required. The network lives or dies with the host system, which for the proposed control system is acceptable because without a functioning host no data transfer is needed. This arrangement requires many interfaces at the host.

The various type of communication networks considered are illustrated in Figure 15.

A modification of the star linkage was ultimately decided on. A multiplexing arrangement was designed and installed on the monitor system so that only one node is received at a time. Since the timing of the messages from the node is not dependent on a request to send by the monitor, the node system repeats a dump of all parameters onto the node serial port on a cyclical basis. The monitor listens to a node transmission until a complete, error-free dump is received.

The monitor to node side of the communications link was implemented using a single serial output from the monitor which feeds every node on a buss arrangement. The monitor broadcasts messages which are received at every active node. Action is taken on the message only if the node software determines that the message is intended for that node. This arrangement requires that each node have an address assigned so that a message can be scanned for destination. This was accomplished by a single byte in each node control program. Because physical distance between systems is short, separate wiring from the monitor to each node was installed rather than a "daisy chain" arrangement. A single break

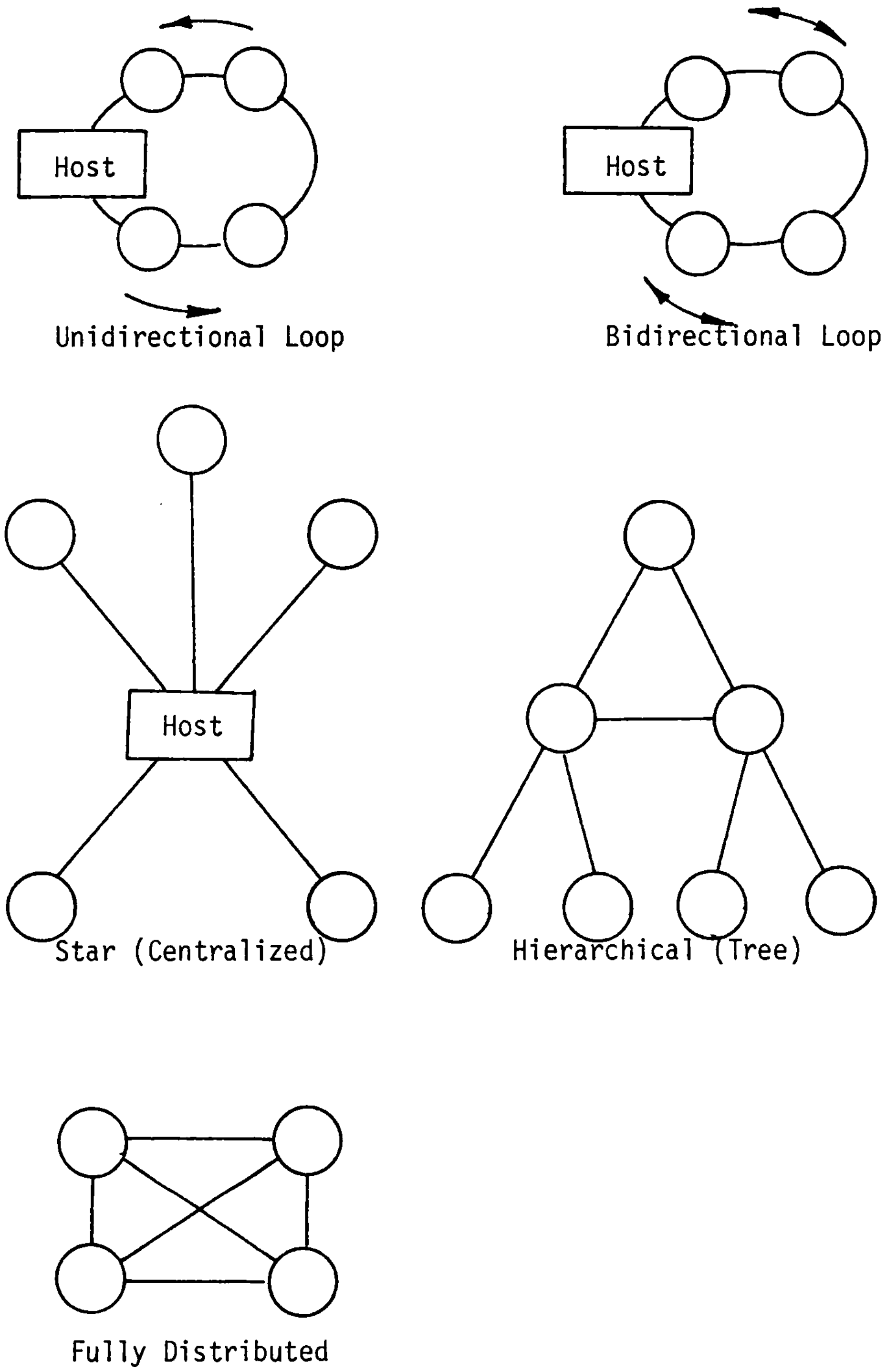


Figure 15. Communications Networks Considered.

in a communication cable would then mean loss of communications that node only. This arrangement also dictates that the serial input at each node be interrupt driven since messages are not synchronized to the node control program.

Communication Codes and Error Handling

Each byte of information to be transferred in either direction on the communication link is hardware checked for odd parity in the UART section of each processor board. Additionally the software of each system transmits a checksum byte for every sixteen bytes of data. Several error correcting codes were considered such as hamming, etc. but were not used in an effort to simplify the node control program. A retransmission is used to correct any error detected in transmission.

The node program will send a snapshot of all system variables every few seconds. If the monitor software detects an error by either a parity error or a bad checksum, the monitor may simply disregard that transmission and wait for the next. The time wasted by such a scheme is insignificant because of the low volume of serial communications needed to meet communications objectives. The message, a byte showing transmission error and type, and the variables to be affected by the message are all part of the variable space to be cyclically transmitted by the node. When a message is broadcast by the monitor to a specific node, the results of the message can be evaluated by a examining a subsequent transmission from the node to the monitor. A retransmission by the monitor may be in order if a problem is discovered in an earlier transmission.

This modified star scheme means that the node control program need only check and generate checksums and take action on a received message. The uart section of the node processor takes care of parity generation and checking. All software to evaluate whether a retransmission is needed is a part of the monitor program.

CHAPTER V

SYSTEM TRADEOFFS AT THE PROCESSOR LEVEL

Who Gets Control?

A question that arises in a system where several computers are capable of controlling a piece of equipment is who gets control?

One approach is to allow the monitor system to have complete discretion. The monitor software can decide in a godly fashion which of the three processors gets absolute control. This approach makes changeover in the event of a node failure both swift and automatic. Hardware to facilitate a switch of control is unnecessary because the outputs from a node processor could be made contingent on an enabling message received via the communications link from the monitor. It is clear, however, that certain failure modes of the monitor system could have control switched from functioning nodes to failed or nonexistant processors with catastrophic results. This scheme was not chosen because of the fear that a single failure in the monitor system could cause loss of computer control at several nodes threatening the objective of overall reliability.

Voting among node processors is an interesting alternative. This democratic scheme allows each of the three processors to present their digital control signal to a arbitrating circuit where the majority will rule. The arbitration circuit could be designed in several different ways with the simplest being a ROM. A 1K PROM could be used to allow votes form three processors on three control points. Reduction of the number of valid control states might allow control of even more points using a single 2708 PROM. This scheme is reliable but requires custom hardware exterior to the node processor. Also there is the question of what to do if a node has failed and the equipment removed for repair. If two of the three nodes assigned to a given reactor fail, the third cannot control the reaction unless the corresponding outputs from the two failed nodes are forced to opposite states.

Because of the stated objectives of the system and the drawbacks to other approaches, manual changeover in the event of a node failure was chosen for this system. To make this decision easier for the operator, the node watchdog timer circuit was visually indicated at the operator interface for that node. Additionally, the monitor processor was configured to read the state of the 30 manual transfer switches on a periodic basis to report all control assignment changes.

Operator Interface Distribution

How much of an operator interface is needed for each node? On one extreme, each system could have a complete and independent interface consisting of switch inputs and visual displays. On the other extreme, the operator could interface at the monitor level through a terminal or hardware interface with no interface at the node.

A decision was made to have an operator interface at each node which was complete except for some developmental changes which can only be changed through the monitor terminal. This allows each node to function and be accessed independently of the monitor system. No reports or records are kept at the node level. This noncontrol function, a secondary one as far as the objectives of the system is concerned, is relegated solely to the monitor system.

Maintenance Considerations

Every effort was made to make troubleshooting easy. The decision to make each node an independent system makes testing of a failed processor less cumbersome and lessens the chances of affecting other processors while checking or repairing a failed unit. Since each node processor is identical to all the others, the number of spare parts to stock is lower and the education of maintenance personnel is reduced. This also allows functioning processors to be moved to critical areas where a node has failed.

A program was written for the sole purpose of allowing a maintenance person to read all inputs to a node and change any output. By changing five jumpers on the processor board, the maintenance person can view and change status of input/output points on a 110 baud terminal driven from the serial interface. Judicious compacting and optimization of this program allowed it to fit on a single 2708 PROM chip. This means that with the communication link removed and the terminal installed, only one PROM must be changed to run the maintenance program.

CHAPTER VI

EVALUATION OF THE SYSTEM PERFORMANCE

Were System Objectives Met?

The primary objective, reduction in time required to process a batch, has been met. A reduction in batch time of from 15 to 20% has been realized using the new control system. The actual percentage of batch time reduction is a function of the type of product being made. The reduced batch times allow purchase of four complete reactors and associated peripheral chemical equipment to be deferred perhaps indefinitely. This savings is not necessarily tied to the fact that a distributed computer system has been applied, but is also due to the new methods of control and adjustments described.

The total control system has been quite reliable when compared with previous control schemes. The mean time between failures of the node processors has proven shorter than hoped; but the ability to transfer control to other nodes has made this a minor problem. Certainly the severity of a failure or group of failures has been substantially reduced.

Because production problems upstream from a reactor are very often responsible for making a batch uncontrollable and because adequate records have not previously been kept, reduction in the number of thermal runaway batches is difficult to evaluate. "Gut feeling" by those familiar with this equipment for many years indicates that the number of thermal runaway batches has been reduced somewhat.

Since the batch time has been reduced, the energy used in a batch production cycle has also been reduced, but not in direct proportion. Because of the vastness of this complex and because the reactors use common headers, reduction in energy usage is difficult to determine quantatively. If four new reactors had been installed to increase production, the header systems capacity would also have needed expanding. The new system does not need expanded headers to realize this same increase in production.

Besides time reduction, the most impressive result of the project is operator acceptance and assistance in fine tuning the new system. The enthusiasm and help of the operators responsible for operating this equipment was gone a long way toward making the new control system a success.

Possible Improvements

The monitor system has the most potential for improvement. The information and storage and reporting functions in the monitor are rather rudimentary. Plans have already been laid to expand the monitor software to print full reports on a scheduled basis and do some statistical analysis on the data. The new monitor software will probably be written in a high level language (probably FORTRAN) to facilitate easy future modification of the monitor program.

The node processor will probably not be changed in any way. Every decision made in design of the node system seems to have been at least as good as other alternatives. Adding new node processors to control new reactors is a possibility.

CHAPTER VII

SUMMARY AND CONCLUSIONS

A distributed system was designed and developed by the author to control 30 batch chemical reactors. The system was designed to read reactor temperature and take control action based on parameters input by the operator through a custom operator station at each reactor.

The system met or exceeded all objectives for reliability and reduction of batch cycle times. This system allows capital expenditures for equipment to increase production capacity to be deferred indefinitely and at no reduction in the quality of the reacted product. This system is far more flexible than previous control schemes.

Further improvements of the system will probably be directed toward the central monitor system. The monitor system has a good deal of potential to make batch record keeping easier and to give the process engineer an excellent handle on the process.

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VITA

William Darrell Corpening was born on January 8, 1952, in Johnson City, Tennessee. After graduating from Science Hill High School in Johnson City in 1970, he enrolled at The University of Tennessee, Knoxville, in September 1970. He received a Bachelor of Science degree in Electrical Engineering in June 1974.

He has been employed at Tennessee Eastman Company in Kingsport, Tennessee as an electrical engineer since June 1974. His job involves design of advanced process control systems to control chemical processes. This primarily involves application of computers to industrial controls. In 1979 he became a Licensed Professional Engineer in the State of Tennessee. He entered The University of Tennessee Graduate School Extension, Kingsport, in September 1974, working toward a degree of Master of Science in Electrical Engineering.

He has been married to the former Karen Collins since 1973 and they have two daughters, Kimberly and Kelly.