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Instruments

AUTOMATION OF A LONGITUDINAL-COMPARISON
THERMAL CONDUCTIVITY APPARATUS

MASTER

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UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the ATOMIC ENERGY COMMISSION under U. S. GOVERNMENT Contract W-7405 eng 26

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UNION CARBIDE CORPORATION
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Y-12 PLANT

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THERMAL CONDUCTIVITY APPARATUS

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ABSTRACT

A digital computer has been used to automate a longitudinal-comparison thermal conductivity apparatus. The computer is used to control temperatures inside the device and to store data for future readout when all specified conditions have been satisfied. The computer reduces the time necessary to acquire data, and it allows use of the apparatus during off shifts when no personnel are present.

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SUMMARY

A small digital computer is used to control and acquire data from a longitudinal-comparison thermal conductivity (LCTC) apparatus. Thirteen temperatures inside the device are monitored by the computer. These, along with set-point temperatures, are used to establish the axial and radial heat-flow conditions necessary to determine thermal conductivity. This procedure is repeated every 1.5 seconds until the condition of zero radial heat flow from the sample-standard stack has existed for a preprogrammed period. The stack temperatures are stored for future readout and new stack set points are read from memory. The operation is then repeated. Upon detecting a "complete" code, the computer will shut down the system.

Manual and automated tests were made on an Armco iron sample and standard. A comparison with published data showed good agreement between methods.

INTRODUCTION

The longitudinal comparison method is commonly used for determining the thermal conductivity of materials. This method is valuable because it does not require calorimetric means to determine heat flow and it provides a comparison of thermal conductivity between materials. Also, the method utilizes a simpler apparatus and more readily fabricated samples than other methods.⁽¹⁾

In a typical apparatus, the unknown specimen is placed in a column between two standards through which heat is flowing at a known rate. After stack radial heat flow is eliminated, the temperature drop across the sample is measured and the thermal conductivity calculated by comparing the temperature drop across the sample with that of each standard whose thermal conductivity is known. A thermal gradient across the stack is established by heaters at the extremes of the stack; radial heat flow is prevented by guard heaters along the long side of the stack. Practical difficulties arise in handling large sample loads because of the time required for an operator to establish the gradient and balance out the radial heat flow for each temperature at which the thermal conductivity is desired. Several days may be required to obtain all the information required for one sample.

An automated system can provide several obvious advantages. In addition to a reduction in the time required to obtain data from a sample, it will eliminate the need for constant attention of the operator. Also, data could be taken during off shifts, increasing the load factor of the machine.

This report discusses a system which achieves control and data acquisition of a commercial longitudinal-comparison thermal conductivity (LCTC) apparatus^(a) by use of a laboratory digital computer.^(2,3) Considerable detailed information is presented in the appendixes. Operation and maintenance procedures are presented in Appendix A; schematics and block diagrams of the entire system are presented in Appendix B; computer programs and device selector commands are listed in Appendixes C and D, respectively.

(a) 3M-model TC-200, manufactured by the Minnesota Mining and Manufacturing Company.

DESCRIPTION OF THE LCTC SYSTEM

Some appreciation for the problems associated with manual operation of this system may be gathered from the schematic representation of the thermal conductivity stack shown in Figure 1. A thermal gradient across the stack is established by Heaters 1 and 9. The condition of zero radial heat flow is established by simultaneous satisfaction of the equations listed in Table 1. The unmodified instrument requires that the operator read all 13 thermocouples and adjust the corresponding heaters to achieve the balance. The computer, however, reads all thirteen thermocouples through a multiplexed analog-to-digital converter under its control and inserts the data in heater control formulas that force the zero radial heat-flow condition. These data are then checked against the conditions for balance; that is, proper temperature and satisfaction of the zero radial heat-flow condition for at least 15 minutes. At this time, the temperatures are stored for later printout and the computer is automatically programmed for the next higher temperature. Upon completion of the last temperature, the system automatically shuts down. A block diagram of the system is shown in Figure 2.

Figure 1. THERMOCOUPLE ARRANGEMENT FOR THE LONGITUDINAL-COMPARISON THERMAL CONDUCTIVITY APPARATUS.

Table 1
CONDITIONS FOR ZERO RADIAL HEAT FLOW

$$T_{13} - T_1 = 0 \pm 1^\circ \text{C}$$

$$\frac{T_{10} + T_9}{2} - T_5 = 0 \pm 1^\circ \text{C}$$

$$\frac{T_{13} + T_{12}}{2} - T_2 = 0 \pm 1^\circ \text{C}$$

$$\frac{T_9 + T_8}{2} - T_6 = 0 \pm 1^\circ \text{C}$$

$$\frac{T_{12} + T_{11}}{2} - T_3 = 0 \pm 1^\circ \text{C}$$

$$T_8 - T_7 = 0 \pm 1^\circ \text{C}$$

$$\frac{T_{11} + T_{10}}{2} - T_4 = 0 \pm 1^\circ \text{C}$$

Figure 2. AUTOMATED LONGITUDINAL-COMPARISON THERMAL CONDUCTIVITY APPARATUS.

System performance was evaluated using Armco iron,⁽²⁾ a material whose thermal properties have been extensively studied. The upper limit of temperature control was determined to be approximately 700°C ; therefore, the condition of zero radial

heat flow could be established at any temperature in this range. It was necessary to establish some guidance for selection of the temperature gradient across the stack, since this appeared to affect the results. The problem was studied by establishing five differentials across the stack for each temperature at which data were desired. Each of the resulting five sets of thermal conductivity values was averaged, and the one set differing the least from the mean was chosen as the best value. Once the best gradient for a material and temperature range has been established, it may be used for future samples. The results of these tests are plotted in Figure 3, where they may be compared with published data and data obtained from the same instrument using manual control.

Figure 3. THERMAL CONDUCTIVITY OF ARMCO IRON.

The computer controlled LCTC can establish the zero radial heat flow and recover from a change of 100° C in programmed set points in less than one-half hour. However, best results are obtained if the stack is controlled to remain at each set point for one hour before taking data. The computer is programmed to establish and maintain this condition without operator attention.

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APPENDIX A

OPERATION AND MAINTENANCE PROCEDURE

System Operation

Prior to operation, the entire system should be allowed one-half hour for warmup. This step can be accomplished while the control programs, floating-point package, and temperature set points are being read into the computer. When applying power to the control rack, always make sure that the 220 volts (AC) to the longitudinal comparison thermal conductivity is off and the heater variance apparatus on the control rack is adjusted to zero.

A step-by-step procedure for system operation is outlined in the sections that follow. A more detailed description of computer procedures is listed in the PDP-8 Users Handbook.⁽⁴⁾

Initial Setup and Program Input -

1. Turn the 220-volt AC power to the LCTC apparatus to the "off" position.
2. Position the manual-auto switch on the LCTC to "manual".
3. Adjust the control racks nine variacs to zero.
4. Turn the control racks power switch to the "on" position.
5. Set the LCTC thermocouple selector to the "off" position.
6. Turn the computer power on.
7. Turn the interface power on.
8. Turn the high-speed reader power to the "on" position or set the ASR-33 switch to the "line" position if the binary tape is input by the low-speed reader.
9. Place the FPKS 4 binary tape in the input device (teletype or high-speed reader).
10. Set the computer switch register to Octal 7777 and depress the load-address switch.
11. When using the high-speed reader, set the switch register to Octal 3777; otherwise, proceed to Step 12.

12. Depress the start switch and the tape will be read. After the reader has stopped, the accumulator indicators should all be off. If any light is on, repeat Steps 9 - 12.
13. Place the control program binary tape in the read-in device and repeat Steps 10 - 12.

Stack-Gradient Set-Point Input -

1. Set the ASR-33 switch to the "line" position.
2. Set the switch register to Octal 3000 and depress the load-address switch.
3. Depress the start switch.
4. Enter the set points from the ASR-33 teletypewriter. The set points may vary from 0001 to 9999 microvolts. When inputting setpoints, always type four numbers with no decimal and insert a carriage return-line feed after each set point. Always enter the top set point first with the bottom set point following. Up to nineteen set points consisting of 38 temperatures may be stored. The last two numbers must be 0001 with 0000 following. After entering 0000, the computer will stop.

Starting the Control Program -

1. Set the switch register to Octal 0200 and depress the load-address switch.
2. Depress the start switch to start the program.
3. Position the manual-auto switch of the LCTC to "auto".
4. Adjust the variac for 1.75 amperes for temperatures below 200° C. After this point has been passed, adjust the heater currents to three amperes. Thermocouple outputs may be monitored by an oscilloscope at the input to the ADC unit. Do not monitor the temperature with the universal potentiometer.
5. The computer will turn off the AC power to the control racks and halt itself after the last set point is completed.

Output of the Stored Data -

1. Set the switch register to Octal 2000 and depress the load-address switch.

2. Depress the start switch.
3. If the data are not listed, depress the stop switch, then: (1) set the switch register to Octal 0062, (2) depress the load-address switch, (3) depress the exam switch (If the accumulator indicators are all out, seek help.), (4) depress the load-address switch, (5) set the switch register to Octal 0000, (6) raise the dep switch, and (7) repeat Steps 1 - 3.
4. The computer will stop after the 13th temperature is listed.
5. Repeat Steps 1 and 2 for each two set points initially entered.
6. Data are listed in volts, E format, with proper tags.

System Maintenance

Overall System - When initially adjusting the heater currents just after the control program has been started, all heaters should be on. If not, parallel Channel 2 input of a dual-beam oscilloscope with the input of the ADC unit. Connect Channel 1 to 5A Pin D of the interface electronics and adjust the oscilloscope to positively trigger off this channel. Adjust the oscilloscope amplifiers and sweep rate to the settings listed in Figure A-1. The observed trace should resemble that shown in Figure A-1.

Figure A-1. MULTIPLEX THERMOCOUPLE SIGNALS. (Sweep Rate = 0.205 sec/cm)

Most problems that are encountered can usually be traced back to the fact that the computer programs have been partially destroyed. Generally, difficulties can be resolved by reentering the binary tapes, inserting temperature set points, and re-starting the control program. If problems still persist, an attempt should be made to isolate the unit from which the problem originates.

Detailed maintenance and troubleshooting of the computer and teletypewriter is found in the manufacturer's literature (PDP-8 Maintenance Manual).⁽⁵⁾ Periodic preventive maintenance of the computer-teletype combination will prevent many problems that otherwise would occur.

Circuits Pertaining to the Reed Relays in the Multiplexier - Read the LCTC MAIN binary tape into the computer. Load the tape according to the procedures described in the PDP-8 Users Handbook.⁽³⁾ Start the computer at Location 0200 (8) and observe the waveform on the oscilloscope that is connected to the interface and ADC input. A $2/3 - 1/3$ (Figure A-2) duty-cycle square wave on Channel 1 indicates that both the computer and interface are operating correctly. Decrease Channel 2's sensitivity to five volts per centimeter. If the waveform approaches +10 volts during the short-duty cycle and ground during the long-duty cycle, the amplifier and multiplexier Channel 1 are operating correctly. Stop and start the computer repeatedly at Location 0207 (8), observing the waveforms indicated by Table A-1. This operation will check out parts of the interface, the computer, and the multiplexier-amplifier unit. Refer to Table A-2 for trouble indicators and their probable causes. Heater test data are presented in Table A-3.

Table A-1
MULTIPLEXIER-AMPLIFIER INTERFACE TEST

Computer Starting Sequence and Location	Channel 1 Connection	Channel 2 Connection	Component Being Tested
1st Start at Location 200	5A Pin D	ADC Input	Relay 1
1st Start at Location 207	5A Pin F	ADC Input	Relay 2
2nd Start at Location 207	5A Pin J	ADC Input	Relay 3
3rd Start at Location 207	5A Pin L	ADC Input	Relay 4
4th Start at Location 207	5A Pin N	ADC Input	Relay 5
5th Start at Location 207	5A Pin R	ADC Input	Relay 6
6th Start at Location 207	5A Pin T	ADC Input	Relay 7
7th Start at Location 207	5B Pin D	ADC Input	Relay 8
8th Start at Location 207	5B Pin F	ADC Input	Relay 9
9th Start at Location 207	5B Pin J	ADC Input	Relay 10
10th Start at Location 207	5B Pin L	ADC Input	Relay 11
11th Start at Location 207	5B Pin M	ADC Input	Relay 12
12th Start at Location 207	10B Pin L	ADC Input	Relay 13

- (1) The oscilloscope should be adjusted to trigger positively with a sweep rate of 100 milliseconds per centimeter. Set Channel 1 sensitivity to two volts per centimeter and Channel 2 to five volts per centimeter. Always stop the computer before starting the next test. The observed waveforms should be like those shown in Figure A-2(a).

(a) Data Checkout Guide (sweep rate equals 0.1 sec/cm)

(b) Heater Checkout Guide (sweep rate equals 1.0 sec/cm)

Figure A-2. TROUBLESHOOTING GUIDES.

Table A-2
TROUBLESHOOTING GUIDE

Symptom	Probable Cause
1. No waveforms observed for all tests of Table A-1.	Interface power not turned on. Computer started at wrong location. Computer inoperative.
2. Waveforms observed on Channel 1 (interface) and not on Channel 2.	LCTC control rack power not on. Thermocouple amplifier-filter inoperative.
3. First start at Location 200 (8):	
(a) No waveforms on either channel.	Interface electronics for Reed Relay 1 inoperative.
(b) Waveform on Channel 1 but not on Channel 2.	Reed Relay 1 inoperative. Thermocouple 1 open.
4. As the tests of Table A-1 are performed, Symptom 3 and Probable Cause 3 are repeated for the circuits pertaining to the thirteen reed relays.	
5. First start at Location 0600 (8):	
(a) No waveform on Channel 1 and heater does not turn on.	Heater interface electronics inoperative. LCTC switch on manual. Power relay inoperative.
(b) Waveform at Channel 1 but heater will not turn on.	Heater 1 power supply inoperative. SCR and associated circuits inoperative.
6. As the tests of Table A-3 are performed, Symptom 5 and Probable Cause 5 are repeated for the circuits associated with the nine heaters.	
7. The ninth time the computer is started at Location 0606 (8), the power-control relay in the LCTC control chassis will energize two seconds and de-energize one second:	
(a) No waveform on oscilloscope Channel 1 and power relay inoperative.	Power relay interface electronics inoperative.
(b) Waveform on Channel 1, but relay will not actuate.	Relay circuit inoperative.

Table A-3
HEATER TESTS

Computer Starting Location ⁽¹⁾	Connect Channel 1 Probe to Interface	Circuitry Being Checked
1st Start at Location 0600	10A Pin D	Heater 1
1st Start at Location 0606	10A Pin F	Heater 2
2nd Start at Location 0606	10A Pin J	Heater 3
3rd Start at Location 0606	10A Pin L	Heater 4
4th Start at Location 0606	10A Pin N	Heater 5
5th Start at Location 0606	10A Pin R	Heater 6
6th Start at Location 0606	10B Pin D	Heater 7
7th Start at Location 0606	10B Pin F	Heater 8
8th Start at Location 0606	10B Pin J	Heater 9
9th Start at Location 0606 ⁽³⁾	10B Pin M	Power Relay

- (1) Start program at Location 0600 (8) to perform tests on Heater 1. The waveform on Channel 1 of the oscilloscope should be -3 volts for two seconds and ground for one second [Figure A-2(b)]. The heater being tested will be on for two seconds and off one second.
- (2) Set the oscilloscope sweep rate at one second per centimeter with a Channel 1 sensitivity of two volts per centimeter.
- (3) When the program is started the ninth time at Location 0606 (8), the relay in the LCTC control rack will repeatedly actuate for two seconds and de-energize for one second.

Circuits Pertaining to the LCTC Heaters - The LCTC MAIN program is also used to check out the circuits associated with the heaters and the LCTC power-control relay circuits. The program initially starts at Location 0600 (8) with successive starts at 0606 (8). As the tests listed in Table A-3 are performed, Heaters 1 through 9 repeatedly turn on for two seconds and off for one second. (Refer to Table A-2 for trouble indicators and probable causes.) After each heater circuit is checked, stop the computer before proceeding to the next test.

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APPENDIX B

SUBSYSTEMS SCHEMATICS AND BLOCK DIAGRAMS

Standard logic levels for the DEC digital circuits^(b) are 0 and -3 volts, and 0 and -6 volts for the Delco modules. The Delco modules have been modified to accept 0 and -3-volt levels. Logic signal symbolic used in the circuits are:

The electronic modules are as follows:

<u>Type</u>	<u>Function</u>
CD310 ^(c)	Reed Relay ⁽⁴⁾
R113 ^(b)	Nand/Nor Gate
R204 ^(b)	Quadruple Flip-Flop
R107 ^(b)	Inverter
W103 ^(b)	Device Selector

Circuit diagrams for the modules may be found in the literature supplied by the manufacturers. Figures B-1 through B-10 contain schematic diagrams of specifically designed electronics and block schematics of the entire system.

(b) Manufactured by the Digital Equipment Corporation.

(c) Manufactured by the Delco Radio Division, General Motors Corporation.

Figure B-1. AUTOMATED 3M APPARATUS CABLE DIAGRAM.

Figure B-2. COMPUTER INTERFACE CONTROL.

Figure B-3. REED RELAY CONTROL.

Figure B-4. HEATER INTERFACE CONTROL.

Figure B-5. REED RELAY MULTIPLEXIER..

Figure B-6. THERMOCOUPLE AMPLIFIER.

Figure B-7. DIFFERENTIAL AMPLIFIER.

Figure B-8. HEATER CONTROL CHASSIS.

Figure B.9. POWER CONTROL CIRCUIT.

Note:

Wires connected to the manual side of the switch are connected to the 3M manual control.

Figure B-10. 3M ELECTRICAL CIRCUIT.

APPENDIX C

COMPUTER PROGRAMS

Introduction

This section contains a listing and flow diagram for each computer program. A memory usage chart for the computer is presented in Figure C-1.

AUTO-INDEX REG FLOATING POINT CONTROL	CONTROL	FIGUR1	ISDATA
000	200	400	600
GETST1	TEMP SET POINTS	FIGUR2	
1000	1200	1400	1600
DATA LISTING ASR-33	DATA STORAGE	DATA STORAGE	MESAGE
2000	2200	2400	2600
SET-POINT INPUT			
3000	3200	3400	3600
4000	4200	4400	4600
			FLOATING- POINT PACKAGE
5000	5200	5400	5600
FP CONT'D	FP CONT'D	FP CONT'D	FP CONT'D
6000	6200	6400	6600
FP CONT'D	FP CONT'D	FP CONT'D	FP CONT'D AND RIM-BIN LOADERS
7000	7200	7400	7600

Figure C-1. COMPUTER MEMORY USAGE.

Temperature Set-Point Input

This program, diagrammed in Figure C-2 and listed in Figure C-3, allows up to nineteen pairs of temperature set points to be inserted in the computer memory. These points are used by the control program to control the sample temperature and stack gradient.

Computer Locations 3000 through 3041, 3130, and 3133 are used by the program. The floating-point package supplied by the manufacturer, PDP-8 Softwares, ⁽⁶⁾ is also used by this program.

Figure C-2. TEMPERATURE SET-POINT INPUT PROGRAM FLOW.

The program is entered manually from the computer console at Location 3000. It allows temperature set points used by the control program to be entered by the ASR-33 teletypewriter. The set points must be four-digit numbers (microvolt) without any decimal. Up to nineteen pairs of set points may be stored in the computer for future control. When entering the set points, always start with the top set point. After all set points have been stored, type 0001 carriage return and 0000 carriage return. Upon receiving these numbers, the computer will halt.

Control Program

The control program diagrammed in Figure C-4 and listed in Figure C-5 is used to sample temperatures, control the program flow, and regulate the power to the heaters in the LCTC apparatus.

Locations 0200 through 0253 and 0361 through 0374 are occupied by this program. Subroutines used include time delay (DELAY 1), set-point storage (GETSPL), maximum temperature sampled below the set point (FIGUR1), and radial heat flow zero (ISDATA). These subroutines are stored in other computer locations.

This program is entered manually from the computer console at Location 0200 after the temperature set points have been stored in memory. The program sequentially

```

*3000      TCF
          TLS
          KRB
AGAIN,     CLA CLL      /ROUTINE FOR ENTERING SET POINTS FROM
                        /ASR 33 DEVICE
                        /TYPE SET POINT. ENTER TOP SET
                        /POINT FIRST WITH BOTTOM SET
                        /POINT FOLLOWING
                        /ENTER FLOATING POINT PACKAGE
                        /DIVIDE ENTRY BY 2.441
          JMS I Z 5
          JMS I Z 7
          FDIV CON1
          FEXT
          CLA
          TAD Z 44      /FETCH EXPONENT
          SZA SMA      /IS NUMBER <1
          JMP +3        /NO!
          CLA          /YES! FIX IT TO ZERO
          JMP DONE +1
          TAD M13      /NO! SET BINARY POINT AT 11(10)
          SNA          /PLACES TO RIGHT OF CURRENT POINT
          JMP DONE     /IS ALREADY THERE! ALL DONE
          SMA          /TEST TO SEE IF IT IS TOO LARGE
          JMP ERROR    /YES! NUMBER >2**11
          DCA 44      /NO! SCALE COUNT
GO,        CLL        /0 TO CONTENTS OF LINK
          TAD 45      /FETCH MANTISSA
          SPA          /IS IT <0
          CML          /PUT A 1 IN LEFT BIT
          RAR          /SCALE RIGHT
          DCA 45      /RESTORE IT
          ISZ 44      /TEST IF SHIFTED ENOUGH
          JMP GO      /NO! CONTINUE
DONE,      TAD 45      /ANSWER IN C(AC)
          DCA I Z 14   /STORE FOR FUTURE USE
          TAD Z 45     /CHECK FOR LAST SET POINT
          SZA
          JMP AGAIN    /WAS NOT LAST SET POINT
ERROR,     HLT        /LAST SET POINT

/CONSTANTS
*3130
CON1,      0003
          2341
          7762
M13,       7765
          $

```

Figure C-3. TEMPERATURE SET-POINT INPUT PROGRAM LISTING.

scans 13 thermocouple outputs in the LCTC, stores the results in FIGUR2 subroutine, and calls appropriate subroutines for controlling heater power. Subroutine FIGUR1 checks to see if any of the directly controlled temperatures is above the minimum set point. If not, a code is inserted in a computer location (WORDO) that will turn all LCTC heaters on when called. This sequence is repeated until one of the sampled temperatures passes the minimum set point. When this occurs, Subroutine FIGUR2 is entered and changes WORDO's code to force zero radial heat flow and establish the stack differential. Subroutine ISDATA checks to see if radial heat flow has been eliminated for a time period controlled by Subroutine STABLZ. The complete program is repeated until this last condition is satisfied. When this occurs, Subroutine

Figure C-4. 3M THERMAL CONDUCTIVITY APPARATUS CONTROL PROGRAM (TSPT - Max) FLOW.

```

*0005
FLPOIN, 7400 /FLOATING POINT INPUT
FLPOOU, 7200 /FLOATING POINT OUTPUT
ENFLPO, 5600 /ENTER FLOATING POINT PACKAGE

*0010
THERXX, 0551
DATAST, 2177
STRIN, 1177
TEMPLO, 2177
STLOSP, 1177
FLPO, 0000

*0044
EXPONE, 0000
HIMANT, 0000
LOMANI, 0000

*0055
7777
7777

*0062
0000
0004
/3M THERMAL CONDUCTIVITY APP. CONT. PROGRAM (TSPT-MAX)

CRF=6711 /CLEAR REED FLIP-FLOPS
CHF=6712 /CLEAR HEATER FLIP-FLOPS
RARE=6714 /READ ACC TO REED FLIP-FLOPS
TUOF=6722 /TURN CONTROL UNIT OFF
RAH=6724 /READ ACC TO HEATER FLIP-FLOPS
SRN=6721 /SET REED RELAY NO. THIRTEEN
*0200
TCF /CLEAR FLAGS
TIS
KRB
JMS I GETSPL
BEGIN, CLA CLL /START OF PROGRAM
IAC
BEGIN3, TAD RELAST /SCAN RELAYS
RAKE /ENERGIZE SELECTED RELAY
CLL
RAL /SET UP FOR NEXT RELAY
DCA RELAST /STORE
JMS I DELAY1 /DELAY SUBROUTINE
ADC /READ PROPER THERMOCOUPLE
CRF /CLEAR REED FLIP-FLOPS
CLL
RAR /THROW AWAY LEAST BIT OF DATA
DCA I THERXX /STORE DATA

TAD CONST1 /LAST THERMO. NO. 12?
IAC
DCA CONST1
TAD CONST1
CMA
TAD CONST2
SZA CLA
JMP BEGIN3 /NO!
CLA CLL /YES!
DCA CONST1 /RESET CONST1
DCA RELAST /RESET RELAST
TAD TSPTS /RESET THERXX
DCA THERXX
SRN /SET RELAY NO. THIRTEEN
JMS I DELAY1 /110MS DELAY
ADC /READ T.C. 13
CRF /RESET REED NO. 13
CLL
RAR /THROW WAY LEAST BIT
DCA I THER13
JMS I FIGURE /COMPUTATION SUBROUTINE
CHF /HEATERS OFF!
CLA CLL
TAD I WORD0
RAH /TURN HEAT ON!
JMS I ISDATA /IS TIME FOR DATA?
JMP BEGIN /START CONTROL AGAIN

/CONSTANTS
*0361
DELAY1, 0300
ISDATA, 0600
BSPT, 0567
TSPTS, 0551
WORD0, 0525
FIGURE, 1400
CONST1, 0000
THER13, 0566
STORE1, 0000
CONST2, 0015
RELAST, 0000
GETSPL, 1000
STORE, 0000
TIMES, 7772
5

*0300
DELAY, 0000 /DELAY SUBROUTINE
CLA CLL
IAC /COUNT TO 4096(10)
SZA
JMP WAIT1
CLA CLL
TAD STORE /INCREMENT STORE EACH TIME
IAC /4096(10) IS REACHED
DCA STORE
TAD STORE
SZA CLA /THE FIFTH TIME STORE IS
JMP DELAY1 /INCREMENTED, THE 110MS DELAY
CLA CLL /HAS BEEN ACCOMPLISHED
DCA STORE /RESET STORE
JMP I DELAY /JUMP BACK TO PROGRAM

```

Figure C-5. CONTROL PROGRAM AND DELAY 1 SUBROUTINE LISTING.

ISDATA stores the last temperature sampled, reads in new set points, and returns to the beginning of the control program.

Subroutine DELAY

This subroutine, diagrammed in Figure C-6 and listed previously in Figure C-5, is used as a 100-millisecond delay after a multiplexier channel has been sampled, allowing the thermocouple amplifier output to stabilize before it is sampled by the computer ADC.

Figure C-6. 100-MILLISECOND DELAY SUBROUTINE FLOW.

Subroutine DELAY occupies Computer Locations 0300 through 0317, 0375, and 0376. Entry is gained through an indirect command from the control program.

This subroutine counts to 4096 five times. Each count cycle requires approximately six microseconds of computer time.

Subroutine GETST1

This subroutine acquires previously stored temperature set points and inserts them in the control program. This program is diagrammed in Figure C-7 and listed in Figure C-8.

Figure C-7. SUBROUTINE GETST1 FLOW.

This subroutine is entered from both the control program and ISDATA subroutine. It occupies Computer Locations 1000 through 1014, 1020, 1021, 1157, and 1160.

Upon entry, the subroutine will acquire the top set point defined by Auto-Index Register 12 and store it in the control program at Location 0550. Next, the bottom set point, defined by Auto-Index Register 12, is acquired. If it is 0000, the AC power to the LCTC will be turned off and the computer will halt; otherwise the set point is stored in Location 0567 of the control program. Upon completion, the program control reverts back to Location +1 indicated by 1000.


```

*1000
GETST1, 0000
        CLA CLL
        TAD I 2 12
        DCA I TSPTLL
        TAD I 4 12
        SNA
        TUOF
        SNA
        HLT
        DCA I BSPTLL
        TAD REDEV.
        DCA I STABL1
        JMP I GETST1

/CONSTANTS
*1020
REDEV., 6000
STABL1, 0771
*1157
TSPTLL, 0550
BSPTLL, 0567
$

```

Figure C-8. SUBROUTINE
GETST1 LISTING.

Subroutine FIGUR1

Mathematical routines are used to code the computer word WORD0, which is used by the control program to control the power to the LCTC heaters. Bits 0 - 8 of WORD0 are used to respectively control LCTC Heaters 9 - 1. When read into the interface electronics, a "1" in WORD0 will cause its respective heater to turn on. Binary zeros will cause the heaters to turn off. A listing and block diagram of the subroutine are presented in Figures C-9 and C-10, respectively.

Subroutine FIGUR1 occupies Locations 0400 through 0525 and 0550 through 0570. This subroutine operates on the temperatures that were previously stored by the control program.

Temperatures sampled by the control program are inserted in the nine formulas of Table C-1. If the result is negative, a binary "1" is placed in the bit corresponding to the formula being used. When read into the interface electronics, this "1" will cause its corresponding heater to turn on, increasing the temperature defined by the left side of the equation. The coded digital word, WORD0, is stored in Location 0525 for future use by the control program. Upon completion of the subroutine, program command goes to 0246 of the control program which calls for WORD0 and gates it into the interface for heater control.

Subroutine ISDATA

This subroutine tests the 13 temperatures stored in Subroutine FIGUR2 for zero radial heat flow. A flow diagram is presented in Figure C-11, and a listing is presented in Figure C-12.

```

*0400
FIGUR1, CLA CLL
DCA WORD0
TAD TSPT /TEST TSPT, T+13
CIA
TAD T+15
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0
TAD T+15 /TEST T+13, T+1
CIA
TAD T+1
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0
TAD T+15 /TEST T+13, T+12, T+2
TAD T+14
RAR
CIA
TAD T+2
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0
TAD T+14 /TEST T+12, T+11, T+3
TAD T+13
RAR
CIA
TAD T+3
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0
TAD T+13 /TEST T+11, T+10, T+4
TAD T+12
RAR
CIA
TAD T+4
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0

TAD T+12 /TEST T+10, T+9, T+5 /CONSTANTS
TAD T+11
RAR
CIA
TAD T+5
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0
TAD T+11 /TEST T+9, T+8, T+6
TAD T+10
RAR
CIA
TAD T+6
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0
TAD T+10 /TEST T+8, T+7
CIA
TAD T+7
AND MASK
TAD WORD0
CLL
RAR
DCA WORD0
TAD BSPT /TEST BSPT, T+8
CIA
TAD T+10
AND MASK
TAD WORD0
CLL
DCA WORD0
JMP I POWER1
MASK, 4000
WORD0, 0000

TSPT, 0000
T, .
T1, 0000
T2, 0000
T3, 0000
T4, 0000
T5, 0000
T6, 0000
T7, 0000
T8, 0000
T9, 0000
T10, 0000
T11, 0000
T12, 0000
T13, 0000
BSPT, 0000
POWER1, 0246
$

```

Figure C-9. SUBROUTINE FIGUR1 LISTING.

Figure C 10. SUBROUTINE FIGUR1 FLOW.

Figure C-11. SUBROUTINE ISDATA FLOW.

```

TUOF=6722
*0600
ISDATA, 0000
CLA CLL /TEST T+13, T+1
TAD I T+15
CMA IAC
TAD I T+1
SMA
CMA IAC
TAD DEV.
SPA
JMP I ISDATA
CLA CLL /TEST T+13, T+12, T+2
TAD I T+15
TAD I T+14
RAR
CMA IAC
TAD I T+2
SMA
CMA IAC
TAD DEV.
SPA
JMP I ISDATA
CLA CLL /TEST T+12, T+11, T+3
TAD I T+14
TAD I T+13
RAR
CMA IAC
TAD I T+3
SMA
CMA IAC
TAD DEV.
SPA
JMP I ISDATA
CLA CLL /TEST T+11, T+10, T+4
TAD I T+13
TAD I T+12
RAR
CMA IAC
TAD I T+4
SMA
CMA IAC
TAD DEV.
SPA
JMP I ISDATA
CLA CLL /TEST T+10, T+9, T+5
TAD I T+12
TAD I T+11
RAR
CMA IAC
TAD I T+5
SMA
CMA IAC
TAD DEV.
SPA
JMP I ISDATA
CLA CLL /TEST T+9, T+8, T+6
TAD I T+11
TAD I T+10
RAR
CMA IAC
TAD I T+6
SMA
CMA IAC
TAD DEV.
SPA
JMP I ISDATA
CLA CLL /TEST T+8, T+7
TAD I T+10
CMA IAC
TAD I T+7
SMA
CMA IAC
TAD DEV.
SPA
JMP I ISDATA
ISZ STABL2
JMP I ISDATA
CLA CLL
TAD I T+1
DCA I Z 11
TAD I T+2
DCA I Z 11
TAD I T+3
DCA I Z 11
TAD I T+4
DCA I Z 11
TAD I T+5
DCA I Z 11
TAD I T+6
DCA I Z 11
TAD I T+7
DCA I Z 11
TAD I T+8
DCA I Z 11
TAD I T+9
DCA I Z 11
TAD I T+10
DCA I Z 11
TAD I T+11
DCA I Z 11
TAD I T+12
DCA I Z 11
TAD I T+13
DCA I Z 11
TAD I T+14
DCA I Z 11
TAD I T+15
DCA I Z 11
JMS I GETST
JMP I ISDATA
/CONSTANTS
*0751
GETST, 1000
DEV., 0002
T, 0
T1, 0552
T2, 0553
T3, 0554
T4, 0555
T5, 0556
T6, 0557
T7, 0560
T8, 0561
T9, 0562
T10, 0563
T11, 0564
T12, 0565
T13, 0566
STABL2, 6000

```

Figure C-12. SUBROUTINE ISDATA LISTING.

Computer Memory Locations 0600 through 0771 are occupied by ISDATA. Entry is gained through indirect addressing from the control program. The subroutine uses the temperatures stored in Subroutine FIGUR2 by the control program.

The program is entered at Location 0600 by a jump-indirect-to-subroutine instruction in the control program. Control is returned to the Calling Instruction +1 when all tests have been made.

The previously stored temperatures are inserted in Formulas 2 through 8 of Table C-1. If the remainder of any calculation is greater than $\pm 1^\circ \text{C}$, control reverts back to the calling program. Elimination of radial heat flow is accomplished when all formula remainders are less than $\pm 1^\circ \text{C}$. This condition is held a preset time so all temperatures will stabilize. At completion of the stabilization period, the last 13 temperatures sampled are stored in the memory for future listing and the subroutine calls GETST1 which inserts new set points in FIGUR1.

Table C-1
FORMULAS USED BY SUBROUTINE FIGUR1

Formula	Heater	Bit Identification
1. T13 - Top Set Point	1	8
2. T1 - T13	2	7
3. $T2 = \frac{T12 + T13}{2}$	3	6
4. $T3 = \frac{T11 + T12}{2}$	4	5
5. $T4 = \frac{T10 + T11}{2}$	5	4
6. $T5 = \frac{T9 + T10}{2}$	6	3
7. $T6 = \frac{T8 + T9}{2}$	7	2
8. T7 - T8	8	1
9. T8 - Bottom Set Point	9	0

Subroutine FIGUR2

Subroutine FIGUR2, diagrammed in Figure C-13 and listed in Figures C-14 and C-15, is used to decrease the time required for heat stabilization. When called

Figure C-13. SUBROUTINE FIGUR2 FLOW.

/THIS SUBROUTINE WILL TURN ALL HEATERS ON IF THE MAXIMUM
/TEMPERATURE READ IS BELOW THE BOTTOM SET POINT.
*1400

```

FIGUR2, 0000
  CLA CLL
  TAD I BSPTA
  CIA
  DCA BSPTIN
  TAD BSPTIN
  TAD I T15A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T1A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T2A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T3A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T4A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T5A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T6A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T7A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T10A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T10A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD BSPTIN
  TAD I T2A
  SMA
  JMP I FIGUR2
  /CONSTANTS
  *1550
  BSPTA, 0567
  T15A, 0566
  T10A, 0563
  T7A, 0560
  T6A, 0557
  T5A, 0556
  T4A, 0555
  T3A, 0554
  T2A, 0553
  T1A, 0552
  FIGURA, 0400
  BSPTIN, 0000
  ALLHET, 7770
  WORD0A, 0525
  $

```

Figure C-14. SUBROUTINE FIGUR2 LISTING. (BSPT Minimum)

/THIS SUBROUTINE WILL TURN ALL HEATERS ON IF THE MAXIMUM
/TEMPERATURE READ IS BELOW THE TOP SET POINT.
*1400

```

FIGUR2, 0000
  CLA CLL
  TAD I TSPTA
  CIA
  DCA TSPTIN
  TAD TSPTIN
  TAD I T15A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T1A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T2A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T3A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T4A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T5A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T6A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T7A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T10A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T10A
  SMA
  JMP I FIGURA
  CLA CLL
  TAD TSPTIN
  TAD I T2A
  SMA
  JMP I FIGUR2
  /CONSTANTS
  *1550
  TSPTA, 0550
  T15A, 0566
  T10A, 0563
  T7A, 0560
  T6A, 0557
  T5A, 0556
  T4A, 0555
  T3A, 0554
  T2A, 0553
  T1A, 0552
  FIGURA, 0400
  TSPTIN, 0000
  ALLHET, 7770
  WORD0A, 0525
  $

```

Figure C-15. SUBROUTINE FIGUR2 LISTING. (TSPT Minimum)

by the control program, this subroutine will cause all nine heaters to be turned on if the nine heater temperatures are below the minimum set point.

The subroutine listed in Figure C-14 is used when the bottom set point is at a minimum; when the top set point is at a minimum, the subroutine listed in Figure 15 is used. To make the flow diagram of Figure C-13 applicable to the subroutine listed in Figure C-15, change "bottom set point" of the diagram to "top set point".

Subroutine FIGUR2 occupies computer Memory Locations 1400 through 1464 and 1550 through 1565.

The program is entered through a jump-indirect-to-subroutine (JMS I FIGUR2) from the control program. Depending on temperature conditions, the subroutine will either exit to FIGUR2 or back to the control program calling point +1.

This subroutine compares the nine heater temperatures with the minimum-temperature set point. If any temperature is greater than this set point, program flow goes to FIGUR1. When all temperatures are less than the minimum set point, WORDO of FIGUR1 is set to 7770 and flow jumps back to the Calling Address +1 where WORDO is used to turn all heaters on during the next program cycle.

Data Listing Program

This program is used to type out stored data on the ASR-33 teletypewriter. Each time the program is started, thirteen stored temperatures, starting with the location indicated by Auto-Index Register 0013, are listed with proper identification tags.

The program, listed in Figure C-16 and diagrammed in Figure C-17, occupies Computer Locations 2000 through 2067 and 2100 through 2121. It uses subroutine MESSAGE (DEC 8-18-U)⁽⁶⁾ located on Page 600 of the computer, Auto-Index Register 0013, and floating-point-package Digital 8-5D-S. The program is entered manually from the computer console at Location 2000.

When started, the program, through Subroutine MESSAGE, types the identification tag of the first temperature to be listed (TEMP 01 ⇒). The temperature stored in Location +1 indicated by Auto-Index Register 13 is next inserted in the floating-point accumulator, converted to microvolts, and typed by the tag that has just been listed. Control codes for Subroutine MESSAGE are indexed to list the tag of the next temperature to be typed and control reverts back to the program beginning. After the thirteenth temperature has been listed, all program counting codes are reset and the computer is ordered to halt. The computer must be restarted for a listing of each set point's thirteen temperatures.

Figure C-16. LISTING OF OUTPUTTING DATA STORED BY THE CONTROL PROGRAM.

Figure C-17. FLOW OF OUTPUTTING DATA STORED BY THE CONTROL PROGRAM.

Program MAIN I

MAIN I, diagrammed in Figure C-18 and listed in Figure C-19, is used to troubleshoot parts of the interface electronics, the multiplexier, amplifier-filter, and thermocouples.

When read into the computer, MAIN I will replace part of the operating program. It occupies Locations 0200 through 0223, 0300 through 0307, 0400 through 0417, 0450, 0451, 0500 through 0517, 0550, and 0551. Entry 1 is at Location 0200 through the computer console. Successive starts are at Location 0207. The program uses two delay subroutines that are diagrammed and listed in Figures C-13 and C-18.

The program actuates individual channels of the multiplexier. When started at Location 0200 reed, Relay 1 is repeatedly turned on 200 milliseconds and off 100 milliseconds. Successive starts at Location 0207 cause Relays 2 through 13 to be actuated in the same manner. Troubleshooting techniques are presented in Appendix A.

The delay subroutines used by MAIN I are identical to the one described in this Appendix under Subroutine DELAY, Page 35.

Program MAIN II

This program, diagrammed in Figure C-20 and listed in Figure C-21, is used to check parts of the interface electronics pertaining to the heater and AC power control relay, heater power supplies and control circuits, and the power control relay.

MAIN II occupies computer Storage Locations 0600 through 0621, 0700 through 0705, 0750 through 0753, 1000 through 1021, and 1100 through 1121. The program is entered through the console at either Location 0600 or 0606. The program uses two delay subroutines whose operation is identical to that described in this Appendix under Subroutine DELAY, Page 35.

Each of the nine heaters and the AC power control relay are repeatedly turned on for two seconds and off for one second. When started at Location 0600, Heater 1 is controlled. Successive starts at Location 0606 energize Heaters 2 - 9 and the AC control relay. Refer to Appendix A for the proper trouble-shooting techniques.

(a) Main I Program.

(b) Delay Subroutine.

Figure C-18. FLOW OF MAIN I PROGRAM AND DELAY SUBROUTINE USED BY MAIN I & II.

```

CRF=6711          /CLEAR REED FLIP-FLOPS
CRF=6712          /CLEAR HEATER FLIP-FLOPS
KARE=6714         /READ ACC TO REED FLIP-FLOPS
SRN=6721         /SET REED RELAY NO. THIRTEEN

/LCIC MAIN 1
/REFER TO LCIC SYSTEM MAINTENANCE FOR PROPER USE
*0200
      CLA CLL      /CLEAR ACC & LINK
      CRF          /DEENERGIZE ALL REEDS
      CHF          /TURN ALL HEATERS OFF
      IAC          /SET ACC FOR RELAY NO 1
      DCA WHARED   /STORE FOR RECALL
START1, TAD WHARED /SET ACC FOR RELAY NO 1
      JMP BEGIN
START2, CLA CLL    /NEXT RELAY WILL BE ACTUATED AFTER
      TAD WHARED   /COMPUTER IS STARTED AT THIS LOCAT.
      RAL          /SET UP FOR NEXT RELAY
      DCA WHARED   /STORE FOR RECALL
      TAD WHARED
      SNA
      JMP REED13
BEGIN, RARE        /READ ACC TO REED MEMORY
      JMS I DELAY1 /DELAY 200 MS
      CRF          /DEENERGIZE REEDS
      JMS I DELAY2 /DELAY 100 MS
      CLA CLL
      JMP START1

*0300
REED13, CLA CLL
      CRF          /CLEAR ALL REEDS
      SRN          /SET REED NO 13
      JMS I DELAY1 /DELAY 200 MS
      CRF          /DEENERGIZE ALL REEDS
      JMS I DELAY2 /DELAY 100 MS
      CLA CLL
      JMP REED13

*
/CONSTANTS
0350
WHARED, 0000
DELAY1, 0400
DELAY2, 0500

*0400
DELAYA, 0000      /DELAY NO 1, 200 MS
      CLA CLL
      IAC          /COUNT TO 4096(10)
      SZA
      JMP WAIT
      CLA CLL
      TAD STORE    /INCRE STORE EACH TIME 4096
      IAC          /COUNT TO 4096(10) IS REACHED
      DCA STORE
      TAD STORE
      TAD TIMES
      SZA CLA      /THE 11TH TIME STORE IS INCRE-
      JMP DELAYA+1 /MENTED, THE 200 MS DELAY IS COM-
      CLA CLL      /PLETED
      DCA STORE
      JMP I DELAYA

*0450
STORE, 0000
TIMES, 7766

*0500
DELAYB, 0000      /DELAY NO 2 (100 MS)
      CLA CLL
      IAC          /COUNT TO 4096(10)
      SZA
      JMP WAIT1
      CLA CLL
      TAD STORE1   /INCREMENT STORE EACH TIME 4096
      IAC          /COUNT TO 4096(10) IS REACHED
      DCA STORE1
      TAD STORE1
      TAD TIMES1
      SZA CLA      /THE SIXTH TIME STORE IS INCRE-
      JMP DELAYB+1 /MENTED, THE 100 MS DELAY IS COM-
      CLA CLL      /PLETED
      DCA STORE1
      JMP I DELAYB

*0550
STORE1, 0000
TIMES1, 7772
S

```

Figure C-19. LISTING OF MAIN I WITH SUBROUTINES.

Figure C-20. MAIN II PROGRAM FLOW WITH SUBROUTINES.

```

CRF=6711      /CLEAR REED FLIP-FLOPS
CHF=6712      /CLEAR HEATER FLIP-FLOPS
RAH=6724      /READ ACC TO HEATER FLIP-FLOPS
TUOF=6722     /TURN UNIT OFF
SRN=6721      /SET REED RELAY NO 13 AND ACTUATE
              /POWER RELAY

/LCTC MAIN II
/REFER TO LCTC SYSTEM MAINTENANCE FOR PROPER USE
*0600

      CLA CLL
      CRF      /CLEAR REED FLIP-FLOPS
      CHF      /TURN ALL HEATERS OFF
      SRN      /SET REED 13 & ENERGIZE CONTROL
              /RACK POWER RELAY

START,  TAD FIHEAT
        DCA HEATON
        CLA CLL
        TAD HEATON /SET UP ACC.
        RAL      /TURN PROPER HEATER ON.
        DCA HEATON /STORE FOR FUTURE USE
CONTIN, TAD HEATON
        SNA      /WAS LAST HEATER NO NINE?
        JMP POWREL /YES!
        RAH      /NO
        JMS 1 DELAY1 /DELAY FOR 2 SECONDS
        CHF      /TURN HEATERS OFF
        JMS 1 DELAY2 /WAIT FOR 1 SECOND
        JMP CONTIN /REPEAT HEAT CYCLE

*0700
POWREL, CHF      /TURN ALL HEATERS OFF
        SRN      /TURN UNIT ON
        JMS 1 DELAY1 /WAIT 2 SECONDS
        TUOF      /TURN UNIT OFF
        JMS 1 DELAY2 /WAIT 1 SECOND
        JMP POWREL /REPEAT

/CONSTANTS
*0750
FIHEAT, 0004
DELAY1, 1000
DELAY2, 1100
HEATON, 0000

*1000
DELAYA, 0000 /2 SECOND DELAY
        CLA CLL
        IAC      /COUNT TO 4096(10)
        SZA
        JMP WAIT
        CLA CLL
        TAD STORE /INCREMENT STORE EACH TIME 4096(10)
        IAC      /IS REACHED
        DCA STORE
        TAD STORE
        TAD TIMES
        SZA CLA /THE 112TH TIMES STORE IS INCREMENTED
        JMP DELAYA+1 /THE 2 SECOND DELAY IS COMPLETE
        CLA CLL
        DCA STORE
        JMP 1 DELAYA

/CONSTANTS
*1020
STORE, 0000
TIMES, 7621

*1100
DELAYB, 0000 /1 SECOND DELAY
        CLA CLL
        IAC      /COUNT TO 4096(10)
        SZA
        JMP WAIT1
        CLA CLL
        TAD STORE1 /INCREMENT STORE1 EACH TIME 4096(10)
        IAC      /IS REACHED
        DCA STORE1
        TAD STORE1
        TAD TIMES1
        SZA CLA /THE 56TH TIME STORE IS INCREMENTED,
        JMP DELAYB+1 /THE 1 SECOND DELAY IS COMPLETE
        CLA CLL
        DCA STORE1
        JMP 1 DELAYB

/CONSTANTS
*1120
STORE1, 0000
TIMES1, 7710
$

```

Figure C-21. LISTING OF MAIN II WITH SUBROUTINES.

APPENDIX D

DEVICE SELECTOR COMMANDS

Table D-1 lists the device selector commands and describes the function each performs.

Table D-1
DEVICE SELECTOR COMMANDS

Menemonic	Octac	Function
CRF	6711	Deenergizes all reed relays.
CHF	6712	Turns all heaters off.
RARE	6714	Gates accumulator into interface relay memory for controlling relays.
SRN	6721	Actuates reed Relay 13 and AC power control relay.
TUOF	6722	Deenergizes AC power control relay.
RAH	6724	Gates accumulator into interface heater memory for controlling heaters.

REFERENCES

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- (5) PDP-8 Maintenance Manual, F-87; Digital Equipment Corporation; Maynard, Massachusetts (1966).
- (6) PDP-8 Softwares; Digital Equipment Corporation; Maynard, Massachusetts (1966).