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SOFTWARE FOR DIGITAL ACQUISITION SYSTEM AND APPLICATION TO ENVIRONMENTAL MONITORING

By

G.E. Copeland

Funded by
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November 1975
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Criteria for selection of a mini-computer for use as a core resident acquisition system are developed for the ODU Mobile Air Pollution Laboratory. A comprehensive data acquisition program named MONARCH has been instituted in a DEC-8/E-8K 12-bit computer. Up to 32 analog voltage inputs are scanned sequentially, converted to BCD, and then to actual numbers. As many as 16 external devices (valves or any other two-state device) are controlled independently. MONARCH is written as a foreground-background program, controlled by an external clock which interrupts once per minute. Transducer voltages are averaged over user specified time intervals and, upon completion of any desired time sequence, outputted are: day, hour, minute, second; state of external valves; average value of each analogue voltage (E Format); as well as standard deviations of these values. Output is compatible with any serially addressed media.
INTRODUCTION

The need for development of a computer based data acquisition and control system arose during the evolution of a comprehensive Mobile Air Pollution Laboratory at Old Dominion University. This laboratory, housed in a mobile trailer (see figure 1), monitors at four different heights the following environmental parameters: wind speed and direction; temperature; concentrations of ozone \((O_3)\); nitrogen oxides \((NO, NO_2, NO_x)\); carbon monoxide \((CO)\); total hydrocarbons \((THC)\); and sulfur compounds \((H_2S, SO_2)\). Additionally measurements at one height are: relative humidity; insolation; atmospheric pressure; and the \(b\)-scattering coefficient (visibility). All of these analog voltage instruments were initially measured sequentially by a multipoint recorder which produced 14,000 data points per level per day. Transcription and averaging of this data base required more effort than maintenance of the instruments during the course of month-long field experiments. It soon became obvious that a computer based data acquisition and control system must be installed to provide near real time analysis of the environmental parameters and to provide convenient expansion and modification via software when additional instrumentation became available.

This system was named MONARCH.

A detailed analysis of present and future requirements for MONARCH suggested the following hardware configuration.

1. Data acquisition. A mixture of analog voltage, bridges, and digital BCD input channels must be available. The software must select order and frequency of scanning for a high precision low-speed A/D. All inputs to the A/D are set in the range \(-10.00\) to \(+10.00\) volts, so that each input slot has its own amplifier to change the incoming voltages to this range. Cost constraints prohibited use of a programmable gain amplifier.
2. All data averaging is done in software.

3. Master Control. A crystal controlled clock provides interrupts once per minute. Software design is based upon counting clock interrupts. When read, the clock provides Julian date, hour, minute, and second in three 12-bit BCD words.

4. Control Functions. Computer must initiate all scans of instruments, read the clock, and be able to control external valves for level shifting as well as inserting scrubbers, span and zero gases at appropriate times into air pollution instruments.

5. Input/Output. The entire system should work in a conversational mode so that field personnel may control its actions. Output medium should be versatile so that changes from paper tape to cassette tape or to tele-communications is possible.

Criteria were established for selection of a computer for MONARCH. Realizing that none of the investigators had ever dealt with minicomputers or assembly languages, one of the major criteria for selection was the existence of clearly worded comprehensible software documentation. Other criteria were: ease of interfacing, possibility of future expansion, cost, availability of service and software personnel, and our in-house hardware capability. The final selection of the minicomputer was a PDP8/E with 8K 12-bit word core memory.

HARDWARE CONFIGURATION

A block diagram of the hardware system is shown in figure 2. All I/O is handled by a 33ASR teletype. The clock was built in-house and interfaced to the PDP8/E. The clock (device code 13) interrupts once per minute and provides day (000-365), hour (00-24), minute and second (00-60) in three 12-bit words. It can be reset manually to 000d10h00m00s.
The valve control unit (device code 15) accepts from the PDP8/E one 12-bit word. Each bit (0 or 1) controls the state of one valve system. Once a valve is set via software command it maintains that state until it is reset. This device is expandable to 36 valve states.

Since MONARCH can control measurements at four levels (15, 25, 50, 75 feet) three of the valve states are used (figure 3). Four glass and teflon manifolds are brought into the trailer where each molecular instrument is attached to each manifold via 1/4" I.D. teflon tubing. Switching is accomplished by valves A, B, C which are solenoid activated teflon 3-way divert valves. This arrangement leaves eight unused states for cycling of scrubbers. If zero air or span gases are desired, they are easily incorporated with these additional valve states.

Device 14 is the A/D scanner and input level shifters for 14 input data channels. It is expandable up to 18 additional analog channels. Channel selection is via transfer of a positive binary number from the accumulator to the decoder where the appropriate channel is selected and its mercury relay is closed and data conversion begins. Upon finish of data conversion this device interrupts and one 12-bit BCD number can be read by the computer. Thus this device both accepts and sends information. If digital information is available from any instrument, they can be assigned their own device codes as needed.

DATA ACQUISITION SOFTWARE

MONARCH operates with the interrupt enabled, and a background program which endlessly rotates one bit through the link and accumulator of the PDP8/E. When the indicator selector switch is in the AC setting, one light moves across the display at a rate and direction dependent upon the switch registers (1). Any similar program can be substituted.
An initial start up sequence, START, operates with interrupt off and a dialogue takes place between the operator and MONARCH (figure 4). This sequence sets the number of levels, instruments, samples per instrument per minute, the length of time MONARCH spends per level and time periods between zero and span cycles. At the end of START all software counters are initialized. MONARCH gives messages to the operator, sets the valves and then halts.

MONARCH operates using a Digital Equipment Corporation 23-bit floating point package (FPP) (2), series of teletype service routines, and a BCD-binary conversion subroutine. Use of the FPP enables accuracy of six significant digits and greatly enhances the ease of arithmetic and data manipulation as well as I/O operations. Figures 5 through 10 give the flow diagram for MONARCH. A listing of MONARCH in PAL III assembly language constitutes Appendix A.

After the operator has interacted with MONARCH and supplied the required information, the computer halts. Upon pressing the CONTINUE switch, all flags are cleared, the interrupt is turned on and the background program is entered. At this point we will assume four levels, 14 instruments, five minutes per level and 100 samples per instrument per minute. At the first clock interrupt (Zeroth minute) MONARCH goes to location 0000 and executes the instruction stored in location 0001 which is an effective jump to the Service routine. The Service routine stores the current value of the accumulator and link. Location 0000 has stored in it the next instruction that was to be performed before interrupt occurred. The SERVE routine is a skip chain which tests to see which device needs attention. At this moment the clock is determined and a jump to CLKSER occurs. Since this is the first clock interrupt, the clock is not read. Several counters are incremented (counted up to zero), and the scanner is instructed to start conversion on instrument 14. Then the program jumps to EXIT where the accumulator and link are restored, and program control is returned to background.
The next interrupt is the scanner signalling that instrument 14 has finished conversion. A jump to SERVE occurs where the scanner is detected and a jump to SCNSER happens. SCNSER clears the scanner interrupt flag, sends one 12-bit BCD word to the accumulator. Since the A/D has been designed to accept -10 to +10 volt signals, it is necessary to determine the algebraic sign of the data. This is implemented in hardware. If the least significant digit (LSD) is 0, then the number is negative. If 1, it is positive. This means valid outputs from the A/D are even numbers (negative); odd numbers (positive) over the range -998 to +999. Over range is signalled by all bits zero and must be differentiated from real zero by software if needed.

SCNSER checks the LSD and converts BCD to binary via a service routine, BCDBIN. The floating point package (FPP) is entered and the one word binary data is converted to floating point (3 words). This data is level shifted to all positive (range 0 to 2000) and added indirectly to the 14th floating point buffer location. The Buffer was set to zero in START. Next the scanner is sent instructions to process instrument 13 and control is passed to background.

This process continues until SCNSER detects the fact that each instrument has been read the specified number of times (100, in this example). At that point the scanner is not sent a start conversion signal and program returns to background to wait for the second clock interrupt.

This procedure (clock interrupt, read sequentially each instrument 100 times, wait until clock interrupts) continues until the fourth clock interrupt. At that time a valve in the NOx instrument is energized and the same procedure continues.

At the fifth clock interrupt a new sequence is initialized. First, the valve state (level) is changed. The clock is now read (BCD 3 words). The clock words are masked and converted to binary, and then to 12-bit words corresponding to units of seconds, minutes, days, tens of seconds, minutes, days, and hundreds
of days. Next the state of the NOx valve is changed. Data output is now indicated via the routine DTAOUT. An example output is shown in table 1. Extensive use is made of the FPP and teletype routines for output and format control (may be FORTRAN E or F format). Output is sequentially printed on three TTY lines; Line 1: DAY, HOUR, MIN., SEC., VALVE LEVEL CODE. Line 2: DATA FROM INSTRUMENT ONE TO SEVEN. Line 3: DATA FROM INSTRUMENT EIGHT TO FOURTEEN. Each outputted value is a decimal number and each are separated by blanks except carriage return line feed at the end of lines. The values are the arithmetic mean of the voltages of each instrument averaged over the number of times it was read. DTAOUT then zeroes all the data storage buffer and returns to background via EXIT. Since the output is to TTY paper tape, a maximum of 600 characters may be punched before the next interrupt occurs. DTAOUT operates with the interrupt off, so that no confusion is possible.

Included in the SERVE Skip Chain are two other service routines. TTYSER gives a warning to the operator if the TTY keyboard is struck. This can be used to input and modify future states of the program. ERROR is a routine at the bottom of the skip chain which can only be entered if interrupt occurs when no real device has caused such. This routine gives an error message and returns to background. It is of importance in cases where the electromagnetic environment is noisy.

**FUTURE EXPANSION PLANS**

Even though MONARCH presently resides in an 8K machine, it is entirely contained in Field 5 (Lower 4K memory). The upper 4K memory is not used. Thus, MONARCH can be used with only minor modification in any 4K PDP 8 system. Since the instruction set utilized is shared by the PDP/5 system, MONARCH will work in these older machines if the interrupt service routine is modified. If mass
storage devices are incorporated for I/O operations, then the TTY service routines and FPP FOUT function must be modified.

The present version of MONARCH is fixed to a previously existing four-level value structure shown in figure 3. If the number of external levels are increased, additional value routines are necessary. Decreasing from four levels requires no change. If zero and span cycles are desired, they may be inserted in the ZERO routine or they may be assigned levels five and six and thus will automatically be cycled through in the same time intervals as the first four levels.

Many of the instructions used in the floating point package are not currently used. Additional storage may be obtained by deleting these. Examples would be the floating trig and log functions. One modification that would be desirable, from a data analysis viewpoint, would be the incorporation of statistical variances of the quantities being measured. This could be implemented without greatly increasing data storage requirements (it would double \( 14 \times 3 \times 2 = 84 - 12 \) bit words). Presently, the data storage buffer has stored in each location (3 word) the sum of the data from each instrument over the sample interval. Using the FSQU instruction and doubling the size of the buffer, one could have stored

\[
\sum_{i=1}^{N} X_i
\]

and

\[
\sum_{i=1}^{N} X_i^2
\]

where \( X_i \) is the measurement, \( N \) is the number of times the quantity is measured. At output, it is a simple matter to output (already done)
\[ <x> = \frac{1}{N} \sum_{i=1}^{N} x_i \]

and also

\[ \sigma^2 = <x^2> - <x>^2 = \frac{1}{N} \Sigma x_i^2 - \left( \frac{1}{N} (\Sigma x_i) \right)^2 \]

The variances have physical interpretations for meteorological quantities (wind speed, temperature, etc.) which are related to turbulence. Variances should be known so that estimates of the reliability and validity of the data may be obtained.

If reliable calibration equations are available, the floating point package can be used to provide output in engineering units directly. Although this may appear to be a desired goal in design of MONARCH, it can easily produce invalid results if calibration of any instrument changes. As a check against this happening for the computer hardware, it is suggested that at least one data port be used to monitor a fixed voltage (Standard cell).
Table 1. Example of MONARCH output.

<table>
<thead>
<tr>
<th>Line 1</th>
<th>Day</th>
<th>Hour</th>
<th>Min</th>
<th>Sec</th>
<th>Valve State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 2</td>
<td>Inst # 1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Line 3</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inst</th>
<th>Day</th>
<th>Hour</th>
<th>Min</th>
<th>Sec</th>
<th>Valve State</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+401.0</td>
<td>+14.0</td>
<td>+53.0</td>
<td>+0.0</td>
<td>+5.0</td>
</tr>
<tr>
<td></td>
<td>+75.4</td>
<td>+75.3</td>
<td>+75.3</td>
<td>+75.2</td>
<td>+75.3</td>
</tr>
<tr>
<td></td>
<td>+75.3</td>
<td>+75.3</td>
<td>+58.9</td>
<td>+69.7</td>
<td>+64.7</td>
</tr>
<tr>
<td></td>
<td>+401.0</td>
<td>+14.0</td>
<td>+56.0</td>
<td>+0.0</td>
<td>+4.0</td>
</tr>
<tr>
<td></td>
<td>+76.9</td>
<td>+78.6</td>
<td>+77.2</td>
<td>+78.8</td>
<td>+77.3</td>
</tr>
<tr>
<td></td>
<td>+78.8</td>
<td>+77.3</td>
<td>+62.1</td>
<td>+73.2</td>
<td>+69.0</td>
</tr>
<tr>
<td></td>
<td>+401.0</td>
<td>+15.0</td>
<td>+3.0</td>
<td>+0.0</td>
<td>+2.0</td>
</tr>
<tr>
<td></td>
<td>+77.5</td>
<td>+77.4</td>
<td>+77.5</td>
<td>+77.6</td>
<td>+77.6</td>
</tr>
<tr>
<td></td>
<td>+77.7</td>
<td>+77.6</td>
<td>+60.8</td>
<td>+71.9</td>
<td>+69.1</td>
</tr>
<tr>
<td></td>
<td>+401.0</td>
<td>+15.0</td>
<td>+8.0</td>
<td>+0.0</td>
<td>+0.0</td>
</tr>
<tr>
<td></td>
<td>+74.7</td>
<td>+76.0</td>
<td>+74.9</td>
<td>+76.1</td>
<td>+74.9</td>
</tr>
<tr>
<td></td>
<td>+76.2</td>
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<td>+2.0</td>
</tr>
<tr>
<td></td>
<td>+75.8</td>
<td>+79.4</td>
<td>+76.0</td>
<td>+79.5</td>
<td>+76.1</td>
</tr>
<tr>
<td></td>
<td>+79.6</td>
<td>+76.0</td>
<td>+62.9</td>
<td>+71.0</td>
<td>+70.2</td>
</tr>
</tbody>
</table>
Figure 1. ODU Mobile Air Pollution Laboratory.
Figure 2. Block diagram of the hardware configuration of MONARCH.
A, B, C, E ARE
3 WAY TEFILON
DIVERT VALVES
NO: NORMALLY OPEN

Figure 3. Four level valve configuration.
I AM MONARCH
INPUT THE NUMBER OF DATA PORTS
14
INPUT THE NUMBER OF LEVELS
4
INPUT THE TIME(MIN) SPENT PER LEVEL
5
INPUT NUMBER OF SAMPLES TAKEN
BY EACH INSTRUMENT PER LEVEL
100
INPUT THE NUMBER OF TIMES UP TOWEL
BETWEEN ZERO CYCLES
3

CLOCK CAN BE RESET ONLY AT

000 DAYS
0 Unit
00Min
00Sec
WHEN I STOP TURN ON PUNCH AND HIT CONTINUE

Figure 4. Initial Dialogue between MONARCH and OPERATOR.

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Figure 5. MONARCH flow diagram - start up and background.
Figure 6. MONARCH - interrupt routines.
Figure 7. CLKSER (clock service) routine.
Figure 8. Valve switching and output.
Figure 9. Service routines.
Figure 10. Service routines.
REFERENCES


2. DEC-08-NFPPA-A-PAL.
APPENDIX

MONARCH Written in PAL III
BUFF=4000

ENTER,  CLA CLL
        TLS
        CLA CLL
        DCA AC
        JMS I PTYPX
        ENTMS3
        CLA CLL
        TAD CHAN
        DCA INDXR3+2
        CLL
        JMS I 7
        FGET INDXR3
        FPUT R16

ZERIST, FGET ZERO00
         FPUT I R16
         FISZ R20 /*ALL DONE?*/
         FJMP ZERIST /*NO*/
         FGET INDXR3 /*SET UP R16*/
         FPUT R16
         FEXT
         CLA CLL
         TLS
         JMS I PTYPX
         ENTMS1
         CLA CLL
         JMS I PTYPX
         ENTMS2
         HLT /*STOP BEFORE ROTATE CHECK PAPER TAPE*/
         CAF
         ION
         JMP I PROTAT

ENTMS3,  3700 /*CR-LF*/
ENTMS2,  2710 /*WH*/

0516 /*EN*/
4011 /*I*/
4023 /*S*/
2417 /*T0*/
2040 /*P*/
2425 /*TU*/
2216 /*RN*/
4017 /*O*/
1640 /*N*/
2025 /*PU*/
1603 /*NC*/
1040 /*H*/
0116 /*AN*/
0440 /*D*/
1011 /*HI*/
2440 /*T*/
*400

DTAOUT, CLA CLL
TLS
JMS I PTYPX /+2LF/CR
OPMS1
CLA CLL
IAC /PUT >0 IN AC
DCA 56 / TAKE OUT OF E FORMAT
TAD FORONE / F7.0
DCA 57
DCA DECON
DCA 60
DCA 55 /0 LEFT IN AC, PUT IN 55 SUPPRESS CR/LF
JMS I 7
FGET DAYS
FOUT
FGET HOURS
FOUT
FGET MINS
FOUT
FGET SECS
FOUT
FEXT
CLA CLL
TAD CVS
SZA /-0?
JMP NO1 /NO
IAC /YES
IAC /2 IN AC
JMP VALOUT

NO1, CLA CLL / IS IT 2?
CLA CLL CMA RAL / -2 IN AC
TAD CVS
SZA /IS CVS=2?
JMP NO2 /NO
CLA CLL /NO
CLA CLL IAC RTL / PUT 4 IN AC
JMP VALOUT

NO2, CLA CLL
CLA CLL IAC RTL
CLA
TAD CVS
SZA /IS=4?
JMP NO3 /NO =5 STATE
CLA CLL /YES
TAD CVS
IAC
JMP VALOUT

NO3, CLA CLL
JMP VALOUT
VALOUT, DCA 44 /ENTER WITH VALVE STATE IN AC
JMS I 7

A-3
OUT PUT LEVEL IN OCTAL VALVE CODE

cle l
jmp 1 poutdt

*76

poutdt, outdt

*3000

outdt, clacll

l5
jms 1 ptypx
opms2 /1cr-lf
clacll
tad fortwo
dca 57
tad dectwo
dca 60 / f8.1
tad lsn
dca 44
jms 1 7 /* OF SAMPLES PER LEVEL PER INSTR.

fput fput fplsn
fput indxri
fput r16

flop1, fget i r16
fdgv fplsn
fput
fisz r20 /*DONE 1ST HALF?
fjmp flop1 /*NO
fext /*YES
clacll
jmp 1 ptypx
opms2
clacll
jms 1 7
fget indxri
fput r16

flop2, fget i r16
fdgv fplsn
fput
fisz r20
fjmp flop2 /*NO
fext /*YES ; LAST HALF DONE
clacll
jmp 1 ptypx
opms2
jmp 1 ptypx
opms1
clacll
jms 1 7
fget indxri
fput r16

zerlop, fget zero00

a-4
FPUT I R16
FISZ R20  /DONE ALL INSTR?
FJMP ZERLOP  /NO
FEXT
CLA CLL
JMP I PEXIT
OPMS1, 3737 /2CR-LF
0000 /@0
OPMS2, 3700 /CR-LF0
FORTWO, 0010
DECTWO, 0001/ F8.1 FORMAT
FPLSN, 01010
INDXR1, BUFF-3101-7
INDXR2, BUFF+22101-7
*16
R16,0
R17,0
R20,0

*30
INDXR3, BUFF-31 BUFF-31 -16
PAUSE

-CSIF=6145
S DTAC=6146
*600
SCNSER, CLA CLL  /CLEAR SCANNER INTERRUPT FLAG
CSIF  CLA CLL
S DTAC
DCA TEMDAT
TAD TEMDAT
AND MASLSD  /CK TO SEE IF <O,MASLSD=0001
SZA  /SKIP IF AC=0 ONLY
JMP UP
CLA CLL  /YES NUM<0
TAD TEMDAT
JMS I PBCDBN
CIA  /CONVERT AND NEGATE
DCA TEMDAT
JMP DATAIN
UP,  CLA CLL  /NO IT IS >0
TAD TEMDAT
JMS I PBCDBN  
A-5
DCA TEMDAT
JMP DATAIN

TEMDAT, 0
MASLSD.0001
DATAIN, CLA CLL
TAD TEMDAT
DCA 44
JMS I 7
FLOT
FMPY NCSL0P / SLOPE IS ONE TO ONE FOR NUMBER SCALE
FADD NCZERO / INTERCEPT IS +998 (USED 1000 TEMP)
FADD I R16
FPUT I R17
FISZ R20 / FINISHED ALL INST?
FJMP NOTYET
FGET INDEXR3 / YES RESET INDEX REG.
FPUT R16
FEXIT
JMP SNDCHN

NOTYET, FEXIT
JMP SNDCHN

NCSL0P, 0001; 2000; 0000
NCZERO, 0012; 3720; 0000
SNDCHN, CLA CLL
ISZ CHAN / IS CHAN -0?
JMP EX1 / NO
TAD NI / YES, SO RESET CHAN
CIA / NEGATE
DCA CHAN
ISZ NSL / IS NSL = 0?
JMP EX1 / NO
CLA CLL / YES, RESET NSL
TAD LSN
CIA
DCA NSL
NOP / WAIT FOR LAST CLOCK INTERRUPT
JMP I PEXIT

EX1, CLA CLL
TAD CHAN
CIA
CNTSN / SEND TO SCANNER
JMP I PEXIT

EXIT, CLA CLL
CAF
TAD FLAGS
RTF
CLA
TAD AC
JMP I 0

ERROR, CLA CLL

ORIGINAL PAGE IS OF POOR QUALITY
CAF /CLEAR ALL FLAGS
TLS
JMP I PTYPX
ERRME1
CLA CLL
CAF
JMP I PEXIT
ERRME1: 0522 /ER
2217 /RO
2240 /R
1116 /IN
4023 / S
1311 /KI
2040 /P
0310 /CH
0111 /AI
1640 /N
3700 /-0
#115
PEXIT /EXIT
PERROR / ERROR
PAUSE

SICFS=6137
SISFS=6147
CNTSN=6141
CCIF=6135
RCW1=6131
RCW2=6132
RCW3=6133
*1000
SERVE: DCA AC
GTF
DCA FLAGS
CLA /SKIP CHAIN
SICFS /SKIP IF CLOCK FLAG SET
SKP
JMP CLKSER
SISFS /.Skip IF SCANNER FLAG SET
SKP
JMP I PSCNSR
KSF /KEYBOARD SET FLAG?
SKP
JMP I PTTYSR
JMP I PERROR
CAF
JMP I PEXIT / SHOULD NEVER GET HERE
CLKSER: CLA CLL

ORIGINAL PAGE IS OF POOR QUALITY
CCIF /CLEAR CLOCK INTERRUPT FLAG
ISZ CIC /IS CIC-0?
SKP /NO
JMP CLKRED /YES
CLA CLL
IAC /PUT 1 IN AC
TAD CIC
SMA
JMP NOVOFF

RENTER, CLA CLL
JMS I 7
FGET INDXR3
FPUT R16
FEXT
CLA CLL
// THIS RESETS INDEX FOR ADDING TO THE DATA FILES
TAD NI
CIA
DCA CHAN
TAD CHAN
CIA
CINTSN /START CONVERSION ON 1ST INST
CLA CLL
JMP I PEXIT

NOVOFF, CLA CLL
TAD CVS
SACTV /SEND TO VALVES
JMP RENTER

CLKRED, CLA CLL
CCIF /CLEAR CK INTERRUPT FLOG
RCW1 /READ 1ST CLK WORD
DCA FSTWRD
RCW2 /READ 2ND WORD
DCA SNDWRD
RCW3
DCA THRWRD
TAD MINS5
CIA /NEGATE
DCA CIC /RESET THE CIC COUNTER
JMP CLKPRO

FSTWRD, 0
SNDWRD, 0
THRWRD, 0

CLKPRO, CLA CLL
TAD FSTWRD
JMS MSK1 /SAME PAGE
DCA UNSSEC
TAD FSTWRD
JMS MSK2 /SAME PAGE
DCA TNSSEC
TAD FSTWRD
JMS MSK3 /SAME PAGE
DCA UNSMIN
CLL
TAD SNDWRD "2ND WRD PROCESSOR"
JMS MSK1
DCA TNSMIN
TAD SNDWRD
JMS MSK2
DCA UNSHRS
TAD SNDWRD
JMS MSK3
DCA TNSHRS
CLL
TAD THWRD "3RD WORD"
JMS MSK1
DCA UNSDYS
TAD THWRD
JMS MSK2
DCA TNSDYS
TAD THWRD
JMS MSK3
DCA HNDDYS
CLL
JMP I PDTMSR
MSK1,0
AND MASKT1
CLL
RTR
RTR
RTR
RTR
JMS I PBCDBN
JMP I MSK1
MSK2,0
AND MASKT2
CLL
RTR
RTR
RTR
RTR
JMS I PBCDBN
JMP I MSK2
MSK3,0
AND MASKT3
CLL
JMS I PBCDBN
JMP I MSK3
MASKT1,7400
MASKT2,0350
MASKT3,0017
*72
CVS,0
*70
AC,0
*101
PBCDBN,BCDBIN
*160
UNSSEC,0
TNSSEC,0
A-9
UNSHRS, 0
TNSMIN, 0
UNSHRS, 0
TNSHRS, 0
UNSDYS, 0
TNSDYS, 0
HNDussy, 0

*102
PSCNSR, SCNSER
PTTYSR, TTYSER
PDTMSR, DTMSTR
PVALVR, VALVER

*1
JMP I PSERVE
*5
PSERVE, SERVE
PAUSE

*1200

DTMSTR, CLA CLL
TAD UNSSEC
DCA 44
JMS I 7
FLOT
FPUT SECS
FEXT
CLA CLL
TAD TNSSEC
DCA 44
JMS I 7
FLOT
FMPY TEN
FADD SECS
FPUT SECS
FEXT
CLA CLL
TAD UNSMIN
DCA 44
JMS I 7
FLOT
FPUT MINS
FEXT
CLA CLL
TAD TNSMIN
DCA 44
JMS I 7
FLOT
FMPY TEN
FADD MINS
FPUT MINS
FEXT
CLA CLL
TAD UNSHRS
DCA 44

A-10
JMS I 7
FLOT
FPUT HOURS
FEKT
CLA CLL
TAD UNSDYS
DCA 44
JMS I 7
FLOT
FMPY TEN
FADD HOURS
FPUT HOURS
FEKT
CLA CLL
TAD UNSDYS
DCA 44
JMS I 7
FLOT
FPUT DAYS
FEKT
CLA CLL
TAD TNSDYS
DCA 44
JMS I 7
FLOT
FMPY TEN
FADD DAYS
FPUT DAYS
FEKT
CLA CLL
JMP I PYEARS

TEN, 4; 2400; 0
BCDBIN, 0
DCA TEMPH
TAD TEMPH
AND LDIGIT
CLL RTR
DCA CUNT
TAD CUNT
RAR
TAD CUNT
CMA IAC
TAD TEMPH
DCA TEMPH
DCA TEMPH
TAD TEMPH
AND MDIGIT
CLL RTR
DCA CUNT
TAD CUNT
RAR
TAD CUNT
CMA IAC
TAD TEMPH

A-11
JMP I BCDBIN
LDIGIT, 7400
MDIGIT, 7760
CUNT, 0
TEMPL, 0
*76
PYEARS, YEARS
*3200
YEARS,
CLA CLL
TAD HNDDYS
DCA 44
JMS I 7
FLOT.
FMPY HUN100
FADD DAYS
FPUSI DAYS
FEXT
CLA CLL
JMP I PVALVR
HUN100, 7;3100;0
*123
SECS,0;0;0
MINS,0;0;0
HOURS,0;0;0
DAYS,0;0;0
PAUSE

*120
ZERO00, 0;0;0
*2400
ZERO,
CLA CLL
TAD NCLUT
CIA
DCA TULCN
JMP I PNOVAL
/ THIS ROUTINE WILL BE WRITTEN LATER(MAY 23, 1974)
/ CURRENT SYSTEM WILL NOT ZERO BUT ONLY A SMALL CHANGE IS
/ NEEDED.
*112
PNOVAL, NOVAL
*71
FLAGS, 0
PAUSE
A_12
SACTV=6151
*1400

VALVER, CLA CLL
ISZ VL / IS VL=0?
JMP VLNZ / NO
TAD NLV / YES, NLV=+4= # LEVELS
CIA
DCA VL / RESET VL
.clal CLL
IAC
RTL
IAC
IAC
DCA CVS
TAD CVS / CURRENT VALVE STATE (A,B,C)
SACTV / PUT 101 ON AC, SEND TO VALVES
ISZ TULCN / READY TO ZERO?
JMP NOVAL / NO; NCLUT=# CYCLES UP TOWER
JMP I PZERO / YES

VLNZ, CLA CLL
.VL=-1-2-3
IAC
IAC
TAD VL / PUT +2 IN AC, TAD VL, RES +,0,-
SPA
JMP SEVFIV / VL=-3,75 FOOT
SZA
JMP TWFIV / VL=-1,25 FEET
CLA CLL
IAC
IAC
DCA CVS
TAD CVS
SACTV / SET 010 IN AC, SEND TO VALVES, 50 FEET
JMP NOVAL

SEVFIV, CLA CLL
IAC
RTL / 100 IN AC
DCA CVS
TAD CVS
SACTV / 75 FEET
JMP NOVAL

TWFIV, CLA CLL
DCA CVS
TAD CVS
SACTV / 000 IN AC', SEND TO VALVES, 25 FEET
JMP NOVAL

NOVAL, CLA CLL
IAC / NO VALVE TURN ON
RTL
RAL / MAKE 1000 IN AC
TAD CVS / ADD CURRENT VALVE STATE
SACTV
CLA CLL

ORIGINAL PAGE IS
OF POOR QUALITY

A-13
*1600

START

IOF

KCC /CLEAR KEYBOARD FLAG
CLA CLL
TLS
JMS I PTYPX
MESG01
JMS I PTYPX
MESG02
JMS INPT
CLA CLL
TAD 150
DCA NI
TAD NI
CIA
DCA CHAN / SET CHAN=NI
CLA CLL
JMS I PTYPX
MESG03
JMS INPT
CLA CLL
TAD 150
DCA NLV / SET UP NLV(#OF LEVELS)
TAD NLV
CIA
DCA VL / SET UP VL=NLV
CLA CLL
JMS I PTYPX
MESG04
JMS INPT
CLA CLL
TAD 150
DCA MINS5 / SET UP TIME / LEVEL(MINS=5 TYPICAL)
TAD MINS5
CIA
DCA CIC / SET UP CIC
CLA CLL
JMS I PTYPX
MESG05
JMS INPT
CLA CLL
TAD 150
DCA LSN
TAD LSN
CIA
DCA NSL / SET NSL
CLA CLL
JMS I PTYPX
ZERCYM
JMS INPT
CLA CLL
TAD 150

A-15
1405 /LE
2605 /VE
1423 /LS
3700 /-0
PRESTR. CLA CLL
IAC
RTL
IAC
DCA CVS
TAD CVS
SACTV /SET UP 15 LEVEL
CLA
IAC
RTL
RAL
TAD CVS
SACTV
CLA CLL
JMP I PENTER
*2700

ZERCY. 1116 /IN
2025 / PU
2440 / T
2410 / TH
0540 / E
1625 / NU
1502 / NB
0522 / ER
4017 / O
0640 / F
2411 / TI
1505 / ME
2340 / S
2520 / UP
4024 / T
1727 / OW
0524 / ER
3702 / -B
0524 / ET
2705 / WE
0516 / EN
4032 / Z
0522 / ER
1740 / O
0331 / CY
0314 / CL
0523 / ES
3700 /-0
PAUSE

A-17
*2000

TYPX, 0
CLA CLL
TAD I TYPX
DCA TYPNT
ISZ TYPX

TYPX1, TAD I TYPNT
RTR
RTR
RTR
JMS TYPY
TAD I TYPNT
ISZ TYPNT
JMS TYPY
JMP TYPX1

TYPNT, 0
TYPY, 0
AND TK77
SNA
JMP I TYPX
TAD TKM37
SZA
JMP TYPY1
TAD TK215
JMS TLSX
TAD TKM125

TYPY1, SPA
TAD TK100
TAD TK237
JMS TLSX
JMP I TYPY

TK77, 77
TKM37, -37
TK215, 215
TKM125, -125
TK100, 100
TK237, 237
TLSX, 0
TSF
JMP -1
TLS
CLA
JMP I TLSX

KRBX, 0
KSF
JMP -1
KRB
JMP I KRBX

KREAD, 0
CLA CLL
TAD I KREAD
ISZ KREAD
DCA KRPNT
TAD I KREAD
DCA KRCNT

KRB1, JMS KRBX
DCA I KRPNT
TAD KRTAB
DCA KRBKS
TAD I KRPNT
ISZ KRBKS
SNA CLA
JMP I KRBKS
ISZ KRBKS
TAD I KRBKS
SZA
JMP KRB3
JMS KRBKS
ISZ KRCNT
JMP KRB6
TAD TK207

KRBS. TAD I KRPNT
ISZ KRBKS
SNA CLA
JMP I KRBKS
ISZ KRBKS
TAD I KRBKS
SZA
JMP KRB3
JMS KRBKS
ISZ KRCNT
JMP KRB6
TAD TK207

KR5. JMS TLSX
CLA CMA
TAD KRCNT
JMP KRB1-1

KR6. TAD I KRPNT
ISZ KRPNT
JMS TLSX
JMP KRB1

KRUB. CLA CMA
JMS KRBKS
ISZ KRFIAG
TAD I KREAD
CLA
TAD KRCNT.
SNA CLA
JMP KRUB1
CLA CMA
TAD KRPNT
CLA CMA
TAD I KRPNT
DCA KRPNT
TAD I KRPNT
JMP KRB5

KRUB1. TAD TK237
JMS TYPY
JMS KRBKS
JMP KRB1

KRCR. JMS KRBKS
TAD TK237
JMS TYPY
DCA I KRPNT
ISZ KREAD
JMP I KREAD

KRBS. O
TAD KRFIAG
SZA CLA
TAD TK334
SZA
JMS TLSX

A-19
DCA KRFLAG
JMP I KRBK

KRFLAG, 0
KRPNT=TYPNT
KRCNT=TYPX
TK207, 207
TK334, 334

KRTAB,

JMP KRB1
-200;
JMP KRB1
-212;
JMP KRB1
-215;
JMP KRCR
-377;
JMP KRUB
0

PAUSE

*2600

MESG04, 1116 /IN
2025 /PU
2440 /T
2410 /TH
0540 /E
2411 /TI
1505 /ME
5015 /(M
1116 /IN
5140 /)
2320 /SP
0516 /EN
2440 /T
2005 /PE
2240 /R
1405 /LE
2605 /VE
1440 /L
3700 /→9

MESG05, 1116 /IN
2025 /PU
2440 /T
1625 /NU
1502 /MB
0522 /ER
4017 /O
0640 /F
2301 /SA
1520 /MP
1405 /LE
2340 /S
2401 /TA
1305 /KE
1637 /N-
0231 /BY
4005 /E
0103 /AC
1040 /H
1116 /IN
2324 /ST
2225 /RU
1505 /ME
1624 /NT
4080 /P
0522 /ER
4014 /L
0526 /EV
0514 /EL
3700 /-0

*100

PTYPX, TYPX

*140

NI, 0
CHAN, 0
NLV, 0
VL, 0
MINS5, 0
CIC, 0
LSN, 0
NSL, 0
PAUSE

FIXMRI FJMP=0000
FIXMRI FJMS=7000
FISZ=0000
FEXT=0000
FSQU=0001
FSQR=0002
FSIN=0003
FCOS=0004
FATN=0005
FEXP=0006
FLOG=0007
FNEG=0010
FIN =0011
FOUT=0012
FFIX=0013
FLOT=0014
FNOR=7000
FCDF=7001
FSWO=7002
FSW1=7003
FHLT=7004
FSMA=7110
FSZA=7050
FSPA=7100
FSNA=7040
FNOP=7010
FSKP=7020
PAUSE

A-21