RESEARCH AND DEVELOPMENT BRANCH

DEPARTMENT OF NATIONAL DEFENCE
CANADA

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

DREO TECHNICAL NOTE 81-20

DATA ACQUISITION USER'S GUIDE-1 FOR FUEL/ENGINE EVALUATION SYSTEM APPLIED TO AN EXPERIMENTAL AIR STIRLING ENGINE

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JULY 1981
OTTAWA

ABSTRACT

This technical note describes the Data Acquisition (DA) System used in the evaluation of Experimental Air Stirling Engine No. 1 which had previously been designed and built as a part of the "Advanced Engines" studies for the Fuels/Powerplants Technical Subprogram 25B.

The DA system and capability is presented. Brief programming guidelines for controlling various peripheral electronic equipment through a mini-computer are given. The program software used in testing the Stirling engine is described. Finally, some limitations of the DA system are listed.

RÉSUMÉ

La présente note technique décrit le système d'acquisition des données (AD) dont on se sert pour évaluer le moteur expérimental d'avion n° 1 de marque Stirling; ce dernier avait déjà été conçu et construit dans le cadre des études sur les "moteurs avancés" menées pour le compte du sous-programme technique 25B des carburants et des groupes-moteurs.

Nous présentons le système et les ressources d'AD. Nous donnons aussi des directives de programmation sommaires sur le contrôle de divers équipments électroniques périphériques au moyen d'un mini-ordinateur. Nous décrivons le logiciel que l'on utilise pour faire l'essai du moteur de marque Stirling. Finalement, nous décrivons certaines limites du système d' AD.

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1.0 INTRODUCTION

The Canadian Forces (CF) have a number of uses for a small (1.0 Kw), lightweight (10 Kg), nondetectable power source. The most prominent application is in the main battlefront area where such a power source would be used to activate command post electronic systems. As part of "Advanced Engines" studies for the Fuels/Powerplant Technical Subprogram 25B, Stirling Engines have been investigated for this application.

Stirling Engines have the potential to be quiet power sources as a result of using external combustion radiation heat transfer. It was realized soon after initial DREO thermodynamic modelling and experimentation [1], that Stirling Engines still require a great deal of additional development to increase efficiencies and improve performance. Part of this development is limited by the inability of existing materials to perform in the high temperature combustor area. For these reasons Stirling Engine activity at DREO has proceeded at a low level of priority and has been limited to modelling and experimental studies of the heat and mass transfer mechanisms. DREO's previously acquired Stirling Engines will be used as test beds to evaluate such material advancements as machineable ceramic combustor tubes and pistons.

One of the Stirling Engines that has been investigated is the Canadian designed and developed Experimental Air Stirling Engine No. 1 (EASE-1). To study advanced engines like EASE-1 and conventional engines, a Fuel Engine Evaluation System (FEES) has been developed. This system is comprised of a hard-wired network of transducers that sense engine related phenomena and pass the information to a data acquisition (DA) system. The DA system has the capability of sensing both transient and non-transient signals. The system will calculate engine speed, torque, indicated power, Carnot efficiency, brake power, power consumption, overall efficiency, indicated mean effective pressure and brake specific fuel consumption. In addition, power piston or piston displacement, pressure, dV or PdV waves can be recorded graphically.

The following report briefly discusses the FEES DA capability and describes many of the software techniques not properly described in the operation manuals. The report should be viewed as a user's guide to document the system capability to date. It is meant to be a supplement for use with the existing system operation manuals. The software developed is for use with EASE-1 and a sample of the output has been included along with the program listing.

2.0 SYSTEM STRUCTURE

The heart of the Data Acquisition (DA) system within the overall Fuels/Engines Evaluation System (FEES) is a Tektronix 4052 mini-computer (hereafter called the 4052). Linked to the 4052 and directly controlled by it are the following three peripheral devices: a 60-channel Fluke datalogger for measuring non-transient signals (temperatures); a 2-channel Digital Processing Oscilloscope (DPO) for measuring transient signals (cylinder pressure) and a 3-drive floppy disc storage bank. A schematic of the system is shown below:

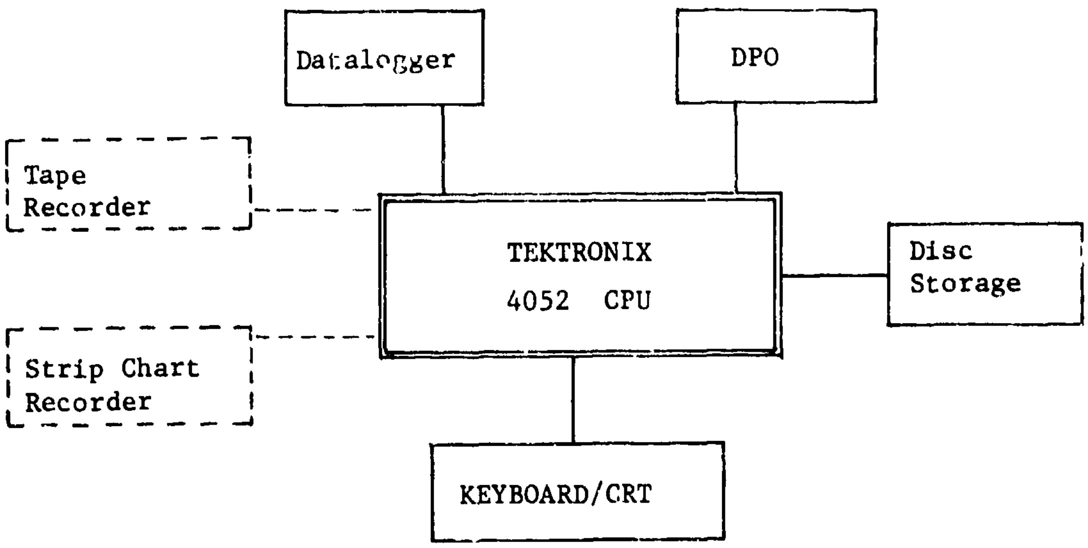


Figure 1

A 16-track tape recorder and a 6-track strip chart recorder are available for additional analog input but are not currently controlled by the 4052.

The system capability is summarized below:

a. 4052 Tektronix microcomputer
   -64 kilobytes random access memory

b. P7001 Tektronix digital processing oscilloscope
   -2 channel DC-coupled differential input
   -4 kilobyte internal core memory
   -1 M hz sampling rate
   -signal conditioning and coversion to digital data;
      6.5 microseconds/data point
      512 points/waveform
      resolution of 10 bits (1 part in 1024)

c. 2240 B Fluke data logger
   -60-channel input
   -15 readings/sec A/D conversion

d. 3-drive floppy disc storage
   -630 kilobytes memory each disc
   -1300 bytes/sec transfer rate

In the EASE-1 program, the 4052 has two functions:

a. to control the above mentioned peripheral devices; and

b. to analyze the information collected from the EASE-1 engine.

The datalogger monitors engine torque and the following temperatures: power piston, block, coolant in and out and heater heads.

Cylinder pressure and power piston displacement are measured through the DPO.

Both raw and processed data are stored on floppy disc along with the main program listing. The program is downloaded into 4052 memory for every test period.

3.0 4052/PERIPHERAL INTERFACE

Communication between the 4052 and various peripheral devices follows distinct and fairly strict programming rules. The software needs for the datalogger, DPO and disc drives will be individually discussed after briefly reviewing the 4052 logic for external device control.

The General Purpose Interface Bus (GPIB) used by the 4052 is the IEEE 488 Bus. All programming instructions from the 4052 to the peripheral and all data from the peripheral to the 4052 travel along this bus.

When a peripheral device transmits data to the 4052, the device first generates a Service Request (SRQ) along one channel of the GPIB. At this point, if the 4052 has been enabled (programmed) to handle SRQ's, the current line of main program is executed and a "ON SRQ THEN (line number)" statement directs control to a user-written SRQ handler routine. To determine which device actually requested the service, a serial "poll" is taken. A normal "handshaking" acknowledgement occurs along the bus indicating that the 4052 is ready to accept data and data is then transmitted. Finally, the SRQ signal is cancelled and the 4052 control returns to the next line of the main program.

If the 4052 has not been enabled to handle SRQ's, generating an SRQ will cause termination of the main program. An error message (NO SRQ ON UNIT - MESSAGE NUMBER 43) will appear on the CRT.

In summary, the IEEE 488 bus is the actual hardware link between the peripheral device and the 4052. The SRQ is a software signal (flag) generated by the peripheral requesting service. The 4052 (enabled to handle SRQ's) polls its peripherals (as determined by its program) upon receiving an SRQ and finds the correct device. Lines of communication are then opened to transmit data.

3.1 Fluke Datalogger

Programming rules for the datalogger:

a. When communicating with the datalogger, the 4052 must always be in the double-space mode, enabled by a "PRINT @37,26:1" command. (It is disabled by a "PRINT @37,26:Ø" command.)

b. Scan control must be the last instruction programmed to the datalogger. When the scan control mode is set, a scan is immediately taken, generating an SRQ. Until the SRQ is answered, the datalogger is unable to accept further programming instructions.

c. The 4052 must be enabled to handle SRQ's before the datalogger is used.

d. The datalogger must be polled after each SRQ is generated.

e. The date, the fixed data and the output from every channel programmed (in that order) must be read from the output buffer of the datalogger after each scan has been completed. Data is read into a character string.

f. Scan control must be disabled (PRINT @2:"SØ/") when the datalogger is no longer going to be read.

A sample program showing how the datalogger is used is listed and documented in Appendix A.

3.2 Digital Processing Oscilloscope

Communication between the DPO and the 4052 is best categorized into two areas:

a. waveform storage, input and scaling information; and

b. program "call button" usage.

To store a waveform, the DPO first digitizes the wave into a 512 point array assigning each point an integer number from 0 to 1024 corresponding to the height of the wave on the CRT grid. (The CRT grid is 512 points wide and 1024 points high. Therefore, the location of the point within the array is its horizontal position, and the value of that point is its vertical position.) This digitized waveform, or array, is stored in DPO memory along with its appropriate scaling information. (Time base and vertical scale.) This data can then be transferred to the 4052. For further programming instructions refer to References numbers [2] and [3].

The purpose of the 15 "call buttons" located on the front panel of the DPO is to allow convenient control over data analysis and program direction while the main program is loaded and running. Pressing any call button generates an SRQ. By determining which button was pushed control may be remotely directed to another part of the program; i.e. another stage of analysis.

The rules for using the call buttons are:

a. The 4052 must be enabled to handle SRQ's. (Note: The 4052 need only be enabled once in a program - by a serial poll it can determine if the datalogger or the DPO requested service.)

b. The DPO must be polled before any further SRQ's may be generated.

c. The SRQ interrupt flag must be cleared (PRINT @1:"CLI") before the call buttons may be used again.

3.3 Disc Drives

Disc drives programming information is plentiful and extremely well documented so it will not be discussed here. Refer to Tektronix Guide No. 4907 entitled "File Manager - Operator's Manual". No SRQ is generated with any disc to memory operation.

4.0 EASE-1 PROGRAM STRUCTURE

The EASE-1 program has two functions:

a. to monitor the EASE-1 while running (torque, speed, temperature) displaying constantly updated information on the CRT; and

b. to process and analyze inputted data.

Monitoring the engine consists of fo[illegible]ting and displaying data from the datalogger (set to scan every 5 seco[illegible]) and from the DPO. Changes in engine behaviour are displayed on [illegible] CRT calculated on a percentage change basis from one scan to the next.

Processing and analyzing the inputted data is accomplished in stages. The sequence is controlled by the operator. A block structure of the stages is shown in Figure 2 below. The blocks' functions are:

a. "Monitor" returns the program to the EASE-1 monitoring mode. The program automatically starts here when first loaded and run.

b. "Monitor Interrupt" shuts off the datalogger and prepares the DPO to store wavefor[illegible].

c. "Capture" stores and inputs [illegible]ne waveforms and scaling information into the 4052. It then scales the waves from voltage to their respective units.

d. "P-V" displays the P-V diagram on the CRT and integrates the area under the curve (indicated work).

e. "Calculations" calculates and lists the engine performance characteristics: temperatures, speed, torque, indicated power, Carnot efficiency, brake power, power consumption, overall efficiency, IMEP and BSFC.

f. "Smoothing" smooths out the pressure and volume trace and displays a smoothed P-V diagram.

g. "Display" graphs power piston or displacer piston displacement, pressure, dV, or PdV waves.

h. "Compare" produces a plot of any two engine parameters, keeping a third parameter constant at any level within any range, for all previous runs stored on disc. It then plots the current test run point allowing the operator to visually compare the current run with past runs.

i. "Store" stores both raw and calculated data on disc.

j. "Recall" will recall a previous run for examination. (At time of writing this block had not been implemented.)

k. "End" terminates the program from anywhere within the program.

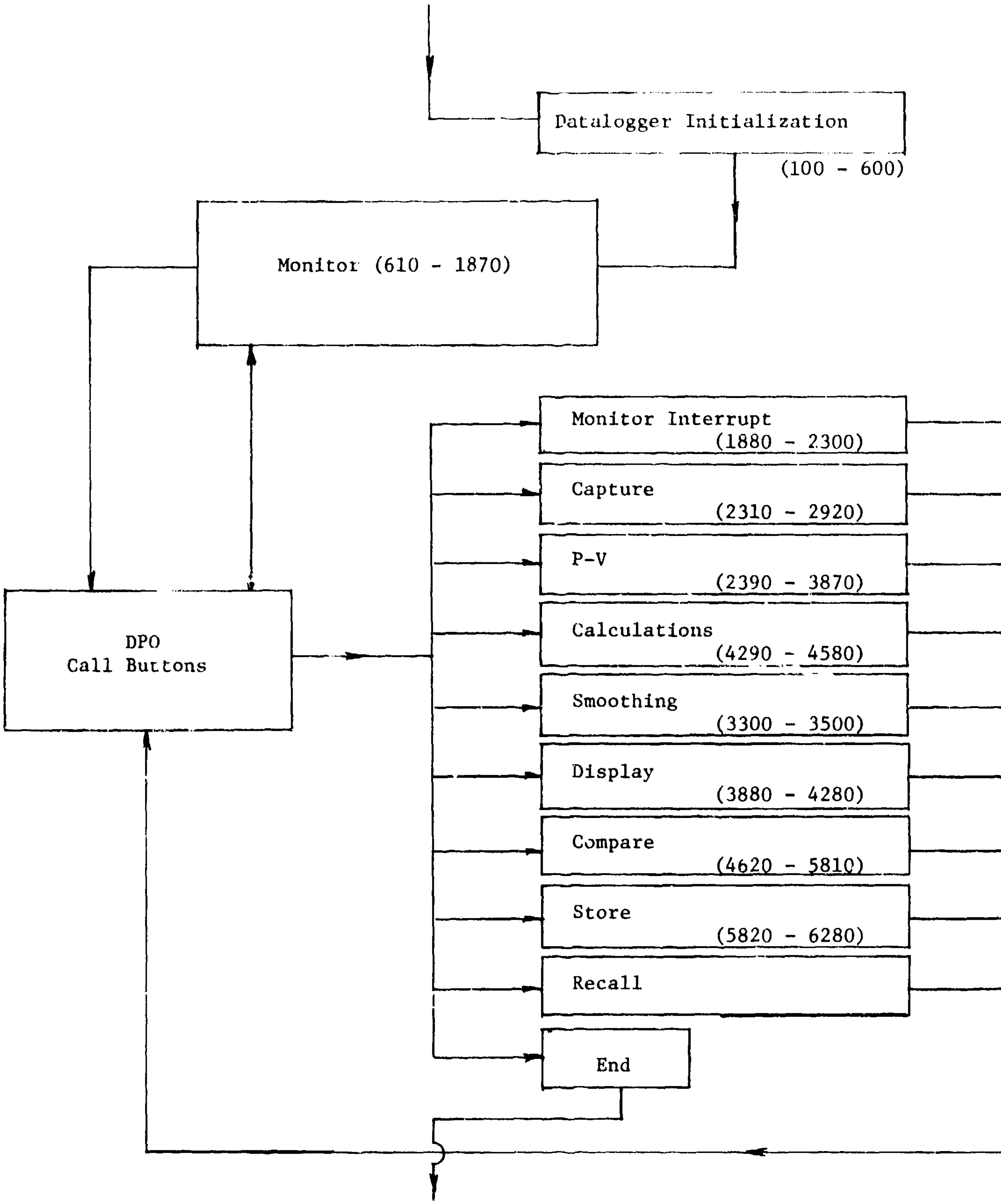

Datalogger Initialization
(100 - 600)
Monitor (610 - 1870)
DPO
Call Buttons
Monitor Interrupt
(1880 - 2300)
Capture
(2310 - 2920)
P-V
(2390 - 3870)
Calculations
(4290 - 4580)
Smoothing
(3300 - 3500)
Display
(3880 - 4280)
Compare
(4620 - 5810)
Store
(5820 - 6280)
Recall
End

Figure 2

Each block described above is a separate subroutine in the EASE-1 program. This structure enables more analysis capability to be easily added at a later stage.

Program control is effected from the 15 DPO call buttons. Pressing a call button generates an SRQ halting the program in its current subroutine. Depending upon which button was pushed, the program control is redirected to the desired subroutine. Therefore, data analysis and handling proceeds directly under the operator's control. This approach also aids in trouble shooting problems and debugging new or revised stages. A full listing of the EASE-1 program is given in Appendix B along with sample output. It is suggested, however, that familiarity be gained both with the necessary software to communicate with the peripherals and with the block structure of the program before attempting to fully understand the actual software version of the EASE-1 program.

5.0 SYSTEM LIMITATIONS

As previously mentioned, the 4052 has 64 kilobytes of RAM (Random Access Memory). Each 512 point array requires just over 4 kilobytes of 4052 memory. Therefore, in order to have an entire program listing reside in 4052 memory, economical use of arrays is necessary.

The DPO, in its current configuration, has only two channels of input. Since the DPO is the only A/D (Analogue to Digital) device capable of measuring transients, the overall FEES - EASE-1 system is limited to 2 transient signals. If necessary, the DPO could be enlarged to 4 channels by replacing the single channel input amplifiers with dual channel input amplifiers. However, it remains to be seen if 64 kilobytes of memory in the 4052 is sufficient to handle and manipulate the additional data the two channels would gather.

REFERENCES

1. DOUCET, Louis, "Computer Model of a Stirling Engine", Undergraduate Thesis, University of Ottawa, 1980.

2. Tektronix Guide No. 021-0206-00, "P7001/IEEE 488 Interface".

3. Tektronix Operator's Guide, "Digital Processing Oscilloscope".

APPENDIX A

SAMPLE DATALOGGER PROGRAMMING

This program instructs the datalogger to scan two channels (numbers 10 and 11) every five seconds for a total of five scans. After each scan is completed, the data is fed into the 4052 and then displayed on the CRT.

100	Reset all variables
110	Enable 4052 to handle SRQ's
120	4052 double-space mode
130-220	Program datalogger - scan control set last
230-250	Loop to wait for SRQ generation
260	Turn off scan control
270	4052 single-space mode
280	End
1000	SRQ handler routine
1010	Serial poll of datalogger and DPO
1020	Determine which device requested service
1030-1070	Input data into character string and display input for date, fixed data and each channel programmed
1080	Returns program control to next line of main program (line 250)

APPENDIX B

EASE-1 PROGRAM LISTING AND SAMPLE OUTPUT

The FEES - EASE-1 monitor and data analysis program is given here in its entirety. Remark statements are scarce because of RAM limitations. Again, for further explanation, refer to the block structure previously described and to the recommended Tektronix Guides for software code.

The output shown is a Pressure - Volume diagram and a list of engine performance characteristics. The engine was idling and not loaded for this particular run.

```
100 INIT
110 ON SRQ THEN 1000
120 PRINT @37,26:1
130 PRINT @2:"T120,00,00,00/"
140 PRINT @2:"H777777/"
150 PRINT @2:"F010/"
160 PRINT @2:"L011/"
170 PRINT @2:"C010,5/"
180 PRINT @2:"C011,5/"
190 PRINT @2:"X0/"
200 PRINT @2:"W2/"
210 PRINT @2:"I00,00,05/"
220 PRINT @2:"S2/"
230 FOR J=1 TO 5
240 CALL "WAIT"
250 NEXT J
260 PRINT @2:"S0/"
270 PRINT @37,26:0
280 END
1000 REM  ****  SRQ HANDLER ****
1010 POLL A,B;2;1
1020 GO TO A OF 1030,1080
1030 PAGE
1040 FOR I=1 TO 4
1050 INPUT @2:A$
1060 PRINT A$
1070 NEXT I
1080 RETURN
```

```
100 REM **FEES-EASE-1 MONITOR AND DATA  ANALYSIS
110 REM **                  PROGRAM
120 REM
130 REM
140 INIT
150 DIM B(10),X(20)
160 DIM K(10)
170 DIM L(10)
180 K=1
190 L=1
200 B=1
210 X=1
220 T=1
230 F7=0
240 ON SRQ THEN 770
250 REM**
260 REM** GET DATE, INTERVAL
270 PAGE
280 PRINT "DATE?(DDD,HH,MM,SS)"
290 INPUT D$
300 D$="T"&D$
310 D$=D$&"/"
320 REM*****NOW PROGRAM FLUKE
330 PRINT @37,26:1
340 PRINT @2:D$
350 PRINT @2:"I00,00,05/"
360 PRINT @2:"F019/"
370 PRINT @2:"L052/"
380 PRINT @2:"C019,4/"
390 PRINT @2:"C020,0/"
400 PRINT @2:"C021,0/"
410 PRINT @2:"C022,0/"
420 PRINT @2:"C023,0/"
430 PRINT @2:"C024,0/"
```

```
440 PRINT @2:"C025,0/"
450 PRINT @2:"C026,0/"
460 PRINT @2:"C027,0/"
470 PRINT @2:"C028,0/"
480 PRINT @2:"C029,0/"
490 PRINT @2:"C030,0/"
500 PRINT @2:"C031,0/"
510 PRINT @2:"C032,0/"
520 PRINT @2:"C044,8/"
530 PRINT @2:"C045,8/"
540 PRINT @2:"C046,8/"
550 PRINT @2:"C047,8/"
560 PRINT @2:"C048,8/"
570 PRINT @2:"C051,7/"
580 PRINT @2:"C052,7/"
590 PRINT @2:"X0/"
600 PRINT @2:"W2/"
610 PRINT @37,26:1
620 PRINT @2:"S2/"
630 PRINT @37,26:0
640 F7=0
650 REM**WAIT FOR SRQ***
660 REM
670 CALL "WAIT"
680 IF F7=1 THEN 700
690 GO TO 670
700 GO TO 610
710 REM **SHUT DOWN DATALOGGER**
720 REM
730 PRINT @37,26:1
740 PRINT @2:"S0/"
750 PRINT @37,26:0
760 END
770 REM
780 REM**SRQ HANDLER AND DATA DISPLAY****
```

```
790 REM
800 POLL A,C;2;1
810 GO TO A OF 830,1700
820 REM
830 REM **DATA FROM DATALOGGER**
840 REM
850 PRINT @37,26:1
860 PAGE
870 INPUT @2:M$
880 FOR I=1 TO 8
890 INPUT @2:N$
900 IF I=1 THEN 940
910 N$=SEG(N$,8,6)
920 B(I)=VAL(N$)
930 GO TO 970
940 INPUT @2:N$
950 N$=SEG(N$,5,11)
960 B(9)=VAL(N$)
970 NEXT I
980 B(9)=0.0072*(B(9)*200+1)
990 REM *** CONVERSION FROM IN-OZ TO N-m ****
1000 PRINT @37,26:0
1010 REM** INPUT SPEED FROM DPO***
1020 REM
1030 PRINT @1:"STO A,C"
1040 PRINT @1:"HOL A,C"
1050 PRINT @1:"CHL A2"
1060 PRINT @1:"SCL?"
1070 INPUT @1:F$
1080 Z$=SEG(F$,10,1)
1090 X1=42-ASC(Z$)
1100 F=VAL(F$)
1110 F=F/10↑X1
1120 PRINT @1:"CHL A6"
1130 PRINT @1:"SCL?"
```

```
1140 INPUT @1:G$
1150 M=POS(G$,"S",1)
1160 T$=SEG(G$,M-1,1)
1170 M=POS("mump",T$,1)
1180 F=F*10↑(-3*M)
1190 IF F=0 THEN 1220
1200 S=60/F
1210 GO TO 1230
1220 S=0
1230 REM
1240 REM**DISPLAY INFO**
1250 M$=SEG(M$,2,12)
1260 PRINT "TIME",M$
1270 PRINT "J"
1280 PRINT "    ","      TEMPERATURES (DEGREES C)"
1290 PRINT "J"
1300 REM
1310 PRINT "                    ","PRESENT SCAN","LAST SCAN","CHANGE"
1320 PRINT "                    ","------------","---------","------"
1330 FOR I=2 TO 10
1340 L(I)=INT((B(I)-K(I))/K(I)*1000)/10
1350 NEXT I
1360 PRINT "COOLANT IN:",B(2),K(2),L(2);" %"
1370 PRINT "COOLANT JACKET:",B(3),K(3),L(3);" %"
1380 PRINT "BLOCK TEMP:",B(4),K(4),L(4);" %"
1390 PRINT "COOLANT OUT:",B(5),K(5),L(5);" %"
1400 PRINT "HEATER HEAD(51):",B(7),K(7),L(7);" %"
1410 PRINT "HEATER HEAD(52):",B(8),K(8),L(8);" %"
1420 PRINT "POWER PISTON",B(6),K(6),L(6);" %"
1430 PRINT "J"
1440 PRINT "TORQUE (N-m):",B(9),K(9),L(9);" %"
1450 REM PRINT S
1460 G=INT((S-T)/T*100)
1470 PRINT "ENGINE RPM:",INT(S),T,G;"%"
1480 T=INT(S)
```

```
1490 IF T=0 THEN 1510
1500 GO TO 1520
1510 T=1
1520 PRINT "JJJJ"
1530 IF ABS(B(7)-B(8))>10 THEN 1600
1540 FOR I=2 TO 8
1550 IF ABS(L(I))>1 THEN 1600
1560 NEXT I
1565 IF ABS(L(9))>5 THEN 1600
1570 G=ABS(G)
1580 IF G>2 THEN 1600
1590 GO TO 1630
1600 PRINT "                ***FAILED STABILITY CHECK***"
1610 REM
1620 GO TO 1640
1630 PRINT "                ***STABILITY REACHED***"
1640 PRINT "JJJ"
1650 PRINT "TO PROCESS DATA PRESS CALL BUTTON 2"
1660 PRINT "TO END PROGRAM PRESS CALL BUTTON 15"
1670 K=B
1680 RETURN
1690 REM
1700 REM** SRQ FROM DPO ***
1710 POLL A,C;2
1720 PRINT @37,26:1
1730 PRINT @2:"S0/"
1740 PRINT @37,26:0
1750 PRINT @1:"FPI?"
1760 INPUT @1:F7
1770 IF F7=1 THEN 1840
1780 IF F7>9 THEN 1820
1790 GOSUB F7 OF 620,1890,2060,3410,3310,4290,3930,3970,4010
1800 PRINT @1:"CLI "
1810 RETURN
1820 F7=F7-9
```

```
1830 GOSUB F7 OF 4060,4110,4600,5820,1860,1870
1840 PRINT @1:"CLI "
1850 RETURN
1860 RETURN
1870 PRINT @1:"CLI "
1880 END
1890 U=1
1900 DELETE J
1910 DIM P1(512),D(512),W1(512)
1920 PAGE
1930 REM      P1--PRESSURE WAVE D--LVDT
1950 C$=D$
1960 PRINT @1:"STO ";"A","C"
1970 PRINT "CHECK THAT PRESSURE SIGNAL IS ON CHANNEL  A"
1980 PRINT "AND THAT LVDT SIGNAL IS ON CHANNEL  B"
1990 PRINT "JJ"
2000 PRINT "PRESSURE TRANSDUCER SENSITIVITY ON CHARGE AMPLIFIER"
2010 PRINT "SHOULD BE SET AT 8.0 MV/PSI AND LVDT VOLTAGE AT 24 V"
2020 PRINT "JJ"
2030 PRINT "TO CAPTURE WAVES PRESS CALL BUTTON 3"
2040 RETURN
2050 INPUT Z$
2060 REM OUTPUT FROM AMPL. OF PRESSURE TRANS. IS 10 PS1/VOLT
2070 P=68947.6
2080 REM CONVERSION TO NEWTONS/METER↑2 MULT. BY 10 PSI/VOLT
2090 PRINT @1:"HOL ";"A,C"
2100 PRINT @1:"DPA?"
2110 INPUT @1:P1
2120 PRINT @1:"DPC?"
2130 INPUT @1:D
2135 PRINT @1:"CHL A2"
2140 PRINT "JJJJJJJ"
2150 PRINT @1:"SCL?"
2160 INPUT @1:F$
2170 Z$=SEG(F$,10,1)
```

```
2180 X1=42-ASC(Z$)
2190 F=VAL(F$)
2200 F=F/10↑X1
2210 PRINT @1:"CHL A6"
2220 PRINT @1:"SCL?"
2230 INPUT @1:G$
2240 M=POS(G$,"S",1)
2250 T$=SEG(G$,M-1,1)
2260 M=POS("munp",T$,1)
2270 F=F*10↑(-3*M)
2280 GOSUB 2320
2290 PRINT "FOR P-V DIAGRAM PRESS BUTTON 4"
2300 RETURN
2310 END
2320 REM
2330 REM*****************************************************************
2340 REM
2350 REM  SUBROUTINE TO SCALE WAVEFORMS
2360 REM
2370 REM*****************************************************************
2380 DELETE V
2390 X$="CHL AX"
2400 Y$="3"
2410 Z$="S"
2420 GOSUB 2800
2430 H=V/51.2
2440 Y$="0"
2450 Z$="V"
2460 GOSUB 2800
2470 V=P*V/102.4
2480 P1=P1*V
2490 I=INT(F/H)
2500 CALL "MAX",P1,M1,L4
2510 CALL "MIN",P1,M2,K4
2512 P1=P1-(M1+M2)/2
```

```
2514 CALL "CROSS",P1,0,L5,1
2516 CALL "CROSS",P1,0,K5,2
2520 K4=K4-(K5-L5)/2
2530 FOR J=K4 TO 520
2540 IF P1(J)-P1(J+I)<0 THEN 2560
2550 NEXT J
2560 IF ABS(P1(J)-P1(J+I))>ABS(P1(J-1)-P1(J+I-1)) THEN 2590
2570 E7=(P1(J)+P1(J+I))/2
2580 GO TO 2600
2590 E7=(P1(J-1)+P1(J+I-1))/2
2600 P1=P1-E7
2610 Y$="1"
2620 GOSUB 2800
2630 CALL "MIN",D,M,I
2640 D=D-M
2650 V=V/102.4
2660 D=D*V
2670 D=D/8.39
2680 REM CALIBRATION MULT FACTOR @ 24 VOLTS INPUT
2690 D=D*0.0254
2700 REM LVDT SIGNAL  IS NOW IN METERS
2710 CALL "MAX",D,T1,I
2720 CALL "MIN",D,T2,I
2730 IF T1>0.0695 OR T2<-1.0E-3 THEN 2780
2740 D=D/T1
2750 D=D*0.0679
2751 DELETE V
2752 DIM V(512)
2753 Z1=PI*0.03175↑2
2754 V=D*Z1
2760 REM NORMALIZED DISPLACEMENT AND MULT.BY STATIC STROKE LENGTH
2770 GO TO 2790
2780 PRINT "***ERROR***DISPLACER INPUT OR CALC.DISPLACEMENT ERROR"
2790 RETURN
2800 REM***********************************
```

```
2010 REM**********************************
2020 X$=REP(Y$,6,1)
2030 PRINT @1:X$
2040 PRINT @1:"SCL?"
2050 INPUT @1:S$
2060 REM
2070 V=VAL(S$)
2080 M=POS(S$,Z$,1)
2090 T$=SEG(S$,M-1,1)
2900 M=POS("munp",T$,1)
2910 V=V*10↑(-3*M)
2920 RETURN
3300 REM ***SUBROUTINE TO SMOOTH OUT PRESSURE AND VOLUME WAVES
3310 FOR J=1 TO 3
3320 FOR I=2 TO 510 STEP 2
3330 V(I)=(V(I+1)+V(I-1))/2
3340 P1(I)=(P1(I+1)+P1(I-1))/2
3350 NEXT I
3360 FOR I=3 TO 511 STEP 2
3370 V(I)=(V(I+1)+V(I-1))/2
3380 P1(I)=(P1(I+1)+P1(I-1))/2
3390 NEXT I
3400 NEXT J
3410 REM ***  SECTION TO CALCULATE INDICATED WORK
3420 DELETE P3,P4
3425 DIM D1(512)
3430 W=0
3431 CALL "CROSS",P1,0,K1,1
3432 CALL "CROSS",P1,0,L1,3
3440 CALL "DIF3",V,D1
3450 DIM P3(512),P4(512)
3460 P3=P1*D1
3470 CALL "INT",P3,P4
3480 W=2*(P4(L1)-P4(K1))
3490 GOSUB 3510
```

```
3500 RETURN
3510 REM
3520 REM*************************************************************
3530 REM
3540 REM           GRAPHING ROUTINE TO GET P-V DIAGRAM
3550 REM
3560 REM*************************************************************
3570 REM
3580 PAGE
3590 V=V*1000000
3600 REM ** CONVERSION FROM CUBIC METERS TO CC **
3610 WINDOW 0,220,-20000,150000
3620 VIEWPORT 15,110,20,100
3630 AXIS 20,15000
3635 P1(L1)=P1(K1)
3636 V(L1)=V(K1)
3640 MOVE V(K1),P1(K1)
3650 FOR I=K1 TO L1
3660 DRAW V(I),P1(I)
3670 NEXT I
3680 MOVE 0,-30000
3690 PRINT "WORK/CYCLE IS ";INT(1000*W)/1000;" (J/REV) AT ";INT(S);" RPM"
3700 PRINT "          INDICATED POWER IS ";INT(10*W*S/60)/10;" WATTS"
3710 PRINT "          DATE OF RUN: ";D$
3720 FOR I=135000 TO -15000 STEP -15000
3730 I=INT(I)
3740 MOVE 0,I
3750 PRINT "HHHHHHH";I
3760 NEXT I
3770 FOR I=20 TO 200 STEP 20
3780 MOVE I-5,-7000
3790 I=INT(I)
3800 PRINT I
3810 NEXT I
3820 MOVE 80,-15000
```

```
3030 PRINT "VOLUME (CC)"
3040 MOVE 3,145000
3050 PRINT "PRESSURE (Pa)"
3060 V=V/1000000
3070 RETURN
3080 REM************************************************************3
3090 REM
3900 REM  GRAPHING SUBROUTINE FOR DISP.,PRESS.,dV,dV/dT,PdV WAVES
3910 REM
3920 REM*************************************************************
3930 W1=D*100
3940 Z$="POWER PISTON DISPLACEMENT (cm)"
3950 GOSUB 4160
3960 RETURN
3970 W1=P1
3980 Z$="PRESSURE (Pa)"
3990 GOSUB 4160
4000 RETURN
4010 REM
4015 W1=V*1000000
4020 Z$="VOLUME (cc)"
4030 GOSUB 4160
4050 RETURN
4060 CALL "DIF3",V,W1
4070 Z$="dV/dT"
4080 GOSUB 4160
4090 INPUT Z$
4100 RETURN
4110 CALL "DIF3",V,W1
4120 W1=W1*P1
4130 Z$="P*dV/dT"
4140 GOSUB 4160
4150 RETURN
4160 PAGE
4170 CALL "MIN",W1,M1,I
```

```
4180 CALL "MAX",W1,M2,I
4190 O=(M2-M1)/20
4200 WINDOW 0,512,M1-O,M2+5*O
4205 VIEWPORT 15,110,20,100
4210 A9=INT(M2*1000000)/10000000
4220 AXIS 50,A9
4230 CALL "DISP",W1
4240 MOVE 0,M1-2*O
4250 PRINT Z$
4260 MOVE 0,M1-3*O
4270 PRINT "VERTICAL TIC INTERVAL IS: ";A9
4280 RETURN
4290 PAGE
4300 PRINT "JPOWER BEING USED?"
4310 INPUT B(10)
4320 REM*****************************************
4330 REM***DATA CRUNCHING**
4340 REM*****************************************
4350 X(2)=0.5*(B(7)+B(8))
4360 X(1)=B(6)
4370 X(3)=INT(S)
4380 X(4)=B(9)
4390 X(5)=W*S/60
4400 X(6)=INT(1000*(1-(X(1)+273)/(X(2)+273)))/10
4410 X(7)=2*PI*X(4)*S/60
4420 X(8)=B(10)
4430 X(9)=INT(X(7)/X(8)*10000)/100
4440 X(10)=X(5)*60/(S*2.15E-4)
4450 REM X(11)=X(8)*1000/X(7)
4460 PAGE
4470 PRINT "JTEMP. LOW:",X(1),"(C)"
4480 PRINT "JTEMP. HOT:",X(2),"(C)"
4490 PRINT "JENGINE RPM:",X(3)
4500 PRINT "JTORQUE:",X(4),"(N-m)"
4510 PRINT "JIND. POWER:",X(5),"(W)"
```

```
4520 PRINT "JCARNOT EFFEC.",X(6),"%"
4530 PRINT "JBRAKE POWER:",X(7),"(W)"
4540 PRINT "JPOWER CONSUMPTION:",X(8),"(Watts)"
4550 PRINT "JEFFECIENCY:",X(9),"%"
4560 PRINT "JIMEP:",X(10),"(Pa)"
4570 PRINT "JBSFC:"
4580 RETURN
4590 REM ***REM  SUBROUTINE TO COMPARE THIS  RUN WITH PREVIOUS RUNS
4600 PAGE
4610 CALL "UNIT",2
4620 PRINT "JDO YOU WANT THE DATA DISPLAYED?(Y/N)"
4630 INPUT Z$
4640 R$=SEG(Z$,1,1)
4650 IF R$="N" THEN 5810
4660 PRINT "JWHAT ARE THE PARAMETERS OF INTEREST?"
4670 PRINT "J1. TEMP"
4680 PRINT "2. SPEED"
4690 PRINT "3. TORQUE"
4700 PRINT "4. IND. POWER"
4710 PRINT "5  CARNOT EFFECIENCY"
4720 PRINT "6. BRAKE POWER"
4730 PRINT "7. POWER CONSUMPTION"
4740 PRINT "8. OVERALL EFFECIENCY"
4750 PRINT "9. IMEP"
4760 PRINT "10.BSFC"
4770 PRINT "JJINPUT TWO NUMBERS: FIRST HORIZONTAL AXIS AND SECOND"
4780 PRINT "IS VERTICAL AXIS.  SEPARATE THEM BY A COMMA AND HIT"
4790 PRINT "RETURN AFTER THE SECOND NUMBER"
4800 DELETE Y8
4810 DIM Y8(2)
4820 INPUT Y8
4830 PRINT "JWHAT IS TO BE HELD CONSTANT?"
4840 INPUT Y9
4850 PRINT "JCONSTANT AT WHAT VALUE?"
4860 INPUT Y6
```

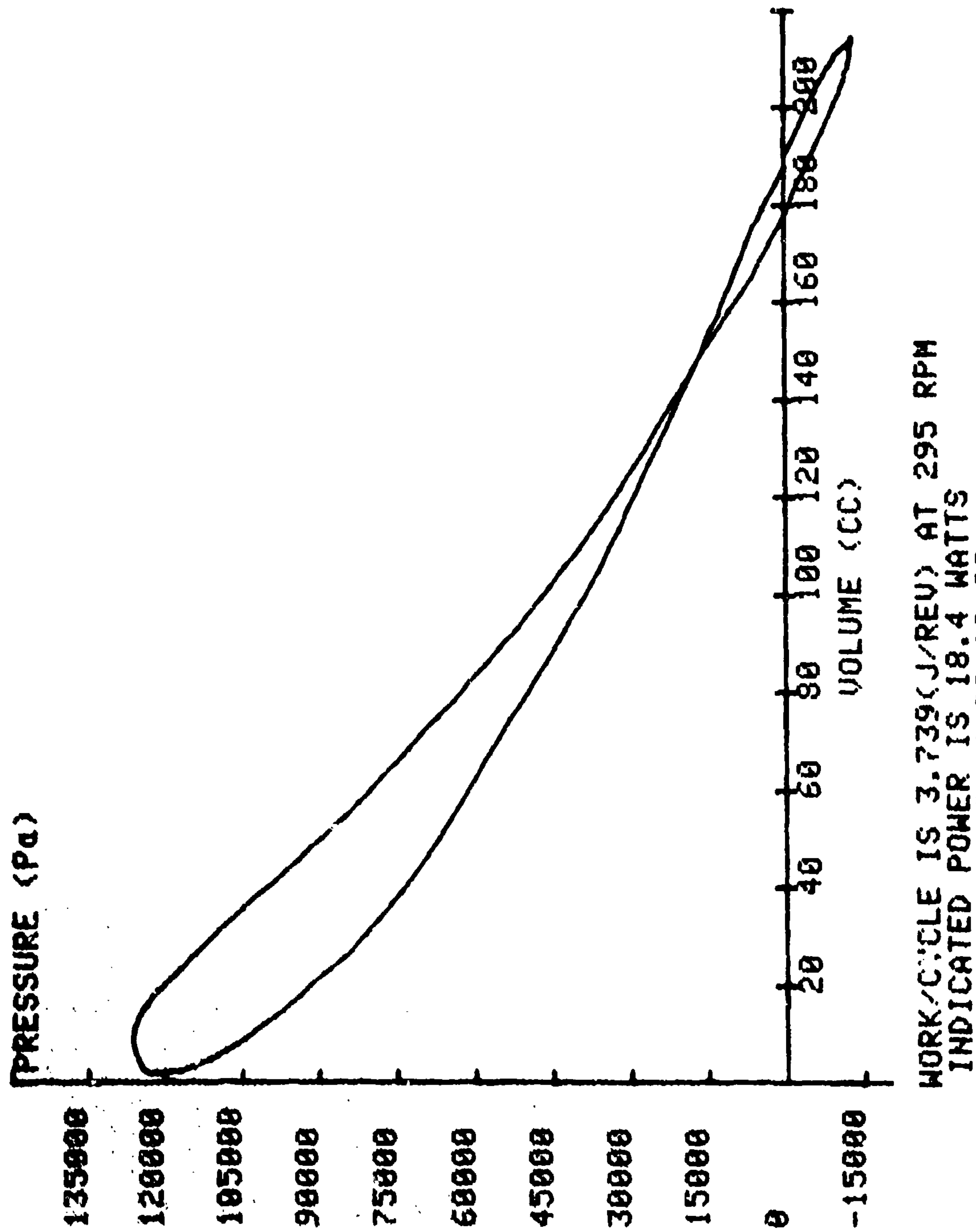
```
4870 PRINT "JWITHIN WHAT RANGE?(i.e.+ OR - WHAT VALUE?)"
4880 INPUT Y3
4890 PAGE
4900 U9=1
4910 PRINT "JFROM WHICH FILE IS DATA TO BE TAKEN?"
4920 DELETE X5
4930 DIM X5(20)
4940 GO TO 5930
4950 N=0
4960 CALL "UNIT",2
4970 OPEN R$;1,"R",A$
4980 READ #1,1:A
4990 DELETE X6
5000 DIM X6(A-1,2)
5010 X6=0
5020 FOR I=2 TO A
5030 READ #1,I:H$,L$,X5
5040 IF X5(Y9+1)<Y6-Y3 OR X5(Y9+1)>Y6+Y3 THEN 5080
5050 N=N+1
5060 X6(N,1)=X5(Y8(1)+1)
5070 X6(N,2)=X5(Y8(2)+1)
5080 NEXT I
5090 CLOSE 1
5100 M6=N
5110 IF N=0 THEN 5340
5120 M9=0
5130 FOR I=1 TO M6
5140 IF X6(I,2)<M9 THEN 5160
5150 M9=X6(I,2)
5160 NEXT I
5170 GOSUB 5510
5180 REM SUBROUTINE TO SORT VECTOR
5190 PAGE
5200 WINDOW 0,X6(N,1)*12/10,0,M9*12/10
5210 VIEWPORT 20,130,20,100
```

```
5220 AXIS X6(N,1)/10,M9/10,0,0
5230 MOVE X6(1,1),X6(1,2)
5240 IF N=1 THEN 5300
5250 FOR I=1 TO N
5260 MOVE X6(I,1),X6(I,2)
5270 PRINT "+"
5280 NEXT I
5290 GO TO 5310
5300 PRINT "+"
5310 MOVE X(Y8(1)+1),X(Y8(2)+1)
5320 PRINT "*"
5330 GO TO 5360
5340 PRINT "J ***ERROR*** NO DATA POINTS IN RANGE SPECIFIED"
5350 RETURN
5360 VIEWPORT 0,130,0,100
5370 WINDOW 0,130,0,100
5380 GOSUB 6290
5390 MOVE 65,15
5400 PRINT H$
5410 MOVE 20,10
5420 PRINT Y$;" CONSTANT AT ";Y6;" WITHIN ";Y3
5430 MOVE 0,100
5440 FOR I=1 TO LEN(V$)
5450 X$=SEG(V$,I,1)
5460 PRINT "J";X$
5470 NEXT I
5480 MOVE 20,5
5490 PRINT "HOR. TIC INT: ";X6(N,1)/10,"  VERT. TIC INT: ";M9/10
5500 RETURN
5510 REM ***********************************
5520 REM BUBBLE VECTOR SORT
5530 REM TWO DIMENSIONAL ARRAY IS SORTED
5540 REM BY INCREASING SIZE OF FIRST SUBSCRIPT
5550 REM OF EACH VECTOR PAIR
5560 REM ***********************************
```

```
5570 REM N  SIZE OF VECTOR
5580 REM X6(N,2) VECTOR TO BE SORTED
5590 REM Y7(2) TEMPORARY REGISTER
5600 REM
5610 DELETE Y7
5620 DIM Y7(2)
5630 L6=0
5640 C4=0
5650 IF C4 THEN 5810
5660 I=1
5670 C4=1
5680 FOR I=1 TO M6-1
5690 IF X6(I+1,1)=>X6(I,1) THEN 5780
5700 Y7(1)=X6(I,1)
5710 Y7(2)=X6(I,2)
5720 X6(I,1)=X6(I+1,1)
5730 X6(I,2)=X6(I+1,2)
5740 X6(I+1,1)=Y7(1)
5750 X6(I+1,2)=Y7(2)
5760 L6=I
5770 C4=0
5780 NEXT I
5790 M6=L6
5800 GO TO 5650
5810 RETURN
5820 PAGE
5830 U9=0
5840 REM *** SUBROUTINE TO STORE DATA ON DISC
5850 PRINT "JDO YOU WANT TO FILE DATA?(Y/N)"
5860 INPUT Z$
5870 R$=SEG(Z$,1,1)
5880 IF R$="N" THEN 6280
5890 PRINT "JENTER ANY COMMENTS NOW (LESS THAN ONE LINE)"
5900 INPUT C$
5910 PAGE
```

```
5920 PRINT "JFILE MANAGEMENT:"
5930 PRINT "J1. BUNSEN BURNER TESTING"
5940 PRINT "J2. ELECTRIC HEAT TESTING"
5950 PRINT "J3. CATALYTIC HEAT TESTING"
5960 PRINT "JJJJJENTER NUMBER"
5970 INPUT P$
5980 GO TO VAL(P$) OF 6010,6030,6050,6070
5990 PRINT "G"
6000 GO TO 5910
6010 P$="@DATA/BUN"
6020 GO TO 6080
6030 P$="@DATA/ELEC"
6040 GO TO 6080
6050 P$="@DATA/CAT"
6060 GO TO 6080
6070 P$="@DATA/TEST"
6080 REM
6090 CALL "UNIT",2
6100 R$=P$&"/CAL"
6110 IF U9=1 THEN 4950
6120 OPEN R$;1,"F",A$
6130 READ #1,1:A
6140 A=A+1
6150 WRITE #1,A:D$,C$,X
6160 WRITE #1,1:A
6170 CLOSE 1
6180 PRINT "JCALCULATED DATA IS IN FILE  ";R$;",    RECORD#";A
6190 R$=STR(A)
6200 R$=SEG(R$,2,2)
6210 R$="/RAW"&R$
6220 R$=P$&R$
6230 PRINT "JRAW DATA IS IN FILE    ";R$
6240 CREATE R$;11000,0
6250 OPEN R$;1,"F",A$
6260 WRITE #1:D$,H,P1,D
```

```
6270 CLOSE 1
6280 RETURN
6290 REM SUBROUTINE TO ASSIGN AXIS LABELS
6300 FOR I=1 TO 2
6310 Y4=Y8(I)
6320 GO TO Y4 OF 6330,6350,6370,6390,6410,6430,6450,6470,6490,6510
6330 E$="TEMPERATURE  C"
6340 GO TO 6520
6350 E$="SPEED  RPM"
6360 GO TO 6520
6370 E$="TORQUE   N-m"
6380 GO TO 6520
6390 E$="IND. POWER  W"
6400 GO TO 6520
6410 E$="CARNOT EFF. %"
6420 GO TO 6520
6430 E$="BRAKE POWER  W"
6440 GO TO 6520
6450 E$="POWER CONS. W"
6460 GO TO 6520
6470 E$="OVERALL EFF. %"
6480 GO TO 6520
6490 E$="IMEP  Pa"
6500 GO TO 6520
6510 E$="BSFC  g/kW-hr"
6520 IF I>2 THEN 6610
6530 IF I=1 THEN 6560
6540 V$=E$
6550 GO TO 6570
6560 H$=E$
6570 Y4=Y5
6580 NEXT I
6590 I=3
6600 GO TO 6320
6610 Y$=E$
```


PRESSURE (Pa)
135000
120000
105000
90000
75000
60000
45000
30000
15000
0
-15000
20
40
60
80
100
120
140
160
180
200
VOLUME (CC)
WORK/CYCLE IS 3.739(J/REV) AT 295 RPM
INDICATED POWER IS 18.4 WATTS
DATE OF RUN: T204,09,10,00/

TEMP. LOW:	35.8	(C)
TEMP. HOT:	443.7	(C)
ENGINE RPM:	295	
TORQUE:	0.006048	(N-m)
IND. POWER:	18.4326853547	(W)
CARNOT EFFEC.	56.9	%
BRAKE POWER:	0.187332166988	(W)
POWER CONSUMPTION:	300	(Watts)
EFFECIENCY:	0.06	%
IMEP:	17391.1957654	(Pa)
BSFC:		

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DOCUMENT CONTROL DATA – R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATING ACTIVITY Defence Research Establishment Ottawa Shirley Bay, Ottawa, Ontario, K1A 0Z4	2a. DOCUMENT SECURITY CLASSIFICATION Unclassified 2b GROUP

3. DOCUMENT TITLE

Data Acquisition User's Guide-1 For Fuel /Engine Evaluation System Applied To An Experimental Air Stirling Engine

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, middle initial)

Bingham, Ian R. and Webster, Gary D.

6. DOCUMENT DATE July 1981	7a. TOTAL NO. OF PAGES 42	7b. NO. OF REFS 3

8a. PROJECT OR GRANT NO. TP 25B00	9a ORIGINATOR'S DOCUMENT NUMBER(S) DREO TN 81-20
8b. CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10. DISTRIBUTION STATEMENT

Unlimited Distribution

11. SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY DREO

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This technical note describes the Data Acquisition (DA) system used in the evaluation of Experimental Air Stirling Engine No. 1 which had previously been designed and built as a part of the "Advanced Engines" studies for the Fuels/Powerplants Technical Subprogram 25B.

The DA system and capability is presented. Brief programming guidelines for controlling various peripheral electronic equipment through a mini-computer are given. The program software used in testing the Stirling engine is described. Finally, some limitations of the DA system are listed.

UNCLASSIFIED
Security Classification

KEY WORDS

Data Acquisition User's Guide
Engine Data Acquisition
Performance Combustion Data Acquisition
Tektronix 4052 Engine Analyzer
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Stirling Engine Test Analysis Software

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